DILEMMA OF A CONSTANT BLOOD/BREATH RATIO OF ETHANOL IN CHEMICAL TEST EVIDENCE OF INTOXICATION

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Summary. The notion of a constant blood/breath ratio of ethanol for all subjects under all conditions of testing continues to cause litigation and debate when results of breath analysis are used as evidence of impairment. A person's apparent blood/breath ratio depends on a host of factors that cannot be adequately controlled in forensic practice. Among others, the source of blood analyzed; artery, capillary or vein, the sampling site, the subject's breathing technique and the phase of an exhalation captured for analysis will contribute to variations in the blood/breath ratio. Whether the concentration of alcohol in blood is rising or falling at the time of testing is also an important consideration. The magnitude of random errors in the methods of alcohol analysis in specimens of blood and breath, and any systematic bias in instrument calibration will seriously distort the calculated blood/breath ratio. This paper explores some problems and solutions to the use of a constant blood/breath ratio of ethanol in traffic law enforcement.

Introduction.

Since its beginning, chemical test evidence of intoxication has had many proponents and critics. One of the most troublesome aspects of breath-alcohol testing is the assumption of a constant blood/breath conversion factor. The accurately measured breath-alcohol concentration (BrAC) is translated into the presumed blood-alcohol concentration (BAC) and the BAC then used as evidence of impairment. To understand the reasons for converting BrAC into BAC, one must look at the history of chemical testing for alcohol in traffic law enforcement.

The alcohol a person drinks must reach the brain before it exerts any untoward effects on performance and behavior. The concentration of alcohol in blood reaching the central nervous system (arterial blood) therefore offers the best possible, but least practical, specimen for medicolegal alcohol determination. Norway and Sweden, enacted punishable limits of alcohol in blood in 1936 and 1941 respectively. Widmark's micromethod was especially designed to cope with specimens of capillary (fingertip) blood (Widmark, 1922). A person's BAC therefore became the norm when other countries introduced their alcohol-traffic legislation. But instead of taking capillary blood, many jurisdictions opted to use venous blood as the biological specimen for alcohol analysis. Blood was blood and any differences in concentration in different parts of the vascular system were considered negligible or zero.

A pioneer work on the physiology of alcohol excretion in breath and the concept of a blood-breath ratio was published by Liljestrand and Linde (1930). These scientists reported breath-alcohol concentration as mg per 2000 ml breath and not as the presumed concentration per ml blood. In other words, breath alcohol measurements were not multiplied by a factor and masqueraded as the presumed concentrations in blood. Breath-testing equipment, sufficiently robust for use by policemen outside of a laboratory, appeared in the 1940s. Although by modern standards these instruments were fairly crude, they gave reliable enough results to support or challenge clinical signs and symptoms of intoxication.
The classic Breathalyzer was invented by R.F. Borkenstein in 1954.

The first breath-alcohol instruments were calibrated empirically with a factor so that the readout was presumed coexisting BAC. Legal limits of alcohol in blood already existed and it was probably considered an easier task to make this mathematical conversion rather than rewrite the statute. Obviously, the accuracy of the estimated BAC depended on the test person's apparent blood/breath ratio of alcohol compared with the instrument calibration value. As might be expected, the blood-breath conversion factor became a hot topic for litigation in the courts. To quench early controversy and debate about the validity of breath-test evidence of intoxication, a committee of experts was called together in 1955. They drafted a statement endorsing the use of 2100:1 as the blood/breath conversion factor for clinical and legal purposes. New research on the blood/breath ratio of alcohol appeared in the early 1970s and the validity of the 2100:1 ratio again came under attack. This factor was considered too low for unbiased estimates of BAC and inter- and intra-subject variations in the ratio were now well documented. Another group of experts met in 1972 and came to essentially the same conclusions as in 1955, namely, that the continued use of a constant blood/breath ratio of 2100:1 was justified. The final text statement mentioned, however, that "approximately 2.1 liters of expired alveolar air contain the same quantity of alcohol as 1 ml blood". The 2100:1 ratio was considered forensically acceptable because most studies showed that BACs, estimated indirectly by breath-analysis, were almost always less than the actual values.

