ASB Best Practice Recommendation 122, First Edition
2024

Best Practice Recommendation for Performing Alcohol Calculations in Forensic Toxicology

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ASB Approved Xxxxx 2024

ANSI Approved Xxxxx 2024

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Foreword

Forensic toxicologists and other experts are frequently requested to perform calculations related to alcohol (ethanol), but there can be a high degree of variability in how this work is performed. Adherence to this best practice recommendation will improve the quality and consistency of this type of work and is intended to help mitigate cognitive bias. This best practice recommendation can be used by experts working in public or private laboratories or as independent forensic consultants; they can be applied to matters related to criminal and/or civil proceedings.

There are numerous factors that must be taken into consideration when providing estimates related to alcohol consumption and alcohol concentrations. Alcohol pharmacokinetics vary within the population, but also within an individual. A person's exact volume of distribution and elimination rate at a given time cannot be known. Alcohol results may or may not include measurement uncertainty. Other factors in the process, such as time and weight, may have unknown degrees of accuracy associated with them, depending on the source of the information. These factors do not prohibit reasonable estimates from being determined, but do require experts to be conservative, knowledgeable about the limitations, and thorough in their work.

The approach taken in this document is to provide a framework to conduct the calculations which result in a reasonable estimate of the range which encompasses the value of interest, and then apply that range to the question at hand with consideration of the assumptions that may or may not be made. For example, in a situation where there is a delay between the incident and the blood draw, an expert may be asked what the subject's blood alcohol concentration was at the time of the incident. Due to the factors discussed within this document, the science does not support being able to provide a single value. Rather an estimated range can be provided and applied to the case, while clearly stating any assumptions that may impact that application. The calculations are applied to an individual and since that individual may not be average, a range is considered most appropriate. Annex A illustrates how this approach can be applied in various scenarios.

Future editions of this document will work toward applying a statistical approach to the calculations. There are approaches in the literature that provide uncertainties for some of the variables contained within the calculations. For example, regarding elimination rate and volume of distribution, there is a significant amount of scientific literature that one may be able to use to reasonably estimate an average value with an associated uncertainty and level of confidence. The body of knowledge in peer reviewed literature is continually increasing and may eventually allow for estimations of the variances associated with additional parameters.

The American Academy of Forensic Sciences established the Academy Standards Board (ASB) in 2015 with a vision of safeguarding Justice, Integrity, and Fairness through Consensus Based American National Standards. To that end, the ASB develops consensus based forensic standards within a framework accredited by the American National Standards Institute (ANSI) and provides training to support those standards. ASB values integrity, scientific rigor, openness, due process, collaboration, excellence, diversity, and inclusion. ASB is dedicated to developing and making freely accessible the highest quality documentary forensic science consensus Standards, Guidelines, Best Practices, and Technical Reports in a wide range of forensic science disciplines as a service to forensic practitioners and the legal system.

ASB is accredited by the American National Standards Institute (ANSI) according to ANSI's "Essential Requirements: Due Process Requirements for American National Standards.[1] ASB documents are developed by volunteers working in Consensus Bodies (CBs) and Working Group (WGs) that conform to ANSI requirements of openness, transparency, due process, and consensus.

This document was revised, prepared, and finalized as a standard by the Toxicology Consensus Body of the AAFS Standards Board. A draft of this standard was developed by the Forensic Toxicology Subcommittee of the Organization of Scientific Area Committees (OSAC) for Forensic Science.

Questions, comments, and suggestions for the improvement of this document can be sent to ASB Secretariat, asb@aafs.org or 401 N 21st Street, Colorado Springs, CO 80904.

All hyperlinks and web addresses shown in this document are current as of the publication date of this standard.

ASB procedures are publicly available, free of cost, at www.aafs.org/academy-standards-board.

Keywords: *alcohol (ethanol), retrograde extrapolation, pharmacokinetics*

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Table of Contents *(to be finalized upon completion)*

Best Practice Recommendation for Performing Alcohol Calculations in Forensic Toxicology

1 Scope

This document provides recommendations for performing alcohol (ethanol) calculations to include retrograde extrapolation, forward estimations, minimum drinks consumed, and other scenarios. Recommendations are also provided for evaluation of post absorptive stage, various specimen types, population variances, and reporting of calculations.

The principles and practices outlined in this best practice recommendation may also apply to postmortem scenarios, but there are additional variables to be considered that are outside the scope of this document.

Expert opinions based on the results of these calculations are outside the scope of this document.

2 Normative References

There are no normative references. Annex B, Bibliography, contains informative references.

3 Terms and Definitions

For purposes of this document, there are no terms and definitions.

4 Background Information

This section provides background information on the basic principles of alcohol pharmacokinetics and the various factors that experts may need to consider when doing this type of work. It is not intended to contain any requirements.

4.1 Alcohol Pharmacokinetics

4.1.1 General

Understanding the mechanisms of alcohol absorption, distribution, and elimination throughout the body is essential to performing alcohol calculations. The following provides an elementary overview of alcohol pharmacokinetics.

