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Standardization of Alcohol Calculations in Research

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Background: Nonstandardized reporting of alcohol consumption, definitions of what constitutes a standard drink, and incomplete dosing or estimates of intoxication are common problems in many areas of alcohol research. To enhance communication among scientists and to make interpretation of results more accurate and meaningful, researchers need to apply systematically current scientific principles in calculating drinks, doses, and alcohol concentrations. Basic formulas are compiled and explained to assist alcohol researchers and standardize the reporting and interpretation of alcohol data.

Methods: Basic alcohol calculations are reviewed, and 20 mathematical calculations in alcohol pharmacokinetics and pharmacology are derived. Examples of how each calculation works are presented.

Results: The formulas presented enable researchers to calculate accurately and systematically the amount of alcohol in any beverage and estimate the blood alcohol concentration in a range of subjects with individual characteristics and drinking patterns.

Conclusions: Accurate estimates of alcohol use and intoxication are important in many areas of research. Applying standards to the way alcohol is measured and interpreted enables better communication, more accurate analyses, and, in some cases, may impact the interpretation of results. Regardless of the field of study, alcohol researchers are encouraged to and can apply uniform standards in measuring alcohol consumption and estimating the effects of alcohol using the scientific methodologies described.

Key Words: Standard Drink, Alcohol Contents, Pharmacokinetics, Alcohol Calculations.

SUBJECTIVE REPORTING OF ethanol (alcohol) use as well as objective results from chemical testing are common variables in alcohol research. Often, there is considerable inconsistency in the reporting and interpretation of alcohol test results across studies. Occasionally, errors in reporting occur apparently based upon a misunderstanding of how alcohol is commercially formulated, quantified, and reported by different laboratory techniques; what constitutes "a drink"; or how to estimate the number of drinks consumed (Kerr et al., 2005; Turner, 1990). In other instances, drink equivalents are not clearly described. For example, in a recent study, "a drink" was defined as either 1 oz of distilled spirits containing 43% ethanol, 6 oz of wine containing 12% to 14% ethanol, or 12 oz of beer containing 6% ethanol (Chiu et al., 2004). However, when calculated using the formulas described herein, 6 oz of 14% wine contains about twice as much alcohol as 1 oz of 86-proof alcohol. Thus, these drinks are not equivalent at all.

This communication is intended to assist in the standardization and reporting of such data by presenting thorough but easy-to-follow guidelines for physicians, psychologists, sociologists, and scientists not trained in this area to better estimate alcohol intake and exposure based upon subjective and objective data.

Alcohol research scientists and, in particular, epidemiologists, often report on the medical and psychosocial consequences of acute or chronic drinking. In most instances, the information collected regarding total alcohol intake is based upon blood or breath alcohol test results or self-report data, which are then standardized in some way to the number of "drinks" consumed over some period (e.g., days, weeks, months). Such data can be used to correlate alcohol intake with some dependent variable of interest. For example, the National Highway Traffic Safety Administration (NHTSA) published guidelines for legislators to calculate blood alcohol concentrations (BACs) to assist in their deliberations regarding drinking-driving laws. This publication demonstrated the need for such information but did not provide detailed "how to" hand calculations to estimate alcohol consumption or intoxication, for example. Another area of particular interest where the importance of defining a drink is recognized is on the risks and benefits of moderate drinking (Dufour, 1999; WHO, 2000). For example, modest alcohol intake of less than 1 drink per day is associated with higher bone density, but chronic consumption of relatively low amounts of alcohol (1 to 2 drinks per day for women; 3 to 4 drinks per day for men) can interfere with the normal metabolism of nutrients, which may or

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may not be a major cause of alcohol-induced bone disorders. However, in a review of other studies, it was found that 2 to 6 drinks per week significantly increases the risk of fractures in men, compared with subjects who consume less than 2 drinks per week (Brick, 2004). Indicators of acute and chronic alcohol-related harm, including the amount of alcohol consumed, can be obtained from many sources and can impact on medical, psychosocial, economic, and other life events (WHO, 2000). The physiological consequences of alcohol abuse are complex, but it is clear how variations in what constitutes a "drink" can significantly affect the interpretation of results.

The reliability of self-report alcohol consumption data is somewhat controversial, but the validity of such data increases if certain methodological protocols are implemented (Babor et al., 1987; Cohen and Winson, 1995; Sommers et al., 2000). While some researchers appreciate the importance of the "concept of a standard drink" in self-reported survey data (Sommers et al., 2000), methodological details or assumptions regarding what constitutes a drink for individual subjects are rarely reported or not considered in many studies. Variability from self-report data is further complicated when researchers erroneously interpret their own or someone else's data. For example, it is often useful to relate self-reported drinking quantity and frequency or to express an objective alcohol test in terms of how many alcoholic drinks were consumed. In both instances, it is important to determine how much alcohol was contained in each drink, as what constitutes "a drink" varies depending upon type of beverage, and the way in which governments, researchers (Turner, 1990; WHO, 2000) or subjects (Kerr, 2005) define "a drink."

Failure to collect such data in a systematic and sound manner may skew the results, a problem that may be exacerbated when scientists attempt meta-analyses or compare the effects of drinks per day within or between studies or countries. For example, if a subject in Great Britain reports consuming 5 beers or whiskey drinks a day, is that the equivalent to 5 drinks a day in the United States or elsewhere? Given the range of beverage formulations of beer (Case et al., 2000) or spirits (Miller et al., 1991), the drinks are probably not equivalent unless the investigator has asked each subject to describe what constitutes a drink so that data can be compared across studies. Recently, Kerr et al. (2005) found substantial variation in the way subjects reported drinks of wine or spirits, but less so with beer.

Some investigators administer alcohol based upon body weight and then measure some effect of the dose administered. If body weight alone is the only consideration, it is likely that the resulting BACs will vary considerably among subjects. The interpretation of such an approach is even more complicated when practical or financial constraints preclude objective alcohol test measurements. In such cases, a standardized dosing protocol that accounts for individual physiological characteristics such as age, gender, height, and weight will result in more homogeneous results within and between studies.

Finally, studies reporting BAC often do not specify whether alcohol test results are from blood, serum, or plasma. Results from different specimens are not equivalent and failure to identify the specimen can result in further inconsistency in interpreting alcohol data.

To describe and interpret more systematically self-report and BAC results in research and applied settings, 3 topics are reviewed: calculating alcohol equivalents; dosing methodologies; and alcohol test results. The purpose of this review is to explain how various alcohol estimates are calculated with the recommendation that scientists use a consistent language in both data collection and interpretation.

