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RESEARCH ARTICLE

Alcohol Policies and Motor Vehicle Crash Deaths Involving Blood Alcohol Concentrations Below 0.08%

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Introduction: Motor vehicle crashes are a leading cause of injury death in the U.S. Restrictive alcohol policies protect against crashes involving alcohol above the legal blood alcohol concentration of 0.08%. Characteristics of motor vehicle crash fatalities involving blood alcohol concentrations below the limit and their relationships to alcohol control policies have not been well characterized.

Methods: Motor vehicle crash fatality data and crash and decedent characteristics from 2000 to 2015 came from the Fatality Analysis Reporting System and were analyzed in 2018−2019. Alcohol Policy Scale scores characterized alcohol policy environments by state-year. Generalized estimating equation alternating logistic regression models assessed these scores and the odds that a fatality involved alcohol below the legal threshold.

Results: Of 612,030 motor vehicle crash fatalities, 223,471 (37%) died in alcohol-involved crashes, of which 33,965 (15% of alcohol-involved fatalities or 6% of all fatalities) had a blood alcohol concentration <0.08%. A 10 percentage point increase in Alcohol Policy Scale score, approximating the interquartile range among states, was associated with reduced odds of fatalities involving alcohol <0.08% vs 0.00% (AOR=0.91, 95% CI=0.89, 0.93). These findings held across multiple subgroup analyses by decedent and crash characteristics. Similar results were found for odds of alcohol involvement <0.05% vs 0.00% (AOR=0.90, 95% CI=0.88, 0.93), and ≥0.05% but <0.08% vs <0.05% (AOR=0.93, 95% CI=0.89, 0.96).

Conclusions: The number of lower blood alcohol concentration fatalities is substantial. States with more restrictive alcohol policies tend to have reduced odds of lower blood alcohol concentration motor vehicle crashes than states with weaker policies.

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INTRODUCTION

Motor vehicle crashes (MVCs) are a leading cause of injury death in the U.S. In 2017, more than 12,000 MVC fatalities involved a driver with a positive blood alcohol concentration (BAC).[1] There is a strong, graded relationship between BAC and the risk of MVCs and crash fatalities, and physiological impairment begins well below the current legal limit of 0.08%, with significantly elevated risk at BACs exceeding 0.02%.[2−8] Restrictive state alcohol policies have been associated with reduced odds of alcohol involvement at or exceeding the legal BAC limit in MVC fatalities among adults and underage youth within the U.S.[9,10]

Because the BAC limit used to legally define impairment is considerably higher than BACs resulting in physiological impairment, crash fatalities associated

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with BACs below 0.08% may also be caused by alcohol but are overlooked as a potentially preventable public health problem.[2,6] Although detailed characteristics of fatalities and crash characteristics involving BACs below 0.08% in the U.S. have not been well described, previous research suggests that such crash fatalities are relatively common in the U.S. and in other countries.[2,3,7,9,11,12] For example, a laboratory study of alcohol concentrations and simulated driving found decreased risk taking at BACs of 0.05% compared with 0.08%,[8] and a meta-analysis suggested declines in alcohol-related crashes with the adoption of a 0.05% threshold.[13] Although there has been resistance to changes in legal BAC limits for driving in the past 2 decades,[14,15] the National Transportation Safety Board and the National Academies of Science, Engineering, and Medicine in 2018 recommended reducing the legal BAC limit to 0.05%.[16] In December 2018, Utah became the first state to do so.[17]

To address the gap in knowledge around lower BAC crashes and the restrictiveness of the overall alcohol policy environment, including policies targeting excessive drinking as well as subsequent driving, a repeated, lagged cross-sectional analysis was conducted involving MVC fatalities with alcohol below the legal limit and alcohol policies within the U.S. The objectives of this study were to (1) describe alcohol-involved MVC fatalities below the legal BAC limit of 0.08% in comparison with higher BAC fatalities and (2) analyze the relationship between more restrictive state alcohol policy environments and the odds of alcohol involvement in MVC fatalities involving alcohol below 0.08% compared with no alcohol involvement.

The hypothesis was that stronger state alcohol policy environments would be associated with lower odds of alcohol involvement below the legal limit compared with no alcohol involvement. The relationships between more restrictive state alcohol policy environments and the odds of alcohol involvement at other BAC thresholds of <0.05% compared with 0% and between 0.05% and 0.08% compared with <0.05% were also examined.

