
Jennifer F. Limoges
1 Associate Director/Toxicology at the New York State Police Forensic Investigation Center
2 BS in Chemistry from Clarkson University; MS in Forensic Science from University of New Haven
3 Over 30 years experience in forensic toxicology
4 Actively engaged in educating toxicologists, attorneys, law enforcement and other traffic safety professionals
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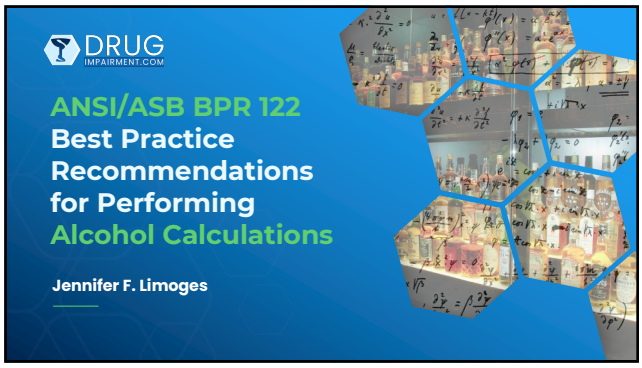
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ANSI/ASB BPR 122
Best Practice Recommendations for Performing
Alcohol Calculations
Jennifer F. Limoges

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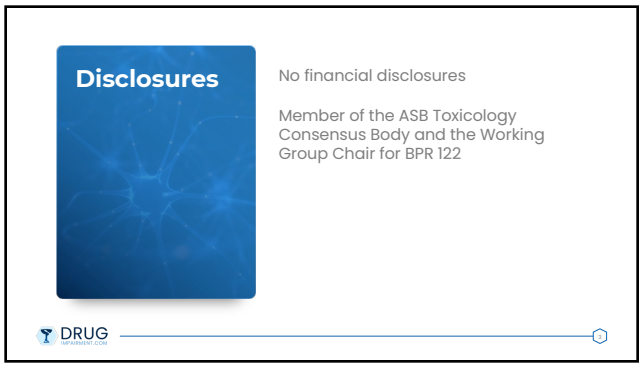
Disclosures
No financial disclosures
Member of the ASB Toxicology Consensus Body and the Working Group Chair for BPR 122
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Learning Objectives

1. Provide an overview of alcohol pharmacokinetics
2. Educate the attendee on the best practice recommendations for performing alcohol calculations
3. Demonstrate how the best practices can be used in typical forensic situations

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Case Example

- Subject starts drinking beer at 7:30 pm
- Crashes at 9:30 pm
- Blood draw at 11:00 pm
- BAC 0.12% by weight
- Claim they were below 0.08 at the time of the crash

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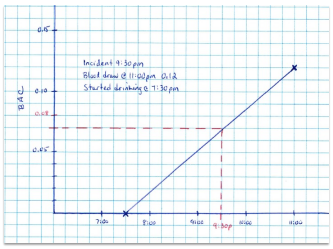
Case Example



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Why do we need a document on alcohol calculations?

- **Significant variability in current practices**
  - Oversimplification – single elimination rate, Widmark rho factor, assume everyone is always post-absorptive
  - Complex statistical approaches – do we have sufficient knowledge of the potential error associated with each parameter?

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Why do we need a document on alcohol calculations?

- **Significant variability in current practices**
  - Rates and ranges can differ significantly – even within the same laboratory
  - Change based on case circumstances

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UKIAFT Guidelines for Alcohol Calculations

- **Started in 2012 and first released in May 2014**
- **Updated publication released in January 2024 (version 4.4)**

www.ukiaft.co.uk/image/catalog/documents/ukiaft-gtd-v4.4.pdf

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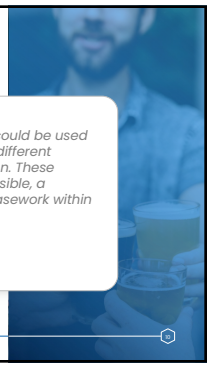
UKIAFT Guidelines for Alcohol Calculations



> *There are potentially many parameters that could be used for such calculations which could produce a different evidential outcome from the same information. These Guidelines are designed to ensure, where possible, a consistent approach to alcohol calculation casework within the United Kingdom and Republic of Ireland.*

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Standard or Best Practice

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Who does this apply to?

