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Best Practice Recommendation for Performing Alcohol Calculations in Forensic Toxicology

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Best Practice Recommendation for Performing Alcohol Calculations in Forensic Toxicology

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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 may help mitigate bias. These best practice recommendations 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. Many forensic blood alcohol results are based on replicate analyses and are reported with an estimation of measurement uncertainty, however, many other results (e.g., breath tests, medical tests) may not provide an 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 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/may not be made. For example, in a situation where there is a long 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 range does not put any greater likelihood that the subject was at the high or low end of the range, nor that they were likely in the middle. The Appendix illustrates how this approach can be applied in various scenarios.

Future editions of this guideline will work toward applying a statistical approach to the calculations. There are approaches in the literature that provide estimated 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 with an associated uncertainty. The body of knowledge in the peer reviewed literature is continually increasing and may eventually allow for estimations of the variances associated with all the 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.

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 AAFSASB 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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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 typical situations. Recommendations are also provided for evaluation of post absorptive stage, various specimen types, population variances, and reporting of calculations.

2 Normative References

The following references are documents that are indispensable for the application of the standard. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

Maskell, P. and G. Cooper. "The Contribution of Body Mass and Volume of Distribution to the estimated Uncertainty Associated with the Widmark Equation." *Journal of Forensic Sciences,* 2020.

Maskell, P., W. Jones, A. Savage, and M. Scott-Ham. "Evidence based survey of the distribution volume of ethanol; comparison of empirically determined values with anthropometric measures." *Forensic Science International*, 2019.

3 Terms and Definitions

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

4 Background Information

4.1 Alcohol Pharmacokinetics

4.1.1 General

The mechanisms of absorption, distribution, and elimination of alcohol throughout the body must be considered when performing alcohol calculations. It is expected that persons performing this type of work have a thorough understanding of pharmacokinetics, along with relevant education and experience. 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 blood stream 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 the rate of absorption. Studies support that it can take up to 2 hours for complete absorption after the last drink [2, 3, 7, 9, 12, 14-16, 20, 29, 30]. The time needed to reach the peak alcohol concentration (AC) is not the same as the time to complete absorption.

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. 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 [5, 19, 24, 27, 28]. 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, total body water (TBW), or rho 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, caution must be used when comparing, or attempting to average, these various formulas since they do not all calculate the same variable.

4.1.3.2 If a fixed value is used for Vd, research supports a range of 0.45 L/kg to 0.81 L/kg (Maskell, Cooper 2020). Due to the high variability among the population, the use of a single factor for a fixed Vd is inappropriate.

4.1.3.3 An individual's apparent Vd may be estimated using anthropometric calculations when sex, weight, and height are known. The equations derived by Watson (28) and Maskell (as detailed in the normative references), along with the variability, are considered the best approaches at this time. These calculations estimate the TBW and Vd for an individual and estimate the variance (see 5.2.2). Individuals performing calculations outlined in this document shall have a foundational understanding of the two normative references by Maskell, et al (2019) and Maskell, Cooper (2020).

Since there are physiological limitations to the minimum TBW, calculation results should be evaluated carefully, and caution should be 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 have been shown to be less reliable for transgender individuals [4]. A fixed Vd range may be more appropriate in these situations.

4.1.3 Elimination

4.1.3.1 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. The linear rate can only be applied when elimination is the only pharmacokinetic parameter occurring, in other words, the subject is post absorptive. While the AC may be declining after the subject reaches their peak AC (post peak), the linear rate is not applicable until the post absorptive state.

4.1.3.2 An elimination rate range of 0.010 g/dL/hour to 0.025 g/dL/hour encompasses the majority of the population regardless of age, sex, ethnicity, and drinking experience [8, 10, 11, 12, 13, 21, 22, 25, 31].

4.1.3.3 At concentrations below 0.020 g/dL, the elimination rate may not be linear as zero order kinetics may no longer apply [1, 11].

4.2 Case History

4.2.1 The type of information, and source of that information, will vary from case to case. Experts should be clear as to 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 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 serum/plasma to blood ratio of 1.04 to 1.26 [6].

4.3.2 Urine is an elimination product which 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 has 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 determining 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" is defined as a beverage containing approximately 14 grams of alcohol [32].

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

5.1 Alcohol Test Results

5.1.1 Calculations presented are valid for both blood (g/dL) and breath (g/210L).

5.1.2 Serum/plasma results shall be converted to a whole blood equivalent prior to other calculations. The range should be 1.04 to 1.26 serum/plasma to blood ratio. Further calculations shall then be applied to both converted AC results.