METHODS

Study Sample

Data on MVC fatalities from 2000 to 2015 came from the National Highway Traffic Administration's Fatality Analysis Reporting System (FARS),[18] which encompasses a census of MVCs resulting in at least 1 fatality within 30 days of the crash occurring on public roadways in all 50 U.S. states, the District of Columbia, and Puerto Rico annually.

Demographic characteristics were extracted for those who died in MVCs, including sex, age, and race/ethnicity; driver/passenger status; and BAC level. Crash data characteristics were also extracted, including number of vehicles, time of day, and day of week. Because BAC levels are not directly measured among all drivers involved in fatal crashes, FARS provides 10 imputed sets to address missing BAC levels using a validated multiple imputation technique.[19] Thus, all drivers involved in fatal crashes have either a measured BAC or 10 imputed BACs available in the FARS data. Analyses were compared with and without imputed data as a sensitivity analysis.

Measures

A crash-level BAC was assigned to all fatal crashes based on the highest recorded or imputed BAC of any driver(s) involved in the crash in each of the 10 data sets. All fatalities stemming from each fatal crash were assigned its corresponding crash-level BAC, and all fatalities (including drivers, passengers, bikers, and pedestrians) were assessed in the study. For the main analysis, a fatality was considered to have the outcome of alcohol involvement if at least 1 driver in the crash had a BAC >0.00% but <0.08%. For the secondary analysis, fatalities were considered to have the outcome of alcohol involvement if at least 1 driver in the crash had a BAC >0.00% but <0.05%, or ≥0.05% but <0.08%.

State alcohol policy environments were characterized using the Alcohol Policy Scale (APS) from 1999 to 2014, the years for which the APS is currently available.[20,21] The APS is currently the only measure of the aggregate policy environment in U.S. states and allows for the characterization of the state alcohol policy environment based on multiple existing policies, weighted by their theoretical efficacy and degree of implementation by state-year. More specifically, APS scores are based on the presence of 29 alcohol policies in each U.S. state, selected by 10 alcohol policy experts. A relative efficacy rating was obtained for each policy based on panelist voting; efficacy ratings were invariant by state-year. In addition, a standardized implementation index was developed for each policy; implementation ratings could vary by state-year. The APS includes 21 policies designed to reduce excessive alcohol consumption generally, as well 8 policies specifically designed to reduce the likelihood of impaired driving. Policies included in the APS that were rated with highest overall efficacy included taxes, state monopolies, outlet density laws, and wholesale and retail price restrictions. Policies to reduce impaired driving included laws pertaining to administrative license revocation, BAC per se limits, ignition interlocks, and zero tolerance laws. APS scores are standardized on a scale from 0 to 100, with higher APS scores indicating more restrictive policy environments. The APS has been used to assess the relationship between alcohol policies and alcohol involvement in underage motor vehicle fatalities and binge drinking, among other outcomes.[10,20,22−26] The exposure was a 10 percentage point increase in state APS score. This increase approximates the IQR among state scores and can be interpreted as a shift from a less restrictive to a more restrictive state alcohol policy environment.

Statistical Analysis

Descriptive characteristics were compared between low BAC and high BAC crash fatality victims using chi-square or Fisher's exact tests as appropriate. Generalized estimating equation logistic regression models were used to assess the relationship between a 10 percentage point increase in APS score and the odds that a crash fatality was alcohol-involved up to thresholds of 0.08% and 0.05% and between 0.05% and 0.08%. Alternating logistic regression models were used to account for clustering of multiple deaths within a crash and multiple crashes occurring within a state.[27] As

FARS utilizes 10 imputed data sets to account for missing BAC values, results were calculated for each of the 10 imputation sets and then pooled to calculate the average coefficient estimate and the SE estimate, per recommended FARS methodology. A lagged analysis was used such that policies in any given year were related to crash fatality outcomes in the subsequent year. For example, APS scores from 2005 were related to crash fatality data from 2006. Analyses were also conducted without a lag, with similar results.

