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Variability of the Blood/Breath Alcohol Ratio in Drinking Drivers

REFERENCE: Jones AW, Andersson L. Variability of the blood/breath alcohol ratio in drinking drivers. J Forensic Sci 1996; 41(6):916–921.

ABSTRACT: The ratio of blood-alcohol concentration (BAC) to breath-alcohol concentration (BrAC) was determined for 799 individuals apprehended for driving under the influence of alcohol (DUI) in Sweden. The BrAC was determined with an infrared analyzer (Intoxilyzer 5000S) and venous BAC was measured by headspace gas chromatography. The blood samples were always taken after the breath tests were made and the average time delay was 30 ± 12 min (± SD), spanning from 6 to 60 min. The blood/breath ratios of alcohol decreased as the time between sampling blood and breath increased ($F = 15.4$, $p < 0.001$), being 2337 ± 183 (6 to 15 min), 2302 ± 202 (16 to 30 min), 2226 ± 229 (31 to 45 min), and 2170 ± 225 (46 to 60 min). When the BAC was corrected for the metabolism of alcohol at a rate of 0.019 g%/h, the mean blood/breath ratios were 2395 ± 193 (6 to 15 min), 2416 ± 211 (16 to 30 min), 2406 ± 223 (31 to 45 min), and 2407 ± 210 (45 to 60 min); no significant differences ($F = 0.197$, $p > 0.05$). The overall mean time-adjusted blood/breath ratio (± SD) was 2407 ± 213 and the 95% limits of agreement (LOA) were 1981 and 2833. During 1992, 1993, and 1994, the mean blood/breath ratios of alcohol were remarkably constant, being 2409 ± 288, 2407 ± 206, and 2421 ± 235, respectively, and the values were not significantly influenced by the person's age, gender, or blood-alcohol content. In 34 individuals (4.3%), the blood/breath ratio was less than 2100 after compensating for metabolism of alcohol between the times of sampling blood and breath. This compares with 156 individuals (19.6%) having a blood/breath ratio less than 2100:1 without making any correction for the metabolism of alcohol.

KEYWORDS: forensic science, forensic toxicology age, alcohol, analysis, blood analysis, breath analysis, blood/breath ratio, drunk drivers, variability

Quality assurance of evidential breath-alcohol testing in Sweden requires, among other things that two separate and consecutive breath samples are analyzed from each suspect (1). If the results of the two tests agree within certain predefined tolerance limits, the average value is used for prosecuting drunk drivers after making a deduction to allow for uncertainty in the measurement process (1). However, it sometimes happens that DUI suspects refuse to provide a second sample of breath, or they might be incapable of blowing for sufficiently long enough to satisfy the sampling parameters of the instrument. When this happens, specimens of venous blood are taken instead, and the concentrations of ethanol are determined by headspace gas chromatography (2). Accordingly, the result of a single evidential breath-alcohol test as well as the concentration of alcohol in venous blood were available for several hundred drinking drivers. This gave us the opportunity to investigate the relationship between blood- and breath-alcohol and its variability under operational field conditions. Surprisingly, few large scale studies of the blood/breath ratio have been made in actual drinking drivers with the results published in a peer-reviewed journal.

We present a statistical analysis of BAC/BrAC ratios in 799 drinking drivers when modern analytical technology was used for measuring the concentration of alcohol in blood and breath samples. The results were evaluated as a function of the person's age, gender, BAC, and the time interval between sampling blood and breath.

Material and Methods

Breath-alcohol analysis for evidential purposes was introduced in Sweden in 1989 and began on a relatively small scale. The system became fully operational by February 1991 and about 160 instruments (Intoxilyzer 5000S) are currently being used by the police for traffic law enforcement. The Intoxilyzer 5000S operates on the principle of infrared spectrometry by monitoring the absorption of radiation at three wavelengths (3.39, 3.48, and 3.80 μm). The results of breath-alcohol testing are reported in units of milligram alcohol per litre of breath (mg/L). A two-tier statutory BrAC limit exists in Sweden at 0.10 and 0.50 mg/L that corresponds to 0.021 g/210 L and 0.105 g/210 L expressed in the concentration units used in US. The corresponding statutory limits of BAC in Sweden are fixed at 0.20 mg/g blood (0.021 g/100 mL) and 1.00 mg/g (0.105 g/100 mL). This implies that a 2100:1 blood-to-breath relationship was endorsed to set the statutory BrAC limits. The history of developments in blood- and breath-alcohol testing for legal purposes in Sweden was recently reviewed (1).

