# Ethanol Calculations

## Table of Contents

# Ethanol Calculations

## 1 INTRODUCTION

In the course of toxicological investigations, questions may arise concerning blood alcohol concentration (BAC), number of drinks consumed, or other ethanol-related scenarios. The case situations often involve driving under the influence (DUI) or drug-facilitated crimes (DFC) scenarios. The types of calculations, broadly, fall into one of three categories:

A. Back extrapolation: estimating the BAC at an earlier point in time
B. "Widmark"/Volume of distribution: estimating the number of drinks or resulting BAC
C. A combination of A and B.

Due to the variety of requests that may be received, this technical procedure is designed to ensure, where possible, a consistent approach to such casework requests. The examples provided are intended to provide guidance and are not an exhaustive list of the possible case scenarios or applications.

## 2 SCOPE

This document provides guidance for performing ethanol-related calculations in a consistent manner. The terms ethanol and alcohol for the purposes of this document are used interchangeably. This document applies to authorized personnel who perform or review the described tasks, singly or in combination.

## 3 PRINCIPLE

Blood alcohol calculations originated in the 1920s when Widmark first characterized alcohol distribution in the human body. Critically, he noted that the proportion of water in the body as a whole was less than the proportion of water in the blood. Effectively, this gives a BAC that is higher than that which would be expected if only simple dilution calculations were considered. Widmark put forth an equation which took into account the mass, gender and alcohol intake of an individual, and calculated an estimate of the BAC. Subsequent researchers provided additional methods of estimating the BAC, including other factors such as body mass index and total body water. Such calculations are often described as "modified Widmark" equations.

Retrograde extrapolation (also called back extrapolation) is a mathematical process in which an individual's BAC at an earlier point in time is estimated from a subsequent BAC test. This calculation is based on the average rate of alcohol elimination by the human body. Under specific assumptions, a range of likely BACs may be estimated which can provide useful information in an investigation involving the consumption of alcohol.

## 4 EQUIPMENT

### 4.1 Software

- Microsoft Excel (Windows 95 or later)
- TOX-002 Ethanol Calculations Form

## 5 PROCEDURE

Depending upon the scenario, the required information is obtained and documented in the case record prior to performing calculations (see Section 6).

## 6 DATA ANALYSIS

### 6.1 Calculations

The calculations are used at the discretion of the authorized individual depending on the case scenario.

#### *6.1.1 Back Extrapolation*

An authorized individual may be asked to calculate an individual's estimated BAC at the time of a particular event by applying known ethanol elimination kinetics to a BAC measured in a blood sample taken after the event. These calculations will not be performed if more than ten hours have passed between the incident in question and the collection of the blood specimen.

The FBI Laboratory measured and reported BAC and measurement uncertainty (MU) will be used for these calculations.

A range of 0.010 – 0.025 g%/hr will be used for these calculations. Calculated values will be truncated and reported to the 3rd decimal point.

For example, if an ethanol concentration of 0.050 g% (±0.005 g%, 99.7% confidence level) was measured in a blood sample collected at 0700 on 01/01/01, and the incident under investigation took place at 0430 on 01/01/01, the back extrapolation results would be:

(2.5 hr * 0.010 g%/hr) + (0.050 -0.005) g%= 0.070 g%

(2.5 hr * 0.025 g%/hr) + (0.050 + 0.005) g%= 0.117 g%

If two or more hours have elapsed after drinking cessation, it is assumed that the individual is post absorptive.

If it is known that ethanol was consumed during the two hours prior to sample collection, this will be accounted for in the calculations. (See example in 6.1.4 B.)

If the time of drinking cessation is unknown, the impact of potentially unabsorbed ethanol shall be addressed. This may be accomplished by estimating consumption of a particular amount of ethanol during the two hours prior to blood collection, and including the details on the assumptions. (See example in 6.1.4 B.)

### *6.1.2 Widmark/Volume of Distribution (Vd)*

In order to perform Widmark/Volume of Distribution (Vd) calculations, the following information will be obtained:

- Time of incident
- Time of blood draw/sample collection, if applicable
- Age of donor
- Gender of donor
- Height of donor
- Weight of donor
- Details of recent alcohol consumption (time of drinks, volumes, brands, etc.)

The following information may also be useful if obtained:

- Details of medications
- Medical conditions
- Details of recent food consumption

Option 1: A range shall be used for the Vd in the classic Widmark equation. A range of 0.58-0.83 L/kg will be used for males, and a range of 0.43-0.73 will be used for females.

$$Estimated\ BAC = \frac{A}{Vd} * w$$

A = alcohol, in grams; w = weight in kg
Estimated BAC = the estimated maximum BAC obtained if the entire dose of ingested alcohol was absorbed and distributed instantaneously without any metabolism or elimination occurring.

