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Estimation of Blood Alcohol Concentrations after Social Drinking

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ABSTRACT: Requests for estimates of blood alcohol concentrations (BACs) are often made when blood samples are taken some hours after the time of interest. Many believe that such estimates are not reliable because the subject's alcohol clearance rate is never known and often there is uncertainty as to whether the subject was postabsorptive at the time in question.

In order to evaluate the potential errors associated with BAC estimates under these non-ideal conditions, BAC estimates were compared with empirical data obtained from 24 healthy males, ranging in age from 22 to 56 years, who took part in a three hour social drinking session. One blood sample for alcohol analysis was taken from each subject approximately 1 hour after drinking stopped and another was taken approximately 3.5 hours after drinking stopped.

Estimations of BACs at the blood sampling time points were made assuming each person had a constant blood alcohol clearance rate in the range of 10 to 20 mg/dL/h (0.01 to 0.02 g/dL/h) over the whole of the experimental period. A variety of methods were used to estimate the volume of distribution for alcohol. All BAC estimations were made assuming complete absorption and full equilibration of the total alcohol dose.

The results showed that actual BACs were usually within or very close to the range of "forward" estimates based on the known alcohol doses. Furthermore, most BACs measured about an hour after cessation of drinking were within or very close to the predicted range based on back extrapolation from the actual 3.5 hour BAC result.

KEYWORDS: forensic science, blood alcohol, social drinking, estimation

Alcohol analysis is often performed on blood samples taken several hours after a person was involved in a motor vehicle accident or in some form of crime. In this situation a forensic scientist is sometimes asked to estimate the blood alcohol concentration (BAC) of the person at the time of the accident or crime. Such estimates have been called "retrograde extrapolations" or "back estimations" because they work back in time from a known to an unknown BAC (1).

In other situations the forensic scientist is asked to estimate a BAC at the time of an accident or crime when no blood specimen has been taken. In this case supposedly reliable information concerning the person's alcohol intake prior to the event in question is usually available. We will call such estimates "forward estimations" because they work forward in time from a stated dose of alcohol (2). Back estimations will be accurate under the following "ideal" conditions: (a) The person is postabsorptive with respect to alcohol between the time of the accident/crime and the time of blood sampling. Under these conditions any changes in the person's BAC are caused only by metabolism and excretion of alcohol. (b) The decrease in the person's BAC over the period in question is a known function of time.

For practical purposes, the postabsorptive decay in BAC can be assumed to be a linear function of time, especially when back estimations are performed over just a few hours and the starting point for the calculation is a BAC above about 10 mg/dL (3,4). Therefore under the above conditions it is a simple matter to multiply the blood alcohol clearance rate [Widmark's β_{60} (5)] by the appropriate time period ($t_2 - t_1$) and add the known BAC at the time of blood sampling (BAC_2) to give the BAC at the time in question (BAC_1).

$$\text{i.e., } BAC_1 = BAC_2 + \beta_{60} \times (t_2 - t_1)$$

Forward estimations will be accurate under the following "ideal" conditions: (a) The person is post absorptive at the time of the accident/crime; (b) The person's (post absorptive) blood alcohol clearance rate is known; (c) The person's alcohol dose is known; (d) The person's volume of distribution (V_D) for alcohol is known; and (e) From the time drinking starts, the person metabolizes alcohol at a constant rate, reflected by the person's post absorptive blood alcohol clearance rate.

Because alcohol is distributed almost exclusively in the water phase of the body (2), the V_D can be calculated if the total body water (TBW) volume is known. However, as the V_D is a purely theoretical entity we prefer to use the TBW as the basis of our calculations.

Therefore, under the above "ideal" conditions, the following equation applies:

$$BAC = (D/TBW) \times Blw \times 100 - \beta_{60} \times t$$

where:
- BAC = Blood alcohol concentration in units of milligrams per 100 milliliters (mg/dL) at the time in question
- D = Dose of alcohol (grams)
- TBW = Total body water volume (liters)
- Blw = The fraction of water in the blood (v/v)
- β_{60} = Blood alcohol clearance rate (mg/dL/h)
- t = The time (hours) between the start of drinking and the event in question.

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The above equation can be expressed in the following simpler way:

$$BAC_t = BAC_0 - \beta_{60} \times t$$

where BAC_t is the BAC at time "t" and BAC_0 is the theoretical BAC which would exist at time "zero" if the total alcohol dose was distributed instantaneously throughout the total body water at that time. It is equivalent to "C_0" as defined by Widmark (5). In this context, time "zero" is the time drinking starts.