Analyses were adjusted for individual-level covariates, which included age, sex, race/ethnicity, and year, and state-level covariates. State-level covariates included proportion male, race/ethnicity proportions, proportion of population aged ≥21 years, level of urbanization, median household income, proportion of individuals with a college education, state policing rates, and the average number of vehicle miles traveled per person. State-level covariates were extracted from the U.S. Census Bureau's American Community Survey and Current Population Survey,[28] the Federal Highway Administration,[29] and the Bureau of Justice Statistics.[30] Yearly estimates of vehicle miles traveled were available from each state with the exceptions of 2012 and 2013, which were carried over from 2011. Before finalizing the adjusted model, collinearity was assessed between the APS scores and covariates, and all included covariates had a correlation coefficient with the APS less than the a priori threshold of 0.4.

A stratified analysis was performed on the basis of demographic and crash-related characteristics. All analyses were conducted from 2018 to 2019 using SAS, version 9.4. All *p*-values were two-sided and considered significant at $p<0.05$. This study was deemed not to be human subjects research by the IRB at Boston University Medical Campus.

RESULTS

From 2000 to 2015, there were 612,030 MVC fatalities in the U.S., of which 223,471 (37%) occurred in crashes involving 1 or more drivers with a positive BAC. Of these, 33,965 (15% of alcohol-involved crash fatalities or 6% of all fatalities) were from an MVC involving a BAC >0.00% but <0.08% (Table 1). During the study period, the proportions of alcohol-involved MVCs, including those below and above the BAC threshold of 0.08%, remained largely constant (Figure 1).

Table 1. Characteristics of MVC Decedents by Crash-Level BAC

Characteristic	0<BAC<0.08 % (*n*=33,965)	BAC≥0.08 % (*n*=189,506)	*p*-value phi coefficient (≥0.08 vs >0 to <0.08)
Drinking driver status			
Drinking drivers	45.2 (15,357)	58.8 (111,438)	**<0.0001**
Nondrinking drivers	18.0 (6,097)	13.2 (25,031)	0.1021
Passengers	26.3 (8,937)	21.4 (40,488)	
Others[a]	10.5 (3,574)	6.6 (12,549)	
Sex			
Male	74.0 (25,123)	77.5 (146,931)	**<0.0001**
Female	26.0 (8,834)	22.5 (42,534)	−0.0304
Age, years			
<21	19.6 (6,648)	14.0 (26,451)	**<0.0001**
21–34	32.7 (11,099)	38.8 (73,504)	0.0863
35–54	29.2 (9,933)	34.0 (64,471)	
≥55	18.5 (6,285)	13.2 (25,080)	
Race/ethnicity			
White, non-Hispanic	57.4 (19,489)	56.3 (106,668)	**<0.0001**
Black, non-Hispanic	12.8 (4,345)	11.3 (21,336)	0.0247
Hispanic	12.1 (4,110)	13.7 (25,948)	
Other	17.7 (6,021)	18.8 (35,554)	
Weekend			
No	48.1 (16,353)	43.2 (81,863)	**<0.0001**
Yes	51.9 (17,609)	56.8 (107,606)	0.0358
Time of day			
6:00AM to 5:59PM	35.9 (12,076)	22.3 (41,639)	**<0.0001**
6:00PM to 5:59AM	64.1 (21,532)	77.7 (145,216)	0.1143
Vehicles			
Single vehicle crash	55.8 (18,944)	65.8 (124,649)	**<0.0001**
Multiple vehicle crash	44.2 (15,021)	34.2 (64,857)	−0.0749

Note: Boldface indicates statistical significance ($p<0.05$). BAC divided into 2 categories, (1) BAC >0.00 but <0.08 and (2) ≥0.08, based on the highest BAC of any driver in a single crash.
[a]Includes cyclists and pedestrians.
BAC, blood alcohol content; MVC, motor vehicle crash.

