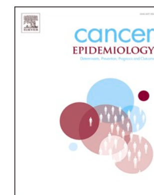
Cancer Epidemiology 71 (2021) 101893

Contents lists available at ScienceDirect

Cancer Epidemiology

journal homepage: www.elsevier.com/locate/canep



Proportion of cancer cases and deaths attributable to alcohol consumption by US state, 2013-2016

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ARTICLE INFO

Keywords:
Alcohol
Attributable fraction
Burden
Cancer
Mortality

ABSTRACT

Background: Alcohol consumption is an established risk factor for several cancer types, but there are no contemporary published estimates of the state-level burden of cancer attributed to alcoholic beverage consumption. Such estimates are needed to inform public policy and cancer control efforts. We estimated the proportion and number of incident cancer cases and cancer deaths attributable to alcohol consumption by sex in adults aged ≥30 years in all 50 states and the District of Columbia in 2013–2016.
Methods: Age-, sex-, and state-specific cancer incidence and mortality data (2013–2016) were obtained from the US Cancer Statistics database. State-level, self-reported age and sex stratified alcohol consumption prevalence was estimated using the 2003–2006 Behavioral Risk Factor Surveillance System surveys and adjusted with state sales data.
Results: The proportion of alcohol-attributable incident cancer cases ranged from 2.9 % (95 % confidence interval: 2.7 %–3.1 %) in Utah to 6.7 % (6.4 %–7.0 %) in Delaware among men and women combined, from 2.7 % (2.5 %–3.0 %) in Utah to 6.3 % (5.9 %–6.7 %) in Hawaii among men, and from 2.7 % (2.4 %–3.0 %) in Utah to 7.7 % (7.2 %–8.3 %) in Delaware among women. The proportion of alcohol-attributable cancer deaths also varied considerably across states: from 1.9 % to 4.5 % among men and women combined, from 2.1% to 5.0% among men, and from 1.4 % to 4.4 % among women. Nationally, alcohol consumption accounted for 75,199 cancer cases and 18,947 cancer deaths annually.
Conclusion: Alcohol consumption accounts for a considerable proportion of cancer incidence and mortality in all states. Implementing state-level policies and cancer control efforts to reduce alcohol consumption could reduce this cancer burden.

1. Introduction

Alcohol consumption is an established risk factor for several cancer types [1]. We previously estimated that alcohol consumption accounted for 5.6 % of incident cancer cases and 4.0 % of cancer deaths among adults ≥30 years in the United States in 2014 [2], but state-level variations in alcohol consumption are likely to result in differences in alcohol-related cancer burden across states. However, there are no contemporary published estimates of state-level burden for alcohol-related cancer cases or deaths. This information would be useful for prioritizing state-level cancer prevention and control efforts, as many public health policies to reduce alcohol consumption are decided at the state level [3]. Herein, we estimate the proportion and number of incident cancer cases and cancer deaths attributable to alcohol consumption by sex in all 50 states and the District of Columbia in 2013–2016.

2. Methods

2.1. Data sources

Cancer types associated with alcohol consumption were selected according to the International Agency for Research on Cancer's

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https://doi.org/10.1016/j.canep.2021.101893
Received 9 November 2020; Received in revised form 5 January 2021; Accepted 6 January 2021
Available online 19 January 2021
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Monographs on the Evaluation of Carcinogenic Risks to Humans and included cancers of the oral cavity and pharynx, larynx, esophagus (squamous cell carcinoma [SCC] only), liver, colorectum, and female breast [1]. Relative risks (RRs) and corresponding 95 % confidence intervals (CIs) for dose-response associations between alcohol use and individual cancer types from observational studies were based on equations presented in a report as selected by the World Health Organization Technical Advisory Group on Alcohol and Drug Epidemiology (Supplemental Table 1) and were controlled for major confounding factors by cancer type, including smoking [4]. Total numbers of incident cancer cases and deaths diagnosed/recorded from 2013 through 2016 for each evaluated cancer type were obtained by sex, age group (30–49, 50–59, 60–69, 70–79, and ≥80 years), and state from the United States Cancer Statistics (USCS) public use database using SEER*Stat software version 8.3.5 [5]. Mortality data were based on information from all death certificates for U.S. residents; incidence data from cancer registries also covered 100 % of the population for all 50 states and the District of Columbia during the study period. To minimize any effects of variations in detailed histological information across states, we applied the proportions from national incidence data to estimate the number of esophageal SCC cases and deaths at the state level.