Unfortunately, in forensic science practice, the ideal conditions listed above are not likely to exist and back and forward estimations of BAC can be subject to large errors for the following reasons: (1) The person's β_{60} is never known. β_{60} values vary greatly from person to person and values ranging from as low as 8 to more than 30 mg/dL/hr have been reported (6). Furthermore, over a period of many hours, it may be inappropriate to assume that β_{60} is constant (4,7); (2) It is very difficult to predict when a drinker will become postabsorptive with respect to alcohol. The rate of absorption of alcohol into the blood is dependent on a number of variables such as the amount and type of food consumption prior to and during drinking, the type of beverage, and drinking history (8–10); and (3) V_D and TBW values are not known in most forensic situations. V_D and TBW can vary greatly between lean and obese subjects (11,12).

For these reasons some forensic scientists refuse to perform either back or forward estimations of BAC, regarding the potential for serious error as far too high.

Our approach to this problem has been to make the estimates but to clearly state all the major assumptions on which the results depend.

For back estimations our assumptions have usually been listed as follows: (1) At the time in question "X" had already absorbed, into his/her bloodstream, all the alcohol (s)he had consumed prior to the accident/alleged crime; (2) At the time in question "X" cleared alcohol from his/her blood at a rate within the approximate range of 10 to 20 mg per 100 mL per hour; and (3) "X" did not consume any alcohol between the time of the accident/crime and the time the blood sample was taken for alcohol analysis.

For forward estimations assumptions 1 and 2 are the same and assumption 3 is unnecessary. However the subject's height, weight, and age is stated because this information is used to estimate the subject's TBW, using the equations developed by Watson et al. (2). The alcohol dose is also stated, along with any assumptions made in determining this dose, e.g., the alcohol content of a given beverage said to have been consumed.

Our results are usually presented in the following way: "If the listed information and assumptions are correct, "X" would have had a blood alcohol concentration within the approximate range of "x" to "y" mg per 100 mL at the time of the accident/alleged crime." If we have good reasons to suspect that any of the assumptions could be wrong, the relevant consequences are explained.

There is a large amount of published data relating to rapid bolus consumption of alcohol under controlled laboratory conditions (6,13–16). This data strongly suggests that the most important factor affecting the validity of both forward and back estimations of BAC is the rate of absorption of alcohol into the bloodstream immediately after drinking. If absorption is very slow, both forward and back estimations of BAC will tend to be too high until the total dose has been absorbed. If absorption is very rapid a BAC "overshoot" can occur. Under these conditions, both forward and back estimations can be too low until the total dose has been absorbed and equilibrated throughout the body water.

However the rapid bolus consumption of alcohol is uncommon under normal social drinking conditions. It seems likely that most people who develop BACs sufficiently high to be of forensic relevance, attain them by drinking over a number of hours, possibly a whole evening or afternoon. Drinking binges lasting for one or more days may also occur. In these situations the amount of alcohol consumed near the end of the drinking session is likely to be only a small proportion of that already consumed, absorbed and equilibrated over the preceding hours. Therefore any rapid or delayed absorption of the last few drinks is not likely to have a large influence on an already high BAC.

Although there are some published studies of social drinking (17–20) there are very few dealing with drinking over a period of several hours (20). Therefore in order to better understand the errors associated with back and forward estimations of BAC under these conditions, we carried out our own study in which the results of BAC estimations were compared with accurate BAC data obtained from healthy males who took part in a social drinking session lasting approximately three hours.

Experimental

Subjects

Twenty four healthy male volunteers took part in a simulated social drinking session in which they consumed alcoholic beverages of their choice. Immediately prior to drinking, the heights and weights of the subjects were measured. A summary of anthropometric data for the subjects is given in Table 1.

Each volunteer recorded his daily alcohol consumption for a total of 15 days prior to the simulated social drinking session. This drinking "diary" was used to estimate each volunteer's mean daily alcohol consumption. The estimates ranged from 1 to 112 g of absolute alcohol per day (mean = 32, SD = 27).

In the discussion of the results of this study, the subjects have been identified by 24 letters, "Z" through to "C."

Alcohol and Food Consumption

For each subject, drinking started between 13:20 and 14:41 hours. All subjects ate lunch at least an hour before drinking started but no attempt was made to control the type or quantity of food consumed.

TABLE 1—*Anthropometric data for experimental subjects.*

	Height (cm)	Wgt (kg)	Age (Years)	TBW* (L)	TBW** (L)	TBW§ (L)	TBW§§ (L)
Mean	178	85	41	46.3	46.6	52.0	46.7
SD	9	16	10	6.1	6.0	7.5	8.8
Min	162	58	22	35.8	34.8	38.5	31.8
Max	203	116	56	56.9	57.5	66.7	63.6

*Calculated using the equation of Watson et al. (2), using the height, weight and age data.

**Calculated using the method of Forest (22), using the height and weight data only.

§Calculated from the specific volume of distribution determined as described by Lewis (12).

§§Calculated using a mean Widmark Factor of 0.68.

$n = 24$ for all variables.

Alcoholic drinks were consumed by each volunteer for a period ranging from 2.33 to 3.92 hours (mean = 3.01, SD = 0.36), during which they sat and talked, watched television and consumed (*ad lib*) a variety of snack food (e.g., salted peanuts, potato crisps, and pretzels).