4.1.2 Absorption

The absorption of alcohol is a complex dynamic process that begins as soon as drinking begins. Alcohol is primarily absorbed into the bloodstream through the small intestine, but some absorption occurs in the stomach and mouth. Absorption rates are highly variable and are not linear. Factors such as the presence of food in the stomach, the type and volume of beverage consumed, other drugs consumed, and the condition of the gastrointestinal tract, can impact absorption rates. Studies support that it can take up to 2 hours to reach the post absorptive phase after the last drink [2, 3, 5, 6, 10, 12, 13, 15, 22, 30, 32]. The time needed to reach the peak alcohol concentration is not the same as the time to reach the post absorptive phase.

4.1.3 Distribution

4.1.3.1 Alcohol is water soluble and rapidly distributed throughout the total body water by the blood supply. For alcohol, the volume of distribution (Vd) is closely correlated with the total body water (some literature refers to this as *rho*). Numerous factors impact an individual's Vd including sex, body mass index (BMI), and age. In general, Vd is typically lower for women, obese individuals, and the elderly. Numerous publications propose mathematical approaches to estimate an individual's Vd based on certain factors (height, weight, sex), and attempt to provide ranges for the Vd of alcohol [4, 21, 26, 29, 31]. However, there are significant limitations to these studies. For example, the number of participants in many studies is quite small, and the ethnic diversity is often unknown. There are also differences in whether Vd or total body water (TBW) were measured. Some involved bolus drinking, while others used a social drinking scenario. Alcohol concentration may have been measured in whole blood, serum, plasma, or breath. Therefore, it may not be appropriate to directly compare or average these various formulas since they do not all calculate the same variable.

4.1.3.2 Due to the high variability within the population, the use of a single fixed Vd is inappropriate. Research supports a Vd range of 0.45-0.81 L/kg, or specifically 0.58-0.83 L/kg for males and 0.43-0.73 L/kg for females (17). These values represent a 95 percent range for each data set.

4.1.3.3 Alternatively, an individual's Vd may be estimated using anthropometric calculations when sex, weight, age (males), and height are known. The equations derived by Watson (30) and Maskell (16, 19), along with the variability, are considered the best approaches at this time. These calculations estimate the TBW and Vd for an individual and the respective variances (see 5.2.2).

Since there are physiological limitations to the minimum TBW, calculation results should be evaluated carefully, and caution applied when results are below 30 L for males and 23 L for females [18]. The anthropometric calculations refer to male/female as the sex assigned at birth. These calculations may be impacted by gender affirming hormone therapy in transgender individuals [20].

4.1.4 Elimination

4.1.4.1 Alcohol is primarily eliminated via enzyme metabolism in the liver; however, a small amount is removed through first pass metabolism or excreted unchanged in the breath, sweat, oral fluid, and urine. Alcohol is eliminated at a constant, linear rate (zero order kinetics) until low concentrations are reached.

4.1.4.2 An elimination rate range of 0.010-0.025 g/dL/hour encompasses the majority of the population regardless of age, sex, ethnicity, and drinking experience [7, 8, 9, 10, 11, 23, 25, 27, 32].

4.1.4.3 At concentrations below 0.020 g/dL, the elimination rate may not be linear as zero order kinetics may no longer apply [1, 9].

4.1.4.4 The linear elimination rate only applies when the subject is in the post absorptive phase.

4.2 Case History

4.2.1 The type of information and source of that information will vary from case to case. Experts should clearly communicate the information they rely upon and the assumptions they make. On occasion, that information may change as the case proceeds.

4.2.2 The time of the incident and the timing of drinking both play a role in the assumptions that can be made and the associated calculations. For example, the time of last drink based on video surveillance may be considered differently than a time based on the subject's self-reported drinking history. This may impact the assessment of whether the subject was post absorptive at the time of the incident.

4.2.3 When there is evidence of the type of beverage consumed, it may be appropriate to calculate the number of drinks based on that information. However, in other situations, it may be more appropriate to reference a "standard drink" (see 4.5), such as when there is no history or the subject consumed unknown quantities of various types of drinks.

4.3 Specimen Considerations

4.3.1 Serum and plasma have a higher water content than whole blood. Research supports a 95 percent range for a serum or plasma to whole blood ratio of 1.13-1.19 [14].

4.3.2 The alcohol concentration of urine is influenced by hydration and time since last void. Results from urine alcohol testing, including urine results that have been converted to a whole blood equivalent, are not amenable to extrapolation.

4.4 Propagation of Uncertainty

The variance and distribution for all parameters used in the calculations have not been fully characterized in the scientific literature at this point. Therefore, as an initial best practice recommendation, a statistical approach incorporating the uncertainties for each of the parameters is not presented. This guideline does not prohibit the expert from applying accepted statistical models within the calculations. These calculations should be clearly presented, with references or stated assumptions for the associated uncertainties and the method of evaluating the uncertainty.

If known, the range associated with the measurement uncertainty of the test result may be incorporated.

4.5 Standard Drink

A "standard drink" may be defined as a beverage containing approximately 14 grams of alcohol [24].

e.g., 12 oz, 5% beer
5 oz, 12% wine
1.5 oz, 80 proof liquor (40%)

4.6 English/Metric Conversions (if applicable)

The sources of information may be received in English and/or metric units, and conversions are typically required.