Alcohol consumption data and corresponding standard errors by sex, age group, and state were obtained from the 2003–2006 Behavioral Risk Factor Surveillance System (BRFSS) surveys. BRFSS is a state-level telephone survey of adults ages 18 years and older [6]. The median overall survey response rates were 42.1 %, 41.2 %, 36.5 %, and 35.4 % from 2003 to 2006, respectively (range across states and over time: 20.5%–65.5%), and no data were available for Hawaii in 2004. The total analytic sample size for exposure data was 1,204,372 (men: 462,267; women: 742,105), which excluded those with invalid data for alcohol consumption (n = 20,896, 1.7 %). Age groups for 2003–2006 exposure data were defined as 20–39, 40–49, 50–59, 60–69, and ≥70 years to allow for a lag period of approximately 10 years between the prevalence of exposure and cancer occurrence (2013–2016), although lag time for some cancer types is not known. The number of alcoholic drinks per day was calculated for respondents who reported consuming at least one alcoholic beverage in the previous month; others were considered to have consumed zero drinks per day. Using the BRFSS data for the current study, we were unable to capture exposure among those who consume less than 1 drink per month; however, alcohol-associated cancer risk is most pronounced at higher levels of alcohol consumption, which we were able to measure. Additionally, we used contemporary exposure data (2013–2016) by sex and age group (30–49, 50–59, 60–69, 70–79, and ≥80 years) from BRFSS for comparison with previously published national-level estimates that used contemporary exposure data from the National Health Interview Survey (NHIS) [2]. Despite differences in the methods of administration and study questions, the average absolute difference in alcohol consumption amount between BRFSS and NHIS has been small across years [7,8].

While overall trends of self-reported alcohol consumption are similar to sales data [9], self-reported alcohol consumption is potentially underreported, the extent of which likely differs by consumption level and drinking patterns [10–12]. To account for this, we adjusted self-reported consumption data with per-capita sales data for the same time period [11–14]. As a result of the low alcohol tax rate, sales data are likely inflated for New Hampshire due to cross-border sales to residents of other New England states [13]. Therefore, we used the average sales of the six New England states (Connecticut, Maine, Massachusetts, New Hampshire, Rhode Island, and Vermont) for those states. Sales data are also likely inflated for the District of Columbia due to substantial levels of tourism [13]. Thus, for the District of Columbia, we applied the average sales data from the District of Columbia and surrounding states of Maryland and Virginia.

All analyses were conducted between August 2019 and June 2020. Only deidentified, publicly available data were used in this study; therefore, Institutional Review Board approval and patient written consent were not required.

2.2. Statistical analysis

Weighted, state-level prevalence estimates of alcohol consumption overall, by sex, and age group were calculated using SAS callable SUDAAN release 11.0.1 and accounted for the complex survey design. Sales-adjusted alcohol consumption per day was categorized as follows, assuming 14 g of alcohol per drink [15]: 0 drinks (0 g), >0 to <1 drinks (>0 to <14 g), 1 to <2 drinks (14 to <28 g), 2 to <3 drinks (28 to <42 g), 3 to <4 drinks (42 to <56 g), 4 to <8 drinks (56 to <112 g), and ≥8 drinks (≥112 g). Although the more granular categories were used for analyses, consumption patterns are summarized in Supplemental Figures 1 and 2 [16]. Cancer type-specific RRs were calculated using the mid-point grams/day for each of the above consumption categories (e.g., >0 to <1 drinks/day = 7 g/day). For the highest category with an open-ended upper bound (≥8 drinks/day), consistent with previously published work [17], we considered the exposure level to be approximately 1.2 times the lower bound, i.e., 10 drinks (140 g) per day.

For each sex, age group, and state stratum, we applied a simulation method and generated numbers from 1000 repeated draws for all RRs, exposure levels, and number of cases and deaths to account for uncertainties associated with these data and calculate 95 % CIs for the point estimates [18]. We assumed that RRs (in logarithmic scale) and exposure levels followed normal distributions, whereas cancer counts followed a Poisson distribution. Standard errors were available from the survey data for alcohol consumption categories, and for LogRRs, they were back-calculated based on the reported 95 % CIs. The sex-, age-, and state-specific population attributable fractions (PAFs) were calculated using the prevalence of six categories of alcohol consumption (*P1 to 6*) in each sex '*i*', age group '*a*', and state '*s*' stratum and the corresponding RR (*RR1 to 6*) [19] for all 1000 replications (see formula below). PAFs represent estimates of the proportion of a given outcome attributable to a given risk factor.

$$PAF_{ias} = \frac{P_{1ias}(RR_1 - 1) + P_{2ias}(RR_2 - 1) + \ldots + P_{6ias}(RR_6 - 1)}{P_{1ias}(RR_1 - 1) + P_{2ias}(RR_2 - 1) + \ldots + P_{6ias}(RR_6 - 1) + 1}$$

