Patrick N. Friel,[1] *B.S.; Barry K. Logan,*[1] *Ph.D.; and John Baer,*[2] *Ph.D.*

An Evaluation of the Reliability of Widmark Calculations Based on Breath Alcohol Measurements

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ABSTRACT: This study evaluated the reliability of Widmark calculations, based on breath ethanol readings (BrACs), for estimating the amount of alcohol consumed. A standard ethanol dose (males 0.51 g/kg; females 0.43 g/kg) was given to 115 college seniors, and BrACs were measured for two hours. Calculations of ethanol dose were performed using BrACs taken at 60, 75, 105, and 125 minutes after drinking. Mean calculated ethanol doses were lower than actual doses at each time point ($P < 0.001$). Mean underestimates were 13, 12, 15, and 14 mL of 100 proof vodka at 60, 70, 105, and 125 min after drinking. Calculated doses overestimated actual doses in 11, 10, 3, and 3 subjects at 60, 75, 105, and 125 min after drinking. The maximum overestimates were 13, 11, 6, and 8 mL of vodka at 60, 75, 105, and 125 min after drinking. At the 95% confidence level, the calculated dose at 105 and 125 min did not overestimate the true dose, but could underestimate it by as much as 30 mL vodka.

KEYWORDS: toxicology, breath alcohol, Widmark calculations

In practice today, most forensic alcohol analyses are conducted by quantitative evidential breath alcohol analyzers [*1*]. Forensic scientists often are asked to estimate the amount of alcohol consumed based on the breath alcohol concentration (BrAC) that is obtained. These calculations are based on Widmark's formula, which relates the amount of alcohol consumed (A) to a subsequent blood alcohol concentration (C), at time t [*2*]. A general form of the equation is:

$$A = r \times p \times (Ct + (\beta \times t)$$

where r is a constant relating ethanol dose and blood alcohol concentration (analogous to the volume of distribution), p is body weight, and β is the zero order elimination rate constant. Using blood alcohol-time data from 30 research subjects, Widmark estimated population mean values for r of 0.68 in 20 men and 0.55 in 10 women; the population mean for β was estimated at .015 g%/h [*2*].

In order to perform a Widmark calculation using a BrAC, one must substitute the BrAC for the blood alcohol concentration (C) in the formula. This substitution inevitably adds to the error inherent in using Widmark's formula, since blood and breath alcohol concentrations agree closely, but not perfectly [*3*]. Additional criticisms of the use of Widmark's formula include the fact that the original estimates of β and r were based on a small sample size, and that the values for β and r vary considerably between individuals [*4*]. The purpose of this study was to assess the reliability of the use BrACs in Widmark's formula, by comparing actual and calculated ethanol doses from a research study involving a large number of subjects.

Methods

The data used in this paper were collected as a part of a study designed to evaluate and follow-up a large sample of college seniors who drink. Subjects entering the study were 21 to 25 years old, and reported a pattern of drinking enough alcohol to reach an estimated blood ethanol level of at least 0.12 g% at least twice a month. Eighty eight percent of the subjects were white. In the initial laboratory phase of the study, subjects (after a four hour fast) were given a standard ethanol dose (males 0.51 g/kg, females 0.43 g/kg ethanol, as 100 proof vodka, diluted 1:5 with carbonated mixer). Subjects were given 10 minutes to drink the alcohol (some subjects finished drinking in less than 10 min). During the lab protocol, subjects were seated alone at a desk with a computer in a small room. They were kept mentally active by computer-based questions, and by performing BrAC tests. Stress stimuli, consisting of the anticipation (via auditory tone) and experience of mild electric shocks, were administered at intervals during the laboratory. BrAC readings were collected at approximately 15, 30, 45, 60, and 75 minutes after the start of drinking. Additional readings were taken if needed at 105 and 125 minutes and continued at intervals until the BrAC was 0.03 g/210L, when the subjects were discharged from the laboratory. Duplicate readings were collected for each of the 15 to 75 min samples; thereafter only single BrAC readings were available for most subjects.

BrACs were collected using the BAC Verifier Datamaster II (National Patent Analytical Systems Inc., Mansfield, Ohio), which was calibrated before the study using an alcohol-water simulator solution providing vapor ethanol concentration of 0.10 g/210L at 34°C. Imprecision of $\leq 3\%$, and inaccuracy of $\leq 5\%$ were verified in a routine quality assurance procedure prior to the study.