CALCULATING ALCOHOL EQUIVALENTS

Alcohol is manufactured in different concentrations to accommodate different drinking preferences. Although the amount of alcohol in a typical drink varies based upon drink configuration, cost, glass size, etc., in the United States, for example, a standard drink equivalent can be operationally defined as a 5-oz glass of wine (12% v/v), a 12-oz beer (5% v/v), or a mixed or straight drink containing 1.5 oz of 80-proof alcohol (i.e., 40% v/v), as each of these drinks contains approximately the same amount of alcohol, about 14 g, or proportionally less with smaller-sized servings or lower concentrations per drink and vice versa. A standard drink may vary geographically. The calculation of these amounts is explained below along with examples, so that such data can be better understood when they are collected and reported regardless of the country of origin.

To begin with, the concentration and volume of alcohol must be known to estimate consumption. The most basic formula to determine the concentration of a solution is the following.

Formula 1: Basic equation to calculate the strength of a solution

$$C_s = g/v,$$

where C_s is the concentration (%) of a solution, g is the weight in grams (of alcohol), and v is the volume of fluid. When $v = 100$ mL, 1 g, or 1,000 mg of a dissolved substance, the solute, in 100 mL in water, results in a 1% concentration of that solution.

Some alcoholic beverage concentrations are expressed in "percent" such as for beer and wine whereas distilled spirits (e.g., rum, vodka, gin, whiskey) are usually expressed as "proof," an indirect expression of percentage. The term "proof" is derived from a 17th-century method to quantify alcohol by combining gunpowder and alcohol. The wet gunpowder would ignite only if the alcohol content was high enough (and the water content low enough). If the gunpowder ignited, it was "proof" that the alcohol concentration was sufficient. In the United States, the proof is 2 times the concentration in volume. For example, a 100-proof beverage alcohol is 50% by volume (50% v/v).

In the preceding paragraphs, alcohol concentrations were expressed as % v/v, meaning the percent of alcohol by volume. The volume percent (% v/v) is defined as the (volume of solute/volume of solution) $\times$ 100. This is the standard way manufacturers report alcohol concentrations. In many scientific calculations, it is more useful to know the concentration of alcohol by weight (% w/v). The percent weight (% w/v) is defined as the (weight of solute/weight of solution) $\times$ 100. Therefore, alcohol by volume (% v/v) is not the same as alcohol by weight (% w/v). By standardizing drinks by the weight of alcohol in grams (not the percent volume), a more accurate comparison among beverages is possible. As alcohol has a different density than water, the total amount of alcohol by weight in a 50% v/v solution is less, in proportion to the specific gravity (weight of fluid relative to the weight of water) of the alcohol, which is approximately 0.79 g/mL (Weast, 1974). Although various physical factors including temperature may affect the specific gravity, we follow the general convention among alcohol researchers to use a value of approximately 0.79 g/mL as the specific gravity of alcohol (Miller et al., 1991; Turner, 1990; WHO, 2000). Therefore, the total amount of alcohol in any alcoholic beverage can be calculated, assuming one US fluid ounce of alcohol = 29.57 mL and weighs 0.79 g/mL. The following formulas show how the total amount of alcohol in distilled spirits, beer, or wine is calculated.

Formula 2: Equation to convert "proof" to percent alcohol by volume and weight

Percentage of alcohol (A) by weight (w/v) for distilled spirits can be calculated as follows:

$$A_{w/v} = (\text{Proof of beverage}/2) \times (0.79)$$
$$\text{Example}: 80\,\text{proof}/2 = 40\%\,\text{v/v}$$

Then, to convert concentration by volume (v/v) to concentration by weight (w/v):

$$40\%\,\text{v/v} \times 0.79 = 31.6\,\text{g of alcohol per }100\,\text{mL} = 31.6\%\,\text{w/v}$$

In the United Kingdom, Canada, and Australia, where Imperial units are used rather than Apothecaries' system used in the United States, proof is defined differently. Under the Imperial proof system, 100 proof is defined differently by comparing equal volumes of water and alcohol. When the alcoholic beverage weighs 12/13ths of water, it is deemed proof that the alcohol concentration is 50% (100 proof). In the United States, 1 degree of proof is equal to 0.50% alcohol by volume (100 proof = 50% v/v), but in the United Kingdom, for example, 1 degree of proof is equal to about 0.571% alcohol by volume. Thus, in the United Kingdom 100 proof is 57.1% v/v and 46 proof in the United States would be equal to 81 Imperial proof units (46/57.1 = 80.6). Therefore, in the United States, the percentage of alcohol by volume is the proof divided by 2, but in the United Kingdom, Canada, and Australia, Imperial proof divided by 1.751 (Formula 3) gives the equivalent percentage of alcohol by volume (v/v).

Formula 3: Calculation of percentage of alcohol by weight for liquor in imperial units

$$(80\,\text{proof}/1.751) \times 0.79 = 36.1\%\,\text{w/v}$$

It has been noted in the United Kingdom, that in the more recent years, drinks are described as "units." A standard drink "unit" is defined as 8 g of alcohol. Formula 4 calculates the number of "units" in a metric proportioned drink.

Formula 4: Calculating "units" of alcohol in a drink

$$\frac{\text{Av/v}(\%) \times \text{mL per container}}{1{,}000}$$

Example: 750 mL of 12% v/v wine contains 9 units

$$\frac{12 \times 750}{1{,}000} = 9\,\text{units per }750\,\text{mL bottle}$$

Example: 330 mL of 6% v/v beer contains ~2 units

$$\frac{330 \times 6\%\ \text{v/v}}{1{,}000} = 1.98$$

Although "units" are a standardized way to describe the contents of an alcohol drink, the unit is an alcohol of volume measurement. This difference must be appreciated and noted when comparing drink units with other standard drink equivalents.

Beer and wine manufacturers usually list the percentage of alcohol by volume (% v/v) on their labels. To determine the total amount of alcohol per ounce of serving, the percentage of alcohol by weight (% w/v) can be calculated using Formula 5.

Formula 5: Calculating percentage of alcohol by weight (w/v) in beers and wines

$$A_{w/v} = (A_{v/v}) \times (0.79)$$

Example: 4.75% v/v beer contains 3.753 g of alcohol per 100 mL (3.75% w/v)

Example: 12% v/v wine contains 9.48 g of alcohol per 100 mL (9.48% w/v)

Once the percentage of alcohol by weight for any beverage is known, alcohol intake estimations across different types of drinks and studies can be performed. This makes it possible to compare grams of alcohol consumed per person across an infinite range of beverages and beverage sizes. Formula 6 takes this analysis one step further by calculating total grams of alcohol per ounce.

