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REVIEW ARTICLE

Alcohol Consumption and 15 Causes of Fatal Injuries: A Systematic Review and Meta-Analysis

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Introduction: The proportion of fatal nontraffic injuries that involve high levels of alcohol use or alcohol intoxication was assessed by cause of injury to generate alcohol-attributable fractions. Updated alcohol-attributable fractions can contribute to improved estimates of the public health impact of excessive alcohol use.

Methods: Peer-reviewed and gray literature for 1995−2019 on 15 causes of fatal nontraffic injuries in the U.S., Canada, or Mexico were systematically reviewed, and state data systems were queried for available estimates of fatalities with recorded blood alcohol concentration levels and proportions of decedents with blood alcohol concentrations ≥0.10 g/dL by cause of injury. For each injury cause, alcohol-attributable fractions across studies were synthesized by meta-analysis of single proportions using generalized linear mixed models.

Results: In total, 60 published studies and 40 additional population-level data points from 6 state data systems were included. The meta-analyzed alcohol-attributable fractions by cause of injury are as follows: air-space transport (0.03), aspiration (0.24), child maltreatment (0.09), drowning (0.31), fall injuries (0.37), fire injuries (0.34), firearm injuries (0.24), homicide (0.29), hypothermia (0.29), motor vehicle nontraffic crashes (0.42), occupational and machine injuries (0.08), other road vehicle crashes (railroad trespasser injuries) (0.63), poisoning (not alcohol) (0.20), suicide (0.21), and water transport (0.27), yielding an overall median alcohol-attributable fraction of 0.27.

Discussion: Excessive alcohol use is associated with substantial proportions of violent and nonviolent injury deaths. These findings can improve the data used for estimating alcohol-attributable injury deaths and inform the planning and implementation of evidence-based strategies (e.g., increasing alcohol taxes, regulating alcohol outlet density) to prevent them.
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INTRODUCTION

Excessive alcohol use is a leading cause of preventable death in the U.S.[1] and was responsible for an average of >95,000 deaths each year during 2011−2015.[2] It is a risk factor for both unintentional and intentional injuries.[3] Binge drinking (i.e., the consumption of 4 or more drinks for women or 5 or more drinks for men on an occasion or in about a 2-hour period, which generally raises one's blood alcohol concentration [BAC] level to 0.08 g/dL or higher) is associated with an increase in the likelihood of fatal injuries.[2,4] Nearly one seventh of U.S. high-school students reported binge

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drinking in 2019,[5] as did one sixth of adults in 2018, and 25% of adults did so at least weekly.[6]

Alcohol-attributable fractions (AAFs) measure the contribution of alcohol use to a given health outcome or cause of death and are important for estimating alcohol-related morbidity and mortality. Direct estimates of AAFs (i.e., the proportion of persons dying from a particular alcohol-attributable condition that had a BAC above a specified level) are often used to measure the contribution of alcohol to acute causes of death, such as injuries. With approximately 10,000 deaths from alcohol-impaired driving recorded each year, AAFs for fatal motor vehicle crashes are well monitored in the U.S. relative to those of other causes of alcohol-related injuries, and such data are accessible from the Fatality Analysis Reporting System.[7]

Earlier reviews have examined the role of alcohol use in fatal injuries.[8−10] However, limited current data are available on alcohol involvement in fatal nontraffic injuries, and more are needed to improve the estimates of the public health burden of excessive alcohol use. The most recent meta-analysis on alcohol involvement in fatal nontraffic injuries in the U.S. was published >20 years ago using data from medical examiner reports from 1975 to 1995.[9] Given the increases in binge drinking and alcohol-related emergency department visits since then,[11−13] findings from earlier studies may no longer reflect the current situation. For example, binge drinking is a risk factor for other substance use,[14] and high levels of alcohol are commonly involved in drug overdoses.[15] Use of alcohol at the same time as benzodiazepines or opioids can increase the risk of a fatal overdose.[16] With the rise in drug overdose deaths,[17] the extent to which high levels of alcohol are involved in fatal drug overdoses and other poisonings may have changed since earlier reviews.

The purpose of this systematic review and meta-analysis is to assess the proportion of fatal nontraffic injuries that involve high levels of alcohol (BAC ≥0.10 g/dL or indications of alcohol intoxication) by cause of injury. The results from this meta-analysis can improve the data used for estimating alcohol-attributable deaths from nontraffic injuries, such as in data systems that rely on AAFs (e.g., the Centers for Disease Control and Prevention's [CDC] Alcohol-Related Disease Impact [ARDI] application). The findings from this study could also inform the planning and implementation of evidence-based population-level strategies[18] to reduce binge drinking and associated injuries and deaths.

METHODS

A total of 15 mutually exclusive acute causes of death from alcohol-attributable nontraffic-related injuries were included in this systematic review and meta-analysis: air-space transport, aspiration, child maltreatment, drowning, poisoning (not alcohol), fall injuries, fire injuries, firearm injuries, homicide, hypothermia, motor vehicle nontraffic crashes, other road vehicle crashes, occupational and machine injuries, suicide, and water transport. These categories align with the acute causes of death from partially alcohol-attributable nontraffic-related injuries that are used in CDC's ARDI application[19] and are identified primarily by the International Classification of Diseases, Ninth Revision and ICD-10 codes (Appendix 1, available online). Deaths from homicide or suicide are characterized as intentional injuries. Deaths from child maltreatment included unintentional and intentional injuries. All other causes of death included only unintentional injuries.