In an attempt to mimic a normal social drinking situation, each subject was allowed to drink at a rate they found comfortable and no attempt was made to control the number or type of beverages consumed. However the volume of liquor consumed by each subject was accurately recorded in order to calculate his total alcohol dose. Each separate beverage (beer, wine, gin, whisky, brandy) was sampled for analysis of its alcohol content. Alcohol dose rates ranged from 0.61 to 2.07 g/kg body weight (mean = 1.20, SD = 0.3).

Approximately 1 to 1.5 hours after drinking stopped, a two course dinner was served to the volunteers together with coffee or tea.

Blood Sampling

During the experiment, three blood samples were taken from an antecubital vein of each volunteer. Each sample was analyzed for alcohol by head space gas chromatography (21). The same technique was used to determine the alcohol content of the alcoholic beverages. The coefficient of variation for the analysis method was 1%.

Blood sample 1 was a blank sample taken immediately prior to the drinking session. Sample 2 was taken between 0.78 and 1.38 hours (mean = 1.04) after drinking stopped, i.e., before the meal, and sample 3 was taken between 2.13 and 4.27 hours (mean = 3.26) after drinking stopped, i.e., after the meal. The results obtained upon analysis of these samples were called BAC1, BAC2 and BAC3.

For the purposes of a forward estimation of BAC, blood sampling time 2 was considered to be a potentially unreliable "target time" because the post absorptive state could not be guaranteed such a short time (0.78 to 1.38 hours) after cessation of drinking. For this reason, forward estimation to sampling time 2 was considered a good test of the forward estimation methodology under social drinking conditions. However blood sampling time 3 was regarded as a more reliable target time for a forward estimation, more time being available for absorption and distribution of the total alcohol dose.

Back Estimations

These were performed using the following equation:

$$BAC2_{est} = BAC3 + \beta_{60} \times t$$

where

$BAC2_{est}$ is the *estimated* BAC at blood sampling time 2.
BAC3 is the *measured* BAC at blood sampling time 3.
"t" was the elapsed time between the taking of blood sample 2 and blood sample 3.

Forward Estimations

Forward estimations of BAC at blood sampling times 2 and 3 were made so that the estimates could be compared with the two measured BAC values.

The main method used for forward calculation was that described by Watson et al. (2). This is the method we use routinely for general casework and it involves use of the following equation described in the introduction:

$$BAC = (D/TBW) \times Blw \times 100 - \beta_{60} \times t$$

where

$$(D/TBW) \times Blw \times 100 = BAC_0$$

The TBW value for each individual was estimated using the following equation, the derivation of which is also described by Watson et al. (2):

$$TBW = 2.447 - 0.09516(age) + 0.1074(height) + 0.3362(weight)$$

where TBW is in liters, age is in years, height is in cm and weight is in kg. This formula relates specifically to males.

The water content of blood was taken to be 80% v/v, as used by Watson et al. (2), although 85% v/v has been used by others (12).

Three other methods of forward calculation were also used, the only difference between the methods being the way in which the BAC_0 was determined. Two of the other methods involved use of the following equations:

The Widmark method (5): $BAC_0 = 100 \times 1.055^* \times D/(0.68^{**} \times$ body wgt)

The method of Lewis (12): $BAC_0 = 100 \times D/(Vs§ \times$ body wgt)

With the dose (D) expressed in grams, and body weight in kilograms, the factor of 100 was necessary to give BAC units of milligrams per 100 milliliters (mg/dL), the units used in New Zealand road transport law.

The method of Forrest (22) was the fourth method used. It is the same as that of Watson et al. (2) except that a different method of determining total body water is used.

For the purpose of the forward estimations, it was initially assumed that the β_{60} for each of the volunteers could have been as low as 10 and as high as 20 mg/dL/h. This range was chosen as being representative of most social drinkers, based on reviews of "normal" blood alcohol clearance rates (6,23). It was felt that β_{60} values below this range would be most unlikely in healthy people and values above this range would be relevant mainly to chronic heavy drinkers (6).

In this context it must be noted that Lewis (12) does not recommend use of a constant β_{60} but suggests that the choice of β_{60} should be based on the relevant BAC range over which a forward or back estimation is made. Therefore when referring to Lewis's method of forward estimation we are referring only to his method of determining the volume of distribution for alcohol and BAC_0.

Results and Discussion

BAC Results

No detectable alcohol was found in sample 1 from any of the volunteers. Therefore the results obtained for samples 2 and 3 (BAC2 and BAC3) were due entirely to the alcohol consumed during the experiment.

*Average density of blood (g/mL).
**The mean Widmark factor for males.
§Specific volume of distribution for alcohol (L/kg).