The PAFs were multiplied by the number of cancer outcomes (*N*) in each stratum to calculate the number of attributable cases or deaths in that stratum:

$$Number\ of\ attributable\ cases/deaths_{ias} = PAF_{ias} \times N_{ias}$$

These sex-, age-, and state-specific attributable numbers were then summed over age groups to estimate the number of cancer outcomes (overall and by type) attributable to alcohol consumption by sex and state. That number was then divided by the total number of cancer cases and deaths to estimate overall sex- and state-specific PAFs, in total and by cancer type. Of note, we divided the number of esophageal SCC cases and deaths attributable to alcohol consumption by the total number of esophageal cancers (all subtypes rather than esophageal SCC only), so PAFs for this cancer type in this report represent the proportion of all esophageal cancers attributable to alcohol consumption. To estimate the number and proportion of cancer outcomes attributable to alcohol consumption nationwide, we divided the sum of the number of alcohol-attributable cancer outcomes across all 50 states and the District of Columbia by the total number of corresponding cancer outcomes at the national level. As numbers of attributable cancer outcomes overall and by sex and individual cancer type were generated from separate simulation models, numbers of cancer outcomes or individual cancer types may not sum to totals. The proportions and number of alcohol-attributable outcomes presented herein are the medians of the corresponding values from 1000 replications; the 95 % CIs are the 25th and 975th ordered values. Stata version 15 was used for simulations and subsequent analysis.

3. Results

3.1. Incident cancer cases

Among men and women combined, an estimated 4.8 % (95 % CI: 4.7–5.0; n = 75,199 annually) of cancer cases among adults aged ≥30 years could be attributed to alcohol consumption (Table 1, Supplemental Table 2). The proportion was slightly lower among men (4.7 %, 95 % CI: 4.5–4.9; n = 36,815 annually) than women (5.0 %, 95 % CI: 4.9–5.0; n = 38,384 annually). State-specific estimates ranged from less than 4 % in Tennessee, Kansas, Kentucky, Arkansas, Oklahoma, West Virginia, and Utah to more than 6 % in the District of Columbia, Alaska, New Hampshire, Colorado, Nevada, and Delaware (Fig. 1A and Supplemental Table 2). Estimates and patterns were comparable when 2013–2016 alcoholic beverage consumption data were used (data not shown).

By cancer type, alcohol consumption accounted for 49.8 % (95 % CI: 46.4–53.8; n = 91,017) of oral cavity/pharyngeal cancers and 30.1 % (95 % CI: 26.4–34.5; n = 14,899) of laryngeal cancers nationally during 2013–2016 (Supplemental Table 3). Alcohol consumption also accounted for an estimated 12.1 % (95 % CI: 12.0–12.2) of female breast cancers, equating to an estimated 115,794 cases (approximately three-fourth of all alcohol-attributable cases among women) for 2013–2016 combined. Additionally, 11.1 % (95 % CI: 11.0–11.2; n = 62,766) of colorectal, 10.5 % (95 % CI 10.3–10.6; n = 11,124) of liver, and 7.7 % (95 % CI: 7.3–8.0; n = 5146) of esophageal cancers could be attributed to alcohol consumption. In most states (46 out of 51), ≥45 % of oral cavity/pharyngeal cancers and ≥25 % of laryngeal cancers were attributable to alcohol consumption. For each cancer type evaluated, Delaware had the highest PAF and Utah the lowest, except for breast cancer where West Virginia had the lowest. The difference in proportions across states was also most pronounced for breast cancer where the PAF for Delaware (19.3 %, 95 % CI: 17.8–20.6) was about 2.7 times that of West Virginia (7.2 %, 95 % CI: 6.4–8.0).

By sex, the overall PAF among men ranged from 2.7 % (95 % CI: 2.5–3.0) in Utah to 6.3 % (95 % CI: 5.9–6.7) in Hawaii (Fig. 1B, Supplemental Table 2). The range was wider among women: 2.7 % (95 % CI: 2.4–3.0) in West Virginia to 7.7 % (95 % CI: 7.2–8.3) in Delaware (Fig. 1C). By cancer type, patterns across states were generally similar, but there were some striking differences between men and women with respect to the proportion and number of cancer cases. For example, the proportion of laryngeal cancer cases attributed to alcohol consumption among men nationally (33.6 %, 95 % CI: 29.4–38.7) was about twice that of women (16.1 %, 95 % CI: 14.4–18.4) and accounted for about eight times as many cases over the 2013–2016 timeframe (men: 13,241; women: 1637) (Supplemental Table 3). Similarly, the PAF for liver cancer among men (12.2 %, 95 % CI: 12.0–12.4) was more than double that of women (5.2 %, 95 % CI: 5.0–5.3) and accounted for about seven times as many cases (men: 9762; women: 1363).

3.2. Cancer deaths

An estimated 3.2 % (95 % CI: 3.2–3.3, n = 18,947 annually) of cancer deaths were attributable to alcohol consumption in the United States (men: 3.7 %, 95 % CI: 3.6–3.8; n = 11,430 annually; women: 2.7 %, 95 % CI: 2.7−2.7; n = 7519 annually) (Fig. 2A—C, Table 1, Supplemental Table 2). The distribution of states with highest and lowest PAFs for cancer deaths was comparable to that for incident cases. The proportion of cancer deaths attributable to alcohol consumption ranged from 1.9 % in Utah to more than 4 % in Nevada, Delaware, and the District of Columbia. During 2013–2016, 48.6 % (95 % CI: 45.1–52.6; n = 18,462) of oral cavity/pharyngeal, 29.3 % (95 % CI: 25.7–33.9; n = 4429) of laryngeal, and 11.3 % (95 % CI: 11.1–11.4, n = 18,572) of female breast cancer deaths were attributable to alcohol consumption nationally (Supplemental Table 4).