Volume: 1 oz = 29.6 mL
Weight: 1 lb = 0.454 kg
Height: 1 in = 2.54 cm or 0.0254 m

4.7 Density of Alcohol

The density of alcohol is 0.789 g/mL

5 Calculations

The formulas presented here are designed to illustrate the mathematical relationships for the calculations. In practice, the layout of each formula and the abbreviations used may vary; multiple steps in the calculations may be combined into one equation.

5.1 Alcohol Test Results

5.1.1 Calculations presented are for blood (g/dL); however, they can also be applied to breath (g/210 L).

5.1.2 Serum and plasma results shall be converted to a whole blood equivalent prior to other calculations.

5.1.2.1 The range should be 1.13-1.19 serum (or plasma) to blood ratio.

5.1.2.2 Further calculations shall then be applied to both converted alcohol concentrations.

5.1.3 Retrograde extrapolation shall not be performed based on urine alcohol results, even those converted to a whole blood equivalent.

5.2 Volume of Distribution (Vd)

5.2.1 A range shall be applied for Vd.

5.2.2 If a fixed Vd range based on sex is used, 0.58-0.83 L/kg for males and 0.43-0.73 L/kg for females should be used. For a fixed Vd, independent of sex, a range of 0.45-0.81 L/kg should be used.

5.2.3 If an individualized Vd is applied, the following calculations should be used:

5.2.3.1 Calculate TBW from Watson, et al[31]:

$$TBW\ (male) = 2.447 - (0.09516 \times a) + (0.1074 \times h) + (0.3362 \times w) \quad (1a)$$

$$TBW\ (female) = -2.097 + (0.1069 \times h) + (0.2466 \times w) \quad (1b)$$

where:

TBW = total body water (L)

a = age (years)

h = height (cm)

w = weight (kg)

5.2.3.2 Calculate the individual Vd from Maskell, et al[16, 19]:

$$Vd\ (male) = \frac{TBW}{w \times 0.825} \quad (2a)$$

$$Vd\ (female) = \frac{TBW}{w \times 0.838} \quad (2b)$$

where:

Vd = volume of distribution (L/kg)

TBW = total body water (L)

w = weight (kg)

5.2.3.3 Apply the ± %CV from Maskell, Cooper[16]:

$$Vd\ (male) = Vd\ \pm (Vd\ \times 9.86\%) \quad (3a)$$

$$Vd\ (female) = Vd\ \pm (Vd\ \times 15.00\%) \quad (3b)$$

5.3 Widmark's Formula

5.3.1 The relationship between a dose of alcohol and a resulting alcohol concentration shall be expressed as:

$$AC = \frac{D}{Vd \times w} \quad (4)$$

where:

AC = alcohol concentration (g/L)

D = dose (g)

Vd = volume of distribution (L/kg)

w = weight (kg)

Variations of the formula can be applied to several common scenarios.

Estimating the minimum number of drinks to achieve a particular alcohol concentration may be used to support or refute a particular drinking history, or to establish that someone could not have consumed less than that amount of alcohol.

5.3.2 Theoretical minimum number of drinks to achieve a particular alcohol concentration.

This calculation does *not* account for any drinks eliminated. It provides an estimate of the equivalent dose of alcohol in the body at the time of the blood draw or breath test. See A.1.1 for example.

Minimum dose of alcohol

$$D = AC \times Vd \times w \times 10\frac{dL}{L} \tag{5}$$

where:

D	=	dose (g)
AC	=	alcohol concentration (g/dL)
Vd	=	volume of distribution (L/kg)
w	=	weight (kg)

Using the calculated dose to estimate the minimum number of "drinks" when beverage concentration is known.

$$V = \frac{D}{C \times \rho \times m} \tag{6}$$

where:

V	=	volume (oz)
D	=	dose (g)
C	=	beverage concentration (mL/100 mL)
ρ	=	density of ethanol (0.789 g/mL)
m	=	metric conversion (29.6 mL/oz)

The calculated volume can be converted to the equivalent number of drinks, depending on the type of drink. For example, if the subject was drinking 12 oz beers, a volume of 37 oz would be equivalent to approximately 3 beers.

5.3.3 Maximum alcohol concentration that could theoretically be achieved from a given dose.

These calculations provide the maximum alcohol concentration attainable from a reported number of consumed drinks. They are used to support or refute a particular drinking history. The calculations are used to attempt to answer the question: "If someone had X number of drinks, could they have reached the measured alcohol concentration?" The calculated results can also provide information to account for potentially unabsorbed alcohol or post incident alcohol consumption.

