Original Contribution

Determination of Lifetime Injury Mortality Risk in Canada in 2002 by Drinking Amount per Occasion and Number of Occasions

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Injury is the leading cause of alcohol-attributable mortality in Canada. Risk is determined by amount consumed per occasion and accumulates across drinking episodes. The authors estimated alcohol-attributable injury mortality in Canada for 2002 by combining the absolute risk of injury unrelated to alcohol with relative risks that were specific to gender and consumption per occasion, while taking into account lifetime number of drinking occasions. The absolute risk increased as number of drinking occasions and number of drinks per occasion increased. The absolute risk remained relatively low at fewer than 2 drinking occasions per month, regardless of number of drinks. Absolute risk levels reached 1 in 1,000 at 5 or more drinks once per month for men and at 5–7 drinks once per month for women. The probability of mortality was 1 in 100 for all levels of consumption above 3 drinks 3 times per week for men and above 5 drinks 3 times per week for women. No safe level of consumption is recommended based on these results, although risk is much lower for consuming 3 standard drinks or less fewer than 3 times per week. Absolute risk reflects long-term effects of drinking patterns and is important for risk-communication and alcohol-control policy.

alcohol drinking; mortality; risk assessment; wounds and injuries

Abbreviation: BAC, blood alcohol concentration.

Editor's note: An invited commentary on this article appears on page 1126, and the authors' response appears on page 1130.

Fatal injury is the leading cause of alcohol-attributable mortality in Canada (1). Globally, unintentional injuries account for 28% of the alcohol-attributable burden of disease as measured in disability-adjusted life-years, and intentional injuries make up another 12% of this burden (2,3). Numerous studies have found positive associations between alcohol drinking and many different types of injury and injury-related death in various settings (4–15). Moreover, on the basis of accepted, standard epidemiologic criteria, most reviewers have concluded that alcohol consumption is causally associated with both intentional and unintentional injury (16–19). Likewise, both the risk of injury and the severity of injury follow a dose-response relation with the amount of alcohol present in the body at the time of injury (20–22).

The risks of injury associated with alcohol drinking are normally expressed in terms of relative risk for the amount consumed on a particular occasion. However, such calculations do not reveal much about the absolute risk of alcohol-attributable injury. From a policy perspective (or, for that matter, from the consumer’s perspective), it is important to also know the absolute risk associated with a particular pattern as cumulated over time—for instance, over a lifetime. This is a conventional calculation with respect to some other hazards to human life, such as environmental contaminants or hazardous foodstuffs. For instance, in terms of exposure to carcinogenic compounds in drinking water, the World Health Organization sets a general upper guideline “at the concentration which would give rise to a risk of 1 additional cancer per 100,000 people” on a lifetime basis (23). However, it is clear that thresholds have been set at riskier levels.
in particular instances. A study of regulation of risky substances in the United States and Canada mentions risk thresholds set at 1:22,000 and 1:10,000 (24). For behaviors that are seen as voluntary, such as driving an automobile, higher risks are routinely accepted. For example, in the United States, the lifetime risk of dying in a traffic accident associated with driving 10,000 miles per year (16,000 km/year) has been calculated to be approximately 1 in 60 (25).

While the relation between alcohol consumption and injury is well established, few investigators have assessed the level of absolute risk of alcohol-attributable injury. Our aim in the current study was to fill this gap by estimating the absolute risk of alcohol-attributable injury mortality for Canadians at different amounts of alcohol consumed per occasion and different frequencies of such occasions. This work will allow for quantification of risk for different levels of consumption per occasion and different frequencies of drinking such amounts on a lifetime basis for the Canadian population.

MATERIALS AND METHODS

Estimation of alcohol-attributable injury mortality in Canada required combining the absolute yearly risk of injury mortality with gender- and consumption-specific relative risks, while taking into account the lifetime number of drinking occasions at a particular level, and then calculating the risk per drinking occasion. This required 3 main steps:

1. Determination of injury mortality risk without the impact of alcohol, that is, the risk of dying of an injury on any specific day. This risk was derived from 2002 Canadian mortality data specified for gender and age (unpublished data). First, the overall gender- and age-specific injury risk was determined, and then the alcohol-attributable portion was subtracted.