4. Discussion

We estimated that the proportion of alcohol-attributable incident cancer cases ranged from 2.9 % in Utah to 6.7 % Delaware among adults aged ≥30 years in the United States in 2013–2016. The PAFs of alcohol-associated cancer deaths ranged from 1.9 % in Utah to 4.5 % in Nevada and Delaware. In general, the proportions were higher in New England and Western (except Utah) states than Midwestern and Southern (except Delaware) states. During the study period, alcohol accounted for at least 45 % of oral cavity/pharyngeal and at least 25 % of laryngeal cancer outcomes in most states. Nationally, 4.8 % (n = 75,199 annually; men: 4.7 %, women: 5.0 %) of all cancer cases and 3.2 % (n = 18,947 annually; men: 3.7 %, women: 2.7 %) of all cancer deaths were attributable to the consumption of alcoholic beverages. The proportion of cases and deaths attributable to alcohol consumption was higher among men than women for all cancer types except esophageal cancer, for which PAFs by sex were similar.

State-level differences in alcohol-associated cancer burden are impacted by factors at the individual- and community-level. Such factors influence and modify patterns of alcoholic beverage consumption. An individual's alcoholic beverage consumption behavior is shaped, in part, by social norms and policy-related factors. Policies can help reduce the harmful consumption of alcohol [20–22], and many of these policies are decided or implemented at the state level [3]. For example, restrictions on retail sales (e.g., limiting the number of hours or days allowed to sell alcohol, reducing outlet density, enhancing enforcement for sales to minors) can help reduce alcohol consumption [3,23]. Increasing excise taxes can also lead to an increase in the price of alcoholic beverages, which is associated with a decline in consumption [24–27]. Restricting marketing and alcohol industry sponsorship of youth-oriented events are also effective means to reduce consumption [20,28]. Moreover, recent evidence indicate that restricting alcohol consumption is associated with a reduction in cancer mortality rates. For example, a 10 % increase in the restrictiveness of alcohol policies was associated with an 8.3 % relative decrease in the oropharyngeal cancer mortality rate [29].

Furthermore, individuals may not be aware of or may underestimate the health risks associated with the consumption of alcoholic beverages [30,31]. Healthcare providers and public health practitioners can educate the community to expand the currently limited awareness of the cancer-related risks of alcohol consumption. For this, existing public health recommendations can provide guidance. For example, the American Cancer Society's Guideline for Diet and Physical Activity for Cancer Prevention states that it is best not to consume alcohol; for those who do drink, consumption should be limited to no more than 1 drink per day for women and 2 drinks per day for men [32]. It is also recommended that primary care providers screen adults for alcohol misuse and provide brief behavioral counseling interventions as necessary [33].

Overall PAFs of alcohol-related cancer cases were slightly higher among women than among men, reflecting the association of alcohol consumption with increased risk for female breast cancer. However, higher proportions of alcohol-related cases and deaths for other evaluated cancer types (except esophageal cancer) and higher overall PAFs of cancer deaths among men are due, in part, to the higher levels of alcohol consumption, but also likely reflect historically higher smoking prevalence among men. Concurrent tobacco use and alcohol consumption appears to increase the risk of cancers of the mouth, pharynx, larynx, and esophagus more than the independent effect of either behavior alone [34]. Additional research is needed to better understand cancer burden resulting from the combined effect of tobacco use and alcohol consumption. Unlike other cancer types examined, the PAFs for esophageal cancer for men and women were similar. This similarity may reflect a higher proportion of esophageal SCC of all esophageal cancers in women compared to the proportion of esophageal SCC of all esophageal cancers in men [35].

Overall, the proportion of alcohol-attributable cancer cases and deaths nationally was not substantially different from results of previous

Table 1
Average annual number of alcohol-attributable and total number of cancer cases and deaths, adults age ≥30 years, 2013-2016.