The analysis of breath offers certain advantages over blood as a test of intoxication. Among others, breath tests are non-invasive and give on-the-spot objective evidence of alcohol load in the organism. Another definite advantage of breath over blood is the fact that several confirmatory tests are possible within a few minutes. During blood-alcohol analysis, more often than not, only a single specimen tube is submitted to the laboratory for analysis. The time profile of alcohol in end-expired breath is closer to the arterial blood concentration than the venous blood level. This aspect of alcohol physiology is particularly important during the rising phase of the BAC profile. BrAC therefore mirrors impairment better than venous BAC under conditions of rapid absorption of alcohol from the gut.

Hazards of ratio variables

Statistical analysis of ratio variables is fraught with difficulties. Many conventional statistical tests, including the assumption of Gaussian distributions, cannot be directly applied to ratios. Instead of calculating the ratio of alcohol concentrations in specimens of blood and breath the differences between these measurements and their variation is a more useful parameter. The differences between two random variables tend to be normally distributed whereas their ratio is not necessarily so (Finney, 1952). A ratio is a dimensionless entity the magnitude of which depends on the absolute values of its numerator and denominator. Consider a measured BAC of 20 mg/dl and a Breathalyzer result (2100:1 calibration) of 15 mg/dl. The absolute difference is 5 mg/dl and the apparent blood/breath ratio for this subject is 2800. With a BAC of 50 mg/dl and a Breathalyzer reading of 45 mg/dl, the same absolute difference (5 mg/dl), yields an apparent ratio of 2333. Similarly, at BACs of 100 mg/dl and 200 mg/dl and Breathalyzer readings of 95 mg/dl and 195 mg/dl, the apparent blood/breath ratios are 2210 and 2153 respectively.
Random analytical errors in the methods used to determine alcohol in blood and breath can combine in various ways to distort the calculated ratio. First, assume a mean BAC of 100 mg/dl determined with a precision of 5 mg/dl and therefore a statistical range (2 x SD) of 90 to 110 mg/dl. Second, assume a mean Breathalyzer reading of 95 mg/dl determined with an analytical precision 10 mg/dl and a 95% range of 75 to 115 mg/100 ml. The ratios obtained during the analysis of alcohol in blood and breath can therefore vary from (110/75 x 2100) = 3080 to (90/115 x 2100) = 1643 simply as a result of random variations in the methods of analysis used.

Figure 1 gives an example of blood and breath alcohol profiles obtained in experiments with Alcolmeter EBA calibrated with a 2300:1 blood/breath ratio. Clearly, the apparent blood/breath ratio for this individual changes throughout the entire alcohol-concentration time course. Although the average value was 2413, a perfectly accurate estimate of BAC is not possible even if this average blood/breath ratio is used to calibrate the instrument. Table 1 lists some of the factors that might explain, at least in part, the observed variations in apparent blood/breath ratio reported in the literature.

Many biological factors are distributed according to a lognormal distribution. This implies that logarithms of the variables are normally distributed whereas the frequency distribution of original values are skewed (Gaddum 1934). To avoid problems associated with computing the variance of a ratio, I recommend that investigators transform the individual breath and blood alcohol measurements into logarithms. The difference between the logarithms of two numbers is the logarithm of their ratio. On conversion to the original scale the mean ratio and its confidence limits are obtained directly. Moreover, the percent overestimates and underestimates of BAC by breath-analysis and the range of apparent blood/breath ratios are easily calculated from transformed values.

Discussion

Much of the empirical data on blood/breath ratios generated before 1970 were on shaky ground. Some investigators were analyzing alcohol in venous blood whereas others used capillary or arterial specimens. Most investigators attempted to sample and analyze end-expired alveolar air by trapping the last portion of a prolonged exhalation, but scant attention was given to the volumes exhaled or the existence of an alveolar plateau. Moreover, some workers analyzed breath after subjects had rebreathed the initial exhalation a number of times before sampling. Others calculated the proportion of alveolar air in a deep exhalation from the carbon dioxide content of the breath. The BAC derived from analysis of breath with these different approaches was at best a qualitative estimate.