- Any expert providing this service
- Criminal or civil proceedings
- Laboratory-based forensic scientists, private consultants, physicians, academics, etc.

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What does the document do?

- Sets a consistent way to perform the calculations
- Focuses on the range and its relevance
  - NOT trying to provide an exact BAC at a previous time
  - NOT trying to predict an exact amount of alcohol consumed
- Provides some QA practices for consideration

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What does it not do?

- Does not provide a fully statistical approach to the calculations
- Does not address postmortem considerations
- Does not address the expert opinions that are based on the results of the calculations

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Ethanol Pharmacokinetics

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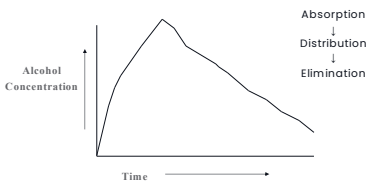
General Ethanol Curve



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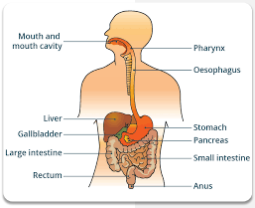
Ethanol Absorption

- **Oral ingestion (approximately):**
  - 5% mouth
  - 20% stomach
  - 75% small intestine
- **Ethanol is not digested**



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Ethanol Absorption Rate

- **Dynamic process**
- **Highly variable, non-linear**
- **Inter- and Intra- individual variations**
- **Can be influenced by food, beverage type/volume, other drugs, GI condition**

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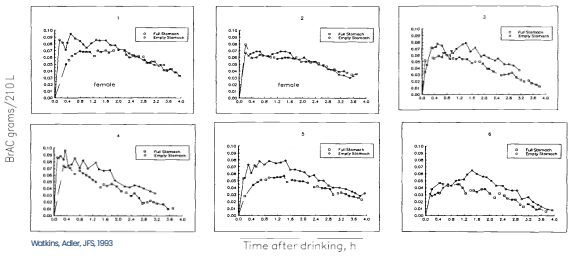
Effect of Food on Absorption



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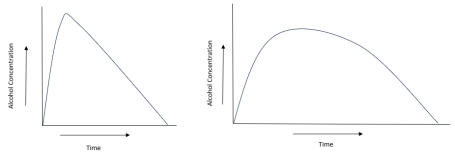
Generalized Alcohol Curves



Absorptive phase = absorption ›› elimination
Plateau phase = absorption ≈ elimination
Post peak phase = absorption ‹ elimination
Post absorptive phase = elimination only or elimination ›› absorption

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Peak vs Post Absorptive

Time to Peak

- Time to reach the maximum AC
- Faster with bolus drinking, empty stomach
- Slower with social drinking, food

Time to Post Absorptive

- Time to reach elimination only phase (absorption irrelevant)
- Varies from time to peak - plateau
- Important for retrograde extrapolation

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BPR 122 - Post Absorptive

- Calculations must consider whether the subject is post absorptive at the time of the incident
- Simply stating the subject is assumed to be post absorptive without information to support that assumption is inappropriate
- If incident is >2 hours from last drink, reasonable to assume post absorptive

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Distribution

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Volume of Distribution (Vd) – Total Body Water (TBW)

- Alcohol is hydrophilic
- Distributes throughout the total body water (~60-70% of body weight)
- Impacted by age, sex, height, weight, muscle mass, disease, hormone treatment

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Widmark's Rho Factor

- From Widmark's work in the 1930s
- Represents the average of his subjects
- Male (n=20) = 0.68 L/kg
  Female (n=10) = 0.55 L/kg