On 799 occasions between 1992 to 1994, the result of a single evidential breath test and venous blood-alcohol concentration were available from drinking drivers. Although each suspect managed to blow once into the Intoxilyzer for the minimum time of 6 s, the evidential test was aborted for various other reasons. Whenever this happened, prosecution for DUI was based on the person's BAC and a sample of venous blood was taken between 6 to 60 min (mean 30 min) after the single exhalation breath-alcohol test.

Samples of venous blood for forensic alcohol analysis are taken with the aid of Vacutainer tubes containing NaF (100 mg) and potassium oxalate (20 mg) (Becton Dickenson, Rutherford, New Jersey), and two of these tubes are filled in rapid succession. The concentration of alcohol in blood was determined by headspace gas chromatography as described in detail elsewhere (2). The mean

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Presented at the 48th Annual Meeting of the American Academy of Forensic Sciences, Nashville, 19–24 Feb. 1996.
Received for publication 22 Jan. 1996; revised manuscript received 1 April 1996; accepted for publication 3 April 1996.

of a triplicate determination was used for calculating blood/breath ratios of alcohol without making any deduction for uncertainty in the method. Furthermore, because the BAC for forensic purposes is reported in mass/mass units (milligram alcohol per gram whole blood), these values were converted into milligram/millilitre by multiplying by 1.055, the average density of whole blood. Finally, the blood/breath ratios were calculated with and without adjusting the BAC values for metabolism of alcohol between the times of sampling blood and breath. The mean rate of alcohol disappearance from blood was 0.19 mg/mL/h (0.019 g/100 mL/h) or 0.0031 mg/mL/min for DUI subjects apprehended in Sweden (3).

Conventional parametric statistical methods were used to evaluate the results of this study including calculation of mean, standard deviation, coefficient of variation, and 95% limits of agreement (LOA) (4). This latter statistic was calculated as mean ± (2 × SD) assuming a normal distribution of values. The relationship between blood and breath alcohol was evaluated by correlation-regression analysis and the difference between groups was assessed by analysis of variance. Six blood-breath pairs were omitted from the statistical analysis because they were obviously outliers. These individual cases either involved instances of very low BAC or interfering substances were present, and this was confirmed by GC analysis of blood samples (5).

Results

Table 1 presents the mean blood and breath alcohol concentration for the whole material of 793 apprehended drivers during the years 1992, 1993, and 1994. The values remained remarkably constant and indicate that DUI suspects in Sweden consume large amounts of alcohol before driving on the highway. Some of the DUI suspects might have been unable to provide a second sample of breath because of their state of pronounced inebriation. Indeed, a failure to provide an appropriate sample of breath for analysis (minimum exhalation time 6 s) was much more frequent in women compared with men as well as in elder individuals compared with younger ones. These trends are well illustrated in Fig. 1.

Figure 2 shows a scatter plot of individual blood/breath ratios as a function of the time between sampling blood and breath. However, the influence of time on blood/breath ratios can be seen more clearly if the results are averaged and subdivided into four groups depending on the time lapse; 6 to 14, 15 to 29, 30 to 44, and 45 to 60 min. The ratios decreased with time from 2337 (6 to 14 min) to 2170 (45 to 60 min), and this trend was statistically highly significant ($F = 15.4, p < 0.001$). Table 2 also shows that when time-corrected BAC values were used to calculate blood/breath ratios, the values no longer decreased with increasing time between taking the samples of blood and breath ($F = 0.197$, $p > 0.05$).

Frequency distributions of nonadjusted and time-adjusted blood/breath ratios are shown in Fig. 3. These distributions demonstrate a shift in the mean blood/breath ratio towards higher values for the time-adjusted blood/breath ratios. Only 34 individuals (4.3%) had a blood/breath ratio less than 2100 when the metabolism of alcohol was taken into account. This compares with 156 individuals (19.6%) before adjusting the BAC values for metabolism of alcohol.