2. Determination of relative risk for drinking different quantities of alcohol before the event.

3. Combination of steps 1 and 2 for estimation of risk per drinking day by alcohol consumption level and total lifetime number of drinking occasions at that level.

Canadian mortality data for the year 2002, with the underlying cause coded according to the International Classification of Diseases and Related Health Problems, Tenth Revision, were obtained from Statistics Canada.

Determination of injury mortality risk

First, based on usual epidemiologic criteria (16, 26, 27), we identified all injury categories in which alcohol has a causal effect and included them in the analyses. These conditions are listed in Table 1, as well as the sources of data on alcohol-attributable fractions. The alcohol-attributable fraction is defined as the proportion of disease that would not occur if the risk factor (in our case, alcohol) were not present. In other words, it is the fraction of total disease directly caused by alcohol. Alcohol-attributable fractions for injuries were based on direct estimates of alcohol involvement where available for Canada (traffic accidents, fire); for other types of injury, they were based on results from the America A region derived from the comparative risk analysis of the Global Burden of Disease Study (3) (for details of calculation, see below).

The gender-specific, population-level absolute risk of injury mortality was calculated by dividing the gender- and age-specific number of injury deaths (by injury category) by the total population at risk in each age and gender category for Canada in 2002. The age categories used were 15–29, 30–44, 45–59, 60–69, 70–79, and ≥80 years. This risk was then multiplied by the age- and gender-specific alcohol-attributable fraction to obtain that portion of the overall risk in each injury category that was attributable to alcohol.

This alcohol-attributable injury mortality rate was then subtracted from the corresponding overall age- and gender-specific risk to estimate the baseline risk. The baseline risk can be defined as the risk of injury mortality that would have been present in Canada in the year 2002 without any involvement of alcohol. In other words, this injury mortality risk was due not to alcohol but to other environmental or personal factors. This baseline injury mortality risk was used for all subsequent calculations.

Determination of relative risk for different alcohol quantities

This injury risk was then multiplied by the relative risk associated with alcohol consumption, as measured in Canadian standard drinks (13.6 g of pure alcohol (28)). Estimation of this risk required a number of steps. First, relative risks corresponding to consumption of standard drinks were identified in a recent World Health Organization-sponsored case-crossover study of hospital emergency rooms in 10 different countries (n = 4,320; 91% response rate), where patients appearing in the emergency room with an injury were given a questionnaire that asked about alcohol drinking prior to the accident which caused the injury (15). These data yielded volume-specific relative risks corresponding to specific numbers of standard drinks. However, since the standard drink size in this study (16 mL of pure alcohol) did not equal the standard drink size of Canada (13.6 g), the data from the World Health Organization study were modeled and linearly approximated for consumption of up to 5 drinks and then converted to Canadian standard drinks on the basis of the linear equation. Beyond 5 standard drinks, the WHO risk data were used. See Table 2 for the raw risk data in 16-mL standard drinks and the corresponding relative risks after conversion to Canadian standard drinks.

Combination of absolute risk data and relative risk data

Multiplying the absolute risk of injury mortality per day by the relative risk for having consumed a specific number of alcoholic drinks prior to the injury yields the absolute risk of dying from injury after consuming a specific number of drinks. For instance, if the risk of 1 person’s dying in a traffic accident is 3/1,000 and the relative risk due to consuming 2 drinks before the event is 2.00, then the resulting conditional probability is 6/1,000 (i.e., 0.003 × 2.00 = 0.006). However, this step accounts for only 1 lifetime drinking
occasion, whereas in fact, the probability of injury mortality increases with the frequency with which a person drinks in addition to how much he/she consumes (see equation 1).