Dose of alcohol from a drink

$$D = V \times C \times \rho \times m \tag{7}$$

where:

D	=	dose (g)
V	=	volume (oz)

C = beverage concentration (mL/100 mL)

ρ = density of ethanol (0.789 g/mL)

m = metric conversion (29.6 mL/oz)

Theoretical maximum alcohol concentration from a given drink(s)

This calculation provides the *theoretical* maximum alcohol concentration. It assumes full absorption with no elimination. See A.1.2 for example.

$$\mathrm{AC}_{drink(s)} = \frac{D}{Vd \times w \times 10\,\frac{dL}{L}} \tag{8}$$

where:

$\mathrm{AC}_{drink(s)}$ = max alcohol concentration (g/dL) from a drink(s)

D = dose (g)

Vd = volume of distribution (L/kg)

w = weight (kg)

5.3.4 Alcohol eliminated during the drinking timeline may be further considered if necessary or applicable.

5.4 Retrograde Extrapolation

5.4.1 Retrograde extrapolation is a mathematical process that uses an alcohol concentration at a given point in time and estimates what the concentration would have been at an earlier time. It is not possible to calculate the exact alcohol concentration at an earlier point in time, but an estimation in the form of a concentration range can be provided.

5.4.2 The basic calculation for retrograde extrapolation shall be expressed as:

$$AC_{inc} = AC_{test} + (\beta \times T) \tag{9}$$

where:

AC_{inc} = estimated alcohol concentration at the time of the incident (g/dL)

AC_{test} = measured alcohol concentration (g/dL)

β = elimination rate (g/dL/hour)

T = time between incident and time of breath test/blood draw (hours)

5.4.3 Retrograde extrapolation calculations shall not be performed on alcohol concentrations below 0.020 g/dL.

5.4.4 The calculation shall be performed using a range of elimination rates.

5.4.4.1 The minimum range shall be 0.010-0.025 g/dL/hour.

5.4.5 An elimination rate calculated from two or more test results shall not be used in place of a range.

5.4.6 The impact of potentially unabsorbed alcohol shall be addressed.

5.4.6.1 If the time of incident is more than 2 hours after the time of drinking cessation, it is reasonable to assume the subject is post absorptive. See A.2 for example.

5.4.6.2 When the drinking history is unknown, it is not reasonable to assume that the subject is post absorptive. Additional calculations should be applied to assess the impact of potentially unabsorbed alcohol. See A.5 for example.

5.4.6.3 If case history indicates that alcohol was consumed after the incident, but before the sample was obtained, this shall be accounted for in the estimates.

5.4.6.4 An option to account for unabsorbed alcohol or post incident alcohol consumption is to subtract the impact of those drinks from the estimated post absorptive alcohol concentrations (determined from Equation 9). See Equation 8 to calculate the maximum AC contribution from a drink.

$$\text{Adjusted } AC_{inc} = AC_{inc} - AC_{drink(s)} \tag{10}$$

where:

Adjusted AC_{inc} = estimated AC at time of the incident, accounting for potentially unabsorbed alcohol or post incident alcohol consumption

AC_{inc} = estimated AC at time of the incident if subject were in post absorptive state (calculated from Equation 9)

$AC_{drink(s)}$ = maximum AC contribution from drink(s) (calculated from Equation 8)

Reference A.3 for an example where the subject is not post absorptive. See A.4 for an example of addressing post incident alcohol consumption.

6 Additional Considerations

6.1 Documentation

Calculations should be documented and assumptions clearly stated. This may be in the form of case notes, an electronic spreadsheet, a written report, etc.

6.2 Protocols

Written protocols should be in place to ensure the forensic service provider applies a consistent methodology to the calculations. Protocols may also include requirements for documentation, reporting, and reviews.

6.3 Technical Review

Where feasible, independent review of calculations by a qualified individual should be done.

6.4 Calculations During Testimony

Performing alcohol calculations is a forensic service request and should not be viewed as just a question during direct or cross examination, or "simple math" that the expert should be able to readily perform. While the expert must respectfully follow the orders of the legal authorities overseeing the testimony (trial, deposition, etc.), performing calculations during live testimony is discouraged due to the inherent risks. When so compelled, it is recommended that the witness document the additional work. Depending on the scope of the new work requested and its complexity, the expert may consider requesting a brief recess to perform the work and allow for its review. In some circumstances, it may be appropriate to discuss the *impact* a change would have on the calculations, instead of conducting new calculations, e.g., if the subject's drinking history changes, one could state that it would raise or lower the estimated AC range provided, without calculating the new range.

Annex A
(informative)

Examples

NOTE This Annex is intended to provide illustrative examples to apply the recommendations contained within the document; it does not represent the only way the recommendations may be applied or presented. For accuracy in the text, rounding was performed at each step. Numbers may vary slightly when calculations are performed using a spreadsheet and rounding is not applied until the end. Summary statements are intended to succinctly summarize the results of the calculations. They are not intended to provide examples of expert opinions that may be involved in casework.

A.1 Support/refute drinking history

History: A male subject was pulled over for suspected impaired driving. He had an evidential breath test result of 0.19 g/210 L. He stated he had been at a local bar for the last 3 hours and only had 2 pints of Brand X beer. He ate chicken wings and french fries.

Question: Is the stated drinking history consistent with the alcohol concentration (AC) result?

This can be answered two different ways: by calculating the minimum number of drinks needed to attain a certain AC, or by calculating the maximum AC attainable from a drinking history.