Option 2: Alternatively, an individualized Vd may be calculated as follows:

1 - Calculate total body weight (TBW in L) from Watson, et al:

| | | | |
|---|---|---|---|
| Watson et al[2] | Female | $TBW = -2.097 + (0.1069 * H) + (0.2466 * W)$ | H = height in cm, W = weight in kg, G = age in years, |
| | Male | $TBW = 2.477 - (0.09516 * G) + (0.1074 * H) + (0.3362 * W)$ | |

2 - Calculate the individual Vd from Maskell, et al:

Vd (female) = (TBW)/(W x 0.838)

Vd (male) = (TBW)/(W x 0.825)

3 - Apply the ± %cv from Maskell, Cooper:

Vd (female) = Vd ± (Vd x 15%)

Vd (male) = Vd ± (Vd x 9.86%)

Option 3: Or, the volume of distribution factor will be calculated using four different methods; these methods will be stated in the report. The four methods used are:

- Widmark
- Watson et al.
- Forrest
- Seidl

### *6.1.3 Methods for Calculating Alcohol using Volume of Distribution/Widmark Factor*

| Method | Sex | R/TBW Equations | $C_0$ Equations | Notes |
|---|---|---|---|---|
| Widmark[1] | Female | $r = 0.60$ | $C_0 = \frac{A}{r} * w$ | |
| | Male | $r = 0.70$ | | |
| Watson et al[2] | Female | $TBW = -2.097 + (0.1069 * H) + (0.2466 * W)$ | $C_0 = A * \frac{0.84}{TBW}$ | C=g/L |
| | Male | $TBW = 2.477 - (0.09516 * G) + (0.1074 * H) + (0.3362 * W)$ | | |
| Forrest[2] | Female | $r = 0.724 * \frac{(W) - \left(\left(\frac{(1.371 * BMI) - 3.467}{100}\right) * W\right)}{W * 0.84}$ | $C_0 = \frac{A}{r} * w$ | BMI = body mass index (kg/m$^2$), r (L/kg) |
| | Male | $r = 0.724 * \frac{(W) - \left(\left(\frac{(1.34 * BMI) - 12.469}{100}\right) * W\right)}{W * 0.84}$ | | |
| Seidl[2] | Female | $r = 0.3122 - (0.006446 * W) + (0.004466 * H)$ | $C_0 = \frac{A}{r} * w$ | |
| | Male | $r = 0.3160 - (0.004821 * W) + (0.004632 * H)$ | | |

W = weight in kg
H = height in cm
G = age in years
A = alcohol, in grams
$C_0$ = the estimated maximum BAC obtained if the entire dose of ingested alcohol was absorbed and distributed instantaneously without any metabolism or elimination occurring.

NOTE: Any unabsorbed alcohol in the stomach is not contributing to the BAC, so a $V_d$ calculation will tend to overestimate the actual BAC if there is unabsorbed alcohol remaining in the stomach.

[1] The average Widmark R-values are used
[2] Values are truncated to four significant figures

### *6.1.4 Performing Calculations for Volume of Distribution/Widmark Factor*

The following two scenarios are examples of situations which commonly present during casework. Other scenarios may require a different approach.

A. Estimation of BAC from the Amount of Alcohol Consumed/Absorbed
    1. Gather required information for the various methods of calculation.
    2. Using the various equations, calculate the estimated BAC/number of drinks as required.

B. A Combination of Estimation of BAC from Amount of Alcohol Consumed/Absorbed and Back Extrapolation
    1. Gather required information for the various methods of calculation.
    2. Using the applicable equations, calculate the estimated contribution of the consumed alcohol, as required.
    3. Perform back extrapolation calculations as if the individual was post absorptive (as in 6.1.1).
    4. Subtract the alcohol calculated in 6.1.4B step 2 above from the two BAC values calculated in 6.1.4B step 3 above.

## 7 REPORTING

The following scenarios provide some examples of the types of statements which may be encountered in casework. Other scenarios are possible.

Note: g% and g/100mL are equivalent units. Either can be used in reporting.

### 7.1 Ethanol Back Extrapolation

The report may state:

> *"Using the 99.7% confidence interval of the measured ethanol concentration, along with an elimination rate range of 0.010-0.025 g%/hour , individual A's blood alcohol concentration (BAC) at 0430 on 01/01/01 could have been between 0.070 and 0.117 g%."*

If the range of calculated values falls above 0.250 g%, the authorized individual will report the end of the range as greater than 0.250 g%.

### 7.2 Estimation of Peak BAC

Mr. A is a 40 year old male that is 6 feet tall and weighs 180 pounds. Mr. A consumed 3 shots (1.5 ounces each) of hard alcohol (40% ethanol, w/v), over a short period of time. The request is to calculate Mr. A's peak BAC.

The report may state:

> *"Using [method name(s)] volume of distribution calculations, Mr. A's maximum BAC could have been xxx g%. This assumes a bolus dose ingestion; under typical drinking conditions the maximum BAC would be lower. These calculations were performed using the [name(s)] method(s)."*

### 7.3 Estimation of Number of Drinks

Ms. B is a 22 year old female that is 5'5" tall, weighing 125 pounds. The request is to estimate how many glasses of wine (one glass = 5 ounces at 12% ethanol w/v) are in her system at the time of the blood draw that yielded a measured BAC of 0.120 ± 0.005 g% (99.7% confidence level).