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Anthropometric Methods for Estimating Vd

Method	Year	Sex	Weight	Height	Age
Widmark	1932	M and F			
Forrest	1986	M and F	x	x	
Watson et al. (Wt, Ht & Age)	1981	M and F	x	x	x
Watson et al. (Wt, Age)	1981	M and F	x		x (M only)
Seidl et al.	2000	M and F	x	x	
Ulrich et al.	1987	M	x	x	
Maudens et al.	2014	M and F	x	x	x

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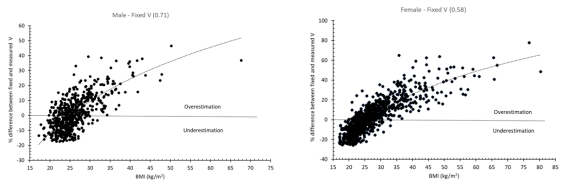
Application of a Fixed Vd



V_d measured using ^2H Dilution
Adapted from Maskell *et al.* (2020) For Sci Int 316, 110532.

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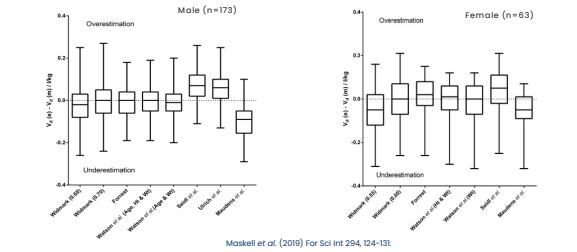
Anthropometric Methods for Estimating Vd



Maskell *et al.* (2019) For Sci Int 294, 124-131.

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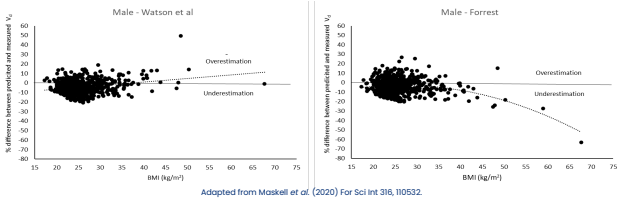
Watson vs Forrest Equations - Males



Adapted from Maskell *et al.* (2020) For Sci Int 316, 110532.

Watson et al gives a better prediction when BMI is > 35 kg/m2

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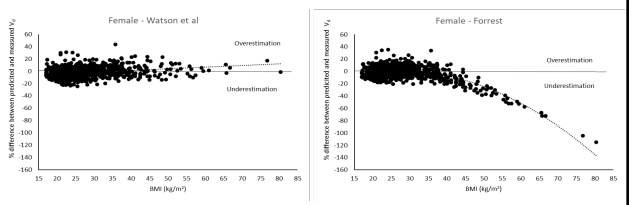
Watson vs Forrest Equations - Females



Adapted from Maskell *et al.* (2020) For Sci Int 316, 110532.

Watson et al gives a better prediction when BMI is > 35 kg/m2

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Watson et al Application

- **Precise and Accurate**
  - Small bias, RMSE ~9 %
- **Valid for wide range of BMIs:**
  - Female (17 to 80 kg/m2)
  - Males (17 to 67 kg/m2)
- **Valid for wide range of ages**
  - 18 - 90 years old
- **Valid for a wide range of ethnicities**
  - African American
  - Hispanic
  - Asian
  - Puerto Rican
  - Caucasian
  - Korean
- **Age, Height, Weight and Sex of individual needed**

Adapted from Maskell et al. (2020) For Sci Int 316, 110532.

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BPR 122 Anthropometric Calculations

- **Estimate the TBW and Vd for an individual, with expected variances**
- **Calculate the TBW from Watson, et al**

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

- **Calculate the Vd from Maskell, et al**

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

- **Apply the ± %CV from Maskell, Cooper**

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

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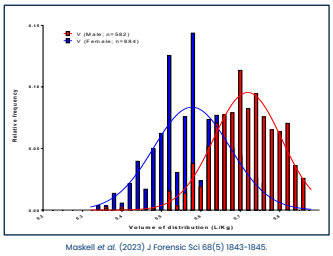
Alternative – Fixed Range for Vd



Maskell *et al.* (2023) J Forensic Sci 68(5) 1843-1845.