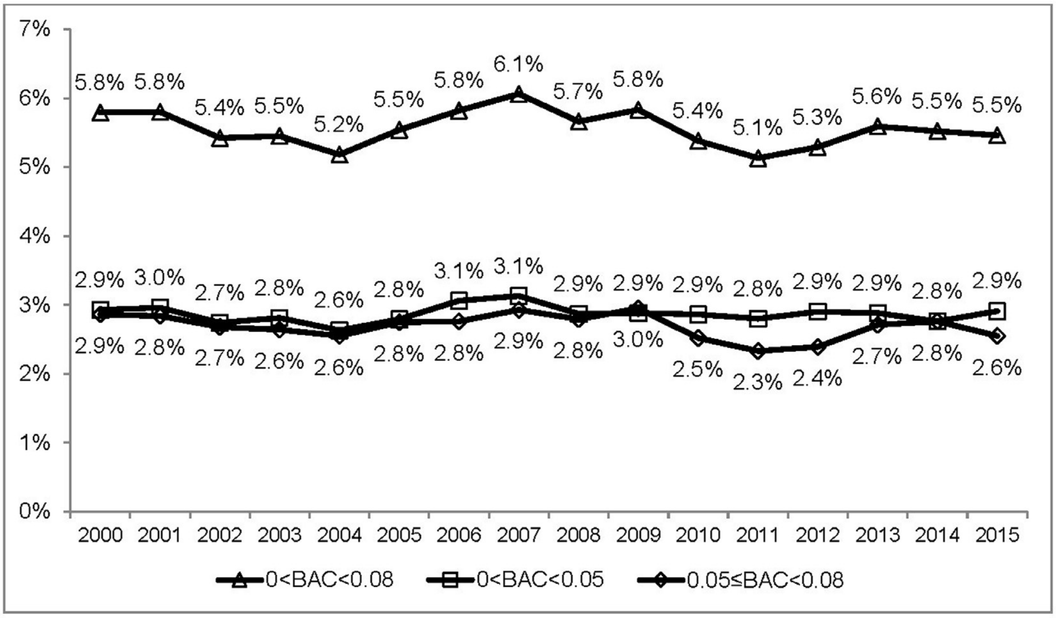

Figure 1. Proportion of motor vehicle crash fatalities involving alcohol below the legal BAC limit of 0.08% and stratified by 0.05% by year, U.S., Fatality Analysis Reporting System, 2000–2015.
BAC, blood alcohol content.

In comparison with fatalities from MVC crashes involving a BAC ≥0.08%, crash fatalities involving alcohol but at lower BAC levels were more likely to include nondrinking driver decedents (18.0% vs 13.2%) and involve multiple vehicles (44.2% vs 34.2%) (Table 1). In addition, compared with crash fatalities involving alcohol at ≥0.08%, decedents in crashes involving alcohol but at lower BACs were more likely to be female (26.0% vs 22.5%) and aged <21 years (19.6% vs 14.0%) and ≥55 years (18.5% vs 13.2%). Of the 6,648 youth who died in lower BAC crashes, 66.8% were not drinking drivers (data not shown in table). Lower BAC crash fatalities were also less likely to occur during a weekend or in the evening (i.e., from 6:00PM to 5:59AM).

When examining MVC fatalities by BAC level strata <0.08%, the number of fatalities generally increased with increasing BAC level (Figure 2). The proportion of victims who were those other than drinking drivers slightly decreased with increasing BAC level. The proportion of lower BAC crash fatalities were approximately split between those <0.05% and ≥0.05% (Figure 1).

In adjusted analyses, a 10 percentage point increase in the restrictiveness of the state policy environment was associated with reduced odds of alcohol involvement in crash fatalities at BACs >0.00% but <0.08% vs 0.00% (AOR=0.91, 95% CI=0.89, 0.93) (Table 2). This relationship was consistent in terms of direction, magnitude, and significance across most subgroups based on decedent and crash characteristics with only a few exceptions (e.g., black, non-Hispanic decedents). In a subgroup analysis restricted to decedents other than drinking drivers (i.e., nondrinking drivers, passengers, pedestrians, and cyclists), a 10 percentage point increase in the restrictiveness of the state policy environment was associated with reduced odds of alcohol involvement in crash fatalities at BACs >0.00% but <0.08% vs 0.00% (AOR=0.90, 95% CI=0.87, 0.93) (data not shown).

In additional analyses examining the odds of crash fatalities being alcohol-involved below and above a BAC level of 0.05%, the results were consistent (Table 2). A 10 percentage point increase in APS score was associated with reduced odds of alcohol involvement in crash fatalities at BACs >0.00% but <0.05% vs 0.00% (AOR=0.90, 95% CI=0.88, 0.93) and BACs ≥0.05% but <0.08% vs <0.05% (AOR=0.93, 95% CI=0.89, 0.96). Findings were similar for most decedent- and crash-level characteristics.