The CDC's ARDI application is a comprehensive tool for estimating state and national alcohol-attributable deaths and years of potential life lost for nearly 60 causes of alcohol-related death. Data on alcohol-related deaths from chronic conditions were not included in this study nor were injuries that are fully alcohol attributable (e.g., alcohol poisoning). Fully alcohol-attributable deaths (AAF=1.0) are those that would not occur in the absence of alcohol; therefore, no estimation is required. Because annual AAFs for fatal motor vehicle traffic crashes are available from the Fatality Analysis Reporting System,[20] they are not estimated in this meta-analysis, although they are included in ARDI. PRISMA guidelines were followed.[21] This study involved secondary analyses of deidentified data; therefore, IRB oversight was not required.

Search Strategy

For each of the 15 causes of fatal nontraffic injuries, published studies in peer-reviewed journals, government reports (e.g., medical examiners' reports), and other gray literature were systematically reviewed to identify studies, reports, and data systems that independently assessed alcohol involvement. Boolean algorithms were submitted to literature search engines that index relevant published studies, including PubMed, ScienceDirect, Web of Science, Cochrane Central, Embase, SCOPUS, CINAHL, Google Scholar, and Epistomonikos. Gray literature was also searched to capture data from sources that might not otherwise be available in the peer-reviewed literature (Appendix 2, available online),[22] including proceedings of professional association meetings, coroners' and medical examiners' reports, and U.S. federal and state government and Canadian reports.

State health surveillance systems, vital death records, and medical examiner/coroner offices have traditionally been the primary sources of data underlying fatal injury AAFs. Therefore, between January 2020 and August 2020, emails were sent to health departments or medical examiner government offices in 20 states that have centralized medical examiner systems or an epidemiologist working on alcohol. Each was provided with a table specifying the 15 causes of fatal injuries and the cause-specific ICD-10 codes. Recent 5 years of data were requested to calculate the number of fatalities with a valid BAC test result and the number of decedents with BAC ≥0.10 g/dL, by cause of injury.

An iterative, snowball search strategy was employed,[23] scanning reference lists and authors' names of primary sources identified as well as citations to studies ascertained through Web of Science to ensure literature saturation. This approach can be particularly effective in systematic reviews of multidisciplinary areas such as alcohol involvement in fatal injuries because primary sources may reference other reports with relevant data or additional literature from other fields. The International Classification of Diseases, Ninth Revision and ICD-10 codes from CDC's ARDI application were used to identify literature on the 15 types of injuries.[24] Systematic reviews were conducted from October 2019 through October 2020. Appendix 2 (available online) contains the details of the search strategy.

Inclusion criteria consisted of studies and reports on any of the 15 causes of fatal nontraffic injuries published from 1995 through 2019 or data from state systems during this period; involving human subjects; based in the U.S., Canada, or Mexico; and written in English. The search started with 1995, being the final year of reports included in the previous comprehensive meta-analysis on alcohol-related nontraffic injuries.[9]

Studies were primarily sought that reported direct AAF estimates or included data to directly assess AAFs (i.e., the proportion of persons that died of a particular injury with BAC ≥0.10 g/dL at the time of injury among those who had a valid BAC test). In other words, AAF is an estimate of the percentage of deaths that are attributed to alcohol. Consistent with CDC's ARDI application, 0.10 g/dL was used as the threshold for determining alcohol involvement instead of 0.08 g/dL (a common threshold level for acute intoxication). Injury fatalities can be due to many nonalcohol-related factors, and the higher BAC threshold provides a greater level of assurance for a death being attributable to alcohol.[9,25] Alcohol measurements from tissues other than blood were not included because of limited comparability with more common BAC measures.[9] BAC measurements are typically, although not always, obtained during injury death investigations conducted by medical examiners, coroners, or other government officials (e.g., forensic toxicology laboratories). These measurements are often included in state and local health surveillance and vital death records systems. Studies in which the AAF was equal to zero were included if selection bias was not suspected. A minimum sample size of at least 5 decedents with BAC test results per cause of death was required for inclusion.

Upon completion of comprehensive full-text reviews, minimal studies with suitable BAC data were identified for 7 fatal injury causes (aspiration, child maltreatment, fall injuries, homicide, hypothermia, occupational and machine injuries, and other road vehicle crashes). Therefore, the inclusion criteria were broadened for these to include descriptions of alcohol intoxication that would approximate BAC ≥0.10 g/dL (i.e., alcohol intoxication, alcohol impaired, inebriated, under the influence, drunk, or alcohol was a factor). This broader approach aligns with the seminal English and Holman meta-analysis on alcohol and numerous related outcomes.[10] Because our study reports AAFs by cause of injury, AAFs for the 7 causes mentioned earlier can be viewed separately from AAFs for the other causes. Appendix 1 (available online) provides further details on study inclusion by cause of death.

All citations identified in the systematic literature reviews were compiled and managed in an EndNote reference management database after initial screening for eligibility by a bibliographic research librarian (NW) on the basis of cause of injury, location, and presence of BAC information. Before data abstraction, 2 investigators closely examined the full-text reports for specificity and linkage of BAC information with fatal injuries, minimum sample size requirements, the remaining eligibility criteria, and any redundancies among reports. Each eligible source was compared with the remaining reports with respect to dates, places of data collection, and populations sampled to exclude duplicates. When the same underlying data were reported by >1 source, the source with the largest number of decedents was included.