State	Cases						Deaths					
	Men and Women		Men		Women		Men and Women		Men		Women	
	Attrib. Cases	Total Cases	Attrib. Cases	Total Cases	Attrib. Cases	Total Cases	Attrib. Deaths	Total Deaths	Attrib. Deaths	Total Deaths	Attrib. Deaths	Total Deaths
Alabama	1039	24,836	573	13,024	465	11,813	268	10,280	179	5628	90	4652
Alaska	162	2645	80	1357	82	1289	38	982	23	532	15	450
Arizona	1470	28,656	676	14,338	793	14,318	415	11,527	239	6206	176	5321
Arkansas	595	15,701	347	8340	248	7361	168	6612	115	3652	53	2961
California	7669	156,830	3651	76,834	4014	79,996	2027	58,232	1199	30,132	829	28,100
Colorado	1319	21,406	549	10,587	770	10,819	284	7514	153	3949	132	3566
Connecticut	1191	19,894	471	9714	721	10,180	235	6613	121	3337	114	3276
Delaware	375	5589	163	2854	212	2736	91	1993	49	1047	41	946
District of Columbia	160	2609	60	1209	101	1400	48	1076	24	516	24	560
Florida	6270	114,067	3199	58,800	3069	55,267	1656	43,309	993	23,404	662	19,905
Georgia	2157	46,752	1099	24,028	1058	22,724	514	16,664	313	8912	201	7752
Hawaii	404	6827	213	3400	191	3427	95	2404	65	1304	30	1100
Idaho	439	7480	204	3817	236	3663	107	2789	60	1506	47	1283
Illinois	3061	64,435	1517	31,649	1544	32,786	743	24,360	451	12,485	291	11,875
Indiana	1348	32,874	726	16,450	622	16,424	328	13,344	208	7107	120	6236
Iowa	754	16,935	414	8653	341	8282	176	6452	115	3430	61	3021
Kansas	553	14,243	295	7245	258	6998	128	5477	82	2878	46	2600
Kentucky	991	25,775	595	13,139	395	12,636	246	10,194	171	5500	76	4694
Louisiana	1304	23,816	706	12,689	596	11,127	366	9294	241	5062	125	4232
Maine	461	8269	209	4093	252	4176	113	3264	66	1727	47	1538
Maryland	1338	28,856	583	14,122	755	14,734	346	10,633	195	5380	151	5253
Massachusetts	2013	33,939	848	16,080	1166	17,859	443	12,707	246	6453	197	6255
Michigan	2416	51,277	1187	25,838	1232	25,439	649	20,660	393	10,765	257	9895
Minnesota	1440	27,365	644	13,834	795	13,531	313	9691	178	5051	135	4640
Mississippi	704	15,378	411	8189	294	7190	208	6484	142	3569	66	2915
Missouri	1549	31,034	797	15,429	752	15,605	392	12,846	246	6760	146	6086
Montana	298	5622	139	2957	160	2665	71	2047	41	1091	30	956
Nebraska	424	9207	219	4696	205	4511	101	3453	62	1814	39	1639
Nevada	738	11,717	347	5843	391	5874	224	4979	133	2660	92	2319
New Hampshire	479	7821	198	3883	281	3938	104	2718	57	1425	47	1293
New Jersey	2290	48,412	994	23,726	1297	24,685	540	16,278	290	8016	250	8262
New Mexico	438	8556	211	4206	227	4351	128	3503	80	1868	48	1635
New York	4712	106,089	2155	52,403	2562	53,687	1119	35,154	636	17,584	482	17,570
North Carolina	2492	51,681	1203	26,183	1290	25,498	605	19,078	366	10,175	240	8903
North Dakota	170	3514	86	1828	84	1686	36	1284	22	685	14	600
Ohio	2639	61,490	1359	30,512	1282	30,978	695	25,186	437	13,151	258	12,036
Oklahoma	670	18,713	396	9509	274	9204	186	8036	129	4356	57	3680
Oregon	1109	19,671	490	9797	618	9874	297	7914	166	4157	131	3757
Pennsylvania	3270	74,623	1621	37,056	1648	37,567	803	28,443	494	14,749	309	13,694
Rhode Island	304	5833	125	2751	180	3082	70	2231	38	1133	32	1099
South Carolina	1267	25,504	658	13,244	610	12,260	336	9938	212	5425	124	4514
South Dakota	229	4332	117	2248	112	2084	55	1641	34	902	21	739
Tennessee	1307	33,942	724	17,462	583	16,480	352	14,107	235	7657	117	6451
Texas	4696	99,805	2562	50,384	2141	49,422	1263	38,734	827	20,799	436	17,935
Utah	276	9592	133	4937	143	4655	59	3018	34	1608	25	1410
Vermont	204	3521	87	1733	117	1788	54	1357	32	726	22	632
Virginia	1852	37,350	862	18,471	993	18,879	466	14,687	267	7693	198	6994
Washington	1871	33,974	813	16,914	1057	17,060	445	12,260	246	6440	198	5820
West Virginia	401	11,227	252	5710	150	5517	110	4754	79	2550	32	2204
Wisconsin	1768	30,575	810	15,654	958	14,921	414	11,370	240	6022	174	5348
Wyoming	124	2539	59	1348	65	1191	31	934	19	501	12	433
United States	75,199	1,552,791	36,815	779,160	38,384	773,631	18,947	588,497	11,430	309,473	7519	279,024
Range (across states)	*124–7,669*	*2,539–156,830*	*59–3,651*	*1,209–76,834*	*65–4014*	*1,191–79,996*	*31–2,027*	*934–58,232*	*19–1,199*	*501–30,132*	*12–829*	*433–28,100*

Attrib.: attributable.
Estimates are based on alcohol consumption from Behavioral Risk Factor Surveillance System, 2003–2006. Total cases and deaths represent average annual number of all cancer cases and deaths (excluding nonmelanoma skin cancers). The numbers of cancer cases and deaths attributable to alcohol consumption in the United States were calculated, respectively, by summing up the cancer cases and deaths attributable to alcohol in all 50 states and the District of Columbia in each sex.