Relevant Information:

The subject is male, 6’1”, 230 lbs, 32 years old

Evidential breath test: 0.19 g/210 L

Alcohol content of Brand X beer ~4.3% [cite reference for that brand’s alcohol content (e.g., manufacturer’s website and access date, published reference)]

1 pint = 16 oz

Calculations:

Weight conversion: $w = 230\ lbs \times 0.454 \frac{kg}{lbs} = 104\ kg$

Height conversion: $h = 73\ in \times 2.54 \frac{cm}{in} = 185\ cm$

A.1.1 What is the minimum number of drinks needed to reach a 0.19 g/210 L alcohol concentration?

a) Calculate with a fixed Vd range

Using Equation 5 and a Vd range for males of 0.58-0.83 L/kg, calculate the dose needed:

$D = AC \times Vd \times w \times 10\frac{dL}{L}$ $\quad\quad$ $D = AC \times Vd \times w \times 10\frac{dL}{L}$

$D = 0.19\frac{g}{dL} \times 0.58\frac{L}{kg} \times 104kg \times 10\frac{dL}{L}$ $\quad\quad$ $D = 0.19\frac{g}{dL} \times 0.83\frac{L}{kg} \times 104kg \times 10\frac{dL}{L}$

D = 115 g　　　　*D = 164 g*

Using Equation 6, calculate the equivalent number of drinks for that dose:

$V = \frac{D}{C \times \rho \times m}$　　　　$V = \frac{D}{C \times \rho \times m}$

$V = \frac{115}{4.3\frac{mL}{100mL} \times 0.789\frac{g}{mL} \times 29.6\frac{mL}{oz}}$　　　　$V = \frac{164g}{4.3\frac{mL}{100mL} \times 0.789\frac{g}{mL} \times 29.6\frac{mL}{oz}}$

V = 115 oz　　　　*V = 163 oz*

Drinks = 115 oz / 16 oz = 7.2 pints　　　　*Drinks = 163 oz / 16 oz = 10.2 pints*

Summary: The subject's stated drinking history is inconsistent with the breath test result. He had the equivalent of ~7 - 10 pints of Brand X beer in his system at the time of the test.

b) Calculate with an individualized Vd

Using Equation 1a, calculate the TBW:

$$TBW\ (male) = 2.447 - (0.09516 \times a) + (0.1074 \times h) + (0.3362 \times w)$$

$$TBW\ (male) = 2.447 - (0.09516 \times 32) + (0.1074 \times 185) + (0.3362 \times 104)$$

$$TBW\ (male) = 54.2$$

Using Equation 2a, calculate the Vd:

$$Vd\ (male) = \frac{TBW}{w \times 0.825}$$

$$Vd\ (male) = \frac{54.2}{104 \times 0.825}$$

Vd (male) = 0.63 L/kg

Using Equation 3a, apply the %CV:

$$Vd\ (male) = Vd \pm (Vd \times 9.86\%)$$

$$Vd\ (male) = 0.63 \pm (0.63 \times 9.86\%)$$

$$Vd\ (male) = 0.63 \pm 0.06 = 0.57 - 0.69\ L/kg$$

Using Equation 5 and a Vd of 0.57- 0.69 L/kg, calculate the dose needed:

$D = AC \times Vd \times w \times 10\frac{dL}{L}$　　　　$D = AC \times Vd \times w \times 10\frac{dL}{L}$

$D = 0.19\frac{g}{dL} \times 0.57\frac{L}{kg} \times 104kg \times 10\frac{dL}{L}$　　　　$D = 0.19\frac{g}{dL} \times 0.69\frac{L}{kg} \times 104kg \times 10\frac{dL}{L}$

D = 113 g　　　　*D = 136 g*

Using Equation 6, calculate the equivalent number of drinks for that dose:

$$V = \frac{D}{C \times \rho \times \mathrm{m}} \qquad V = \frac{D}{C \times \rho \times \mathrm{m}}$$

$$V = \frac{113g}{4.3\frac{mL}{100mL} \times 0.789\frac{g}{mL} \times 29.6\frac{mL}{oz}} \qquad V = \frac{136g}{4.3\frac{mL}{100mL} \times 0.789\frac{g}{mL} \times 29.6\frac{mL}{oz}}$$

V = 113 oz *V = 135 oz*

Drinks = 113 oz / 16 oz = 7.1 pints *Drinks = 135 oz / 16 oz = 8.4 pints*

Summary: The subject's stated drinking history is inconsistent with the breath test result. He had the equivalent of ~7 - 8½ pints of Brand X beer in his system at the time of the test.

A.1.2 What is maximum AC that could be reached from 2 pints of Brand X beer?