Data abstraction forms were developed to collect the following information from each published report: report information (e.g., data source type, funding source); study eligibility (e.g., causes of death, BAC or alcohol intoxication data); study setting; population characteristics; methodology, including study design, sampling frame, selection criteria, fatal injury data sources, and BAC sources and timing; effect size, including the numbers of decedents, BAC tests, BAC test results ≥0.10 g/dL, and missing or unreported BAC tests; and risk of bias assessment.

The risk of bias assessment for individual studies was adapted from the Grading of Recommendations Assessment, Development, and Evaluation (GRADE) approach.[26] The GRADE approach uses specific evaluation criteria to identify the subset of studies likely to yield the most accurate approximation of the effect size of alcohol on each cause of death. It allows for optimal objectivity and clear communication of any subjective judgments. Consistent with this approach, 2 primary investigators with formal epidemiologic training and experience evaluating quality and risk of bias in research (HRA and CMC) independently performed data abstraction and evaluation. Discrepancies were adjudicated by a third epidemiologist investigator (MES), and any remaining issues were discussed and resolved among all investigators before analysis. Calibration exercises were held using clear instructions with explicit evaluation criteria, and a structured approach was employed to ensure transparency.

The potential study-level biases (selection bias, imprecision, missing data, external validity, and reporting bias) relevant to measures of direct AAF estimates (i.e., incidence and proportions) for fatal nontraffic injuries were evaluated following the PRISMA statement and GRADE recommendations.[21,27] Evaluation of non-peer-reviewed data considered internal consistency, reliability, and face validity of the sources. The risk of bias score was increased by 1 point for each type of bias judged to potentially influence the accuracy or precision of the AAF significantly. Points were summed for an overall rating of each study. Published studies that met inclusion criteria were selected for analysis if they had a risk of bias score not >3. In the absence of suitably defined data, emails were sent to authors of 8 potentially eligible studies requesting clarification of reported BAC data or other important missing information or to resolve observed inconsistencies.

Data abstracted included the numerator and denominator of the study-level AAF for each cause of death. The *numerator* was defined as the number of deaths where the decedent (or offender in homicide and child maltreatment cases) either had BAC ≥0.10 g/dL or was reported to be alcohol intoxicated. The *denominator* was defined as the number of deaths where the decedent (or offender) had either a valid BAC test result or a descriptive indication of alcohol involvement. For each cause of death, AAFs across studies were synthesized by meta-analysis of single proportions using generalized linear mixed models. Generalized linear mixed model was used rather than alternative methods (e.g., standard inverse variance methods such as Freeman–Tukey double arcsine transformation) because it avoids potential problems with back transformations by considering the binomial structure of AAF data.[28] The results were summarized in forest plots, which included point estimates and 95% CIs, to facilitate visual inspection of study heterogeneity. In addition, the I^2 statistic[29] was calculated to quantify the percentage of total variance contributed by between-study variance. The meta-analyzed AAFs were derived from the random-effects model, regardless of study heterogeneity. The analysis was conducted using the meta and metafor packages[30,31] implemented in R 4.0.5.[32] A sensitivity analysis was conducted by analyzing U.S.-only data to assess whether results were biased by the inclusion of data from Canadian studies for 6 causes of death (i.e., aspiration, drowning, hypothermia, occupational and machine injuries, suicide, and water transport).

RESULTS

The data in this meta-analysis were sourced from a total of 60 published studies (Figure 1) and 6 state data and surveillance systems (Colorado, Michigan, Minnesota, North Carolina, Utah, and Virginia) that provided data for 40 AAF estimates. Overall, data were included from 28 U.S. states, 5 national-level U.S. studies, and 6 Canadian studies. Characteristics of individual data sources, including study-level AAFs used for calculating the meta-analyzed AAFs, are presented in Table 1.[33−90] The number of original data sources included in the meta-analyses varied by cause of death, ranging from 2 for fall injuries to 19 for suicide (Figure 2). Risk of bias total scores were similar between investigators and reflected a low risk of bias within and across the included studies (Table 1 [33−90]).

The meta-analysis results for the 15 causes of fatal nontraffic injuries are summarized in Figure 2, including AAFs and associated 95% CIs. In alphabetical order, the AAFs were air-space transport (0.03), aspiration (0.24), child maltreatment (0.09), drowning (0.31), fall injuries (0.37), fire injuries (0.34), firearm injuries (0.24), homicide (0.29), hypothermia (0.29), motor vehicle nontraffic crashes (0.42), occupational and machine injuries (0.08),