The report may state:

> *"Ms. B's 0.120 ± 0.005 g% (99.7% confidence level) BAC is equivalent to xx 5 ounce glasses of 12% ethanol containing wine. These calculations were performed using the [name(s)] methods."*

### 7.4 Ethanol Back Extrapolation and Estimation of Number of Drinks

Using the information in the scenario in section 7.3, back extrapolate Ms. B's BAC to a time four hours prior to the blood withdrawal, and determine the number of glasses of wine equivalent to that BAC.

The report may state:

> *"Using the 99.7% confidence interval of the measured ethanol concentration, along with an elimination rate range of 0.010-0.025 g%/hour , Ms. B's BAC 4 hours prior to the blood collection could have been between 0.155-0.225 g%. This BAC is equivalent to xx-xx 5 ounce glasses of 12% ethanol containing wine. These calculations were performed using the [name(s)] methods."*

### 7.5 Required Remarks for Scenarios

#### *7.5.1 Volume of Distribution Calculations*

The following comments will be included in the report when volume of distribution calculations are performed:

> "The volume of distribution calculations performed assume that Person A, a XX year old fe/male measuring X'X" and weighing xxx lbs, consumed X amount of alcohol prior to the incident under investigation. The peak BAC reported may be an overestimation due to the fact that the calculations performed assume instant absorption without considering metabolism and excretion."

#### *7.5.2 Ethanol Back Extrapolation*

The following comments will be included in the report when ethanol back extrapolation calculations are performed:

> "The back extrapolation calculations performed assume an elimination rate range for ethanol of 0.010 – 0.025 g%/hr. The calculations also assume that the Item x blood sample was collected at XX:XX on Month DD, YYYY, and that individual Y ceased drinking at least two hours prior to the time of the incident under investigation to allow for complete ethanol absorption."

In some instances, it may be appropriate to include the following statement in the report:

> "It typically takes up to two hours after drinking ceases for an individual to reach their maximum BAC. Therefore, any ethanol consumed after XXX (time two hours prior to the incident under investigation) should be subtracted from the BAC at XXX (time of incident under investigation)."

When calculations are performed according to this technical procedure, the authorized individual may state the following in the report:

> "Ethanol back extrapolation calculations were performed in accordance with current FBI Laboratory procedures."

Other comments or statements may be added as applicable.

## 8 LIMITATIONS

Back extrapolation calculations will not be performed if:

- More than ten hours have passed between the incident in question and the collection of the blood specimen
- The measured BAC is less than 0.025 g%
- The individual (blood donor) is known to suffer from severe liver disease such as cirrhosis or hepatitis

## 9 REFERENCES

ANSI/ASB Best Practice Recommendation 122, 1st edition, 2024. Best Practice Recommendation for Performing Alcohol Calculations in Forensic Toxicology.

Baselt, R.C., Disposition of Toxic Drugs and Chemicals in Man, 7th ed., Biomedical Publications: Foster City, California, 2004.

Dubowski, K.M., Manual for Analysis of Ethanol in Biological Liquids, 1977.

Garriott, James, Medicolegal Aspects of Alcohol, 3rd ed., Lawyers and Judges Publishing: Tucson, AZ, 1996.

Forrest, A.R.W. Forensic Science Society 1986; 26: 249-252.

Watson, P.E.; Watson, I.D.; Batt, R.D. Journal of Studies on Alcohol 1981; 42(7): 547-556.

Seidl, S.; Jensen, U.; Alt, A. Int J Legal Med 2000; 114: 71-77.

Jones, Alan. (2017). Profiles in Forensic Toxicology: Professor Erik Widmark (1889-1945). TIAFT Bulletin. 47. 6-16.

## 10 REVISION HISTORY

| Revision | Issued | Changes |
|---|---|---|
| 00 | 12/01/2022 | New document that replaces TOX-109<br>2 - Updated scope statement<br>3 - Replaced examiner with authorized individual<br>4 – Included reference to new form TOX-002<br>6.1.2 - Removed DUI and DFC phrases<br>6.1.3 - Update table format, updated Widmark values, clarified Forrest equations, updated Watson/Forrest water content value from 0.80 to 0.84.<br>Moved some reporting and remarks guidance to section 7. |
| 01 | 02/18/2025 | Referenced updated form in 4.1.<br>In Section 6.1.1, 7.1, 7.3 and 7.4 added MU values to examples.<br>In Section 6.1.1 and 8, limited back extrapolation calculations to ten hours, specified BAC value must be measured and reported by FBI Laboratory, and that impact of unabsorbed alcohol shall be addressed.<br>In Section 6.1.2, added ASB options for Vd calculations (options 1 and 2) in addition to FBI's previous approach (option 3).<br>In Section 7, added flexibility to use g% or g/100mL units.<br>In Section 7.1, required calculated value ranges above 0.250 g% to be reported as >0.250 g%.<br>In Section 7.5.2, updated time period for alcohol peak to 2 hours.<br>Added ANSI/ASB 122 to references. |