This study was conducted with the data from the first 125 subjects to complete the study. Ten subjects were excluded because of incomplete data (mainly lack of duplicate BrACs), leaving 115 subjects (61 males, 54 females). Widmark calculations were performed using the equation given in the introduction, as

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[1] Washington State Toxicology Laboratory Seattle, WA.

[2] Dept. Psychology, College of Arts and Sciences, University of Washington, Seattle, WA.

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described by Winek and Esposito [5]. Widmark's mean values for β (0.015 g%/h) and r (0.68 for males, 0.55 females) were used in each calculation [2]. BrACs collected at 60, 75, 105, and 125 minutes after the start of drinking were used for the calculations. BrACs in g/210L were used uncorrected, as estimates of blood alcohol in g%. Exact dosing and sampling times, recorded in minutes for each subject during the study, were used in the calculations. Statistical analyses included paired t-test, linear regression (of duplicate BrACs) and calculation of the 95% limits of agreement [6].

Results

Figure 1 shows a BrAC-Time profile for subject #179. This example was chosen because it shows the rapid ethanol absorption, and distinct absorption and elimination phases typically seen in this study. The mean peak BrAC in the study was 0.06 g/210L (range 0.04 to 0.13 g/210L). The mean times to peak BrAC (measured from the start of drinking) were 39 min (range 10 to 91 min) for males and 39 min (range 8 to 75 min) for females. 89% of subjects had reached their peak BrAC by 60 min after the start of drinking. In 7/115 subjects, a distributive or "diffusion plunge" phase was also noted in the BrAC-Time profile. In these cases, ethanol absorption was very rapid, and BrAC values exceeded the β-elimination line during the first 30 minutes of measurement, while equilibration between blood and tissues was taking place [7]. Duplicate BrAC values were in close agreement when available (60 and 75 minutes from the start of drinking). Correlation coefficients between first and second BrAC were 0.96 and 0.95, and standard error of estimates 0.0025 and 0.0023 g/210L; slopes of plots comparing duplicates were not significantly different from unity at the 0.05 significance level.

As shown in Table 1, mean calculated doses underestimated mean actual doses by 13, 12, 15, and 14 mL of 100 proof vodka, at 60, 75, 105, and 125 min. Analysis by paired t-test indicated that the mean actual dose was significantly higher than the mean calculated dose at each time point ($P < 0.001$). Calculated doses overestimated actual doses in 11 cases when 60 min post-drinking BrACs were used, 10 cases when 75 min. BrACs were used, and in three cases when 105 min and 125 min BrAC's were used. Maximum overestimates varied from 6 to 13 mL vodka. 95% limits of agreement between actual and calculated vodka doses are given in Table 1 [6]. Figure 2 shows the scatter plots for the actual vs. calculated vodka doses at each time period.