Formula 6: Calculation of total grams (Σg) of alcohol per ounce of fluid

$$\sum g = A_{w/v}/100 \times (\text{mL}/\text{oz})$$

From Formulas 2 and 6, it can be calculated that 1 oz of 80-proof liquor contains 9.3441 oz of absolute alcohol. From Formula 2, the total alcohol by weight ($A_{w/v}$) of an 80-proof liquor is 31.6% w/v. The total number of grams per ounce is then calculated using Formula 5 by dividing the % v/v derived from Formula 2 (31.6%) × 100 (to obtain grams per milliliter) and multiplying the result times the number of milliliters per ounce (29.57). This is illustrated in the following example, where the term dL is used. A dL is 100 mL or 1/10 of a liter (L).

$$\text{Example}: (31.6\ \text{g/dL}/100) \times (29.57) = 9.3441\ \text{g of alcohol per ounce of 80-proof liquor.}$$

Applying the above formulas, we can see that the following alcoholic beverages contain approximately the same number of grams of alcohol and are therefore, for all practical purposes, equivalent:

5 oz wine (12% v/v) contains 14.02 g of alcohol.
12 oz of beer (5% v/v) contains 14.02 g of alcohol.
1.5 oz of liquor (80 proof or 40% v/v) contains 14.02 g of alcohol.

Formula 7: Calculation of total grams (Σg) of alcohol per milliliter

$$\text{mL} \times \%\ \text{v/v} \times 0.79$$

When alcoholic beverage containers contain metric volumes (e.g., milliliters), the grams per serving is easily made by first dividing mL by mL/oz or using Formula 7.

$$\text{Example}: \frac{350\ \text{mL} \times 4.75\% \times 0.79}{100} = 13.13\ \text{g of alcohol per serving}$$

These drink-equivalent calculations correspond with data published in the United States, wherein a "standard drink" is often defined as about 14 g or 0.6 oz of absolute alcohol (US Department of Agriculture, 2005). Lower alcohol content beers or smaller servings will proportionally decrease what constitutes a drink. The WHO, for example, notes that in the United States, a standard drink is defined as 12 g but sometimes 14 g of alcohol (WHO, 2000).

Similarly, the total number of grams of alcohol can be recalculated across any drink formulation if you know: (1) the percent or proof of the alcohol (available from any number of sources) and (2) the number of ounces served in each "drink." For example, how does a drinker in Beijing, China, who consumes 3 cans of beer per day each containing 350 mL of 4% (v/v) alcohol, compare with a person in New Hope, Pennsylvania, who drinks three 12-oz beers per day each containing 5.25% (v/v) alcohol or a person in Los Angeles who consumes three 2-oz drinks containing 80-proof gin per day? If a drink is "standardized" to mean 1.5 oz of 80-proof alcohol or the equivalent, then the equivalent comparison among these drinkers is that their daily alcohol intake is about 2.4, 3.2, and 4.0 drinks, respectively, even though all 3 subjects may have reported that they consumed 3 "drinks" per day. The analysis is explained as follows:

Example: Three 350-mL beers each containing 4.0% v/v alcohol
4.0% v/v beer = 0.0316 g/mL = 0.93441 g/oz
350/29.57 = (11.836 oz per drink×0.93441 g/oz) × 3 drinks = 33.179 g
33.179 g/14 g = 2.37 standard drinks per day

Example: Three 12-oz beers each containing 5.25% v/v alcohol
5.25% (v/v) beer = 0.0415 g/mL = 1.2264 g/oz
1.2264 g/oz×12 oz = 14.72 g × 3 drinks = 44.15 g
44.15 g/14 g = 3.15 standard drinks per day

Example: Three 2-oz drinks of 80-proof liquor
80 proof = 0.316 g/mL × 29.57 = 9.3441 g/oz
9.3441 g/oz×2 = 18.69 g × 3 drinks = 56.07 g
56.07 g/14 g = 4.01 standard drinks per day

In these examples, the difference between the lowest and highest calculation is about 1.64 drinks per day. In some studies, this difference could be crucial to understanding and correctly interpreting the threshold effects of cumulative alcohol use. For example, in many epidemiological studies, there are significant differences in risk for various medical conditions based on many factors, one of which is the number of drinks consumed per day. Vaughn et al. (1995) found that people who consume more than 3 drinks per day have a significantly greater risk of esophageal cancer than those who drink less. Fuchs et al. (1985) found that drinking ranging from 1 to 3 drinks per week to 1 to 2 drinks per day was associated with reduced risk of death from cardiovascular diseases. There is a clear value to these complex multivariable studies to understand threshold consequences on health. Yet, it can be seen that a difference of 1 to 2 drinks per day due to miscalculation can significantly alter the interpretation of such results.

Drink equivalents are sometimes described in terms of ounces of absolute or pure alcohol (200 proof) and that a typical alcoholic beverage contains approximately 6/10ths of an ounce of pure (100%) alcohol by volume (US Department of Agriculture, 2005). It is safe to assume that for the general public, the concept of ounces of absolute alcohol per drink has little value. However, for researchers, the calculation of a dose of pure alcohol is obtained from Formula 8. Here, the percentage of the volume of the alcohol serving or container is multiplied by the percentage of alcohol (% v/v).

Formula 8: Calculation of ounces of absolute alcohol (by volume) in any drink

$$\text{Absolute ethanol} = \text{Volume} \times (\%\text{v/v}/100)$$

Example: 12 oz of 4.75% v/v beer = 12.0 × 0.0475 = 0.57 oz of absolute alcohol
1.5 oz of 80-proof spirits = 1.50 × 0.40 = 0.60 oz of absolute alcohol
1.25 oz of 100-proof spirits = 1.25 × 0.50 = 0.63 oz of absolute alcohol
5 oz of 12% v/v wine = 5 × 0.12 = 0.60 oz of absolute alcohol

The number of drinks consumed may be further interpreted based upon an individual's characteristics. Depending upon either drink formulation or the anthropometric characteristics (e.g., age, weight, height, gender) of the drinker and to paraphrase a common belief, a drink is not a drink is not a drink. Failure to consider individual differences can result in misleading conclusions (Devgun and Dunbar, 1990). For example, it is widely recognized that 3 drinks in a 130-pound female will have different pharmacokinetic and pharmacodynamic effects when compared with a 130-pound male, let alone a 200-pound male. Various mechanisms have been proposed over the past 100 years to explain such gender differences, but it is generally accepted that alcohol is distributed throughout the water-containing compartments of the body, and all other factors being equal (e.g., absorption, elimination, weight), the peak BAC produced by any dose will vary as a function of changes in the ratio of muscle to fat. On average, men tend to be more muscular than women and muscle contains more water than fat. Similarly, on average, women have more body fat than men (Deem and Lentner, 1970). Widmark (1932) first noted this gender difference, which he attributed to body water and described as the "ρ" factor. Over the decades, Widmark's original formulas have been updated and modified. For example, Watson et al. (1981), and others, derived various algorithms for calculating total body water (TBW) that can be used to estimate more accurately the resulting BAC based upon individual body characteristics (Goist and Sutker, 1985; Kalant, 2000; Watson et al., 1981).