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Alternative – Fixed Range for Vd

Sex	V_dMin (L/kg)	V_dMax (L/kg)	V_d 5th Percentile (L/kg)	V_d 95th Percentile (L/kg)
Male (n=582)	0.36	0.86	0.58	0.83
Female (n=884)	0.33	0.78	0.43	0.73
All (n=1466)	**0.33**	**0.86**	**0.45**	**0.81**

Maskell *et al.* (2023) J Forensic Sci 68(5) 1843-1845.

Conclusion: Based on these data, Vd results between 0.45 L/kg and 0.81 L/kg should be considered valid

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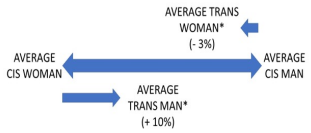
Vd – impact of GAHT

- **Estimated ~1.4 million transgender people in the US**
  ~49% undergoing gender affirming hormone therapy (GAHT)
- **TBW changes after 12 months of GAHT**



Klaver et al (2018) doi.org/10.1530/EJE-17-0496

*Based on fat free mass rather than the determination of TBW.

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Potential TBW Calculation Impact

	Trans Woman		
	Trans woman TBW Equation	Cis man TBW equation	Cis woman TBW equation
Mean % difference in actual vs estimated TBW	0	- 1	-18
Mean % difference in actual vs estimated C_0	0	0	+21

	Trans Man		
	Trans man TBW Equation	Cis man TBW equation	Cis woman TBW equation
Mean % difference in actual vs estimated TBW	0	+7	-11
Mean % difference in actual vs estimated C_0	0	-6	+15

Maskell et al. (2022) *J For Science* 67(4):1624-1631.
Revised Vd equations – theoretical, NOT validated

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BPR 122 - Volume of Distribution

- Use a range for Vd, not an average or single value
- Individualized anthropometric calculations are recommended based on Watson and Maskell
- A generic range may be also be used
  - General 0.45-0.81 L/kg
  - Male 0.58-0.83 L/kg
  - Female 0.43-0.73 L/kg

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Elimination

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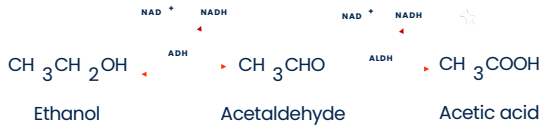
Ethanol Metabolism



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Ethanol Elimination

- **Majority is eliminated via enzyme metabolism**
  - Occurs primarily in the liver
- **Alcohol dehydrogenase (ADH) is primary enzyme**
  - MEOS and catalase also have some activity, especially at higher BACs
- **First pass metabolism (ADH in the stomach)**
- **Unchanged in urine and expired breath**

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Ethanol Elimination

- **Linear rate**
  - Only when post-absorptive
  - Becomes non-linear below 0.02 g/dL
- **Inexperienced drinkers tend to eliminate slower**
- **Experienced drinkers tend to eliminate faster**

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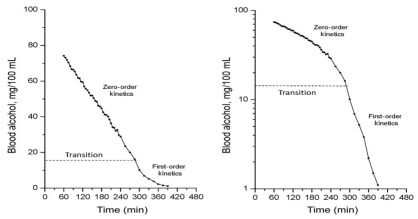
Elimination < 0.02 g/dL



WIREs Forensic Sci, Volume: 1, Issue: 5, First published: 20 May 2019, DOI: (10.1002/wfs2.1340)

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Ethanol Elimination Rates

- **Jones categorizations**
  - Slow 0.008-0.010 g/dL/hr
  - Moderate 0.010-0.015 g/dL/hr
  - Rapid 0.015-0.025 g/dL/hr
  - Ultra-rapid 0.025-0.035 g/dL/hr

Jones, A. J Forensic Sci. 38: 104-118, 1993.