BAC2 ranged from 32 to 200 mg/dL (mean = 108) and BAC3 ranged from 16 to 130 mg/dL (mean = 66). The wide ranges in the BAC values reflect the wide range in total alcohol dose taken by the volunteers. The mean time delay between the taking of blood samples 2 and 3 was 2.22 hours (range: 1.30 to 3.13).

Back Estimations

The results for three subjects are shown in Fig. 1. These results are representative of all others in this study.

Where BAC2 was estimated from BAC3, 67%, 92% and 100%

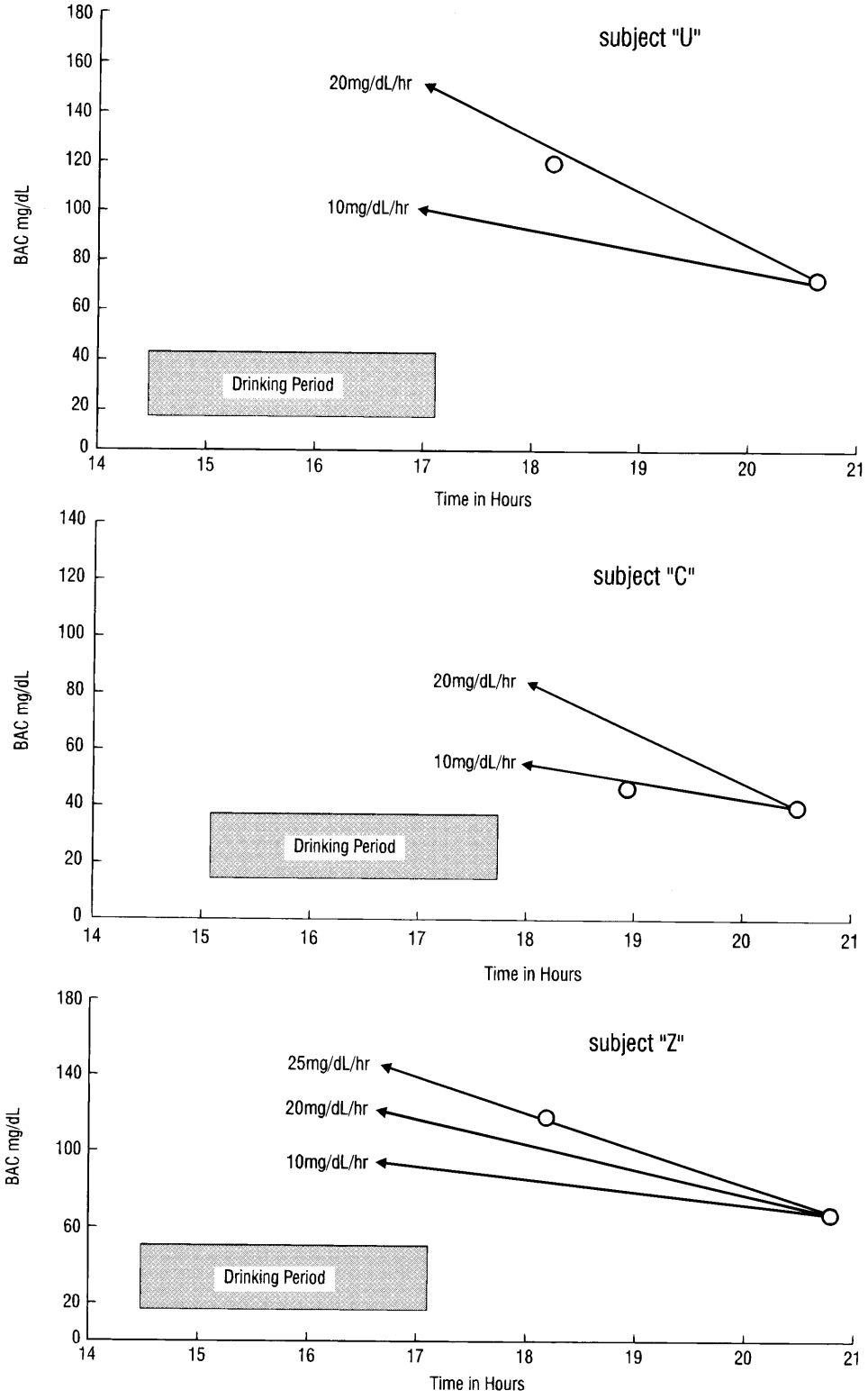

FIG. 1—*Back estimations of BAC2 from BAC3 for subjects "U," "C" and "Z." The two open circles in each graph represent the measured BAC2 and BAC3 values. The range of BAC2 estimates is illustrated by the lines radiating from BAC3 at the different blood alcohol clearance rates used.*

of the experimentally measured BAC2 values were within the range expected, assuming β_{60} elimination rates of 10–20, 10–25 and 8–28 mg/dL/h respectively.

In the case of subject "U" BAC2 lies within the predicted range, if β_{60} is assumed to be in the 10 to 20 mg/dL/h range. Very similar results were obtained for another 15 of the 24 subjects.