TABLE 1—*Mean blood-alcohol (BAC g/100 mL) and breath-alcohol concentrations (BrAC mg/L and g/210 L) in drinking drivers apprehended in Sweden between 1992 and 1994.*

Year	Number of Specimens	BAC ± SD, g/100 mL	BrAC ± SD, mg/L	BrAC ± SD, g/210 L
1992	250	0.209 ± 0.83	0.93 ± 0.37	0.195 ± 0.077
1993	297	0.201 ± 0.82	0.89 ± 0.36	0.187 ± 0.075
1994	252	0.193 ± 0.87	0.84 ± 0.37	0.176 ± 0.077

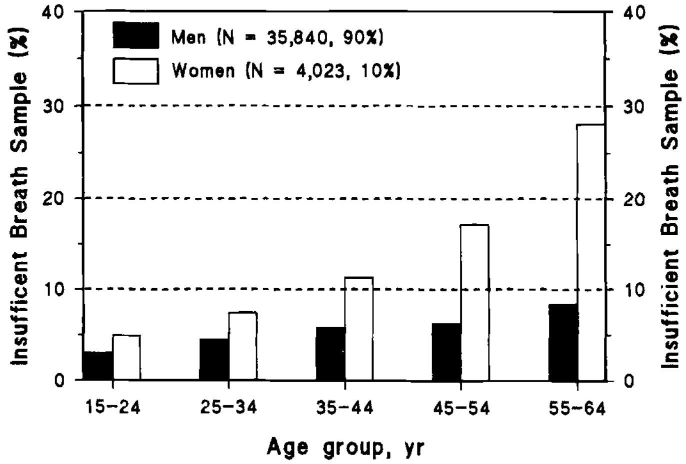

FIG. 1—*Percentage of men and women within various age groups who failed to exhale for the minimum time of 6 s during evidential breath testing with the Intoxilyzer 5000S. For the age groups, 15–24 years (6892 ♂ 677 ♀), 25–34 years (9543 ♂ 1082 ♀), 35–44 years (8837 ♂ 1172 ♀), 45–54 years (7624 ♂ 839 ♀), and 55–64 years (2943 ♂ 253 ♀).*

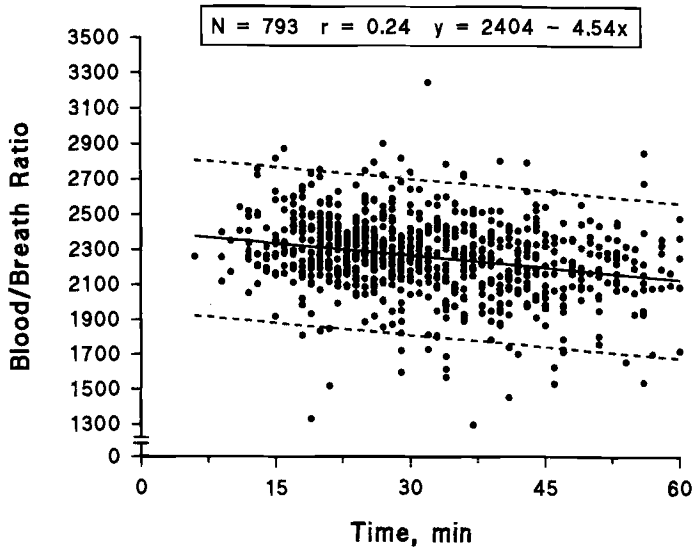

FIG. 2—*Relationship between blood/breath ratio of alcohol and the time lag between obtaining the blood after completion of the Intoxilyzer 5000S breath test.*

The mean blood/breath ratios, standard deviations, and 95% limits of agreed showed excellent agreement for data collected during 1992, 1993, and 1994 (Table 3). This held for the time-adjusted and nonadjusted values ($p > 0.05$). The results in Table 4 indicate that blood/breath ratios for male and female DUI suspects were not significantly different ($t = 0.36$, d.f. = 406, $p > 0.05$).

Figure 4 presents a conventional blood/breath scatter plot demonstrating a high correlation between blood-alcohol and breath-alcohol concentrations ($r = 0.98$). The regression equation was y (BrAC) = $-0.002 + 0.89x$ (BAC), which implies that the breath-alcohol readings (g/210 L) are on the average about 10% less than

TABLE 2—*Variation in the mean blood/breath ratios of alcohol as a function of time between sampling blood and breath. The breath-alcohol tests were always made before the blood samples were drawn.*

Time min	Number of Specimens	Blood/breath Ratio Mean ± SD	CV%	95% Limits of Agreement
6–14	46	2337 ± 183†	7.9	1971–2703
		2395 ± 193*	9.1	2085–2890
15–29	360	2302 ± 202†	8.8	1898–2706
		2416 ± 211*	8.7	1354–3507
30–44	276	2226 ± 229†	10.3	1768–2684
		2406 ± 223*	9.3	1563–3512
45–60	111	2170 ± 225†	10.3	1720–2620
		2407 ± 210*	8.7	1799–3051
6–60	793	2259 ± 220†	9.7	1820–2700
		2407 ± 214*	9.0	1354–3512