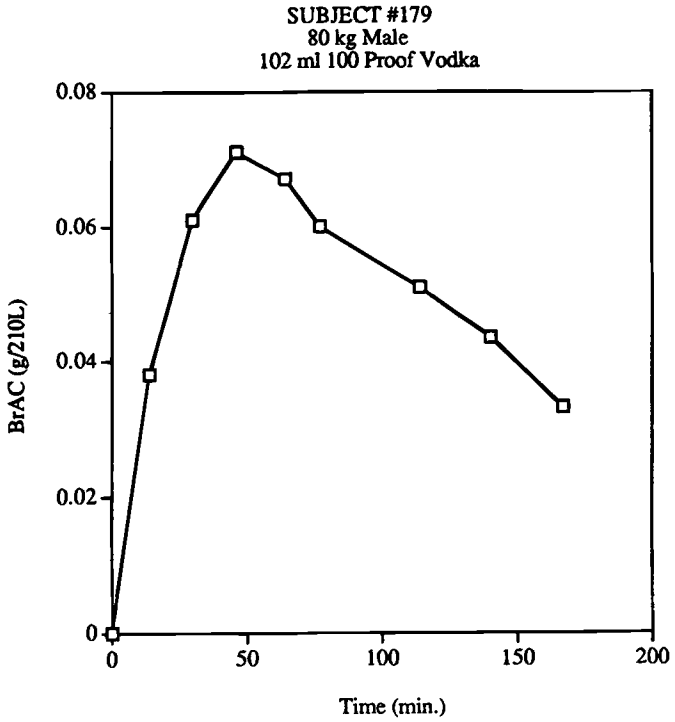

FIG. 1—*BrAC-time profile for one study subject.*

Discussion

Estimation of the amount of ethanol ingested has been an important part of drinking and driving trials since Widmark's time [2]. This study was conducted to determine the reliability of Widmark calculations when BrACs are substituted for blood alcohol concentrations. We evaluated the calculations under optimal conditions, with accurate measurements of body weights, time intervals, and BrACs. Intersubject variability and/or bias in β and r (compared to the values derived by Widmark, which were used in these calculations) could result in differences between actual and calculated ethanol doses. In addition, inaccuracy and/or bias in BrACs, as estimates of blood alcohol concentrations, could contribute to discrepancies between actual and calculated doses.

Statistical analysis showed that in most cases, calculated doses underestimated actual doses (Fig. 2). Overestimates occurred in 10%, 9%, 3%, and 4% of cases at 60, 75, 105, and 125 min post-drinking, respectively.

Table 1 gives the 95% limits of agreement for calculated vodka dose, in relationship to the actual dose. The upper limits of agreement cluster together in a range of 27 to 33 mL. This indicates that the upper edges of the 95% limits of agreement are similar at each time point, corresponding to an underestimate of ~30 mL vodka. The lower edges of the 95% limits of agreement, however, vary with sampling time. The lower limit of −7 mL at 60 and 75 min indicates that the calculated dose may exceed the actual dose by up to 7 mL, and remain within the 95% limits. In contrast, the lower limit of 1 mL at 105 and 125 min indicates that all calculated vodka doses falling within the 95% limits of agreement will be underestimates. In a similar study using blood alcohol data from 22 males to estimate ethanol dose, Wagner et al. found that the two-hour samples gave the best estimates of dose [8].

There are several explanations for the fact that our calculations usually underestimated the true alcohol dose. If the breath alcohol readings in this study underestimated blood alcohol concentration, this would cause a low bias in estimated ethanol dose. Under certain conditions, BrACs measured in g/210L may indeed slightly underestimate blood alcohol concentration, measured in g% [3]. Reduced bioavailability of ethanol, due to the stress procedures used in the study, or first pass metabolism [9], could be a contributing factor. Another possible explanation for the underestimation of dose would be a systematic difference in β and/or r values in this group, compared to the values from Widmark [2] used in the calculations. For example, this group of young adult drinkers may well have a β value greater than 0.015 g%/h [7]. Further study will be needed to test this hypothesis.

Several factors may have contributed to the small number of overestimates seen in this study. Arterial-venous differences in ethanol concentrations during absorption can result in relatively higher BrAC values during the first 60 minutes after drinking, although this effect is most pronounced when BrAC is rising [3].