5.2 Volume of Distribution (Vd)

5.2.1 For a fixed Vd, a range of 0.45 L/kg to 0.81 L/kg is used.

5.2.2 If an individualized Vd is applied, the following calculations are used:

5.2.2.1 Calculate total body water (TBW):

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

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

where:

TBW = total body water (L)

a = age (years)

h = height (cm)

w = weight (kg)

5.2.2.2 Calculate the individual Vd:

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

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

where:

Vd = volume of distribution (L/kg)

TBW = total body water (L)

w = weight (kg)

5.2.2.3 Apply the ± %CV from Maskell, Cooper (2020):

$$Vd\ (male) = Vd\ \pm (Vd\ \times 9.86\%) \tag{3a}$$

$$Vd\ (female) = Vd\ \pm (Vd\ \times 15.00\%) \tag{3b}$$

5.3 Widmark's Formula

5.3.1 The relationship between a dose of alcohol and a resulting alcohol concentration.

$$AC = \frac{D}{Vd * w} \tag{4}$$

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/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 system at the time of the blood draw/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, g/210 L breath)

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/100mL)

ρ = density of ethanol (0.789 g/mL)

m = metric conversion (29.6 mL/oz), if necessary

The calculated volume can be converted to the equivalent number of drinks, depending on the type of drink. E.g., If the subject was drinking 12 oz beers, a volume of 37 oz would be equivalent to ~ 3 beers.

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

These calculations provide the maximum AC attainable from a reported number of consumed drinks. They are used to support/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 AC?" 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/100mL)

ρ = density of ethanol (0.789 g/mL)

m = metric conversion (29.6 mL/oz), if necessary

Theoretical maximum AC from a given drink(s)

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

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

where:

$\text{AC}_{drink(s)}$ = 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 range of concentrations can be provided.

5.4.2 The basic calculation for retrograde extrapolation is:

$$AC_{inc} = AC_{test} + (R \times T) \quad (9)$$

where:

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

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

R = 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. The minimal range shall be 0.010 g/dL/hour to 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 only post absorptive. Additional calculations can 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.

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

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 and Best Practice Recommendations

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

It is recommended that written protocols be in place to ensure the forensic service provider applies a consistent methodology to service requests.

6.3 Technical Review

Where feasible, independent review of calculations by a qualified individual is encouraged.

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 in their head. 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 various risks to quality it may create. 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. 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/lower the estimated AC range provided, without calculating the new range.

6.5 Postmortem Specimens

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 guideline [17, 23].

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. 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 0.19g/210L. He stated he had been at a local bar for the last 3 hours and only had 2 pts of Brand X beer. He ate chicken wings and french fries.

Question: Is the stated drinking history consistent with the 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 6’1”, 230 lbs, 32 years old

Evidential breath test: 0.19g/210L

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

1 pt = 16oz

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 0.19g/210L AC?

a) Calculate with a fixed Vd range

Using Equation 5 and a Vd range of 0.45 L/kg to 0.81 L/kg, calculate the dose needed:

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

$D = 0.19\frac{g}{dL}\ \times 0.45\frac{L}{kg}\ \times 104kg\ \times 10\frac{dL}{L}$

D = 89g

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

$D = 0.19\frac{g}{dL}\ \times 0.81\frac{L}{kg}\ \times 104kg\ \times 10\frac{dL}{L}$

D = 160g

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

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

$$V = \frac{89g}{4.3\frac{mL}{100mL} \times 0.789\frac{g}{mL} \times 29.6\frac{mL}{oz}}$$

V = 89 oz

Drinks = 89oz / 16oz = 5.6 pints

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

$$V = \frac{160g}{4.3\frac{mL}{100mL} \times 0.789\frac{g}{mL} \times 29.6\frac{mL}{oz}}$$

V = 159 oz

Drinks = 159oz / 16oz = 10 pints

Summary: The subject's stated drinking history is inconsistent with the breath test result. He had the equivalent of ~5½ pts to 10 pts 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 L/kg to 0.69 L/kg, calculate the dose needed:

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

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

D = 113g

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

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

D = 136g

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

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

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

V = 113 oz

Drinks = 113oz / 16oz = 7 pints

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

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

V = 135 oz

Drinks = 135oz / 16oz = 8.4 pints

Summary: The subject's stated drinking history is inconsistent with the breath test result. He had the equivalent of ~7 pts to 8½ pts 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 pts of Brand X beer?

Using Equation 7, calculate the dose from 2 pts 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 = 32g alcohol in 2 pts of Brand X

a) Calculate with a fixed Vd range

Using Equation 8 and a Vd range of 0.45 L/kg to 0.81 L/kg, calculate the maximum range of ACs this dose could theoretically reach:

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

$$\text{AC}_{drink(s)} = \frac{32g}{0.45\frac{L}{kg} \times 104kg \times 10\,\frac{dL}{L}}$$

$$\text{AC}_{drink(s)} = 0.068g/dL$$

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

$$\text{AC}_{drink(s)} = \frac{32g}{0.81\frac{L}{kg} \times 104kg \times 10\,\frac{dL}{L}}$$

$$\text{AC}_{drink(s)} = 0.038g/dL$$

Summary: The subject's stated drinking history is inconsistent with the breath test result. If all the alcohol in 2 pts of Brand X were completely absorbed, and none eliminated, the maximum AC range achievable for the subject would be ~0.038 g/dL to 0.068 g/dL.