DISCUSSION

This is, to the authors' knowledge, the first study of how alcohol-involved crashes below the current legal limit in the U.S. relate to aggregate state alcohol control policy environments. There were the following 3 major findings:

1. Lower BAC crash fatalities accounted for a meaningful proportion of all alcohol-involved MVC fatalities;
2. In comparison with MVC crash fatalities involving BACs ≥0.08, lower BAC MVC decedents were more

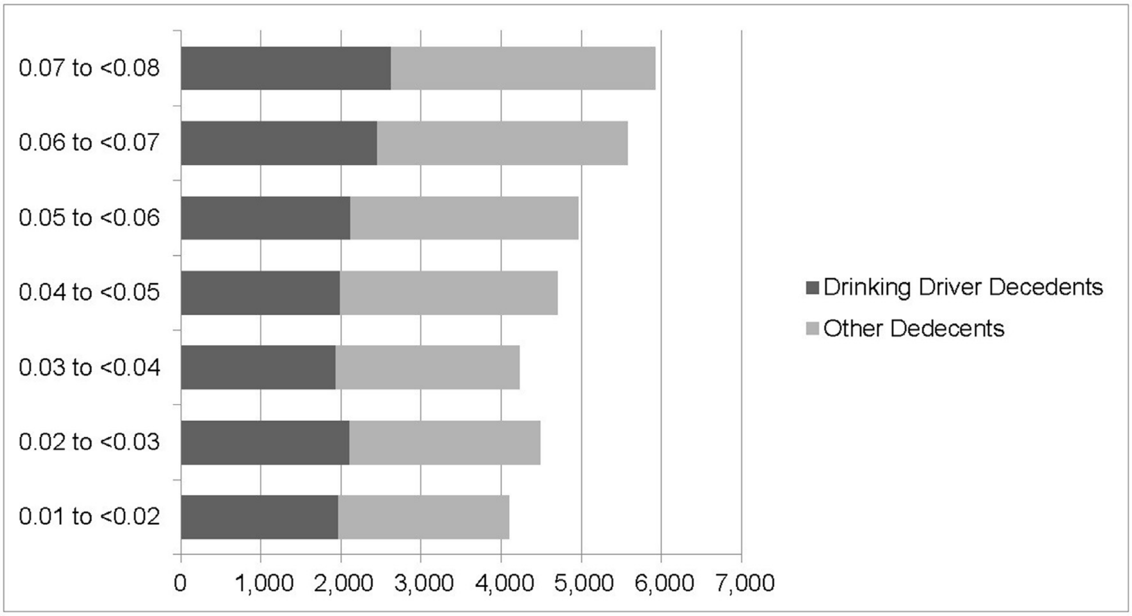

Figure 2. Fatalities from motor vehicle crashes involving a BAC level below 0.08%, by drinking driver status and BAC level, U.S., Fatality Analysis Reporting System, 2000–2015.
BAC, blood alcohol content.

likely to be individuals other than a drinking driver and were more likely to be youths; and

3. More restrictive state alcohol policies were associated with a lesser likelihood of alcohol involvement <0.08%, <0.05%, and from 0.05% to <0.08%.

From 2000 to 2015, approximately 37% of all MVC fatalities involved some alcohol; approximately 15% of these crash fatalities involved BAC levels lower than the current legal limit of 0.08%. Because they involve alcohol below the legal limit but often involve BACs associated with increased risk, lower BAC crash fatalities constitute an overlooked public health problem and an unaddressed source of MVC fatalities. Although it is understandable that research has focused on alcohol-related crashes occurring above the legal limit for driving, because the legal limit for impairment for driving is considerably higher than the level at which risks start to increase, many of these crash fatalities may also be due to alcohol.[8] Although beyond the scope of this study, future research on lower BAC crashes could focus on the role of other factors related to impaired driving such as cannabis use, mobile phone use, and distracted driving legislation.