Differences in first-pass metabolism (metabolism that occurs in the stomach before alcohol enters the circulation) may or may not (Baraona, 2000; Haber, 2000; Levitt and Levitt, 2000) contribute to the observed pharmacokinetic differences between some men and some women. Thus, it might be useful for researchers to both consider the total alcohol intake equivalent in drinks per unit time and also provide an estimate of BAC, based on drinks or grams of alcohol consumed per body size based upon anthropometric characteristics of the drinker. This is an important consideration as the belief that women are more vulnerable to the effects of alcohol than men, may in part, be based upon the failure to express alcohol doses in relation to individual drinker characteristics (Kalant, 2000).

ESTIMATING BAC, ALCOHOL INTAKE, DOSING METHODOLOGIES, AND RELATED FORMULAS

There are several ways to examine alcohol intake, each with varying degrees of sophistication. For the most part, formulas designed to estimate BAC are derived from the work of Widmark in the 1930s. Widmark's contribution to understanding alcohol intoxication is widely recognized and given the instruments of his day, quite notable. However, with technological advances, some of his "factors" and assumptions have been changed and refinements have been made to his basic formula. Therefore, we will review methods of estimating BAC and useful related formulas.

In pharmacology, the most basic approach starts with an estimate of the theoretical maximum concentration of a drug. This purely theoretical maximum, which assumes immediate absorption and distribution, can be expressed by the following formula:

Formula 9: Calculation of the theoretical maximum concentration of alcohol from a drink

$$C = \text{g}/\sum V_{\text{d}} \times Bl_{\text{H}_2\text{O}},$$

where C is the maximum theoretical BAC at time zero, g is the grams of alcohol, ΣV_{d} is the total volume of distribution, and $Bl_{\text{H}_2\text{O}} = 80.65$ (approximate percentage of water in blood).

Example: The maximum concentration from 5 oz of 80-proof alcohol in a man with a ΣV_{d} of 45.

$C = (5 \text{ oz} \times 9.3441 \text{ g}/\Sigma V_{\text{d}}) \times 80.65$
$C = 46.72/45 \times 80.65$
$C = 83.73$ mg/dL

Several new terms have been introduced into Formula 9. The volume of distribution (V_{d}) is a function of the ability of the drug to bind to plasma protein, tissue, etc. In the case of alcohol, which is very hydrophilic, it is distributed primarily to body water including blood and other tissues. According to Kalant (2000), as the dilution of orally administered alcohol yields the same concentration as $H_2^{18}O$ or ^3H_2O, TBW is the same as V_{d}. In recognition of both terms, we prefer to use the term ΣV_{d} here to refer to the total volume (liters) of water in which alcohol can be distributed for an individual of a particular age, weight, height, and gender. This value is based upon the anthropometric algorithms proposed by Watson et al. (1981). A value of about 80.65% is frequently used as an estimate of the water content of blood (Center of Alcohol Studies, 1983; NHTSA 1994).

Many longitudinal studies of alcohol use among school-age children inquire about the frequency in which "5 drinks in a row" is consumed. Similarly, hospital emergency department patients are often asked to provide information about what and how much they drank to assist in diagnoses and treatment decisions. The interpretation of such data could be greatly enhanced if an estimate of the resulting intoxication could also be made. For example, 5 drinks consumed by a small woman in 1 hour would have significantly different medical and legal consequences compared with the same 5 drinks consumed by a large man over 2 or 3 hours. In collecting self-report data about the number of drinks consumed per day, it is recommended that when possible, investigators collect information about the time course or the length of drinking episode, as well as drink size and anthropometric characteristics of the subject. By utilizing assumptions about the rates of alcohol absorption and elimination, a more accurate analysis can be performed (e.g., estimating peak BACs). Several studies have demonstrated that mathematical models can predict BACs if sufficient information is available (Brick et al., 1992; Mumenthaler et al., 2000; NHTSA, 1994; Pieters et al., 1990; Wilkinson, 1980). Some investigators correctly question the reliability of such analyses when the rates of absorption and elimination and V_d are not known, but this criticism can be overcome in most cases by utilizing a range of absorption and elimination rates and anthropometric data to estimate ΣV_d. For example, on average, most social drinkers (i.e., not alcoholics with exceptional metabolic tolerance) eliminate alcohol at an average rate of about 10–20 mg/dL/h. There is evidence that women may eliminate alcohol toward the higher end of this range (Cole-Harding et al., 1987), and alcoholic individuals without liver damage may eliminate alcohol at an average rate of 22 mg/dL (range 13–36 mg/dL/h) during withdrawal (Jones and Sternebring, 1992). While reliable estimates of BACs can be made using averages under some conditions (Brick et al., 1992; NHTSA 1994), total body water provides a more specific estimate of ΣV_d and should be used in lieu of older methods, such as Widmark's "ρ" factor. Watson et al. (1981) developed specific algorithms (Formulas 10a–d) for estimating body water.