\[
Pr(\text{death}|n) = 1 - (1 - (Pr(\text{death})_{id}/Pr(\text{death}_{id})))^n,
\]

where \( n \) = the number of drinking occasions per year (1, 12, 24, 52, 156, 260, or 365); these equate to once per year, once per month, twice per month, once per week, 3 times per week, 5 times per week, and every day, respectively; \( Pr(\text{death}|n) \) = the risk of injury death (per 1,000) given \( n \) yearly drinking occasions; \( Pr(\text{death})_{id} \) = the risk of injury death for 1 drinking occasion per year, depending on the number of drinks per occasion; and \( id \) = adjustment of the yearly risk to reflect the actual risk period, which is the measured time period over which alcohol exerts its effects. \( id \) also varies with the number of drinks consumed on each drinking occasion. For example, for 3 drinks per occasion, we assumed a risk period of 3 hours during the 24-hour period of that day. Thus, \( id \) becomes \( 365 \times (24/3) \), since it is based on the probability of 1 year.

This risk scenario, that is, the relative risk associated with each drinking event, obviously changes as the amount consumed increases for each drinking occasion. After the consumption of 1 standard drink, blood alcohol concentration (BAC) reaches its peak approximately 30–45 minutes after ingestion. Rapid consumption of multiple drinks results in a higher BAC during the period following ingestion, because the liver has a relatively fixed rate of metabolism. In general, in the ensuing 0.5–1.5 hours, the consumption of 1 Canadian standard drink results in a BAC of about 0.02 mg/mL; having 2 drinks in succession leads to a BAC of about 0.05 mg/mL; approximately 3 drinks results in a BAC of 0.07–0.08 mg/mL; and approximately 4 drinks results in a BAC of about 0.09 mg/mL (29). These levels obviously differ among individuals and with respect to the context of

### Table 1. Categories of alcohol-related disease and sources used for determining alcohol-attributable fractions

| Cause of Death | International Classification of Diseases and Related Health Problems, Tenth Revision, Code(s) | World Health Organization Global Burden of Disease Code | Source(s) |
|----------------|-------------------------------------------------------------------------------------------|--------------------------------------------------------|-----------|
| Unintentional injuries | | | |
| Motor vehicle accidents | Specific V-series codes\(^a\) | W 150 | Traffic Injury Research Foundation of Canada (41); Transport Canada (42) |
| Poisonings | X40–X49 | W 151 | Rehm et al. (3); adjusted to Canada by AAF for traffic accidents |
| Falls | W00–W19 | W 152 | Rehm et al. (3); adjusted to Canada by AAF for traffic accidents |
| Fires | X00–X09 | W 153 | Council of Canadian Fire Marshals and Fire Commissioners (43) |
| Drownings | W65–W74 | W 154 | Rehm et al. (3); adjusted to Canada by AAF for traffic accidents |
| Other unintentional injuries | Rest of V-series\(^b\) and W20–W64, W75–W99, X10–X39, X50–X59, Y40–Y86, Y88, and Y89 | W 155 | Rehm et al. (3); adjusted to Canada by AAF for traffic accidents |
| Intentional injuries | | | |
| Self-inflicted injuries | X60–X84 and Y87.0 | W 157 | Rehm et al. (3); adjusted to Canada by AAF for traffic accidents |
| Homicides | X85–Y09 and Y87.1 | W 158 | Rehm et al. (3); adjusted to Canada by AAF for traffic accidents |
| Other intentional injuries | Y35 | W 160 | Rehm et al. (3); adjusted to Canada by AAF for traffic accidents |

Abbreviation: AAF, alcohol-attributable fraction.

\(^a\) Codes V021–V029, V031–V039, V041–V049, V092, V093, V123–V129, V133–V139, V143–V149, V194–V196, V203–V209, V213–V219, V223–V229, V233–V239, V243–V249, V253–V259, V263–V269, V273–V279, V283–V289, V294–V299, V340–V309, V314–V319, V324–V329, V334–V339, V344–V349, V354–V359, V364–V369, V374–V379, V384–V389, V394–V399, V404–V409, V414–V419, V424–V429, V434–V439, V444–V449, V454–V459, V464–V469, V474–V479, V484–V489, V494–V499, V504–V509, V514–V519, V524–V529, V534–V539, V544–V549, V554–V559, V564–V569, V574–V579, V584–V589, V594–V599, V604–V609, V614–V619, V624–V629, V634–V639, V644–V649, V654–V659, V664–V669, V674–V679, V684–V689, V694–V699, V704–V709, V714–V719, V724–V729, V734–V739, V744–V749, V754–V759, V764–V769, V774–V779, V784–V789, V794–V799, V803–V805, V811, V821, V830–V833, V840–V843, V850–V853, V860–V863, V870–V878, and V892.