*Values adjusted for the time between sampling blood and breath by increasing BAC by 0.019 g/100 mL/h,† the differences between the means were not statistically significant (F = 0.197, $p > 0.05$).† Differences between the means were statistically highly significant (F = 15.4, $p < 0.001$).

the corresponding BAC measurements (g/100 mL). Figure 5 shows another kind of scatter diagram making it easier to compare variability in the blood/breath ratio as a function of BAC. The results are summarized in Table 5 showing that the blood/breath ratios decreased slightly with increasing BAC, being 2596 ± 271 (± SD, N = 51) for BAC 0–0.049 g% and 2386 ± 172 (± SD, N = 475) above a BAC of 0.20 g% (t = 7.75, d.f. = 524, $p < 0.001$).

Discussion

Most studies of the relationship between BAC and BrAC have involved the use of healthy volunteers after they ingest known moderate mounts of alcohol under controlled laboratory conditions (6–10). This kind of experimental design allows making comparisons between the concentration of alcohol in end-expired breath and venous blood at exactly timed intervals so that blood/breath ratios during the absorption, the distribution, and the elimination stages of alcohol metabolism can be evaluated (6). However, controlled laboratory studies have obvious limitations if the mean and variability of BAC/BrAC ratios in drinking drivers are of primary interest.

First and foremost, the range of blood-alcohol concentration encountered in laboratory studies rarely exceeds 0.10 g/100 mL because of undesirable impairment effects caused by ingestion of the alcohol needed to reach this concentration. The second limitation with laboratory studies is that the test subjects are usually healthy paid volunteers, often young university students who are highly motivated to provide end-expired samples of breath for determination of alcohol.

Indeed, very few papers have dealt with blood/breath ratios of alcohol in DUI suspects, especially with modern analytical technology being used for measuring alcohol in the blood and breath samples. This might seem surprising considering the long-standing discussion and debate about variability in blood/breath ratios and whether or not breath-alcohol tests overestimate or underestimate a person's venous BAC. Indeed, interest in blood/breath ratios is rapidly decreasing because the statutory alcohol limits for driving are presently defined in terms of a person's breath-alcohol concentration, such as 0.08 or 0.10 g/210 L.

The 2100:1 blood/breath factor has its roots in studies done

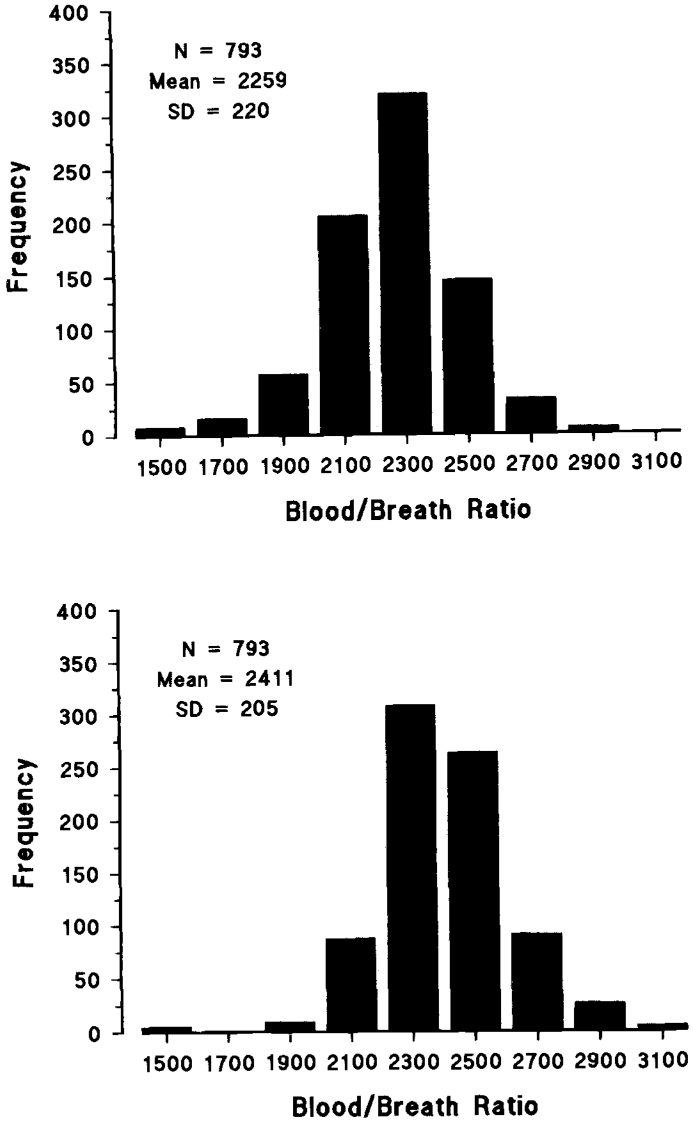

FIG. 3—*Frequency distribution of blood/breath ratios of ethanol in drinking drivers in Sweden. The upper plot shows the results without making an adjustment for metabolism of alcohol and the lower plot after adjusting for metabolism of alcohol (0.019 g%/h) between the times of sampling blood and breath.*