In the case of subject "C" BAC2 is overestimated although it is only 2 mg/dL outside the predicted range. This was the only case where BAC2 was overestimated.

In the case of subject "Z" BAC2 is underestimated if β_{60} is assumed to be in the 10 to 20 mg/dL/h range. There were six other similar cases but in no case was BAC2 more than 14 mg/dL above the upper limit of the predicted range.

Considering that BAC2 was measured approximately one hour after drinking stopped, when absorption and equilibration of alcohol may not have been complete, these results are surprising. They suggest that back estimations up to a relatively short time after cessation of drinking, may not be subject to gross errors after a period of social drinking. This conclusion is supported by other studies involving even shorter periods of social drinking (17–19).

Reliable estimations of post absorptive blood alcohol clearance rates could not be made in this study because the BAC for each subject was not followed for a sufficiently long period. Even at sampling time 3, full absorption and equilibration of the alcohol dose could not be guaranteed because of the unknown effect of the large meal. Therefore we cannot be sure whether post drinking absorption effects, or β_{60} values outside the "normal" range were the main cause of the few apparently inaccurate back estimations for BAC2.

It is the practice of some forensic scientists to use a β_{60} value of 15 mg/dL/h when performing back estimations. This is widely regarded as an average value for "normal" social drinkers (16). The errors associated with the use of this average value are shown in Table 2. In general these errors were not large. The likely reason for this is that the back estimations in this study related to a relatively short time period (1.30 to 3.13 hours). Over longer time periods greater errors would be expected if a β_{60} range is not used (16).

Forward Estimations

The results for three of the volunteers are shown in Fig. 2. Again these are representative of all other results. The forward estimations shown in this figure were made using the method of Watson et al. (2).

In the case of subject "X" BAC2 and BAC3 are within the predicted range, assuming a β_{60} of 10 to 20 mg/dL/h. Another 15 of the 24 volunteers gave similar results. This result was also somewhat surprising given the non-ideal conditions under which the estimates were made.

TABLE 2—*Errors associated with BAC2 back estimates when the blood alcohol clearance rate was assumed to be 15 mg/dL/h.*

	Differences Between Estimated BAC2 Values and Measured BAC2 Values (n = 24)	
	Actual Differences (mg/dL)	% Differences§
Mean	−9	−7
Range	−28 to +10	−26 to +18

§Actual differences as a percentage of measured BAC2 values.

In the case of subject "T" BAC2 and BAC3 are outside the predicted range, assuming a β_{60} of 10 to 20 mg/dL/h. However when the forward estimation for subject "T" was based on a slightly extended β_{60} range of 10 to 25 mg/dL/h BAC3 fell within the predicted range and BAC2 was only just outside the predicted range (by 1 mg/dL). Subject "T" represents the worst overestimate seen although there were five other similar cases.

In the case of subject "H" BAC2 was underestimated although BAC3 fell within the predicted range. There was only one other subject in this category (Subject "L"). BAC2 was outside the predicted range by 16 mg/dL in the case of subject "H" and by 12 mg/dL in the case of subject "L"). These are respectively 14% and 12% deviations from the higher prediction limit.

The apparent underestimation of BAC2 in these two cases is unlikely to have been caused by a genuinely low β_{60}. If this was the case BAC3 would have been underestimated as well. The underestimation was almost certainly caused by a post drinking BAC "overshoot" prior to equilibration. This phenomenon is commonly observed after rapid bolus consumption of alcohol, especially on an empty stomach (6,24) but our results and those of others (20) suggest that it may not be common in a social drinking situation.

Table 3 summarizes the forward estimations made using all four methods.

Because of the small sample number, no rigorous statistical analysis of these results has been carried out. However, they suggest that the forward estimation methods of Watson et al. (2), Lewis (12) and Forrest (22), have a similar degree of accuracy, at least under the conditions of our study. Widmark's method may be less accurate than the other three methods. This would be expected given that this method is the only one of the four methods that does not take into account differences in body build when estimating the TBW or the V_D for alcohol.

The mean TBW value calculated for the 24 volunteers by the method of Watson et al. (46.3 L) was very close to that determined by the method described by Forrest (46.6 L). However TBW values determined for each subject by the two methods differed by up to 7%. Such differences accounted for the apparent differences in prediction accuracy between these two methods.

Although the mean blood water content is 85% v/v (25), the BAC predictions based on the methods of Forrest (22), and Watson et al. (2) were more accurate if a value of 80% v/v was used, as recommended by these authors. Use of the lower value lowered the estimate of BAC_0 by about 6%. Therefore it always lowered predicted BAC results by more than 6%. Although in our experiments the bulk of the BAC2 and BAC3 results fell within or close to the predicted range, there was a tendency for the predicted range to be too high. Therefore any factor which slightly lowered the predicted range increased the apparent prediction accuracy. It is possible that use of an erroneous blood water fraction helps compensate for small errors resulting from failure to take any account of first-pass effects and non-linear alcohol clearance.