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BPR 122 - Elimination Rates

- **Must use a range (not an average)**
- **Minimal range 0.010-0.025 g/dL/hr**
- **Do not attempt to calculate an individual's specific elimination rate**

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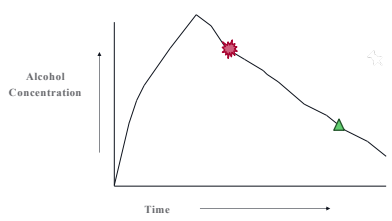
Retrograde Extrapolation



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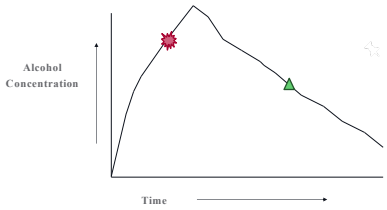
Retrograde Extrapolation



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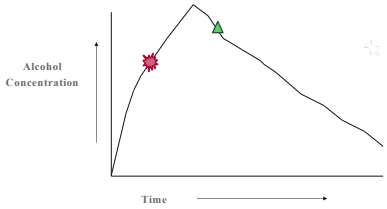
Retrograde Extrapolation



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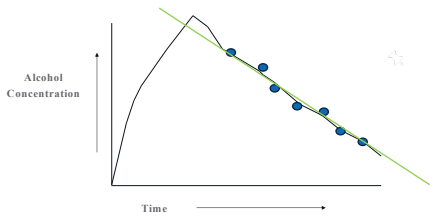
Multiple tests



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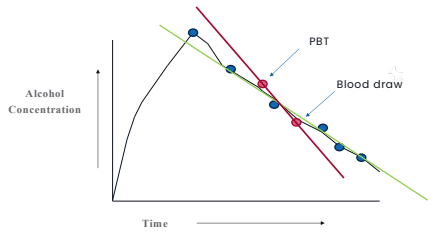
Multiple tests



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Sources of variability in the calculations

- **Largest sources of variability**
  - Elimination rate (β)
  - Volume of distribution (Vd)

Adapted from Maskell & Cooper (2020) J Forensic Sci Int 65(5), 1676-1684.

Calculating C_t

Variable	Value	SD	Percentage of Total Uncertainty
A	112 g		4.7
β	19.00 mg/100mL/h	5.00 mg/100mL/h	53.1
t	5.000 h	0.100 h	0.4
V_d	0.6700 L/Kg	0.0700 L/Kg	38.1
p	81.64 Kg	2.48 Kg	3.7
Total			100.0

Calculating V

Variable	Value	SD	Percentage of Total Uncertainty
C_t	114.00 mg/100mL	3.36 mg/100mL	1.1
β	19.00 mg/100mL/h	5.00 mg/100mL/h	53.2
t	5.000 h	0.100 h	0.3
V_d	0.6700 L/Kg	0.0700 L/Kg	38.0
p	81.64 Kg	2.48 Kg	3.9
EtOH Density	0.789 g/mL	0	0.0
Drink ABV	4.0 %v/v	0.01	2.6
Total			100.0

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Additional Best Practices

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Forensic Service Request

- BAC Calculations are a type of service request of the forensic science service provider
- Not just an expert opinion
- Recommends incorporating quality assurance practices routinely applied to other types of service requests, e.g.
  - Documentation
  - Written protocols
  - Review processes

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Documentation Considerations

- Record of the case specifics
- What is the service request?
- Assumptions clearly stated
  - Post absorptive?
  - No post crash consumption
  - "Standard" drink

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Documentation Considerations

- Case notes
- Police reports
- Test reports
- Spreadsheet
- Extrapolation report

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Written Protocol Considerations