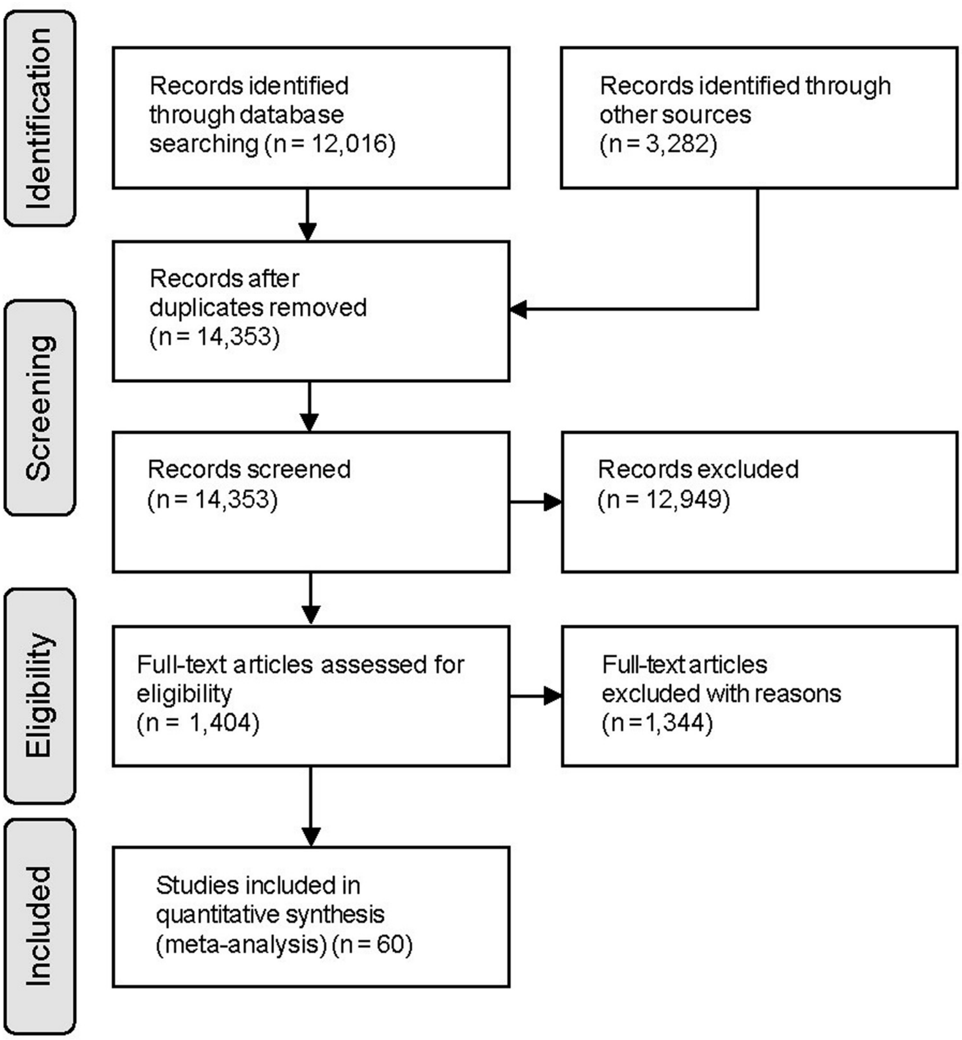

Figure 1. Flowchart of selection of studies for inclusion in the meta-analysis.

Causes	n[a]	BAC ≥ 0.10 g/dL[b]	Tested[c]	AAF [95% CI]	I^2[d]
Air-space transport	5	13	485	0.03 [0.01, 0.05]	0%
Aspiration	4	26	108	0.24 [0.08, 0.54]	88%
Child maltreatment	3	81	857	0.09 [0.08, 0.12]	0%
Drowning	9	1,108	3,067	0.31 [0.21, 0.42]	94%
Fall injuries	2	205	919	0.37 [0.07, 0.83]	100%
Fire injuries	8	544	1,680	0.34 [0.20, 0.51]	96%
Firearm injuries	8	105	553	0.24 [0.14, 0.38]	80%
Homicide	5	210	699	0.29 [0.23, 0.36]	70%
Hypothermia	4	53	189	0.29 [0.20, 0.40]	54%
Motor vehicle nontraffic crashes	7	488	1,036	0.42 [0.28, 0.56]	91%
Occupational and machine injuries	7	47	577	0.08 [0.02, 0.22]	70%
Other road vehicle crashes (railroad trespasser injuries)	4	643	1,191	0.63 [0.49, 0.75]	93%
Poisoning (not alcohol)	8	2,583	14,541	0.20 [0.13, 0.29]	100%
Suicide	19	13,870	62,723	0.21 [0.16, 0.27]	99%
Water transport	7	717	2,522	0.27 [0.22, 0.32]	64%

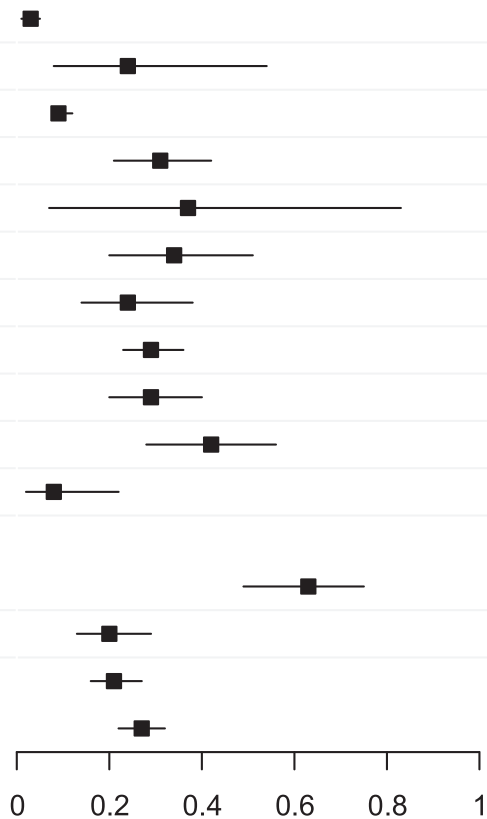

Figure 2. Meta-analysis of AAFs for 15 causes of fatal nontraffic injuries.