Using Equation 7, calculate the dose from 2 pints of Brand X beer:

$$D = V \times C \times \rho \times m$$

$$D = 32oz \times 4.3\frac{mL}{100mL} \times 0.789\frac{g}{mL} \times 29.6\frac{mL}{oz}$$

D = 32 g alcohol in 2 pints of Brand X

a) Calculate with a fixed Vd range

Using Equation 8 and a Vd range for males of 0.58-0.83 L/kg, calculate the maximum AC range this dose could theoretically reach:

$$\mathrm{AC}_{drink(s)} = \frac{D}{Vd \times w \times 10\,\frac{dL}{L}} \qquad \mathrm{AC}_{drink(s)} = \frac{D}{Vd \times w \times 10\,\frac{dL}{L}}$$

$$\mathrm{AC}_{drink(s)} = \frac{32}{0.58\frac{L}{kg} \times 104kg \times 10\,\frac{dL}{L}} \qquad \mathrm{AC}_{drink(s)} = \frac{32}{0.83\frac{L}{kg} \times 104kg \times 10\,\frac{dL}{L}}$$

$$\mathrm{AC}_{drink(s)} = 0.053\ g/dL \qquad \mathrm{AC}_{drink(s)} = 0.037\ g/dL$$

Summary: The subject's stated drinking history is inconsistent with the breath test result. If all the alcohol in 2 pints of Brand X were completely absorbed, and none eliminated, the maximum AC range achievable for the subject would be ~0.037 - 0.053 g/dL.

b) Calculate with an individualized Vd

Using Equation 8 and a Vd range of 0.57 - 0.69 L/kg (see A.1.1.b for calculation), calculate the maximum range of ACs this dose could theoretically reach:

$$\mathrm{AC}_{drink(s)} = \frac{D}{Vd \times w \times 10\,\frac{dL}{L}} \qquad \mathrm{AC}_{drink(s)} = \frac{D}{Vd \times w \times 10\,\frac{dL}{L}}$$

$$\mathrm{AC}_{drink(s)} = \frac{32}{0.57\frac{L}{kg} \times 104kg \times 10\,\frac{dL}{L}} \qquad \mathrm{AC}_{drink(s)} = \frac{32}{0.69\frac{L}{kg} \times 104kg \times 10\,\frac{dL}{L}}$$

$$\mathrm{AC}_{drink(s)} = 0.054\ g/dL \qquad\qquad \mathrm{AC}_{drink(s)} = 0.045\ g/dL$$

Summary: The subject's stated drinking history is inconsistent with the breath test result. If all the alcohol in 2 pints of Brand X were completely absorbed, and none eliminated, the maximum AC range achievable for the subject would be ~0.045 - 0.054 g/dL.

A.2 Retrograde extrapolation, subject is post absorptive

History: A woman was drinking wine at an out-of-town wedding. She left the wedding at 6:00 pm and had a five-hour drive home. At approximately 9:00 pm she crossed over the center line and crashed into an oncoming vehicle. She was injured and transported to the hospital; a blood kit was collected at 11:45 pm. The result of the blood test was 0.068 g/dL. There were no alcoholic beverages in the vehicle. She stated she had not had anything to drink since leaving the wedding.

Question: Was she above the 0.08 legal limit at the time of the crash?

Relevant Information:

The subject is female, 5’3”, 125 lbs, 45 years old

Blood alcohol: 0.068 g/dL at 11:45 pm

Incident: 9:00 pm

Assumptions:

Since there were at least 3 hours between the end of drinking and the incident, the subject is assumed to be post absorptive.

No post incident alcohol consumption.

Calculations:

Elapsed Time = 9:00 pm to 11:45 pm = 2.75 hours

Using Equation 9 and an elimination rate range of 0.010 - 0.025 g/dL/hour, calculate AC range at time of incident:

$$AC_{inc} = AC_{test} + (\beta \times T) \qquad\qquad AC_{inc} = AC_{test} + (\beta \times T)$$

$$AC_{inc} = 0.068\frac{g}{dL} + \left(\frac{0.010\frac{g}{dL}}{hour} \times 2.75\ hours\right) \qquad AC_{inc} = 0.068\frac{g}{dL} + \left(\frac{0.025\frac{g}{dL}}{hour}\ x\ 2.75\ hours\right)$$

$$AC_{inc} = 0.096\frac{g}{dL} \qquad\qquad AC_{inc} = 0.137\frac{g}{dL}$$

Summary: It is estimated that the subject's AC at the time of the incident was ~0.096 - 0.137 g/dL. Therefore, it is likely the subject was above the 0.08 g/dL legal limit at the time of the incident.

A.3 Retrograde extrapolation, subject is not post absorptive

History: A female subject was drinking at a bar. She stopped drinking around 10:00 pm. When she was ready to leave, she paid her tab and got one last shot of tequila. She drank it and immediately left the bar at ~11:00 pm. She crashed her car while trying to leave the parking lot. Her blood was drawn at 12:30 am and was a 0.082 g/dL. Her defense is that she was below 0.08 g/dL at the time of the crash.

Question: Could the subject's AC have been under 0.08 g/dL at the time of the crash?

Relevant Information:

The subject is female, 5'8", 160 lbs, 22 years old

Blood alcohol content: 0.082 g/dL at 12:30 am

Incident: 11:00 pm

80 proof = 40% alcohol concentration

Assumptions:

The alcohol from the last shot of tequila was not completely absorbed at the time of the incident.

Tequila is typically ~80 proof.