In this context it should be noted that Lewis's method generally gave higher TBW estimates than the other three methods (see Table 1). Therefore, regardless of which blood water fraction was used, Lewis's method generally gave lower BAC_0 values than the other methods. This is the reason for the apparently superior accuracy of Lewis's method in estimating BAC2 and BAC3 using the narrowest of the β_{60} ranges (see Table 3).

We can only speculate as to why some authors have used 80% v/v for the blood water content. However one possibility is that

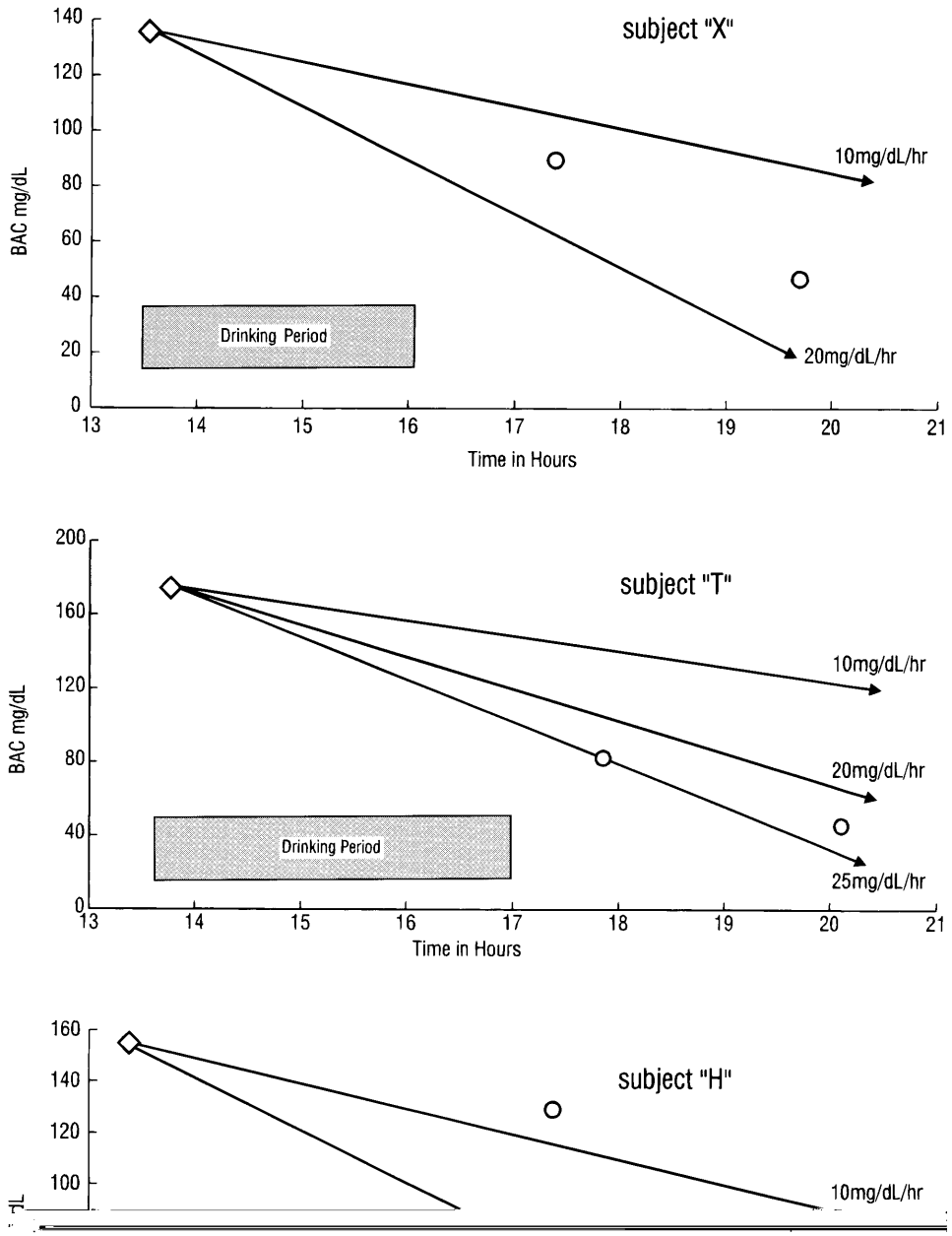

FIG. 2—*Forward estimations for subjects "X," "T" and "H." The two open circles in each graph represent the measured BAC2 and BAC3 values. The diamond represents the theoretical* BAC_0 *calculated from the alcohol dose and estimated total body water (see Experimental). The range of BAC estimates is illustrated by the lines radiating from* BAC_0 *at the different blood alcohol clearance rates used.*

the volume per weight value (approximately 80%) has been confused with the volume per volume value.