[a]*n*: the total number of studies and data from states included for a given cause of fatal injury.

[b]BAC ≥0.10 g/dL: the number of deaths where the involved decedent (or offender in homicide and child maltreatment cases) had BAC ≥0.10 g/dL or were reported to be alcohol intoxicated.

[c]Tested: the number of deaths where the involved decedent (or offender in homicide and child maltreatment cases) had either valid BAC test results or valid measures of alcohol involvement.

[d]I^2: a statistic that describes the percentage of variation across studies that is because of heterogeneity rather than chance.

AAF, alcohol-attributable fraction; BAC, blood alcohol concentration.

Table 1. Study Characteristics and Risk of Bias Scores for 15 Causes of Fatal Nontraffic Injuries

Studies by cause of death	Dates of injuries	Geographical location	BAC ≥0.10g/dL	BAC tests (*n*)	Alcohol-attributable fraction	Risk of bias score[a]
Air-space transport						
Botch and Johnson (2009)[33,b]	1997–2007	U.S.	1	139	0.01	2
Botch and Johnson (2008)[34,b]	2000–2007	U.S.	8	215	0.04	2
Li et al. (1998)[35]	1985–1994	North Carolina	4	101	0.04	2
Virginia data system	2014–2018	Virginia	0	17	0.00	NA
Utah data system	2014–2018	Utah	0	13	0.00	NA
Aspiration						
Boghossian et al. (2010)[36,c]	2000–2005	Quebec, Canada	2	11	0.18	1
Virginia data system	2014–2018	Virginia	4	50	0.08	NA
Utah data system	2014–2018	Utah	5	26	0.19	NA
North Carolina data system	2014–2019	North Carolina	15	21	0.71	NA
Child maltreatment						
Colorado CFPS (2021)[37,c]	2009–2018	Colorado	41	452	0.09	2
Parks et al. (2011)[38,c]	2005–2007	Texas	25	260	0.10	1
South Carolina SCFAC (2019)[39,c]	7/1/2018 – 6/30/2019	South Carolina	15	145	0.10	2
Drowning						
Okuda et al. (2015)[40]	2003–2013	Maryland	8	57	0.14	2
Cummings and Quan (1999)[41]	1975–1995	King County, Washington	91	304	0.30	2
Browne et al. (2003)[42]	1988–1994	New York	58	178	0.33	2
Canadian Red Cross society (2006)[43]	1991–2000	Canada	583	1,500	0.39	0
Lincoln et al. (1996)[44]	1988–1992	Alaska	94	186	0.51	3
Utah data system	2014–2018	Utah	11	130	0.08	NA
Virginia data system	2014–2018	Virginia	83	346	0.24	NA
Minnesota data system	2014–2018	Minnesota	49	136	0.36	NA
North Carolina data system	2014–2019	North Carolina	131	230	0.57	NA
Fall injuries						
Virginia data system	2014–2018	Virginia	89	760	0.12	NA
North Carolina data system	2014–2019	North Carolina	116	159	0.73	NA
Fire injuries						
Levine et al. (2001)[45]	3-year period before 2001	Maryland	45	196	0.23	1
Tridata Corporation (1999)[46]	1993–1996	Minnesota	67	255	0.26	2
U.S. Fire administration (2003)[47]	1996–2002	Minnesota	113	374	0.30	0
McGwin et al. (2000)[48]	1992–1997	Alabama	114	247	0.46	2
Marshall et al. (1998)[49]	2/1/1988 – 1/31/1989	North Carolina	69	130	0.53	0
Utah data system	2014–2018	Utah	5	40	0.12	NA
Virginia data system	2014–2018	Virginia	51	338	0.15	NA

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Table 1. Study Characteristics and Risk of Bias Scores for 15 Causes of Fatal Nontraffic Injuries (*continued*)