Calculations:

Elapsed Time = 11:00 pm to 12:30 am = 1.5 hours

Weight conversion: $w = 160\ lbs\ \times 0.454\,\frac{kg}{lbs} = 73\ kg$

Height conversion: $h = 68\ in\ \times\ 2.54\,\frac{cm}{in} = 173\ cm$

Using Equation 9 and an elimination rate range of 0.010 - 0.025 g/dL/hour, calculate AC range at the time of incident, if the subject were post absorptive:

$$AC_{inc} = AC_{test} + (\beta \times T) \qquad AC_{inc} = AC_{test} + (\beta \times T)$$

$$AC_{inc} = 0.082\frac{g}{dL} + \left(\frac{0.010\frac{g}{dL}}{hour} \times 1.5\ hours\right) \qquad AC_{inc} = 0.082\frac{g}{dL} + \left(\frac{0.025\frac{g}{dL}}{hour} \times 1.5\ hours\right)$$

$$AC_{inc} = 0.097\frac{g}{dL} \qquad AC_{inc} = 0.120\frac{g}{dL}$$

Using Equation 7, calculate the dose of alcohol from a shot of tequila:

$$D = V \times C \times \rho \times m$$

$$D = 1.5oz \times 40\frac{mL}{100mL} \times 0.789\frac{g}{mL} \times 29.6\frac{mL}{oz}$$

D = 14 g alcohol in a shot of tequila

Using Equations 1b, 2b, and 3b, calculate an individualized Vd range:

$$Vd\ (female) = \frac{-2.097 + (0.1069\ \times h) + (0.2466\ \times w)}{w\ x\ 0.838} \pm 15\%$$

$$Vd\ (female) = \frac{-2.097 + (0.1069\ \times 173) + (0.2466\ \times 73)}{73\ x\ 0.838} \pm 15\%$$

$$Vd\ (female) = 0.56\ L/kg \pm 15\% = 0.48 - 0.64\ L/kg$$

Using Equation 8 and a Vd range of 0.48 - 0.64 L/kg, calculate the maximum AC a tequila shot could contribute:

$$\text{AC}_{drink(s)} = \frac{D}{Vd \times w \times 10\,\frac{dL}{L}} \qquad \text{AC}_{drink(s)} = \frac{D}{Vd \times w \times 10\,\frac{dL}{L}}$$

$$\text{AC}_{drink(s)} = \frac{14}{0.48\frac{L}{kg} \times 73kg \times 10\,\frac{dL}{L}} \qquad \text{AC}_{drink(s)} = \frac{14g}{0.64\frac{L}{kg} \times 73kg \times 10\,\frac{dL}{L}}$$

$$\text{AC}_{drink(s)} = 0.040g/dL \qquad \text{AC}_{drink(s)} = 0.030g/dL$$

Using Equation 10, adjust the AC to remove the theoretical maximum contribution the last tequila shot could have contributed (using the calculated ranges of AC_{inc} and $AC_{drink(s)}$):

Adjusted AC_{inc} = AC_{inc} – $AC_{drink(s)}$ Adjusted AC_{inc} = AC_{inc} – $AC_{drink(s)}$

Adjusted AC_{inc} = 0.097 – 0.040 Adjusted AC_{inc} = 0.120 – 0.030

Adjusted AC_{inc} = 0.057 g/dL Adjusted AC_{inc} = 0.090 g/dL

Summary: Assuming the last shot of tequila was not absorbed at the time of the incident, the subject's AC at that time is estimated to be ~0.057 - 0.090 g/dL. Therefore, it is possible she was below the 0.08 g/dL legal limit at the time of the incident. Further, since the initial drinking event ended approximately one hour before the incident, there may be additional unabsorbed alcohol, which would further lower the estimated range.

A.4 Post Incident Consumption

History: A man drove his vehicle through his garage door at ~6:00 pm. A neighbor witnessed the crash and called the police. When the police arrived at the home, the subject greeted them with a partially consumed bottle of vodka in his hand (80 proof, 750 mL), and he appeared to be intoxicated. He was arrested for suspected DUI and had a breath test result of 0.215 g/210 L. The defendant claimed he had not been drinking prior to the crash, and that his AC was from the vodka consumption after the crash. He claimed it was a new bottle; approximately one-third was missing.

Question: Could the consumption of ~1/3 bottle of vodka account for the measured AC?

Relevant Information:

The subject is male, 5'10", 210 lbs, 55 years old

Breath test result: 0.215 g/210 L

80 proof = 40% alcohol concentration

Calculations:

Weight conversion: $w = 210\ lbs\ \times 0.454\,\frac{kg}{lbs} = 95\ kg$

Height conversion: $h = 70\ in\ \times\ 2.54\,\frac{cm}{in} = 178\ cm$

$$Amount\ consumed = 750\ mL\ x\ \frac{1}{3} = 250\ mL$$

Using Equation 7, calculate the dose of alcohol from the vodka

$D = V\ \times C\ \times\ \rho$ *(metric conversion not needed)*

$$D = 250mL\ \times 40\frac{mL}{100mL}\ \times\ 0.789\frac{g}{mL}$$

D = 79 g alcohol in ⅓ bottle of vodka

Using Equations 1a, 2a, and 3a, calculate an individualized Vd range:

$$Vd\ (male) = \frac{2.447 - (0.09516\ \times a) + (0.1074\ \times h) + (0.3362\ \times w)}{w\ \times 0.825} \pm 9.86\%$$

$$Vd\ (male) = \frac{2.447 - (0.09516\ \times 55) + (0.1074\ \times 178) + (0.3362\ \times 95)}{95\ \times 0.825} \pm 9.86\%$$