\(^b\) V-series codes not specified above.
drinking, but the following risk periods (that time following consumption in which risk is significantly higher) can be assumed: 1 drink—>30 minutes; 3 drinks—>2 hours; 5 drinks—>3 hours; 7 or more drinks—>4.8 hours. These were the time periods modeled in the above formula.

RESULTS

Figure 1 and Figure 2 show the results for overall risk of injury mortality per 1,000 population according to the lifetime number of drinking occasions and the number of standard drinks consumed prior to the injury for men and women, respectively. Comparing the 2 graphs, for all numbers of drinking occasions and numbers of standard drinks, men are at an approximately 2-fold higher risk than women. Injury mortality per se is higher among men than among women. However, both men and women show similar patterns of increasing risk of injury mortality as both the lifetime number of drinking occasions and the number of drinks consumed per occasion increases. In addition, a lifetime number of drinking occasions at or under twice per month produces relatively similar risk profiles for men and women, with a major jump in risk seen at 2 drinking occasions per week. For men, the injury mortality risk reaches 1 in 1,000 at a level of 5 or more standard drinks once per month; for women, the risk achieves 1 in 1,000 at consumption of 5–7 standard drinks about once per month. For consuming 7 or more standard drinks approximately every day, men reach a maximum risk of about 66/1,000 and women reach a maximum mortality risk of about 32/1,000. For both men and women, consuming more than 3 drinks at a frequency of 3 or more times per week results in a lifetime injury mortality risk of 1 in 100, or 1%, although this risk is also achieved at different combinations of more drinks/fewer occasions or fewer drinks/more occasions.

DISCUSSION

For both men and women, the risk of injury death increased as both the number of drinking occasions and the number of drinks consumed per occasion increased. The risk was higher for men than for women, particularly at higher numbers of drinks and occasions. In addition, there was a "risk threshold" effect seen between drinking once a month and drinking twice a month—below this marker, the risk of injury was low and relatively equal for all alcohol volumes for men and women, but above this level the risk was significantly higher for both men and women.

These estimates are conservative in the sense that they are based on emergency room studies, that is, studies in which the injured person survived. The relevant literature indicates that injuries tend to be more severe when alcohol is involved, and thus the relative risk and alcohol-attributable fraction are larger for mortality than for morbidity (3). On the other hand, using emergency room studies as the basis for analysis may also have led to an overestimate of the

Table 2. Conversion of alcohol intake volumes from emergency room studies to Canadian standard drinks

| No. of Drinks | Relative Risk | No. of Drinks | Relative Risk |
|---------------|--------------|---------------|--------------|
| 0             | 1.0          | 0             | 1.0          |
| 1             | 3.3          | 1             | 2.3          |
| 2.5           | 3.9          | 3             | 4.9          |
| 4.5           | 6.5          | 5             | 6.5          |
| >6            | 10.1         | ≥7            | 10.1         |

a Based on the data of Borges et al. (15).

b In international settings, an average drink contains approximately 12.5 g of alcohol (15).

c A Canadian standard drink is defined as 13.6 g of pure alcohol (28).
effects. Clearly, persons who go to emergency rooms are not representative of the general population. They may be characterized as higher risk-takers; thus, the relative risk for alcohol consumption in this population may be higher than that in the general population. Unfortunately, we do not have much knowledge with which to test or quantify this potential effect. Our findings are different from accepted norms of alcohol-attributable risk for men as compared with women. It is generally well-accepted that women have a lower tolerance for alcohol, for gender-based genetic and metabolic reasons, including a lower average body weight (29). As a result, everyday wisdom dictates that women ceteris paribus should have higher risks of alcohol-attributable injury than men given that they, on average, become more intoxicated by the same amount of alcohol. The problem in applying this lies in the ceteris paribus clause. Lifetime risks of injury are not equal for men and women. Instead, men have a higher lifetime risk of injury in all cultures, presumably related to a higher propensity for risk-taking. Only if we hold this variable (i.e., risk-taking) constant do we obtain the expected results—that for a given number of drinks or BAC, women have a higher risk of incurring injury (see Borkenstein et al. (30) for an example regarding motor vehicle accidents).