Formula 10: Estimating total body water

Formula 10a: For men below 16 years of age:

$$-21.993 + (0.406 \times \text{pounds}/2.2045) + [0.209 \times (\text{height in inches}/2.54)]$$

Formula 10b: For men 17–86 years old:

$$2.44 - (0.09516 \times \text{age}) + [0.1074 \times (\text{height in inches} \times 2.54)] + [0.3362 \times \text{pounds}/2.2045)]$$

Formula 10c: For women below 16 years of age:

$$-10.313 + [0.252 \times (\text{pounds}/2.2045)] + [0.154 \times (\text{height in inches} \times 2.54)]$$

Formula 10d: For women 17–84 years old:

$$-2.097 + [0.1069 \times (\text{height in inches} \times 2.54)] + [0.2466 \times (\text{pounds}/2.2045)]$$

Example: Consider the following female subject: 23 years old, 110 pounds, and 66 inches tall

$$\begin{aligned} &-2.097 + [0.1069 \times (\text{height in inches} \times 2.54)] + [0.2466 \times (\text{pounds}/2.2045)] \\ &= -2.097 + [0.1069 \times (66 \times 2.54)] + [0.2466 \times (110/2.2045)] \\ &= -2.097 + (17.921) + (12.305) = 28.129 \end{aligned}$$

Alcohol research often requires the investigator to quantify alcohol intake or to dose subjects to evaluate psychosocial behavior or cognitive or motor skills at various BACs. Despite advances in pharmacokinetics, many investigators calculate intake or dose based only on body weight (e.g., g/kg), ignoring other important anthropometric characteristics discussed in the previous section. This method results in excess variability as there are physiological differences between and within men and women. For example, a man and a woman of equal weight who receive the exact same dose of alcohol will usually have different BACs because, on average, men have more muscle mass (and therefore more water) than women (Goist and Sutker, 1985; Li et al., 2000), differences in first-pass (Frezza et al., 1990; Lim et al., 1993) or hepatic (liver) metabolism (Thomasson, 2000), or other factors. Conversely, the amount of alcohol necessary to achieve a particular BAC is a function of many factors and individual characteristics. In some instances, these characteristics or factors are not known, and in other instances, they are known or can be reasonably assumed. For example, alcohol researchers and others have repeatedly demonstrated that BACs can be accurately targeted in men and women when variables such as absorption, metabolism, and gender are considered (Brick et al., 1992; Friel et al., 1999; Gullberg and Jones, 1994; Montgomery and Reason, 1992; Pieters et al., 1990; Stowell and Stowell, 1998; Wilkinson, 1980). Pharmacokinetic models incorporating the basic (Alco-Calculator; Center of Alcohol Studies, 1983) or complex (Levitt and Levitt, 2000; Pieters et al., 1990; Wilkinson, 1980) necessary variables are beyond the scope of this communication, but can be found in the studies just cited.

When information about drinking is limited, the circulating alcohol burden (CAB) is a useful measure of the total amount of alcohol "on board" at the time of a blood or breath test. The CAB is independent of 2 variables, rate of absorption and rate of elimination, and is therefore useful when insufficient information is available to account for these variables. However, CAB estimates assume that alcohol absorption is, for all practical purposes, complete. Circulating alcohol burden may underestimate consumption in some instances because about 80% of alcohol consumed is absorbed within about 30 minutes of the last drink (Gullberg, 1982; Jones and Neri, 1991). As CAB is the alcohol burden at a single moment in time and does not account for elimination, it is a good estimate of minimum alcohol consumption. In other words, the total alcohol intake will always be greater than the CAB.

Consider the following example in which a 23-year-old, 110-pound, 66-inch-tall female has a BAC of 120 mg/dL. Using the total body water or other measure of volume of distribution (calculated from Formula 10d as 28.13), the CAB is estimated using Formula 11, where $\mathrm{BAC_{obj}}$ is an objective chemical measure of BAC.

Formula 11: Calculation of CAB: Alcohol in circulation at time of blood test

$$\mathrm{CAB} = \left(\mathrm{BAC_{obj}} \times \sum V_{\mathrm{d}}\right)/80.65$$

$$\text{Example}: (120\,\mathrm{mg/dL} \times 28.13)/80.65 = 41.86\,\mathrm{g}$$

It can be estimated that a CAB of 41.86 g is equivalent to about 15 oz of 12% (v/v) wine, 4.5 oz of 80-proof liquor, or about 3 standard drinks or about 5.2 "units," as described previously.

While the CAB describes the amount of alcohol in the body at a fixed point in time, it may be more useful to estimate the total alcohol consumed (TAC) over time. Such estimates expand Formula 11 and must include assumptions regarding the rates of alcohol absorption and elimination. Researchers should be mindful of the fact that when alcohol is consumed slowly as in many social settings, or even in some experimental studies, the peak BAC occurs shortly after the last drink. Some experimental studies report that about 80% of the maximum BAC occurs within 12 minutes after drinking ends (Gullberg, 1982; Jones and Neri, 1991). However, larger volumes or very rapid alcohol consumption protocols often used in the laboratory may result in more variability, particularly when the dose is relatively low. The variables that affect absorption are complex and may vary with beverage concentration, volume, presence or absence of food, genetics, or other factors. Consistent with empirical studies, most medical references describe the majority of alcohol as being absorbed within 20 to 30 minutes, with a maximum BAC occurring about 60 to 90 minutes after the last drink (Ellenhorn and Barceleaux, 1988; Hobbs et al., 1996; Pohorecky and Brick, 1990). The accuracy of such estimates can be enhanced by using a range of elimination rates and anthropometric formulas to estimate total body water, such as those developed by Watson and discussed previously. Estimates of TAC from the start of an acute drinking episode to the time a blood or breath sample can be made by algebraically rearranging Formula 11 and including alcohol absorption and elimination to produce Formula 12. This calculation assumes that alcohol is, for all practical purposes, completely absorbed at the time the objective sample was obtained.

Formula 12: Calculating TAC over time

$$\mathrm{TAC} = \sum V_{\mathrm{d}} \times (\mathrm{BAC_{obj}} + \beta_{1-\mathrm{n}} \times t)/Bl_{\mathrm{H_2O}},$$

where TAC is the total alcohol consumed, BAC_{obj} is the objective chemical test result, β_{1-n} is the range of rates of alcohol elimination $(1-n)$, usually 10 to 20 mg/dL/h, t is the time from start of drinking until the time of an objective chemical test, and $Bl_{\mathrm{H_2O}} = 80.65$ (approximate percentage of water in blood).

Example: Estimation of TAC in a subject ($\Sigma V_{\mathrm{d}} = 29.13$) with a BAC of 120 mg/dL 3 hours after the start of drinking and 1 hour after the last drink. Rate of elimination estimated at 10 to 20 mg/dL/h.

$\mathrm{TAC} = \Sigma V_{\mathrm{d}} \times (BAC_{\mathrm{obj}} + \beta_{1-n} \times t)/Bl_{\mathrm{H_2O}}$,
TAC = 29.3 × 120 mg/dL + (10 mg/dL/h×3 hours)/80.65,
TAC = 29.3 × (120 + 30 mg/dL)/80.65 = 54.5 g if the rate of elimination is 10 mg/dL/h,
TAC = 29.3 × 120 mg/dL + (20 mg/dL/h × 3 hours)/80.65,
TAC = 29.3 × (120 + 60 mg/dL)/80.65 = 65.4 g if the rate of elimination is 20 mg/dL/h, and
TAC = 3.9 to 4.7 standard drinks.