Lower BAC fatalities were more likely to involve youth victims and those other than the drinking driver. Approximately 55% of lower BAC decedents were people other than the drinking driver; furthermore, among underage youth victims aged <21 years, two thirds of fatalities were not drinking drivers. The fact that these deaths take place on public roadways, and that most harms accrue to those other than the drinking driver, warrants a strong public health response. This finding undermines the popular misconception that alcohol-involved crashes primarily affect drinking drivers. Viewed in this way, policies designed to restrict impaired driving can be viewed as increasing the freedom from the worry of injury or death among most individuals sharing the roadway who are not drinking alcohol.

In addition, stronger policy environments are associated with reduced odds of alcohol involvement in crashes below the current legal limit of 0.08%. A 10% increase in the aggregate policy environment corresponded to a similar decrease in the odds of alcohol involvement in these crashes. This protective association was similar in magnitude to that which was observed in both adult and youth fatality victims involved in crashes with BACs ≥0.08%.[9,10] Protective associations were consistent throughout multiple strata of characteristics, including among decedents who were not the drinking driver. Therefore, strengthening current alcohol policies could reduce the likelihood of alcohol involvement in fatal crashes at all BAC levels.

Lastly, more restrictive policies were associated with reduced odds of alcohol involvement at BAC levels from 0.05% to 0.08%. In the context of future efforts to reduce the legal limit, it is informative to know that alcohol policies, from individual policy changes such as increasing

Table 2. Relationships Between a 10% Increase in APS and Likelihood of MVC Death by BAC Level

BAC subcategory	>0 to <0.08 vs 0 AOR (95% CI)	>0 to <0.05 vs 0 AOR (95% CI)	0.05 to <0.08 vs <0.05 AOR (95% CI)
Overall	**0.91 (0.89, 0.93)**	**0.90 (0.88, 0.93)**	**0.93 (0.89, 0.96)**
Drinking driver status			
Drinking driver	N/A	N/A	N/A
Nondrinking driver	**0.90 (0.86, 0.95)**	**0.91 (0.86, 0.96)**	**0.90 (0.82, 0.99)**
Passengers	**0.90 (0.86, 0.94)**	**0.89 (0.83, 0.94)**	**0.93 (0.87, 0.98)**
Others	**0.87 (0.81, 0.93)**	**0.88 (0.80, 0.97)**	**0.86 (0.77, 0.96)**
Sex			
Male	**0.91 (0.89, 0.94)**	**0.89 (0.86, 0.92)**	**0.94 (0.90, 0.98)**
Female	**0.91 (0.87, 0.94)**	**0.93 (0.88, 0.98)**	**0.89 (0.84, 0.94)**
Age, years			
<21	**0.92 (0.87, 0.96)**	**0.89 (0.84, 0.95)**	0.95 (0.88, 1.02)
21–34	**0.92 (0.89, 0.96)**	**0.92 (0.87, 0.96)**	**0.93 (0.88, 0.98)**
35–54	**0.92 (0.88, 0.96)**	**0.90 (0.86, 0.95)**	0.94 (0.89, 1.00)
≥55	**0.86 (0.82, 0.91)**	**0.88 (0.83, 0.94)**	**0.85 (0.79, 0.92)**
Race/ethnicity			
White, non-Hispanic	**0.93 (0.90, 0.95)**	**0.92 (0.89, 0.95)**	**0.94 (0.90, 0.98)**
Black, non-Hispanic	0.98 (0.91, 1.06)	0.95 (0.86, 1.05)	1.02 (0.91, 1.14)
Hispanic	**0.86 (0.79, 0.93)**	**0.84 (0.75, 0.95)**	**0.89 (0.81, 0.99)**
Other	**0.83 (0.78, 0.89)**	**0.83 (0.76, 0.90)**	**0.84 (0.77, 0.92)**
Weekend			
Yes	**0.92 (0.89, 0.96)**	**0.92 (0.88, 0.96)**	**0.93 (0.89, 0.98)**
No	**0.90 (0.87, 0.93)**	**0.89 (0.86, 0.93)**	**0.92 (0.87, 0.97)**
Time of day			
6:00AM to 5:59PM	**0.91 (0.88, 0.94)**	**0.91 (0.87, 0.95)**	**0.92 (0.86, 0.98)**
6:00PM to 5:59AM	**0.92 (0.89, 0.95)**	**0.91 (0.87, 0.94)**	**0.94 (0.90, 0.98)**
Vehicles			
Single vehicle crash	**0.92 (0.89, 0.95)**	**0.91 (0.87, 0.94)**	**0.94 (0.90, 0.97)**
Multiple vehicle crash	**0.90 (0.87, 0.94)**	**0.90 (0.86, 0.94)**	**0.91 (0.86, 0.97)**