Predisposing personality and behavioral factors also play a role: That is, if a person simply chooses not to drive a car or enter a potentially risky situation after consuming alcohol, his or her risk of alcohol-attributable motor vehicle or other injury death goes down to 0. In theory this is true, but in practice it assumes that alcohol consumption and risk-taking behavior are independent of each other, whereas the literature clearly shows that they are not, both in terms of risk perception and in terms of behavior, even at moderate doses (31–33).

We also recognize that drinking patterns—frequency and quantity consumed per occasion—may change significantly over the life course. While these formulae can be applied to assess risk for changing consumption patterns over a lifetime, for the purposes of presenting the method and its interpretation, combinations of number of occasions and number of drinks consumed per occasion (of which there are a huge number) are impractical. Figures 1 and 2 are population-based estimations and thus are based not on one individual’s behavior but rather on the behavior of Canadian men and women as a whole in 2002. Members of the Canadian population do not have individual risk profiles but rather have an overall risk profile, and as a group, they were found to have consumed alcohol in about one-third of their motor vehicle accidents in each year from 1999 to 2004 (34–39); this is a stable trend. Thus, regardless of risk-taking behavior, alcohol has been shown to play a major causal role in motor vehicle accidents on an individual level and, more importantly in the context of this article, on a population level. Further work, however, may lead to presentation of calculations for individual risk scenarios based on usual lifetime drinking patterns.

The results of this analysis are important clinically and for population guidelines, as well as for the research community. It is important to disentangle frequency of drinking and amount consumed per occasion. Epidemiologic literature on injury prevention is not well-served by looking merely at the volume of consumption. Injury risk is an acute phenomenon and the amount consumed per occasion must be considered. In addition, this study complements and extends emergency room studies in presenting cumulative risk across episodes for the individual. Absolute risks also tend to be more interpretable and more useful for personal risk communication. They reflect the public health impact of alcohol consumption and drinking patterns better than relative risks or statistics of correlation. Correspondingly, this method and these results are very important from a public health perspective.

These methods were recently adopted to develop low-risk drinking guidelines for Australia (unpublished report) suggesting that relatively high risk (as compared with the accepted risk of other risk factors) is achieved at a level of 3 standard drinks of pure alcohol consumed 3 or more times per week (1 Australian standard drink = 10 g of pure alcohol). This result was one of the factors leading to a proposed revision of the current guidelines for alcohol drinking in Australia (40). Thus, it is important to be able to communicate risk in a form that is palatable for and understandable to the public. For example, how does one’s individual risk of dying due to consuming 3 drinks 3 times per week compare with the mortality risk posed by inhaling asbestos, or by eating fruit that has been grown with toxic pesticides? In fact, alcohol poses a much higher risk than these substances. Asbestos exposure poses a lifetime mortality risk between 1 in 1,000 and 1 in 10,000, and eating pesticide-grown fruit carries a lifetime risk of 1 in 22,000 (24); both of these risks are orders of magnitude lower than the risk of injury death due to alcohol drinking. In addition, the absolute mortality risk increases when long-term effects of alcohol drinking are considered by accounting for alcohol-attributable deaths resulting from chronic diseases such as liver cirrhosis, heart disease, and some cancers (1, 3, 19).

Communication of risks to the public will enable people to understand their own risk profiles and risk tolerance levels and help them to make healthy decisions based on sound analysis and comparison. From a public health standpoint, developing lifetime risk data is important for the construction of low-risk drinking guidelines for both Canadians and others.
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