TABLE 3—*Blood/breath ratios of alcohol between 1992 and 1994 when the breath alcohol was determined with Intoxilyzer 5000S and venous blood alcohol by headspace gas chromatography. The mean time between sampling blood and breath was 30 min (range 5 to 60 min).*

Year	Number of Specimens	Blood/Breath Ratio Mean ± SD	95% Limits of Agreement
1992	250	2264 ± 255	1754–2774
		2409 ± 288*	1833–2985
1993	297	2243 ± 245	1753–2753
		2407 ± 206*	1995–2819
1994	251	2254 ± 259	1736–2772
		2421 ± 235*	1951–2891

*Values adjusted for metabolism of alcohol between the time of sampling blood and breath at a rate of 0.019 g/100 mL/h.

TABLE 4—*Comparison of blood/breath ratios of alcohol in men and women apprehended for DUI in Sweden.*

Parameter	Men (N = 369)	Women (N = 39)
Age, years	40 ± 13	45 ± 11
BrAC, g/210 L	0.178 ± 0.073	0.147 ± 0.079
BAC, g/100 mL	0.184 ± 0.078	0.151 ± 0.086
BAC/BrAC ratio*	2428 ± 261†	2444 ± 232†

*Adjusted for time between sampling blood and breath.
†No statistically significant difference (t = 0.36, d.f. = 406, p > 0.05).

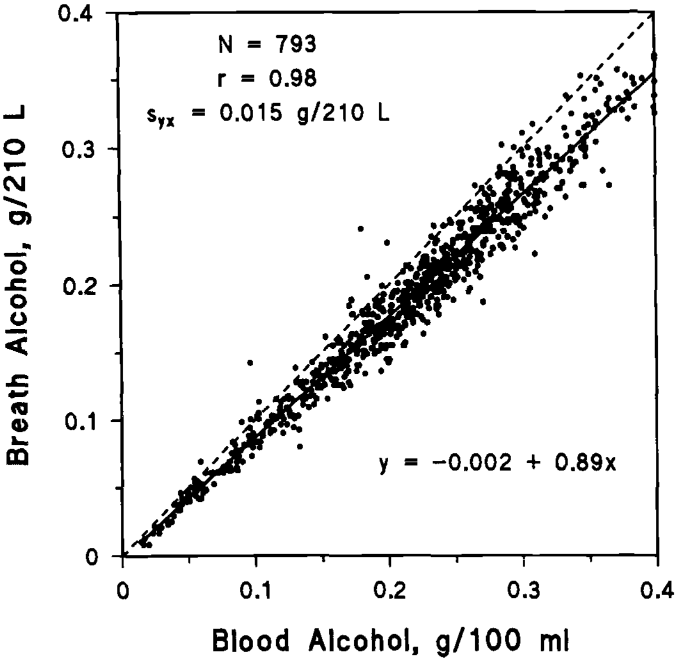

FIG. 4—*Conventional blood-breath scatter plots for apprehended drinking drivers in Sweden.* N = *number of blood/breath pairs,* r = *correlation coefficient,* S_{yx} = *standard error estimate, and* y = −*0.002* + *0.89*x *is the regression equation for the plot.*

with the first generation of breath-alcohol instruments (the Drunkometer, the Intoximeter, and the Alcometer) and also with the classic Breathalyzer device. These breath-alcohol analyzers were initially intended and used to estimate a DUI suspect's blood-alcohol concentration, and inherent variations in the breath to blood conversion factor was not seriously considered. On the other hand, illegal per se laws did not exist in US at the time, and the threshold BAC for prosecution was set at 0.15 g/100 mL in most states. Support for the continued use of a 2100:1 ratio came from several meetings of experts on the subject of breath-alcohol testing (11,12). Later studies indicated that the value of the blood/breath ratio of alcohol necessary to obtain an unbiased estimate of venous BAC in the post-absorptive phase of alcohol metabolism was higher than 2100:1, being closer to 2300:1 or more (7,9). Accordingly, because the statutory BrAC was set at 0.10 g/210 L instead of 0.10 g/230 L, this gives a roughly 10% advantage to the DUI suspect who undergoes an evidential breath test compared with the individual prosecuted on the result of blood-alcohol analysis.