Note: Boldface indicates statistical significance ($p<0.05$). All models adjusted for age, sex, race/ethnicity, year (as a categorical variable), and state-level covariates (proportion ≥21 years, proportion male, race/ethnicity proportions, college education, median household income, level of urbanization, policing rates, and vehicle miles traveled). Alcohol-related MVCs were defined as those in which the BAC of at least 1 driver involved was either >0.00% and <0.08%, >0.00% and <0.05%, or ≥0.05% and <0.08%. A 1-year lag was introduced between APS score and MVC fatalities (e.g., states' mortality rates from 2013 were associated with APS scores from 2012).
APS, Alcohol Policy Scale; BAC, blood alcohol content; MVC, motor vehicle crash.

alcohol taxes or strengthening interlock laws for driving under the influence offenders, to more comprehensive approaches that alter the greater alcohol policy environment such as changing to a 0.05% limit, may have protective effects for alcohol-involved crashes in that BAC range.[13] However, roughly two thirds of people in the developed world live in countries with a 0.05% BAC limit for driving[31] and countries that have reduced the legal BAC limit from 0.08% to 0.05% have seen reductions of 10%−15% in alcohol-related crash fatalities.[7,32] The National Academies of Sciences, Engineering, and Medicine and the National Transportation Safety Board have both recommended reducing the legal BAC limit to 0.05%.[16,33] Utah has enacted this legislation, and other states (e.g., California) are considering similar legislation.[17,34]

Limitations

This study had limitations. This was a repeated cross-sectional study and therefore causality cannot be inferred. Similarly, the analyses assessed the individual-level odds of alcohol involvement rather than state rates of MVC fatalities involving alcohol. Using logistic regression to calculate ORs of alcohol involvement depends on the ratios of fatalities involving and not involving alcohol at various thresholds. Therefore, it is possible that although an increase in APS score is associated with reduced likelihood of fatalities involving alcohol, the numbers of deaths may not actually be reduced. However, alcohol (even at low BAC levels) is an established risk factor for MVC crashes and fatalities, and the use of individual level odds allows a within-state counterfactual scenario that can account for unmeasured state-level confounders and makes it possible to account for individual-level covariates.[9,10,20,22] Future studies could validate this methodology as states change alcohol concentration driving limits. Because of the large sample size, finding significant associations is not surprising. Nonetheless, the fact that the findings for subgroup analyses were similar in direction and magnitude as for the overall results speak to the consistency and robustness of the findings, even among subgroups with considerably smaller sample sizes. The APS is an aggregate measure of policies, and effects of individual policies were not addressed in this study. The APS was developed with the Delphi approach, which relies on a priori expert opinion at a single point in time rather than mathematical prediction rules. APS scores do not account for local or federal policies that may affect alcohol consumption or driving practices. In addition, the causal attribution of alcohol to crashes is less for lower BAC versus higher BAC crashes.[2] Although great care was taken to adjust for multiple individual and state characteristics, there is nevertheless a possibility of residual confounding from factors such as distractions, fatigue, cell phone use, and other drug use. Finally, although FARS provides multiple data sets with imputed values for missing BAC levels, it is possible that state differences in BAC testing may have affected the results in unknown ways. However, using fatalities in which the BAC level was not imputed, similar proportions of crashes were alcohol-involved.

CONCLUSIONS

Lower BAC−related MVC fatalities have been overlooked as a public health issue. More restrictive alcohol policy environments are associated with reduced odds of fatal crashes involving alcohol at levels below the current legal limit, with comparable protective associations as for fatal crashes above the legal limit. This study suggests that strengthening alcohol policies could reduce alcohol-involved crash fatalities at all BAC levels.

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All authors made a substantial contribution to the conception and design of the study, to data acquisition, or to data analysis and interpretation; wrote or critically revised the article; and read and approved the final manuscript. VS conducted the analyses with input from TH. ML drafted the manuscript. TN, MM, TH, and VS provided critical revisions.

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