It would be of interest to repeat this study, following blood alcohol concentrations for several more hours to ensure that full absorption and equilibration of the alcohol dose has occurred. Comparing predicted BAC ranges with actual BAC results under these conditions would give more reliable information on the accuracy of the various forward and back estimation methods.

We cannot rule out the possibility that some of the volunteers had β_{60} values above 20 mg/dL/h and that this was the cause

TABLE 3—*Summary of forward estimation results for BAC2 and BAC3.*

Method of Estimation	Percentage of BAC2 and BAC3 Results Which Were Within the Estimated Range (n = 24)					
	β_{60} = 10–20*		β_{60} = 10–25		β_{60} = 8–28	
	BAC2	BAC3	BAC2	BAC3	BAC2	BAC3
Watson et al.	63	79	88	100	92	100
Lewis	67	92	79	100	92	100
Forrest	63	79	83	100	96	100
Widmark	50	58	79	96	96	100

*Units for β_{60} = mg/dL/h.

of one or more of the apparent discrepancies between actual and predicted results.

Table 4 shows the magnitude of the errors associated with forward estimates made using a fixed β_{60} of 15 mg/dL/h. The results in this table suggest that gross errors are likely if a reasonably wide β_{60} range is not used.

When the results in Table 4 are compared with those in Table 2, it is clear that while the back estimates tended to underestimate actual BAC values, the forward estimates tended to do the opposite. Similar results have been reported by Shajani and Dinn (20). BAC "overshoot" conditions or conditions of incomplete absorption and equilibration do not account for these results. Although there may be more than one factor responsible for this apparent anomaly there are two potential causes which by themselves or in combination could explain the observed results.

The first is the possibility that the average β_{60} for the subjects in our study was above 15 mg/dL/h. Others have found this to be the case in their studies (16,20). Unfortunately, the experimental design of our study did not allow accurate determinations of β_{60} values.

Some of the volunteers in this study would not be regarded as moderate drinkers on the basis of their estimated daily alcohol intake. For example, six of them were consuming more than 40 g per day and four of them were consuming more than 60 g per day on average. These dose rates in men are regarded respectively as "hazardous" and "harmful" by some health professionals (26). Because there appears to be a positive correlation between mean daily alcohol intake and the rate of alcohol metabolism (10), some of our subjects might have had blood alcohol clearance rates well above average. However there was no clear correlation between those subjects whose BAC results fell outside the estimated ranges and high mean daily alcohol intakes.

TABLE 4—*Errors associated with BAC forward estimates when the blood alcohol clearance rate was assumed to be 15 mg/dL/h.*

Method of Estimation	Differences Between Estimated BAC2 Values and Actual BAC2 Values (as a percentage of Actual BAC2 Values) (n = 24)		Differences Between Estimated BAC3 Values and Actual BAC3 Values (as a Percentage of Actual BAC3 Values) (n = 24)	
	Mean	Range	Mean	Range
Watson et al.	+10	−28 to +61	+30	−31 to +93
Lewis	+1	−37 to +8	+14	−47 to +99
Forrest	+9	−30 to +64	+61	−34 to +92
Widmark	+21	−31 to +111	+48	−32 to +125

The second possibility is overestimation of BAC_0. This could occur as a result of underestimation of TBW, or as a result of first-pass effects, or both.

First pass effects appear to be negligible with alcohol dosages much lower than those used in this study (27,28). Our experimental data does not allow us to say whether they might be more significant when higher doses of alcohol are taken together with food.

It seems unlikely that the TBW values are the only cause of the above anomaly. TBW values estimated by the methods of Watson et al., and Forrest, gave mean body water contents of 54 and 55% respectively for the 24 volunteers. The method of Lewis gave a corresponding value of 62%. As the average body water content for males is 59–60% (29) Lewis's method might have been expected to underestimate BAC_0, especially since we did not have a majority of very lean males in our study. Although this method appeared to be slightly more accurate than the other methods of forward estimation, it still tended to overestimate both BAC2 and BAC3 (see Table 4).

Conclusion

Our results support the view that back and forward estimations of BAC can seldom be performed with great accuracy. However they suggest that such estimates are unlikely to be subject to gross errors if the person in question has been in a normal social drinking situation, a β_{60} range of about 10 to 20 mg/dL/h is used, and accurate dose and anthropometric data sufficient to calculate a V_D or TBW value specific to the individual in question, is available.

If there is reason to believe that the subject in question might be a chronic heavy drinker, it may be prudent to use a β_{60} range with a maximum of 30 mg/dL/h in any back or forward estimations.

The results of this study do not show any of the four forward calculation methods as clearly superior to all the others. All are useful as long as their limitations are understood.

In any particular case, the formula available for BAC estimations should be used only as a starting point. The results given by the formula must be interpreted according to the circumstances surrounding the drinking situation. Good interpretation is unlikely to be made unless the forensic scientist has a thorough knowledge of the many factors which influence the absorption, distribution and metabolism of alcohol.