Widmark first used the symbol β to denote the rate of alcohol elimination, which he found to average 15 mg/dL/h. This rate is widely accepted as the average rate of alcohol elimination in healthy humans although there is little doubt that some individuals eliminate alcohol above or below this rate. For example, some investigators reported that women may eliminate alcohol at a higher rate (Cole-Harding and Wilson, 1987; Thomasson, 2000) and some alcohol abusers or alcoholic individuals in detox eliminate at an average rate of about 22 mg/dL with a range of 13 to 36 mg/dL/h (Jones, 1993; Jones and Sternebring, 1992; Stowell and Stowell, 1998). Because there are so many variables in alcohol pharmacokinetics, it is important to utilize a range of absorption and elimination values. It is recommended that alcohol elimination rates of 10 to 20 mg/dL/h be used for healthy subjects, but that rates as high as 20 mg/dL to 30 mg/dL/h be considered when working with heavy drinkers in whom metabolic tolerance may be present. Researchers also need to appreciate that unless the drinking rate is very slow, in most cases, a maximum BAC may not occur for up to 30 to 90 minutes after the last drink. Absorption is considered in Formula 13, in which an estimated BAC is calculated based upon known alcohol intake.

Formula 13: Estimation of BAC based upon alcohol intake

$$\mathrm{BAC} = \mathrm{g}/\sum V_\mathrm{d} \times Bl_{\mathrm{H_2O}} - [(\beta_{1-n} \times (t_\mathrm{s} + t_\mathrm{p})],$$

where g is the grams of alcohol; ΣV_d is the TBW or volume of distribution based on age, weight, height, and gender (from Watson et al., 1981); $Bl_{\mathrm{H_2O}} = 80.65$ (approximate percentage of water in blood); β_{1-n} is a range of alcohol elimination rates (e.g., 10–20 mg/dL/h); t_s is the time from the start of drinking to the last drink; and t_p is the range absorption times from the last drink to estimates peak BAC (e.g., 30–90 minutes).

Formula 13 can be algebraically rearranged to Formula 14, which estimates the required dose of alcohol in grams that needs to be administered to produce a particular BAC. This is a more accurate method of dosing subjects than simply administering g/kg doses of alcohol. The math is described in Formula 13 and is simply a reexpression of Formula 12 (TAC).

Formula 14: Estimating dose to achieve a target BAC

$$\mathrm{g} = \mathrm{BAC}_{\mathrm{target}} + [(\beta_{1-n} \times (t_\mathrm{s} + t_\mathrm{p})] \times \sum V_\mathrm{d}/Bl_{\mathrm{H_2O}},$$

where $\mathrm{BAC}_{\mathrm{target}}$ is the desired BAC, and g is the g of alcohol administered to achieve BAC_{target}.

Example: A 23-year-old female weighing 120 pounds and 66 inches tall ($\Sigma V_\mathrm{d} = 29.13$) eliminating alcohol at 10 to 20 mg/dL/h, drinking for 2 hours, and with an assumed peak or target BAC of 100 mg/dL 30 to 90 minutes after the last drink would need to consume about 54 g of alcohol or about 5.8 oz of 80-proof alcohol. The following calculation shows the math for a rate of alcohol elimination of 20 mg/dL/h and a peak alcohol concentration 30 minutes after the last drink, but in practice a range of absorption and elimination rates should be considered.

g = 100 mg/dL + [(20 mg/dL/h) × (120 + 30 minutes)] × 29.13/80.65.
g = 54.18 or about 5.8 oz of 80-proof alcohol (54.18/9.3441 = 5.798 oz) or 3.9 standard drinks.

ALCOHOL TESTS

The analytical method used by a laboratory to measure alcohol is often overlooked in reporting alcohol results. Sometimes, alcohol units are expressed in nomenclature not known to all scientists.

For example, in some European literature, alcohol concentrations are reported as "pro mille." Pro mille means parts per thousand and is abbreviated ‰. In the United States, Great Britain, and other countries, alcohol is expressed as parts per hundred (%). A BAC of 1.5‰ is equal to 150 mg/dL (0.15%). To convert ‰ to mg/dL (mg%), use Formula 15.

Formula 15: Recalculating Pro Mille (‰) BAC to mg% BAC

$$1‰ \times 100 = \mathrm{mg/dL}$$

In some areas of research, alcohol is expressed as millimoles per liter (mM). A millimole is one one-thousandth of a gram molecule. One molecule of alcohol contains 46.07 gram-molecules/L or 4.607 moles/dL. The conversion of mM alcohol to mg/dL alcohol or converting mg/dL to mM alcohol is easily accomplished using Formulas 16 and 17.

Formula 16: Converting alcohol from to mM to mg/dL concentrations

$$\mathrm{mg/dL} = \mathrm{mM} \times 4.607$$
$$\text{Example}: 22.5\ \mathrm{mM} \times 4.607 = 103.658\ \mathrm{mg/dL}$$

Formula 17: Converting alcohol from mg/dL to mM concentrations

$$\mathrm{mM} = \mathrm{mg/dL}/4.607$$
$$\text{Example}: 91.5\ \mathrm{mg/dL}/4.607 = 19.861\ \mathrm{nM}$$

Alcohol test results from clinical, research, and forensic lab results are expressed in w/v, typically as grams or milligrams of alcohol per fixed volume of fluid (100 mL of blood or serum) or per 210 L of air (for some breath test instruments). Many clinical alcohol researchers measure alcohol in breath because it is convenient, rapid, and accurate; multiple samples can be obtained without discomfort to the subject; and the subject often includes animals (Pohorecky and Brick, 1982). The largest number of breath tests are conducted in the course of police investigations of suspected intoxicated drivers. Outside the United States, breath-alcohol test results are usually reported in grams of alcohol per 210 L of air, whereas in most of the United States, breath testing instruments are calibrated to convert grams per volume of breath into milligrams of alcohol per 100 mL of blood (mg/dL) or grams per 100 mL (g%).