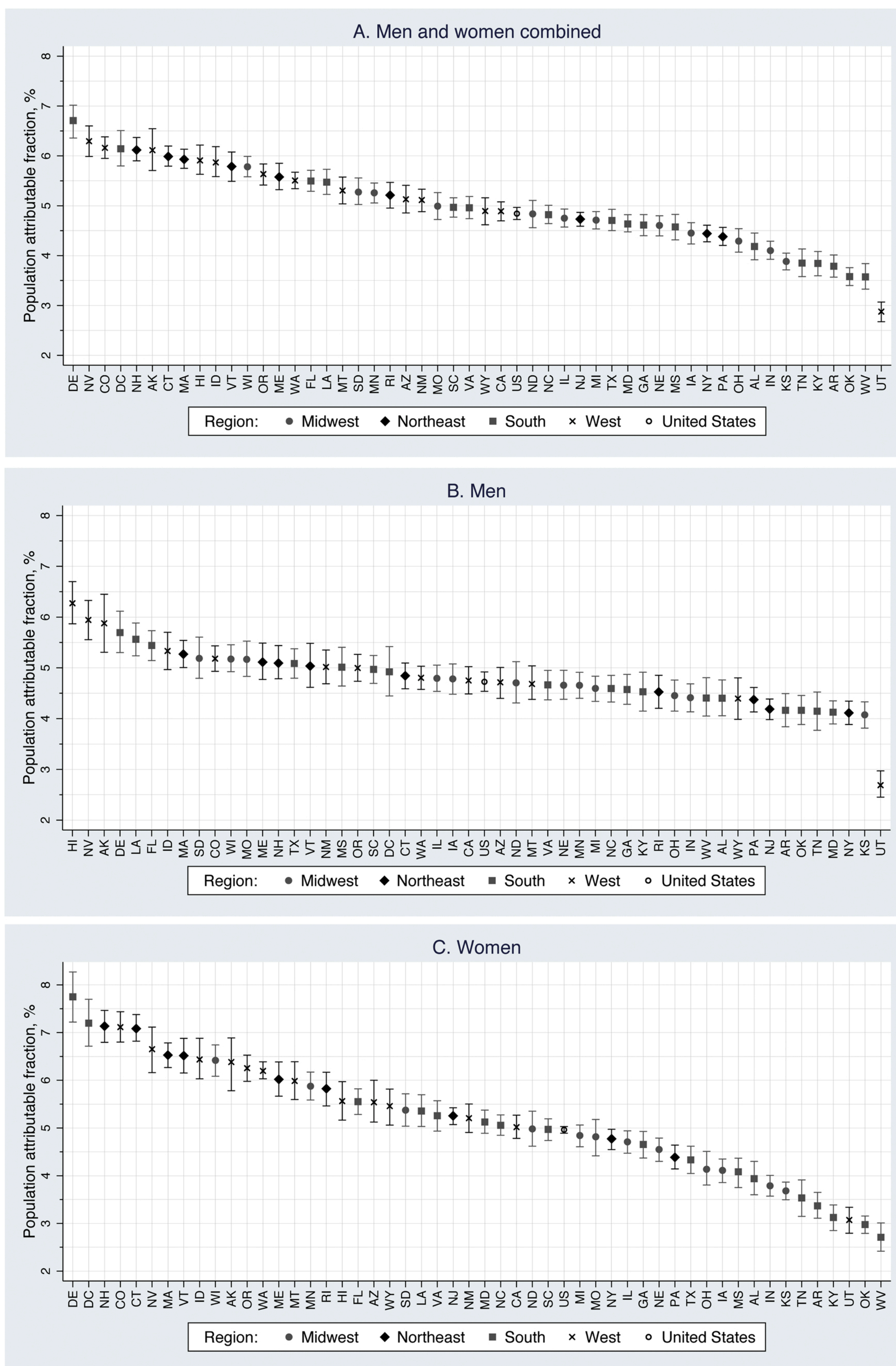

Fig. 1. A-C. Proportion of incident cancer cases attributable to alcohol consumption among adults age ≥30 years by sex and state, 2013-2016. Based on alcohol consumption from Behavioral Risk Factor Surveillance System, 2003–2006.
Note: The estimate for the United States in each sex was calculated by summing up the cancer cases attributable to alcohol in all 50 states and the District of Columbia and dividing that number by the total number of cancer cases at the national level.