Studies by cause of death	Dates of injuries	Geographical location	BAC ≥0.10g/dL	BAC tests (*n*)	Alcohol-attributable fraction	Risk of bias score[a]
North Carolina data system	2014–2019	North Carolina	80	100	0.80	NA
Firearm injuries						
Cherry et al. (2001)[50]	1985–1994	North Carolina	55	351	0.16	0
Collins (2010)[51]	1987–2006	South Carolina	2	7	0.29	2
Shields et al. (2008)[52]	1993–2002	Kentucky	10	20	0.50	3
Minnesota data system	2015–2018	Minnesota	1	17	0.06	NA
Virginia data system	2014–2018	Virginia	7	67	0.10	NA
Colorado data system	2014–2018	Colorado	10	42	0.24	NA
Utah data system	2014–2018	Utah	9	30	0.30	NA
North Carolina data system	2014–2019	North Carolina	11	19	0.58	NA
Homicide						
Spunt et al. (1998)[53,c,b]	1992–1993	New York	41	181	0.23	2
Spunt et al. (1995)[54,c]	1984	New York	86	269	0.32	2
Banks et al. (2008)[55]	1993–2002	New Mexico	12	37	0.32	2
Greenfeld (1998)[56]	1996	U.S.	65	173	0.38	2
Utah data system	2014–2018	Utah	6	39	0.15	NA
Hypothermia						
Koutsavlis and Kosatsky (2003)[57,c]	1994–1998	Montreal Island and Ile-Bizard, Quebec, Canada	3	12	0.25	2
Utah data system	2014–2018	Utah	13	55	0.24	NA
Virginia data system	2014–2018	Virginia	26	101	0.26	NA
North Carolina data system	2014–2019	North Carolina	11	21	0.52	NA
Motor vehicle nontraffic crashes						
Minnesota DNR (2002–2010)[58]	2002–2010	Minnesota	44	166	0.27	1
Hall et al. (2009)[59]	2004–2006	West Virginia	23	52	0.44	1
Wisconsin DNR (2002–2020)[60,d]	2002–2020	Wisconsin	118	245	0.48	1
Minnesota DNR (2001–2015)[58]	2001–2015	Minnesota	81	165	0.49	1
Wisconsin DNR (2001–2020)[61,d]	2001–2020	Wisconsin	206	343	0.60	1
Landen et al. (1999)[62]	1990–1994	Alaska	11	17	0.65	2
Utah data system	2014–2018	Utah	5	48	0.10	NA
Occupational and machine injuries						
West et al. (1996)[63]	1986–1991	Ontario, Canada	0	24	0.00	3
Foster and Dissanaike (2014)[64]	2007–2011	Texas	0	11	0.00	3
Davis and Brissie (2000)[65]	1981–1996	Jefferson County, Alabama	0	10	0.00	2
Fullerton et al. (1995)[66]	1980–1991	New Mexico	29	449	0.06	1
Lucas and Lincoln (2007)[67,c]	1990–2005	Alaska	14	71	0.20	2
Utah data system	2014–2018	Utah	1	5	0.20	NA

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Table 1. Study Characteristics and Risk of Bias Scores for 15 Causes of Fatal Nontraffic Injuries (*continued*)

Studies by cause of death	Dates of injuries	Geographical location	BAC ≥0.10g/dL	BAC tests (*n*)	Alcohol-attributable fraction	Risk of bias score[a]
North Carolina data system	2014–2019	North Carolina	3	7	0.43	NA
Other road vehicle crashes (railroad trespasser injuries)						
North American Management (2013)[68,c]	2005–2010	U.S.	470	940	0.50	1
CDC (1999)[69]	1990–1996	Georgia	40	78	0.51	2
Pelletier (1997)[70]	1990–1994	North Carolina	100	125	0.80	1
North Carolina data system	2014–2019	North Carolina	33	48	0.69	NA
Poisoning (not alcohol)						
Przepyszny and Jenkins (2007)[71]	2000–2003	Cuyahoga County, Ohio	19	84	0.23	1
Moolenaar et al. (1995)[72]	1980–1988	New Mexico	17	74	0.23	2
Levine et al. (1995)[73]	A12-month period before 1995	Maryland	48	119	0.40	2
Utah data system	2014–2018	Utah	170	1,719	0.10	NA
Michigan data system	2017–2018	Michigan	475	4,081	0.12	NA
Virginia data system	2014–2018	Virginia	668	5,576	0.12	NA
Minnesota data system	2019	Minnesota	60	500	0.12	NA
North Carolina data system	2014–2019	North Carolina	1,126	2,388	0.47	NA
Suicide						
Weinberger et al. (2001)[74]	1996–1997	Los Angeles county, California	1	46	0.02	3
Lewis et al. (2007)[75]	1993–2002	U.S.	0	14	0.00	2
San Nicolas and Lemos (2015)[76]	2011–2013	San Francisco county, California	14	102	0.14	1
Bullock and Diniz (2000)[77]	1993–1997	Ontario, Canada	11	77	0.14	2
Davis (1999)[78]	1994–1998	Broward County, Florida	4	24	0.17	2
Wolford-Clevenger et al. (2020)[79]	2013–2019	Jefferson County, Alabama	75	447	0.17	1
Cherpitel (1996)[80]	12/1987–11/1988 and 02/1992–01/1993	Contra Costa county, California and hinds county, Mississippi	17	101	0.17	1
Fisher et al. (2015)[81]	1994–2008	Cuyahoga County, Ohio	380	2,178	0.17	1
Branas et al. (2011)[82]	2003–2006	Philadelphia, Pennsylvania	24	123	0.20	2
Kaplan et al. (2012)[83]	2003–2009	16 states[e]	7,777	39,579	0.20	0
Shields et al. (2006, 2008)[52,84]	1993–2002	Kentucky	656	2,702	0.24	0
Przepyszny and Jenkins (2007)[69]	2000–2003	Cuyahoga County, Ohio	8	31	0.26	1
Conner et al. (2016)[85]	2012	New Mexico	88	224	0.39	3
Utah data system	2014–2017	Utah	485	2,416	0.20	NA
Virginia data system	2014–2018	Virginia	493	2,417	0.20	NA
Minnesota data system	2015–2018	Minnesota	588	2,490	0.24	NA
Colorado data system	2014–2018	Colorado	1,038	4,221	0.25	NA
Michigan data system	2014–2018	Michigan	962	3,645	0.26	NA
North Carolina data system	2014–2019	North Carolina	1,249	1,886	0.66	NA

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Table 1. Study Characteristics and Risk of Bias Scores for 15 Causes of Fatal Nontraffic Injuries (*continued*)