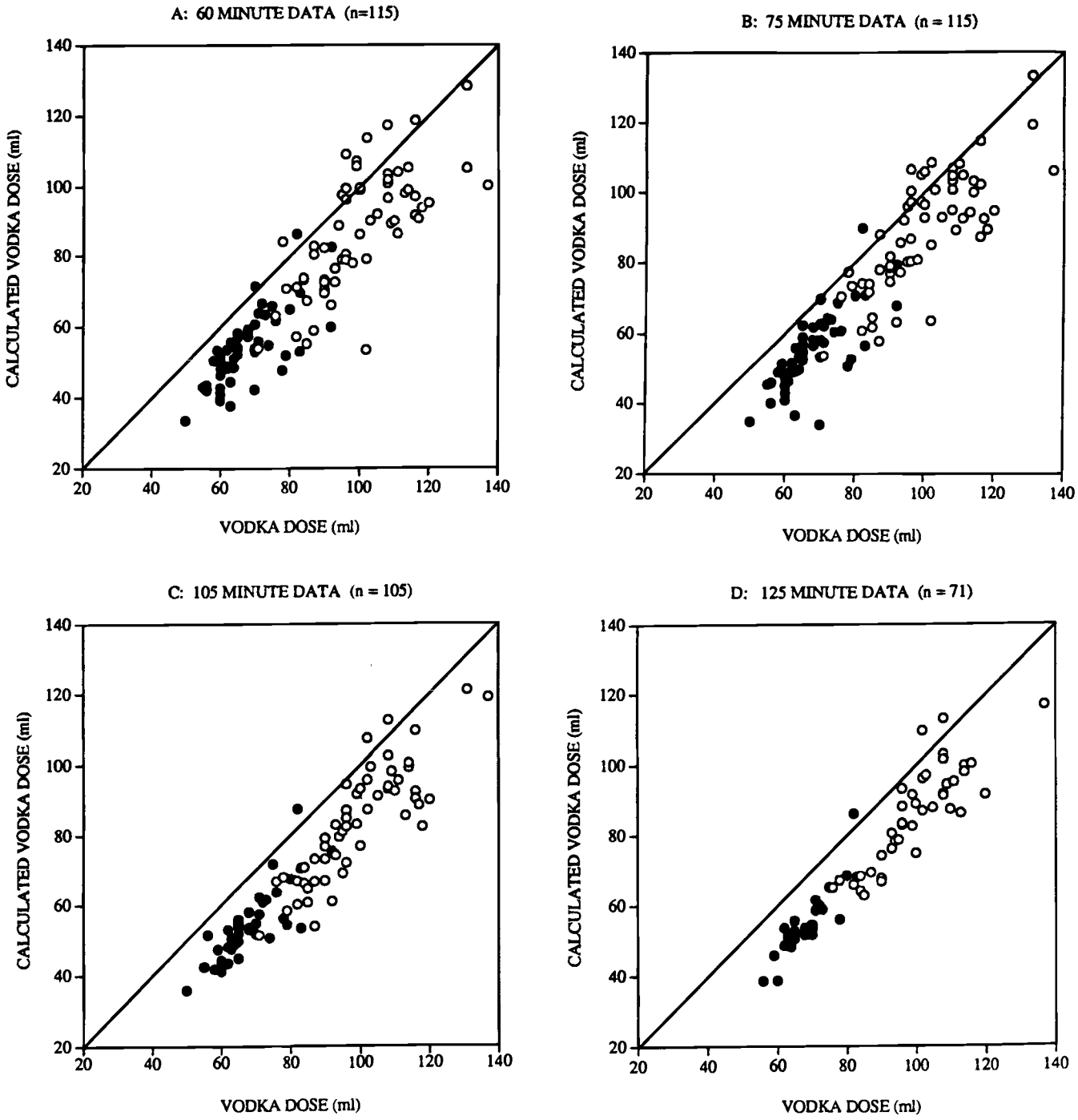

FIG. 2—*Comparisons of actual and calculated vodka doses at various times after drinking. Open circles represent data for males; closed circles represent data for females. Equal values for actual and calculated doses are indicated by the diagonal lines. Points above the line are overestimates; points below the line are underestimates.*

Also, some subjects may have had lower r values than those used in the calculations.

Several caveats concerning the results of this study are in order. First, we studied a relatively homogeneous subject sample of healthy young adults, who drink regularly, at relatively low bolus ethanol doses and BrACs. Our results can only be extrapolated safely to similar individuals. Further studies of other populations, and at higher ethanol doses, are warranted. It would also be of interest to conduct a similar study incorporating a measure of lean body mass, such as height, into the Widmark calculation [*10*]. Finally, this study was performed under optimal conditions, with accurate measures of body weight, time intervals, and BrACs. Uncertainty in body weight or time intervals, or inaccurate BrAC's will clearly reduce the accuracy of dose estimates.

This study shows that under the conditions described above, Widmark's formula usually underestimates the actual ethanol dose, when BrAC's are employed. When 105 min and 125 min BrACs are used, the 95% confidence limits for calculated vodka dose

TABLE 1—*Comparison of actual and calculated 100 proof vodka doses.*

Time of BrAC Used for Calculation[a]	*n*	Mean actual dose (mL)	Mean calculated dose (mL)	95% limits of agreement actual − calculated (mL)	Number of overestimates/ total	Maximum overestimate (mL)
60 minutes (duplicate tests)	115	84.5	71.5	−7 − 33	11/115	13
75 minutes (duplicate tests)	115	84.5	72.8	−7 − 29	10/115	11
105 minutes (single tests)	105	84.3	69.1	1 − 30	3/105	6
125 minutes (single tests)	71	86.6	72.6	1 − 27	3/71	8

[a]Time from start of drinking; maximum drinking time 10 minutes.

were from 1 to 30 mL below the actual dose. Thus, one can state with a high level of confidence that the calculated dose at these times does not overestimate the true dose, and may in fact underestimate it by as much as 30 mL vodka.

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Address requests for reprints or additional information to
Patrick N. Friel
Washington State Toxicology Laboratory
Park 90/5, Suite 360
2203 Airport Way South
Seattle, WA 98134