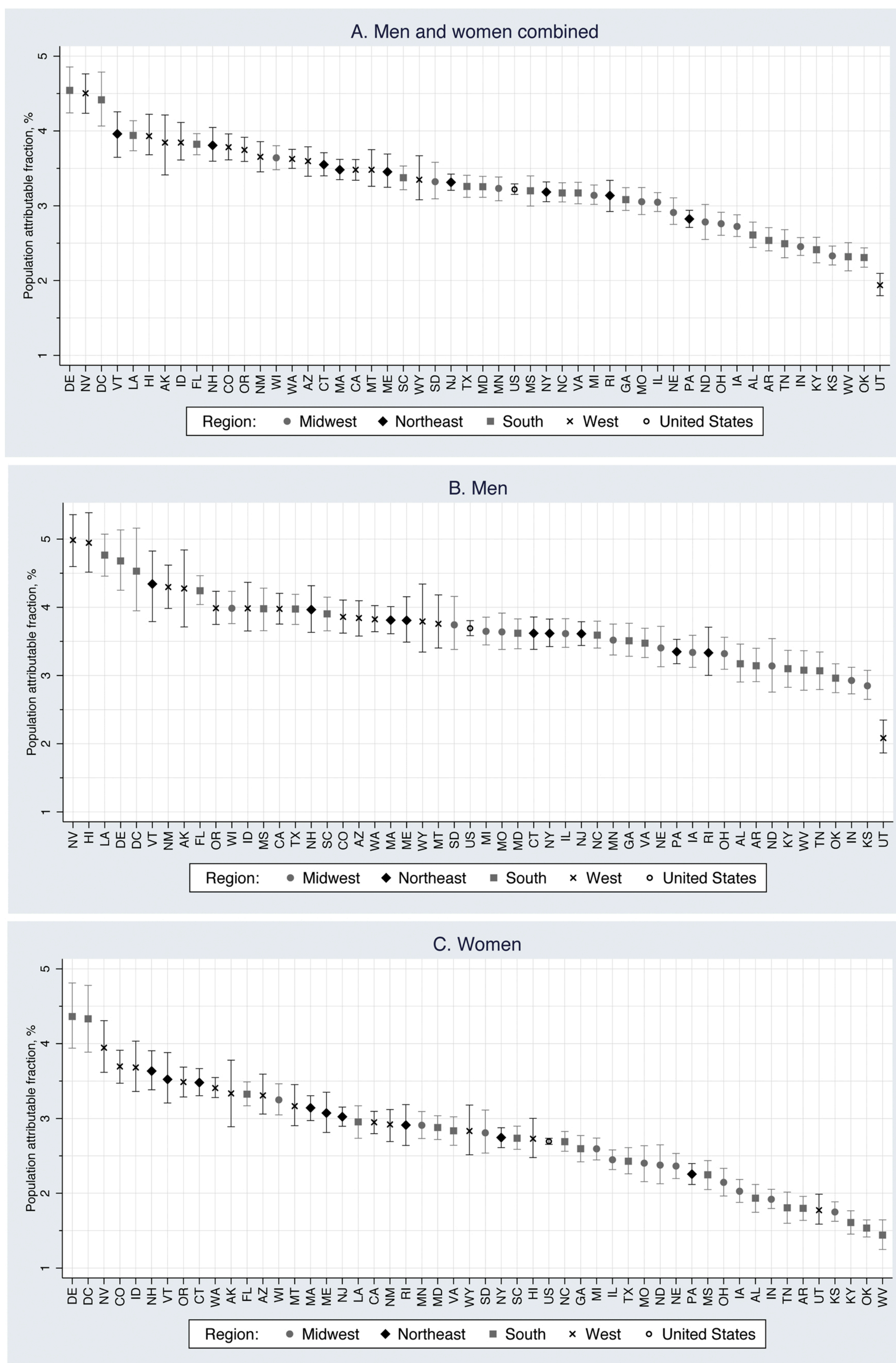

Fig. 2. A-C. Proportion of cancer deaths attributable to alcohol consumption among adults age ≥30 years by sex and state, 2013-2016.
Based on alcohol consumption from Behavioral Risk Factor Surveillance System, 2003–2006.
Note: The estimate for the United States in each sex was calculated by summing up the cancer deaths attributable to alcohol in all 50 states and the District of Columbia and dividing that number by the total number of cancer deaths at the national level.

studies [2,36]. PAFs were slightly lower in this study compared to our previous estimates based on sales-adjusted 2013–2014 NHIS data (5.6 % for cases, 4.0 % for deaths) [2]; the PAF for cancer deaths was more similar to the estimates of another study based on sales-adjusted data from 2 other sources, 2009–2010 National Alcohol Survey (3.2 %) and 2009 BRFSS (3.6 %) [36]. State-specific research on alcohol-attributable cancer outcomes is scant although one study calculated the PAF for alcohol consumption in Texas (2.9 %) [37], which was lower than the 4.7 % presented here, likely reflecting the lack of adjustment for underreporting of alcohol consumption in that study. Other factors that could contribute to variations in PAF estimates across studies include differences in RRs, number of cancer types evaluated, and source and timeframe of exposure and cancer outcome data. Several other studies have estimated proportions of cancer deaths attributable to alcohol consumption worldwide based on modelling of population surveys and sales data in various countries; more recent global PAF estimates include 4.8 % [4], 4.9 % [38], and 5.8 % [39], with wide variations across regions. For example, the PAF ranged from 1.4 % in the Middle East and north Africa to 6.4 % in eastern Europe in one of those studies [38].