- Definition of a standard drink
- Standard conversion factors/ranges to be used
  - English ↔ metric
  - serum/plasma ↔ whole blood
- Minimum case information requested
- How volume of distribution will be estimated
- The range to be used for elimination rates

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Written Protocol Considerations

- The type of analytical results that are acceptable to use (e.g. accredited laboratory blood alcohol result, evidential breath test result)
- The practice for decimal places, rounding/truncating of calculation results
- Documentation and reporting requirements
- Review requirements, including frequency of review
- Situations (if any) in which calculations may not be performed

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Review Considerations

- Technical review by a qualified individual
  - Work conducted in accordance with established procedures
  - Mathematical calculations and data entry are accurate
  - Assumptions are appropriate and based on the case history

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Real Time Calculations Considerations

- Importance of pretrial preparation
- Protocols and reviews still need to be followed
- Request a recess
- Discuss the impact of a change, rather than recalculate

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Training Program Considerations

- Minimum qualifications for the expert
- Alcohol pharmacokinetics
- Required reference readings
- Testimony preparation
- Continuing education

Outside the scope of BPR 122

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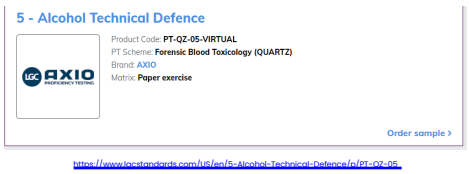
Proficiency Testing Considerations

- LGC AXIO proficiency testing



https://www.lgcstandards.com/US/en/5-Alcohol-Technical-Defence/p/PT-QZ-05_

Outside the scope of BPR 122

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Accreditation

UKAS TESTING
7641
Accredited to ISO/IEC 17025:2017

	Related Opinions and Interpretations	
Alcohol Technical Defence (in relation to RTA and sexual offences) for sample matrix including Blood/urine/breath	Estimation of alcohol consumption and elimination with respect to validity of drinking patterns: 1) Effect of alleged post accident alcohol consumption on measured breath/body fluids alcohol levels 2) Effect of alleged spiked drink 3) Back calculations of breath/ blood/urine alcohol levels to the time of accident or other incident from 8.7µg% / 20mg% / 27mg% and above	Documented in house (SOP 273) using mathematical calculations

https://www.ukas.com/wp-content/uploads/schedule_uploads/00002/7641Testing-Single.pdf

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Examples

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Support/Refute Drinking History

Forensic Service Request:
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?

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Support/Refute Drinking History

Case Information:

- Male, 6'1", 230 lbs, 32 years old
- Evidential breath test 0.19 g/210L
- Drinking Brand X beer (4.3% as per manufacturer's website)

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Support/Refute Drinking History

OPTIONS:

- Fixed Vd or anthropometric approach?
- Two different ways to answer the question
  - Minimum number of drinks to reach the measured AC
  - Maximum AC that could be reached based on drinking history

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Support/Refute Drinking History

DECISION:

- Fixed Vd or anthropometric approach?
- Two different ways to answer the question
  - Minimum number of drinks to reach the measured AC
  - Maximum AC that could be reached based on drinking history

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Support/Refute Drinking History

- Calculate the Vd range (combination of equations 1a, 2a, and 3a):

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

$$Vd\ (male) = \frac{2.447 - (0.09516 \times 32) + (0.1074 \times 185) + (0.3362 \times 104)}{104 \times 0.825} \pm 9.86\%$$

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

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Support/Refute Drinking History

- Calculate the dose of alcohol from 2 pints of Brand X beer (equation 7):

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

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

$$D = 32\ g\ alcohol\ in\ 2\ pints\ of\ Brand\ X$$

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Support/Refute Drinking History

- Calculate the maximum AC from a given dose (equation 8):

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

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

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

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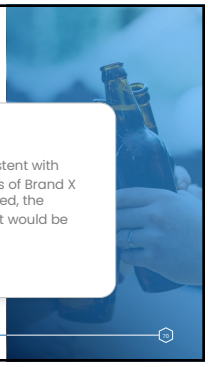
Support/Refute Drinking History



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.