One of the most widely cited laboratory studies of the blood-breath ratio of alcohol appeared in a brief report by Dubowski and O'Neill (8). Based on N = 393 blood-breath pairs, they reported a mean value of 2288 ± 242 (± SD) for healthy male volunteers

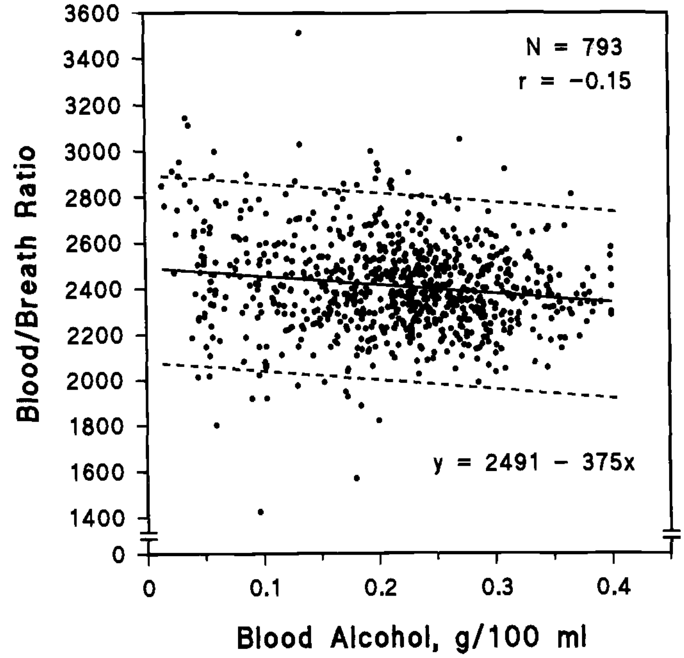

FIG. 5—*Relationship between blood/breath ratio and blood-alcohol concentration.* N = *number of blood/breath pairs,* r = *correlation coefficient, and* y = *2491–375*x *is the regression equation for the plot.*

TABLE 5—*Blood/breath ratios of alcohol as a function of blood-alcohol concentration (BAC).*

Span of BAC, g/100 mL	Number of Specimens	Blood/Breath Ratio Mean ± SD
0.00–0.049	50	1975 ± 353
	31	2596 ± 271*
0.05–0.099	59	2148 ± 251
	64	2433 ± 275*
0.10–0.149	85	2234 ± 224
	76	2428 ± 245*
0.15–0.199	154	2275 ± 219
	144	2401 ± 144*
>0.20	444	2305 ± 161
	475	2386 ± 172*
0.00–0.40	793	2259 ± 220
	793	2411 ± 205*

*Values adjusted for the time between sampling blood and breath at a rate of 0.019 g/100 mL/h. For nonadjusted values, the difference between means was statistically highly significant, F = 34.0, p < 0.001. For adjusted values, the differences between the means was also statistically significant, F = 8.5, p < 0.001.

when end-expiratory breath and venous blood were obtained during the postabsorptive phase of metabolism. The Intoxilyzer 4011, a single wavelength infrared analyzer was used to measure breath-alcohol concentration, and venous blood-alcohol was determined by headspace gas chromatography. With more modern breath test instruments, such as Intoxilyzer 5000, the average blood/breath ratios of alcohol seem to be higher than 2280:1, being closer to 2400:1, and depend on a host of variable factors including the reliability of the methods of alcohol analysis, the person's BAC, and the phase of alcohol metabolism when samples were obtained (7,13–15). The blood-breath ratio is a moving target, and the notion of a constant value for all subjects under all conditions is imaginary (16). Although statutory limits of alcohol concentration are now defined in terms of BrAC, interest in the blood/breath ratio of alcohol and its variability still exist in some quarters. When breath-test devices are used in clinical medicine, the purpose is to estimate a person's coexisting BAC and the alcohol load in the body. The magnitude of variation in the blood/breath ratio between subjects, and from time to time within the same subject, is important to document whenever BAC is estimated indirectly by analyzing the breath (16).