Studies by cause of death	Dates of injuries	Geographical location	BAC ≥0.10g/dL	BAC tests (*n*)	Alcohol-attributable fraction	Risk of bias score[a]
Water transport						
New York State OPRHP (2013–2019)[86]	2013–2019	New York	14	83	0.17	2
Wisconsin DNR (2004–2018)[87]	2004–2018	Wisconsin	37	170	0.22	1
Browne et al. (2003)[88]	1988–1994	New York	18	73	0.25	2
Smith et al. (2001)[89]	1990–1998	Maryland and North Carolina	60	221	0.27	1
Barss (2011)[90]	1991–2008	Canada	565	1,923	0.29	1
Virginia data system	2014–2018	Virginia	3	7	0.43	NA
Minnesota data system	2014–2018	Minnesota	20	45	0.44	NA

[a]State data systems were not assigned a risk of bias score.
[b]Cases are from separate, nonoverlapping samples in Botch et al. reports.
[c]Data were based on descriptive reports of alcohol intoxication, drunkenness, or alcohol being a factor involved in the fatalities.
[d]Cases are from separate, nonoverlapping samples (including snowmobiles and all-terrain vehicles) in the Wisconsin Department of Natural Resources motor vehicle nontraffic crash reports.
[e]States included were Alaska, Colorado, Georgia, Kentucky, Maryland, Massachusetts, New Jersey, New Mexico, North Carolina, Oklahoma, Oregon, Rhode Island, South Carolina, Utah, Virginia, and Wisconsin.
BAC, blood alcohol concentration; CFPS, Child Fatality Prevention System; DNR, Department of Natural Resources; NA, not applicable; OPRHP, Office of Parks, Recreation and Historic Preservation; SCFAC, State Child Fatality Advisory Committee.

other road vehicle crashes (railroad trespasser injuries) (0.63), poisoning (not alcohol) (0.20), suicide (0.21), and water transport (0.27). The AAF for each cause of death can be interpreted as the percentage of deaths attributable to alcohol among those with known BAC levels or intoxication status. For example, 24% of 553 firearm injury deaths with known BAC levels were attributable to alcohol. Overall, cause-specific analyses yielded a median AAF of 0.27. Study heterogeneity, based on I^2, varied by cause of death, ranging from 0% for air-space transport and child maltreatment to 100% for fall injuries and poisoning (not alcohol) (Appendix 3, available online). In sensitivity analysis, no statistically significant differences (based on overlapping 95% CIs) were observed between AAFs derived with and without the inclusion of Canadian data (Appendix 4, available online).

DISCUSSION

This study is the most current and comprehensive systematic review and meta-analysis assessing involvement of excessive alcohol use in deaths from 15 causes of fatal nontraffic injuries. The study shows that excessive drinking was associated with more than one quarter of violent and nonviolent injury deaths. For example, the findings show that almost 1 in 4 unintentional firearm injury deaths, 1 in 3 homicides, 1 in 5 poisonings (not alcohol), and 1 in 5 suicides involved alcohol, with a BAC ≥0.10 g/dL or a descriptive indication of alcohol intoxication. The mechanisms by which excessive drinking might lead to these deaths could include the effects of alcohol and impaired brain function resulting in poor judgment; slow decision making and reaction time; reduced perception and response to hazards; loss of balance and motor skills; and through behavioral effects, such as increased risk taking, reduced inhibitions, reduced processing of communications, and increased aggression.[8,91,92] Some effects of alcohol, including impairment in judgment and motor dysfunction, are apparent at BAC levels <0.10 g/dL.[93]

AAF estimates were determined in this study using the direct method, which is based on the proportion of deaths from a given cause of injury due to alcohol. This method has advantages compared with approaches for estimating alcohol-related injury fatalities that are not based on individual causes of death. For example, applying continuous distributions that consider the prevalence of alcohol use and the RR of dying from a given injury to the estimated number of deaths from that injury generally involves aggregating alcohol-attributable injuries into broad categories (e.g., road injuries, other unintentional injuries, intentional injuries).[94] This is because limited cause-specific data are available to inform risk functions. Others have indicated that a systematic review of data from medical examiners' and coroners' reports on the contribution of alcohol to injury deaths, such as those used in this study, might be more accurate than estimates generated from continuous risk functions.[95]

Unlike other studies on alcohol-related homicides that rely on BAC among victims, a strength of this study is that it uniquely considered alcohol intoxication among homicide offenders.[96] Offender BACs for homicides and child maltreatment are typically not collected by state data and surveillance systems. Sources of homicide and maltreatment data in this study used either offender BAC or alternatively observer or self-reports of alcohol intoxication among offenders.

Most of the poisoning (not alcohol) deaths in this study were from drug overdose fatalities that involved a BAC ≥0.10 g/dL. However, the AAF of 0.20 may underestimate the role of alcohol in drug overdose deaths because alcohol can contribute to overdoses at low levels, particularly when combined with substances such as opioids or benzodiazepines.[97,98] Nevertheless, binge drinking is associated with the use of other substances and increases the risk of concurrently misusing prescription drugs, which increases the chance of overdose.[14]

Limitations

This meta-analysis has limitations. The contribution of alcohol to mortality is generally underestimated in studies, in part owing to incomplete alcohol use documentation in death certificates.[99,100] Alcohol testing rates among decedents vary by decedents' characteristics (e.g., race/ethnicity), cause of death, and state of residence.[100,101] State-level data in this study were from 28 states, including 6 state surveillance systems. Additional states did not provide data from their surveillance systems for reasons provided such as labor intensiveness and insufficient resources during the severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) (coronavirus disease 2019 [COVID-19]) pandemic. The inclusion of data from only some state data systems potentially introduces biases in the AAFs owing to socioeconomic, demographic, policy environment, or social norm differences among states regarding drinking.