When whole-blood alcohol is measured directly using an instrument such as a gas chromatograph, the results are also expressed as w/v (e.g., grams or milligrams per 100 mL blood). Milligrams are easily converted to grams by dividing the value by 1,000, and g% is easily converted to mg/dL by multiplying the value by 1,000. For example, 80 mg/dL = 0.08 g% and 0.15 g% = 150 mg/dL. The preferred nomenclature for some scientific journals is usually mg/dL to avoid confusion with statistical percentages. A BAC of 80 mg/dL is the same as 80 mg%, which is the same as 0.08%.

Researchers relying upon alcohol test results from a hospital laboratory often neglect to inquire or report whether the results are derived from whole blood, serum, or plasma samples. As the ratio of the concentration of alcohol in serum to that of plasma is about 1:1 (Winek and Carfagna, 1987), further discussion will be based upon serum or blood alcohol. Some hospitals specify whether the reading is from serum or whole blood, whereas others in our experience do not. If the laboratory measures alcohol in serum, the results are not equal to whole-blood test results. This may have important implications for scientists comparing test results or in instances where such results are used as evidence in a criminal or civil litigation. As alcohol is distributed throughout the water-containing compartments of the body including the blood, serum alcohol is not the equivalent of a BAC because serum contains more water than the whole blood from which it is derived. Therefore, the concentration of alcohol in whole blood is less than that of the serum in proportion to their respective water contents. In other words, a hospital serum alcohol concentration will be higher than a whole BAC drawn from the same patient at the same time. Early studies reported that the plasma:whole-blood ethanol ratio ranged from 1.10 to 1.35 with an average of 1.18 (Payne et al., 1968). Other studies suggest that the ratio of serum:whole-blood alcohol ranges from about 1.10 to 1.18 (Winek and Carfagna, 1987) to 1.25 (Hodgson and Shajani, 1985). In most cases, the range of the ratio is about 1.10 to 1.20, although Payne's average value of 1.18 has found acceptance in the literature (Baselt, 1996) and corresponds well with our observations comparing serum alcohol measured by the alcohol dehydrogenase (ADH) method with gas chromatography analyses of the same blood sample (unpublished observations). The range of serum:blood ratios for most subjects is small in comparison with the significant difference between alcohol results reported in either serum versus whole blood. The following formulas and examples illustrate the potential differences between serum and whole-blood alcohol readings.

To convert serum alcohol to the minimum and maximum whole-blood alcohol equivalent, we recommend Formula 18, where S_A is the serum alcohol.

Formula 18: Converting serum alcohol to whole-blood alcohol equivalents

S_A/1.10 to 1.20, or multiplying by the reciprocal of the denominator.

Example: 90 mg/dL/1.10 = 81.82 mg/dL whole blood

90 mg/dL × 0.9091 = 81.82 mg/dL whole blood
90 mg/dL/1.20 = 75 mg/dL whole blood
90 mg/dL × 0.8333 = 75 mg/dL whole blood
244 mg/dL/1.10 = 221.82 mg/dL or 244 mg/dL × 0.9091 = 221.82 mg/dL whole blood
244 mg/dL/1.20 = 203.33 mg/dL or 244 mg/dL × 0.8333 = 203.33 mg/dL whole blood

In some instances, both serum alcohol and hematocrit (Hct) values are available in medical records. As the Hct is a quantitative measure of the percentage of cells in a fixed volume of blood, the change in Hct is in part a measure of the water content of the blood. The normal range for human Hct is approximately 47 ± 5 for men and 42 ± 5 for women (Pagana and Pagana, 1995). By recalculating the serum water contents, in men, using Formula 19, serum to whole-blood alcohol conversion estimates can be performed particularly when Hct is abnormal, due to hemodilution from medical intervention (e.g., administration of fluids). When Formula 19 is applied to published (Payne et al, 1968; Winek and Carfagna, 1987) and available data, it predicts with reasonable accuracy the whole BAC (typically within about 5 mg/dL for BACs < 100 mg/dL). Some chronic alcoholic individuals may have an elevated mean corpuscular volume (MCV), which may affect Hct (Seppa et al., 1991; Wu et al., 1974). When applying Formula 19 to women, who have a lower average Hct, use 0.608 instead of 0.645. We have not yet tested this formula on blood, serum, and Hct samples from chronic alcoholic individuals in whom MCV is elevated.

Formula 19: converting serum alcohol to whole-blood alcohol concentrations in men using Hct

$$BAC = ((\mathrm{Hct} \times 0.645) + ((100 - \mathrm{Hct}) \times 0.95))/95$$

Example: Using the following known results, Formula 19 closely estimates the actual BAC. Serum alcohol = 48 mg/dL, whole-blood alcohol = 43 mg/dL, and Hct = 29, [(29 × 0.645)+(100 − 29) × 0.95)]/95 = (18.71 + 67.45)/95, 48 mg/dL × 0.907 = 43.5 mg/dL

Example: Assuming serum alcohol = 230 mg/dL and the whole-blood alcohol = 197 mg/dL and Hct = 50, [(50 × 0.645) + (100 − 50) × 0.95)]/95 = (32.25 + 50)/95 = 0.8658, 230 mg/dL × 0.8658 = 199.13 mg/dL.

In each of the previous examples, the serum alcohol can be divided by the reciprocal of the ratio rather than multiplying it by the initial value. In the second example, the reciprocal of 0.8658 is 1.1550 (1/0.8658). Therefore, a serum alcohol concentration of 230 mg/dL/1.1550 = a whole BAC of 199.13 mg/dL. Formulas 18 and 19 provide similar results. Using a range of ratios (from Formula 18) and the same data from the examples, the expected whole-blood alcohol would be: 40.0 to 42.1 versus 43.5 mg/dL from Formula 19 versus 43 mg/dL from the actual blood sample (first example) and 191.67 to 209.09 mg/dL (vs 199.13 mg/dL from Formula 19 versus 197 mg/dL from the actual blood test (second example). Thus, either approach will provide reasonable estimates of BAC, but each has limitations.

From the examples given, it can be seen that depending upon the serum:whole-blood ratio, the actual BAC varies. At lower BACs, the difference is minimal (usually less than 5 mg/dL), but with very high BACs, such as might be encountered in surveying data from alcoholic individuals or heavy drinkers, the differences are proportionally greater. Researchers should keep this variation in mind when reporting serum (or plasma) alcohol test results or comparing such results with whole-blood alcohol results.

Finally, earlier studies often reported alcohol concentrations in mg/g or g/kg because of the method for analyzing alcohol at that time. Mass/mass units can be converted to mass/volume units based upon the specific gravity of whole blood, which is approximately 1.055 g/mL. Therefore, 1 mg/g = 1.055 mg/mL as indicated in Formula 20.