Many variable factors should be considered when blood/breath ratios of alcohol are calculated and compared in different studies including both analytical and physiological sources of variation (17). The existence of arteriovenous differences in the concentration of alcohol during the absorption phase influences the resulting blood-breath ratio of alcohol (18). The concentration of alcohol in blood, the kind of breath-alcohol analyzer used, and its calibration as well as the breath-sampling parameters, resistance to exhalation, and the design of the mouth-piece and breath inlet tube are important considerations that might explain discrepancies in the results. Note that even when blood/air ratios of alcohol were determined under in vitro conditions, that is, with a series of blood samples drawn at 30 to 60 min intervals from the same person and allowed to reach equilibrium at 37°C, the results obtained varied from blood sample to blood sample depending on the precision of equilibrium temperature control, the procedures used for sampling headspace vapor, and analysis of alcohol.[3]

In the present work, we have assumed that all DUI suspects are in the postpeak phase of metabolism and that alcohol is being eliminated at a rate of 0.019 g%/h. The assumption of a postpeak phase is not unreasonable considering that evidential breath tests are usually made on the average 65 min after arrest and probably even longer after the end of drinking. This appears to be ample time for absorption of the last drink and for the vast majority of DUI suspects to reach the postpeak phase of alcohol kinetics. The assumption of an alcohol burn-off rate of 0.019 g%/h is supported by evaluating double blood samples in over 1000 drinking drivers (3). The mean β-slope was 0.019 g%/h and the 95% limits of agreement spanned from 0.009–0.029 mg/mL/h (3).

When European countries enacted statutory limits of BrAC for driving, there was no general consensus about the mean blood/breath ratio to use. Great Britain and the Netherlands opted for 2300:1 so that 80 mg/100mL in blood became 35-μg per 100-mL breath (Great Britain), and 0.50 mg/mL blood (the Netherlands) became 220-μg/L breath. In the Scandinavian countries, a blood/breath factor of 2100:1 was chosen so that a BAC of 0.20 mg/g (0.21 mg/mL) became 0.10 mg/L in breath (Sweden), and 0.50, mg/g (0.53 mg/mL) in blood became 0.25 mg/L (Norway and Finland). In Austria and France, the blood/breath ratio was taken as 2000:1 so that the pre-existing threshold BAC of 0.80 mg/mL became 0.40 mg/L in breath. The motivation for assuming these different blood/breath ratios of alcohol has not been explained in a satisfactory way.

The most extensive study of the blood/breath ratio of alcohol in drinking drivers was sponsored by the British Government and the results of this work were published in 1985 (19). Breath-alcohol concentrations were determined with an infrared analyzer (Intoximeter 3000) and venous blood alcohol was determined by gas chromatography. Several thousand DUI suspects were tested, and in 815 cases, the specimens of blood and breath were obtained within 10 min of each other. The frequency distribution of the blood/breath ratios was skewed to the right with a modal value between 2300 and 2399. We calculated from this distribution that the arithmetic mean was 2449 ± 231 (± SD) and the coefficient of variation was 9.4%. Four DUI suspects had blood/breath ratios between 1900 and 1999, and in 14 others, the values exceeded 3100. The results of this British study are unfortunately biased because the BAC values used to calculate individual blood/breath ratios were so called "certificate values," that is, the mean analytical result after making a deduction of 6% to allow for measurement uncertainty. Furthermore, the lowest result in two consecutive breath tests was used in the denominator of the ratio. Because many of the duplicate breath-alcohol results were identical and the BAC was always lowered by 6%, the blood/breath ratios are biased towards low values. Accordingly, a direct comparison between this British study and the mean and variability of 2407 ± 213 (CV = 8.8%) and 95% LOA of 1981–2833 in our Swedish study deserves caution. Because the mean blood/breath ratios remained fairly constant over a three-year period in our study (Table 3) this tends to support the validity of the results obtained.

The Intoxilyzer 5000S presently used for forensic purposes in Sweden has also been tested in a controlled laboratory study with healthy volunteers (7). Under these conditions, the mean blood/breath ratio was 2599:1, being much higher than the average value of 2407 in DUI suspects. Although the same methods of alcohol analysis were used, the average BAC in the healthy volunteers was only 0.07 g/100 mL compared with 0.19 g/100 mL in the DUI suspects in this study. As shown here (Table 5) and elsewhere, higher blood/breath ratios are associated with lower BAC, so it is not easy to compare results from laboratory results with results from actual DUI suspects. We found no significant differences between blood/breath ratios of alcohol for male and female DUI suspects confirming an earlier investigation under controlled laboratory conditions (20).