Because AAFs in this meta-analysis were calculated as a percentage among decedents tested for alcohol, the estimates might be high if decedents who were not tested for alcohol had consistently lower BAC levels. Testing rates, procedures for conducting postmortem BAC tests, and timing of alcohol testing (relative to both the time since alcohol was consumed and time after death) likely varied across states,[101] although most potential systematic biases in BAC testing (e.g., lag between death and BAC test) likely led to conservative AAF estimates.[95,102,103] Postmortem BACs used to estimate ante mortem drinking can vary in either direction relative to ante mortem BACs.[101,102,104] Variability exists in AAFs from individual sources within causes of death. Some relatively extreme values might have contributed to the nonstatistically significant differences observed between random-effects and fixed-effect estimates for certain causes. These could also be partially explained by factors such as differences in alcohol use by sex, age, race/ethnicity, or location. However, sufficient data were not available to estimate AAFs by decedents' characteristics, and observed variation in AAFs by location across individual sources improves generalizability.

The sensitivity analyses suggest that biases did not result from inclusion of Canadian data, although the AAFs in this meta-analysis might not reflect those that would be obtained from meta-analyses of exclusively Canadian data. The U.S. and Canada are comparable on several indicators of population-level alcohol consumption (e.g., per capita alcohol consumption, prevalence of heavy episodic drinking),[105] although they may differ in other relevant aspects (e.g., implementation and enforcement of alcohol control policies). These AAFs also might not be generalizable to Mexico because only studies in English were searched.

There were some limitations because of the data available for certain causes of death. Deaths from poisonings have the potential for misclassification of intent (suicide versus unintentional) and for unobserved heterogeneity.[106] For deaths from homicide and child maltreatment, BAC data among offenders are potentially limited because the offenders are often not apprehended immediately at the time of injury. Given the sensitive nature of child maltreatment deaths, further data on alcohol involvement in these deaths may be discovered from restricted sources, such as the National Child Death Review Case Reporting System.

For fall injuries, the AAF estimate was based on the data of >900 decedents, although high study heterogeneity between the 2 data sources and the wide 95% CIs suggest some uncertainty around the estimate. The extent to which excessive alcohol use contributes to deaths from falls might vary by age group. More data pertaining to the age distribution of decedents would be needed to differentially estimate alcohol-related falls among younger and older people. Nevertheless, falls contribute to a substantial number of deaths each year, especially among older adults,[107] and a linear association has been documented between the amount of alcohol consumed and the risk of fall injuries.[108]

Fatal injuries from other road vehicle crashes involve pedestrians or occupants who collide with or fall from pedal cycles, other nonmotor vehicles, or railway trains; however, the available studies of alcohol involvement in these deaths pertained solely to scenarios involving railroad trespassers (i.e., persons on railroad property whose presence was prohibited or unlawful). One of these studies documented that alcohol intoxication was the most frequently reported factor associated with these deaths,[88] as when people walk across railroad tracks while being intoxicated.[89,90] The AAF for these circumstances might not be applicable to different situations of other road vehicle crash deaths.

Available data regarding air-space transport were limited to pilot fatalities. Data reported in one of the studies on aviation-related crashes suggests that the number of aviation passenger deaths per crash did not differ between crashes involving and not involving alcohol.[109] The AAF for this cause of death may therefore be appropriate for estimating the total number of alcohol-attributable deaths among persons who die from air-space transport injuries.

Despite these limitations, the findings in this meta-analysis have public health implications. Effective population-level approaches for preventing excessive drinking include those recommended by the Community Preventive Services Task Force, such as strategies to decrease the availability of and access to alcohol or to increase alcohol prices.[110−112] In addition to reducing the number and concentration of alcohol outlets, having dram shop liability laws to hold retailers accountable for harms incurred by service to intoxicated or underage patrons could also reduce alcohol-attributable injury deaths.[111,113] These population-level alcohol policies have been found to be associated with reductions in several causes of death, including homicides,[114] suicides,[115] and pedestrian injuries.[116] Screening and brief interventions to reduce excessive alcohol use might also reduce alcohol-related injuries if delivered face to face in clinical settings or using electronic devices in a variety of settings (e.g., healthcare facilities, universities, workplaces).[117,118]

CONCLUSIONS

The results of this meta-analysis show that a median of 27% of fatalities from nontraffic injuries are attributable to excessive alcohol use, which is a preventable risk behavior. The updated AAFs in this meta-analysis are fundamental for improving the estimates of alcohol-attributable deaths (as in CDC's ARDI application) and for calculating the economic burden of excessive drinking. Such data are essential for establishing public health priorities. Future research would benefit from more routine and widespread data collection on alcohol involvement in nontraffic fatal injuries, particularly those where previous investigation has been lacking. Our findings underscore the importance of implementing and enforcing evidence-based strategies for preventing excessive drinking and designing and encouraging safer community environments.

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SUPPLEMENTAL MATERIAL

Supplemental materials associated with this article can be found in the online version at https://doi.org/10.1016/j.amepre.2022.03.025.

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