b) Calculate with an individualized Vd

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

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

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

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

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

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

Summary: The subject's stated drinking history is inconsistent with the breath test result. If all the alcohol in 2 pts of Brand X were completely absorbed, and none eliminated, the maximum AC range achievable for the subject would be ~0.045 g/dL to 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 0.068g/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 5'3", 125 lbs, 45 years old

Blood alcohol: 0.068g/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 g/dL/hour to 0.025 g/dL/hour, calculate AC range at time of incident:

$$AC_{inc} = 0.068\tfrac{g}{dL} + \left(0.010\tfrac{g}{dL}/hour \times 2.75\ hours\right) = 0.096\tfrac{g}{dL}$$

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

$$AC_{inc} = 0.068\tfrac{g}{dL} + \left(0.025\tfrac{g}{dL}/hour \times 2.75\ hours\right) = 0.137\tfrac{g}{dL}$$

Summary: It is estimated that the subject's AC at the time of the incident was ~0.096 g/dL to 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 10:00pm. When she was ready to leave, she paid her tab and got one last shot. 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 0.08g/dL at the time of the crash.

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

Relevant Information:

The subject is 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 g/dL/hour to 0.025 g/dL/hour, calculate AC range at the time of incident, if the subject were post absorptive:

$$AC_{inc}\ =\ 0.082\tfrac{g}{dL} + \left(0.010\tfrac{g}{dL}/hour\ \times 1.5\ hours\right) = 0.097\tfrac{g}{dL}$$

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

$$AC_{inc}\ =\ 0.082\tfrac{g}{dL} + \left(0.025\tfrac{g}{dL}/hour\ \times 1.5\ hours\right) = 0.120\tfrac{g}{dL}$$

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 = 14g alcohol in shot of tequila

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

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

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

$Vd\ (female) = 0.56\ L/kg$ ± 15% = **0.48 – 0.64** L/kg

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

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

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

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

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} = 0.097 – 0.040 = 0.057g/dL

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

Adjusted AC_{inc} = 0.120 – 0.030 = 0.090g/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 g/dL to 0.090 g/dL. Therefore, it is possible she was below the 0.08 g/dL legal limit at the time of the incident.

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/210L. 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 5'10", 210 lbs, 55 years old

Breath test result: 0.215g/210L

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 = 79g 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) = 0.61 L/kg ± 9.86% = ***0.55 – 0.67 L/kg***

Using Equation 8 and a Vd range of 0.55 L/kg to 0.67 L/kg, calculate the maximum AC the vodka could contribute:

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

$$\text{AC}_{drink(s)} = \frac{79g}{0.55\frac{L}{kg}\times 95kg\times 10\,\frac{dL}{L}} \qquad \text{AC}_{drink(s)} = \frac{79g}{0.67\frac{L}{kg}\times 95kg\times 10\,\frac{dL}{L}}$$

$$\text{AC}_{drink(s)} = 0.150\ g/dL \qquad \text{AC}_{drink(s)} = 0.124\ g/dL$$

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 ~0.124 g/dL to 0.150 g/dL, below the breath test result of 0.215. The subject's drinking history is inconsistent; there was likely alcohol consumption prior to the incident.

A.5. Minimal Case History Available

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

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

Relevant Information:

The subject is 160 lbs

"Standard" drink = 14g 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 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 g/dL/hour to 0.025 g/dL/hour, calculate the AC at time of incident if post absorptive:

$$AC_{inc} = 0.075\frac{g}{dL} + \left(0.010\frac{g}{dL}/hour \times 2\ hours\right) = 0.095\frac{g}{dL}$$

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

$$AC_{inc} = 0.075\frac{g}{dL} + \left(0.025\frac{g}{dL}/hour \times 2\ hours\right) = 0.125\frac{g}{dL}$$

Using Equation 8 and a Vd range of 0.45 L/kg to 0.81 L/kg, calculate the maximum AC a "standard" drink could contribute:

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

$$\text{AC}_{drink(s)} = \frac{14g}{0.45\frac{L}{kg} \times 73kg \times 10\frac{dL}{L}} \qquad \text{AC}_{drink(s)} = \frac{14g}{0.81\frac{L}{kg} \times 73kg \times 10\frac{dL}{L}}$$

$$\text{AC}_{drink(s)} = 0.043g/dL \qquad \text{AC}_{drink(s)} = 0.024g/dL$$

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 $AC_{drink(s)}$):

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 0.40-0.80)	*0.043*	*0.024*	*0.043*	*0.024*

-1 drink unabsorbed	**0.052**	**0.071**	0.082	0.101
-2 drinks unabsorbed			**0.039**	**0.077**

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

Annex B
(informative)

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