The introduction of evidential breath-alcohol analyzers in Europe has meant that prosecution for DUI can now be based on the person's BAC or BrAC depending on the sample taken. Under some circumstances, the option to provide a breath-alcohol test is not available, e.g., if a person is involved in an accident and needs treatment at a hospital, or when a breath analyzer is not available for use, or for various other reasons. This creates a dilemma for those close to a critical legal alcohol limit because of the roughly 10% advantage obtained by those who were tested on a breath-alcohol analyzer (Fig. 4) compared with analysis of venous blood. The consequences for the individual might be guilty or not guilty depending on whether a breath-alcohol or blood-alcohol test was used for forensic purposes.

[3]Jones AW: Professor, Department of Forensic Toxicology, National Laboratory of Forensic Chemistry, University Hospital, Sweden unpublished work, 1995.

References

(1) Jones AW, Andersson L, Kopp I. Enforcement of drunk driving laws in Sweden with blood and breath alcohol concentrations as evidence for prosecution. Krimin. Forensic, Wissen 1994;82:11–26.

(2) Jones AW, Schuberth J. Computer-aided headspace gas chromatography applied to blood-alcohol analysis; Importance of on-line process control. J Forensic Sci 1989;34:1116–27.

(3) Jones AW. Elimination rate of alcohol from blood and variability in blood/breath ratios of alcohol in drinking drivers. Paper presented at 48th Annual Meeting of the American Academy of Forensic Sciences, Nashville, 1996.

(4) Bland M, Altman DG. Statistical methods for assessing agreement between two methods of clinical measurement. Lancet i 1986;307–10.

(5) Jones AW, Lund M, Andersson E. Drinking drivers in Sweden who consume denatured alcohol preparations; An analytical toxicological study. J Anal Toxicol 1989;13:199–203.

(6) Jones AW. Variability of the blood:breath alcohol ratio in vivo. J Stud Alcohol 1978;39:1931–9.
(7) Jones AW, Beylich KM, Bjorneboe A, Ingum J, Morland J. Measuring ethanol in blood and breath for legal purposes—variability between laboratories and between breath-test instruments. Clin Chem 1992;38:743–7.
(8) Dubowski KM, O'Neill B. The blood/breath ratio of ethanol. Clin Chem 1979;25:11–4.
(9) Jones AW. Electrochemical measurement of breath-alcohol concentration; precision and accuracy in relation to blood levels. Clin Chim Acta 1985;146:175–83.
(10) Gullberg RG. Statistical Evaluation and reporting of blood alcohol/ breath ratio distribution data. J Anal Toxicol 1991;15:343–4.
(11) Friedemann TE, Jetter WW, Muehlberger CW, Carlson AI. Evaluating chemical tests for intoxication. Committee on Tests for Intoxication, National Safety Council, Chicago, IL. 1952.
(12) Statement on the blood/breath ratio of alcohol by an ad hoc Committee of the US National Safety Council, Indianapolis, IN. 1972.
(13) Dubowski KM. Recent developments in alcohol analysis. Alcohol Drugs Driving 1986;2:13–46.
(14) Gullberg RG. An application of probability theory to a group of breath alcohol and blood-alcohol data. J Forensic Sci 1990; 35:1342–52.
(15) Harding PM, Laessig RH, Field PH. Field performance of the Intoxilyzer 5000: a comparison of blood, and breath-alcohol results in Wisconsin drivers. J Forensic Sci 1990;35:1022–8.
(16) Jones AW. Dilemma of a constant blood/breath ratio of ethanol in chemical test evidence of intoxication. In: Perrine MW, editor. Alcohol, drugs and traffic safety: Proceedings of the 11th International Conference; Chicago. Chicago: National Safety Council, 1990;237–44.
(17) Jones AW. Physiological aspects of breath-alcohol measurement. Alcohol Drugs Driving, 1990;6:1–25.
(18) Jones AW, Hahn RG, Norberg A. Comparing the concentrations of ethanol in arterial and venous blood and end-expired breath during and after intravenous infusion. 47th Annual Meeting of the American Academy of Forensic Sciences, Seattle, 1995.
(19) Cobb PGW, Dabbs MDG. Report on breath alcohol measuring instruments. London: Her Majesty's Stationery Office, 1985;1–90.
(20) Jones AW. Metabolism of ethanol in healthy men and women and comparison of Widmark parameters and blood/breath ratios of ethanol between the sexes. In: Valverius M, editor. Women, alcohol, drugs and traffic. Stockholm: DALCTRAF, 1989;169–75.

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