DRUG

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Retrograde Extrapolation

Forensic Service Request:
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 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?

DRUG

71

Retrograde Extrapolation

Case Information:

- Female, 5'8", 160 lbs, 22 years old
- BAC 0.082g/dL at 12:30 am
- Incident at 11:00 pm

Assumptions:

- Alcohol from the last shot was not absorbed
- Tequila is typically 80 proof (40% alcohol)

DRUG

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Retrograde Extrapolation

- Calculate AC range at the time of incident if the subject were post-absorptive (equation 9):

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

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

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

DRUG

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Retrograde Extrapolation

- Calculate the dose of alcohol from 1 shot tequila (equation 7):

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

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

$$D = 14\ g\ alcohol\ in\ a\ shot\ of\ tequila$$

DRUG

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Retrograde Extrapolation

- Calculate the Vd range (combination of equations 1b, 2b, and 3b):

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

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

$$Vd\ (female) = 0.48 - 0.64\ L/kg$$

DRUG

75

Retrograde Extrapolation

- **Calculate the maximum AC from a given dose (equation 8):**

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

$$\mathrm{AC}_{drink(s)} = \frac{14g}{(0.48 - 0.64)\ \frac{L}{kg} \times 104kg \times 10\ \frac{dL}{L}}$$

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

DRUG

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Retrograde Extrapolation

- **Adjust the AC to remove the contribution from the last shot of tequila (equation 10):**

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

Adjusted $AC_{inc} = 0.097 - 0.040$

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

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

Adjusted $AC_{inc} = 0.120 - 0.030$

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

DRUG

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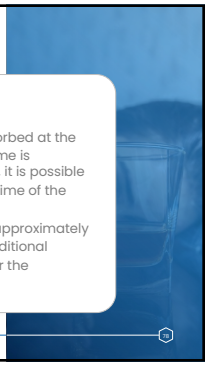
Retrograde Extrapolation

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.



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Minimal Case History

Forensic Service Request:
Driver involved in a crash, no drinking history available.

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

DRUG

79

Minimal Case History

Case Information:

- Female, 160 lbs (height and age not provided)
- BAC 0.075g/dL at 3:00 am
- Incident at 1:00 am

DRUG

80

Minimal Case History

Assumptions:

- With no drinking history, the impact of potentially unabsorbed alcohol must be considered.
- Since there is no information on the type of drinks, a standard drink will be used (14 g).
- Since the height was not provided, a fixed Vd range for females will be applied (0.43 - 0.73 L/kg).

DRUG

81

Minimal Case History

- **Calculate AC range at the time of incident if the subject were post-absorptive (equation 9):**

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

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

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

DRUG

82

Minimal Case History

- **Calculate the maximum AC from a standard drink (equation 8):**

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

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

$$\mathrm{AC}_{drink(s)} = 0.026 - 0.045\ g/d\,L$$

DRUG

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Minimal Case History

- **Adjust the AC to remove the number of drinks that would have to be unabsorbed to get below the legal limit (equation 10):**

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**

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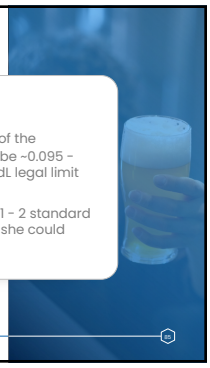
Minimal Case History



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.

DRUG

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ANSI/ASB BPR 122

- Improve the quality and consistency of alcohol calculations in forensic toxicology
- Apply to a wide variety of case scenarios

DRUG

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- Peter Maskell, PhD
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CONTACT
INFORMATION
Jennifer Limoges
Associate Director/Toxicology
New York State Police Forensic Investigation Center
Jennifer.Limoges@troopers.ny.gov
518-457-9612
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