Vd (male) = 0.62 L/kg ± 9.86% = 0.56 – 0.68 L/kg

Using Equation 8 and a Vd range of 0.56 - 0.68 L/kg, calculate the maximum AC the vodka could contribute:

$$\mathrm{AC}_{drink(s)} = \frac{D}{Vd \times w \times 10\,\frac{dL}{L}} \qquad \mathrm{AC}_{drink(s)} = \frac{D}{Vd \times w \times 10\,\frac{dL}{L}}$$

$$\mathrm{AC}_{drink(s)} = \frac{79g}{0.56\frac{L}{kg}\times 95kg \times 10\,\frac{dL}{L}} \qquad \mathrm{AC}_{drink(s)} = \frac{79g}{0.68\frac{L}{kg}\times 95kg \times 10\,\frac{dL}{L}}$$

$$\mathrm{AC}_{drink(s)} = 0.148\ g/dL \qquad \mathrm{AC}_{drink(s)} = 0.122\ g/dL$$

Summary: If all the alcohol from the 1/3 bottle of vodka were completely absorbed, and none eliminated, the theoretical maximum AC range achievable for the subject would be ~0.122 - 0.148 g/dL, below the breath test result of 0.215 g/210 L. The subject's drinking history is inconsistent; there was likely additional alcohol consumption.

A.5 Minimal Case History Available

History: Subject is a 160 lbs female. Crash at 1:00 am, blood draw at 3:00 am, AC 0.075 g/dL. No drinking history available.

Question: What was her AC at the time of the crash?

Relevant Information:

The subject is female, 160 lbs

"Standard" drink = 14 g of alcohol

Assumptions:

With no drinking history, the impact of potentially unabsorbed alcohol is presented.

Since there is no information on the type of drinks, a standard drink will be used.

Since the height was not provided, a fixed Vd range for females will be applied.

Calculations:

Weight conversion: $w = 160\ lbs\ \times 0.454\,\frac{kg}{lbs} = 73\ kg$

Elapsed Time = 1:00 am to 3:00 am = 2 hours

Using Equation 9 and an elimination rate range of 0.010 - 0.025 g/dL/hour, calculate the AC at time of incident if post absorptive:

$$AC_{inc} = AC_{test} + (\beta \times T) \qquad AC_{inc} = AC_{tes} + (\beta \times T)$$

$$AC_{inc} = 0.075\frac{g}{dL} + \left(\frac{0.010\frac{g}{dL}}{hour} \times 2\ hours\right) \qquad AC_{inc} = 0.075\frac{g}{dL} + \left(\frac{0.025\frac{g}{dL}}{hour} \times 2\ hours\right)$$

$$AC_{inc} = 0.095\frac{g}{dL} \qquad AC_{inc} = 0.125\frac{g}{dL}$$

Using Equation 8 and a Vd range for females of 0.43-0.73 L/kg, calculate the maximum AC a "standard" drink could contribute:

$$\mathrm{AC}_{drink(s)} = \frac{D}{Vd \times w \times 10\,\frac{dL}{L}} \qquad \mathrm{AC}_{drink(s)} = \frac{D}{Vd \times w \times 10\,\frac{dL}{L}}$$

$$\mathrm{AC}_{drink(s)} = \frac{14g}{0.43\frac{L}{kg} \times 73kg \times 10\,\frac{dL}{L}} \qquad \mathrm{AC}_{drink(s)} = \frac{14g}{0.73\frac{L}{kg} \times 73kg \times 10\,\frac{dL}{L}}$$

$$\mathrm{AC}_{drink(s)} = 0.045\ g/dL \qquad \mathrm{AC}_{drink(s)} = 0.026\ g/dL$$

Using Equation 10, adjust the AC to remove the number of drinks that would have to be unabsorbed to have the subject be below the legal limit at the time of the crash (using the calculated ranges of AC_{inc} and $AC_{drink(s)}$):

$$\text{Adjusted } AC_{inc} = AC_{inc} - AC_{drink(s)}$$

Estimated AC @ 1:00am	0.010 rate		0.025 rate	
Post absorptive (AC_{inc})	0.095	0.095	0.125	0.125
$AC_{drink(s)}$ (Vd 0.43-0.73 L/kg)	*0.045*	*0.026*	*0.045*	*0.026*
-1 drink unabsorbed	**0.050**	**0.069**	0.080	0.099
-2 drinks unabsorbed			**0.035**	**0.073**

Summary: If the subject was post absorptive at the time of the incident, the estimated AC at that time would be ~0.095 - 0.125 g/dL, so she was likely above the 0.08 g/dL legal limit at that time. However, if the subject had the equivalent of ~1 - 2 standard drinks unabsorbed at the time of the incident, she could have been below the 0.08 g/dL legal limit.

Annex B
(informative)

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