Formula 20: Converting mass/volume alcohol to whole blood alcohol

BAC in mg/g $\times$ 1.055 mg/mL $\times$ 100 = mg/dL
Example: 1.50 mg/g BAC $\times$ 1.055 mg/mL $\times$ 100 = 158.25 mg/dL
Similarly, 150 mg/100 g BAC $\times$ 1.055 mg/mL = 158.25 mg/dL

DISCUSSION

This article describes in detail 20 mathematical formulas and various methods for estimating the amount of alcohol consumed by subjects in epidemiological studies, dosing methods for subjects in laboratory studies estimating BAC, and discussion about the proper interpretation of alcohol results depending upon the analytical technique used to measure alcohol. This information is intended to assist scientists in standardizing the way alcohol values and estimates of alcohol use are calculated and expressed. These formulas may also be useful in studies of accidents and injuries where detailed measures are often available along with individual anthropometric data. However, the use of formulas based upon subjective information is subject to memory bias from self-serving interests, intoxication, or neuropsychological insult, particularly when subjects were traumatized patients, for example. In such instances, objective chemical tests should be used to validate and further interpret subjective reports. The issue of the errors that result when researchers do not take these variables into consideration has been raised previously, but not in such detail. Miller et al. (1991) noted this problem and made a ‘‘plea for consistency’’ in standardizing various alcohol calculations and suggested that progress in the field is impeded by the lack of a common scientific language. Miller and colleagues clearly recognized this problem and pointed out various differences in the amount of alcohol in different alcoholic beverages. However, the only formula they provided was to convert Imperial proof units to United States Apothecary proof. No other standard pharmacological formulas were presented that would enable researchers to collect, interpret, and communicate information accurately. Fifteen years after Miller et al. made their plea for alcohol researchers to speak a common language in describing quantitative aspects of alcohol research, the problem remains.

The NHTSA published guidelines for computing a BAC estimate and calculating the relationship between alcohol consumed and intoxication (NHTSA, 1994). The review was completed to assist legislators debate bills about legal definitions of alcohol intoxication. Although NHTSA acknowledged that alcohol absorption and elimination varied, there was no discussion or explanation for researchers regarding how to compute the alcohol contents of ‘‘a drink.’’

In a review of the beneficial and harmful effects of moderate drinking, Dufour (1999) discussed the importance of defining ‘‘drinks’’ and drink levels and noted that a standard drink should be defined in terms of alcohol content. Dufour brings attention to the fact that drink formulations vary, refers to ‘‘conversion factors’’ to compare the alcohol contents of various beverages, and defines the average alcohol contents of drinks but does not provide guidelines to perform calculations or conversions to allow researchers to standardize their data.

Moreover, Dufour (1999) refers to an earlier publication to define a standard drink (12 fluid ounces of regular beer, 5 fluid ounces of wine, and 1.5 fluid ounces of 80-proof alcohol) as containing approximately 0.5 fluid ounces of absolute alcohol or about 12 g. However, without specifying the percentage of alcohol in the beer or wine, an accurate interpretation of a standard drink is impossible. It is problematic that the drink equivalent information contained in Dufour's otherwise authoritative review appears incorrect. For example, as described in Formula 5 of the current publication, 1.5 oz of 80-proof alcohol contains approximately 14 g of ethanol, not 12. It is this very type of miscommunication that we wish to correct so that researchers will be better able to compare results across studies. For research purposes, a simple approach to standardize drinks may be to use the ‘‘unit’’ method (Formula 4) popular in the United Kingdom, for example, and express ‘‘alcohol units’’ by volume (% v/v). However, this requires converting milliliters to ounces to compare drinks in countries where alcoholic beverages servings or containers contain ounces or the conversion of ounces to milliliters if you are trying to interpret data from the United States, for example. The more practical recommendation is that researchers report consumption in grams of absolute alcohol, as recommended by Dufour (1999). We agree and add that if researchers also want to express their results in terms of ‘‘standard drinks,’’ they also operationally define the number of grams they use for a ‘‘standard drink’’ using the methods described herein.

Kerr et al. (2005) conducted a telephone survey, which included instructions for subjects to prepare and measure the volume contents of their usual alcoholic drinks at home. These investigators correctly calculated the number of grams of alcohol in a standard drink. They also concluded that the 0.6 fluid ounce of absolute alcohol per standard drink ‘‘is not unreasonable absent additional individual-level information; this value may likely be the best single standard for the United States'' (p. 2019). Although Kerr et al. did not explain how to calculate the alcohol contents in beverages, their method of identifying the size of each drink by providing subjects with measuring beakers sets a good standard for other researchers to follow.

Given the many variables discussed, it behooves scientists to collect as much information about the alcoholic beverage as possible including detailed information about the proof, brand, and size of each drink. Beer consumption volume estimates tend to be more accurate than wine or spirits because about 80% of drinkers consume beer in 12-oz servings (Kerr et al., 2005). However, the concentration of beer varies considerably as do liquor and wine glass servings. Following the method of Kerr et al. (2005), when possible, presenting subjects with a comparative sample glass, cup, bottle, etc., may enable them to identify more accurately what they mean by ''a drink.'' In addition, some subjects (and investigators) may not know the alcohol content of the beverages consumed. When such information is not printed on the label, published reviews should be consulted (e.g., Case et al., 2000). Coupled with an inquiry as to the brand of beverage and determination of the concentration or proof of beverages consumed, the formulas described herein can be applied to make more accurate estimates of alcohol consumption.

Finally, alcohol estimates are subject to limitations due to a variety of factors that are often unknown. For example, individual differences in the rates of alcohol absorption and elimination, beverage type, alcohol content, serving size, and other factors are rarely known with absolute certainty, except as noted. However, by using a range of physiological characteristics likely to represent most drinkers, collecting data on beverage type and size, using anthropometric characteristics of the drinker, and assuming a range of absorption and elimination rates, the accuracy and interpretation of reported alcohol consumption and estimates of exposure can be enhanced substantially. We recognize that there is variability in all biological and chemical measurements and in self-report data. Also, in many instances, the formulas reviewed include examples with results to the third or even the fourth decimal place. This is carried out to allow mathematical consistency when comparing different approaches and not to infer BAC precision to fractions of a milligram. Whether we are discussing alcohol units, standard drinks, or interpreting other quantitative aspects of alcohol, the application of these standard formulas should enable alcohol researchers to interpret more accurately and consistently alcohol data and improve communication in our field. This is a goal toward which there should be little variability of opinion.

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