References

1. Montgomery MR, Reasor MJ. Retrograde extrapolation of blood alcohol data: an applied approach. J Toxicol Environ Health 1992; 36:281–92.
2. Watson PE, Watson ID, Batt RD. Prediction of blood alcohol concentrations in human subjects. J Stud Alcohol 1981;42(7):547–56.
3. Forrest ARW. Non-linear kinetics of ethyl alcohol metabolism. J Forensic Sci Soc 1986;26:121–3.
4. Wilkinson PK. Pharmacokinetics of ethanol: A review. Alcohol Clin Exp Res 1980;4(1)6–21.
5. Jones AW. Forensic science aspects of ethanol metabolism. Forensic Sci Prog 1991;5:31–89.
6. Jones AW. Disappearance rate of ethanol from the blood of human subjects: Implications in forensic toxicology. J Forensic Sci 1993; 38(1):104–18.
7. Lewis MJ. Blood alcohol: the concentration-time curve and retrospective estimation of level. J Forensic Sci Soc 1985;26:95–113.
8. Sedman AJ, Wilkinson PK, Sakmar E, Weidler DJ, Wagner JG. Food effects on absorption and metabolism of alcohol. J Stud Alcohol 1976;37(9):1197–213.
9. Dubowski KM. Absorption, distribution and elimination of alcohol: Highway safety aspects. J Stud Alcohol 1985; Suppl 10:98–108.

10. Whitfield JB, Martin NG. Alcohol consumption and alcohol pharmacokinetics: Interactions within the normal population. Alcohol Clin Exp Res 1994;18(2):238–43.
11. Watson PE, Watson ID, Batt RD. Total body water volumes for adult males and females estimated from simple anthropometric measurements. Am J Clin Nutr 1980;33:27–39.
12. Lewis MJ. The individual and the estimation of his blood alcohol concentration from intake, with particular reference to the 'Hip-Flask' drink. J Forensic Sci Soc 1986;26:19–27.
13. Jakus JT, Shajani NK, Image BA. Consumption of a large dose of alcohol in a short time span. Forensic Sci Int 1992;56:113–25.
14. Watkins RL, Adler EV. The effect of food on alcohol absorption and elimination patterns. J Forensic Sci 1993;38(2):285–91.
15. Gullberg RG, Jones AW. Guidelines for estimating the amount of alcohol consumed from a single measurement of blood alcohol concentration: re-evaluation of Widmark's equation. Forensic Sci Int 1994;69:119–30.
16. Al-Lanqawi Y, Moreland TA, McEwan J, Halliday F, Durnin CJ, Stevenson IH. Ethanol kinetics: extent of error in back extrapolation procedures. Br J Clin Pharmac 1992;34:316–21.
17. Jones AW, Neri A. Evaluation of blood ethanol profiles after consumption of alcohol together with a large meal. Can Soc Forens Sci J 1991;24:165–73.
18. Winek CL, Wahdba WW, Dowdell JL. Determination of absorption time for ethanol in social drinkers. Forensic Sci Int 1996;77: 169–77.
19. Gullberg RG. Variation in blood alcohol concentration following the last drink. J Police Sci Admin 1982;10:289–96.
20. Shajani NK, Dinn HM. Blood alcohol concentrations reached in human subjects after consumption of alcoholic beverages in a social setting. Can Soc Forensic Sci J 1985;18(1):38–48.
21. Norris RJ, Muirhead JM, Stone HM. An automated blood alcohol analysis system. Rep Chem Div Dept Sci Ind Res 1979;2291:1–65.
22. Forrest ARW. The estimation of Widmark's Factor. J Forensic Sci Soc 1985;26:249–52.
23. Holzbecher MD, Wells AE. Elimination of ethanol in humans. Can Soc Forensic Sci J 1984;17(4):182–96.
24. Jones AW. Interindividual variations in the disposition and metabolism of ethanol in healthy men. Alcohol 1984;1:385–91.
25. Diem K, Lentner C, editors. Scientific Tables, Ciba-Geigy Ltd, Basle 1971;Edition 7:561.
26. Pols RG, Hawks DV. Is there a safe level of daily consumption of alcohol for men and women? National Health and Medical Research Council of Australia Report 1991.
27. Julkunen RJK, Di Padova C, Lieber CS. First pass metabolism of ethanol—a gastrointestinal barrier against the systemic toxicity of ethanol. Life Sci 1985;37(6):567–73.
28. Caballeria J, Frezza M, Hernandez-Munoz R, Di Padova C, Korsten MA, Baraona E, et al. Gastric origin of the first-pass metabolism of ethanol in humans: Effect of gastrectomy. Gastroenterology 1989;97:1205–9.
29. Diem K, Lentner C, editors. Scientific Tables, Ciba-Geigy Ltd, Basle 1971;Edition 7:518.

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