This study is the first to estimate contemporary proportions and counts of alcohol-attributable cancer cases and deaths for all 50 states and the District of Columbia. Our study was strengthened by adjusting self-reported, state-level exposure data with sales data to attenuate underreporting of alcohol consumption. Furthermore, we used multiple categories of alcohol consumption and RRs based on dose-response associations. In addition to these strengths, our study also had several limitations. First, a relatively low participation rate in BRFSS and variations across states might have introduced some non-response bias, although exposure estimates were based on weighted data to help account for non-response, and BRFSS and national surveys with higher participation rates (e.g., NHIS) have shown comparable estimates for alcohol consumption amount nationally [7,8]. Second, while we did adjust consumption using sales data, the extent of underreporting may differ across population groups [10,40], and the sales data are only available for ages ≥14 years and are not stratified by sex, race/ethnicity, or other demographic characteristics. Evidence suggests that while individuals across the spectrum of socioeconomic status may consume similar amounts of alcohol, those with lower socioeconomic status experience a disproportionate burden of wide-ranging adverse health effects [41]. Furthermore, sales data are likely inflated for states where cross-border sales are common and for states that are major tourist destinations. While we accounted for these factors in our sales data adjustment methods for New Hampshire and the District of Columbia, these factors may also influence the sales data (and in turn, the exposure data) for other states. Nevertheless, historical data suggest that cross-border sales account for a relatively small proportion of total alcohol sales in many states [42], although more research is needed. Sales data also do not account for consumption of alcohol made at home such as homebrewing beer, which is more common in the South [43], and may lead to underestimation of PAFs. Third, using the cross-sectional exposure data we were unable to capture information regarding alcohol consumption earlier in life. Some individuals may not drink currently due to comorbidities, possibly resulting from drinking at younger ages. However, cancer risk declines with increasing years of cessation from alcohol consumption [20]. We also did not account for binge drinking which varies by state. For some cancer types, the binge drinking may carry a higher cancer risk than average daily consumption [44]; this relationship warrants further investigation. Finally, reported RRs for the association between alcohol consumption and cancer may vary across studies. However, our estimated PAFs at the national level are only slightly different from our previous estimates using RRs from other sources [2], including the World Cancer Research Fund/American Institute for Cancer Research reports [45].

5. Conclusion

In the United States, on average, alcohol consumption accounts for 4.8 % of cancer cases and 3.2 % of cancer deaths. While the proportions were generally higher in New England and Western states and lower in Midwestern and Southern states, alcohol accounted for a considerable proportion of cancer incidence and mortality in all states. Alcohol-associated cancer burden could be reduced by implementing state-level cancer prevention and control efforts to reduce alcohol consumption.

Author contributions

Goding Sauer, Islami, Jemal: Study concept and design.
Goding Sauer, Minihan: Acquisition of data.
Islami: Statistical analysis.
Goding Sauer: Drafting of the manuscript.
All authors: Interpretation of data and critical revision of the manuscript for important intellectual content and final approval of the version to be published.

Funding

This work was supported by the Intramural Research Department of the American Cancer Society. The management of the American Cancer Society played no part in study design; in the collection, analysis and interpretation of data; in the writing of the report; and in the decision to submit the article for publication.

CRediT authorship contribution statement

Ann Goding Sauer: Conceptualization, Data curation, Writing - original draft. **Stacey A. Fedewa:** Writing - review & editing. **Priti Bandi:** Writing - review & editing. **Adair K. Minihan:** Data curation, Writing - review & editing. **Michal Stoklosa:** Writing - review & editing. **Jeffrey Drope:** Writing - review & editing. **Susan M. Gapstur:** Writing - review & editing. **Ahmedin Jemal:** Conceptualization, Writing - review & editing. **Farhad Islami:** Conceptualization, Methodology, Formal analysis, Writing - review & editing.

Declaration of Competing Interest

All authors were employed by the American Cancer Society while this work was conducted. The American Cancer Society receives grants from private and corporate foundations, including foundations associated with companies in the health sector for research outside of the submitted work. The authors were not funded by or key personnel for any of these grants and their salary was solely funded through American Cancer Society funds. All authors have nothing else to declare.

Acknowledgement

We are grateful to all cancer registries and their staff for their hard work and diligence in collecting cancer information that was used for this research.

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