A host of variable factors influence the apparent blood/breath ratio of alcohol. Many problems are sidestepped if statutory alcohol limits for drivers are defined directly in terms of the concentration in breath. This indeed is the trend in most jurisdictions; Britain 35 ug/100 ml, Holland 220 ug/liter, Austria 0.40 mg/liter, Norway and Sweden 0.25 mg/liter. This recommendation came initially from USA where legal breath-alcohol limits in some States are stated as 0.1 g/210 liters breath (Mason and Dubowski 1976). The rational for choosing the particular blood to breath conversion factor when setting these
limits is difficult to understand and the values differ among countries; Britain 2300, Holland 2300, Austria 2000, Norway and Sweden 2100, USA 2100.

The BAC and BrAC are functionally related and a quantitative relationship exists between number of drinks, and the resulting concentration of alcohol in these biological specimens. The critical BAC or BrAC for onset of ethanol-induced impairment varies widely depending on a person’s tolerance to alcohol, the phase of alcohol metabolism, and the sensitivity of the tests used. The concentration profile of alcohol in blood and breath follows a similar time course for a wide range of doses and patterns of drinking. During the absorption of alcohol from the gut, the concentration of alcohol in venous blood is less than in the arterial blood. The BrAC mirrors the arterial BAC and is therefore a more sensitive index of the concentration of alcohol reaching the brain early after drinking ends when many drunk drivers are homeward bound.

Equality before the law is an important concept in our society. Accordingly, the probability of being convicted for DUI based on chemical test evidence alone should not depend on whether a breath-test or blood-test was administered. The blood/breath conversion factor selected by the legislature when setting the statutory BrAC limit therefore warrants careful consideration. This speaks against the use of a 2100:1 blood to breath ratio which tends to underestimate the coexisting post-absorptive venous BAC by about 10% in most published studies. Moreover, the practice in USA of truncating the third decimal in the breath-alcohol reading and therefore reporting both 0.109 g% and 0.101 g% as 0.10 g% should be abandoned. The response of modern breath-alcohol analyzers is sufficiently sensitive and stable to justify reporting results to the third decimal. In my opinion, reporting the lowest of two consecutive breath-alcohol tests is also an unfortunate practice. This encourages attempts by DUI suspects to get extreme differences (> 0.02 g/210 L) between the two readings. This tends to discredit the analytical method when both the results are introduced in evidence. The use of control charts to plot the range or the difference between duplicates has much to recommend it. These charts are easy to construct and the day-to-day results can be followed over time. Maintaining these charts up-to-date might help to motivate the police officers who conduct breath testing and in this way improve the reproducibility of results. The legal BrAC limit in Great Britain is 35 ug/100 ml but prosecution is not made until 40 ug/100 ml or more is recorded. This gives a generous advantage to those suspects who are capable of providing breath for medicolegal alcohol analysis. In reality, this creates a higher legal alcohol limit when breath tests are employed. Obviously, BAC and BrAC limits must exist together because under certain circumstances the suspect cannot be offered a breath-test, e.g. after a traffic accident.

Fortunately, duplicate determinations on separate breaths are now becoming a prerequisite for evidential purposes (Dubowski, 1989). It would be hard to defend a breath-test programme with per se statute based on a single determination and without any simultaneous storage of a specimen for later confirmatory analysis. Recording the temperature of expired air and reporting the result alongside the BrAC or even adjusting BrAC to the same temperature (e.g 34°C) for all subjects seems a good one (Mason and Dubowski 1976). Moreover, I consider it essential that a deduction is made from the mean result of duplicate or triplicate determinations of BrAC or BAC. The concentration of alcohol remaining after the deduction becomes the relevant figure for prosecution in DUI trials. In Sweden, reporting the lowest result with 99.9%
confidence is a mandatory requirement for legal purposes. This means that a suspect with a true BrAC just below a critical legal limit runs a 1 in 1000 chance of being conviction. This is accepted by the individual and society as being "beyond a reasonable doubt".

References


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1. Interfering substances in breath when determinations are made with a nonspecific breath-testing instrument.
2. Calculation of ratios at low concentrations of alcohol.
3. Gross errors in blood and/or breath alcohol analysis.
4. Mouth alcohol or regurgitation of stomach contents immediately before exhalation.
5. Unrealistic corrections made for elimination of alcohol between times of sampling blood and breath.
6. Short-term fluctuations in blood-alcohol profile e.g. if samples are analyzed during non-equilibrium distribution of alcohol in the body water.
7. Breath sampled too soon after the start of a prolonged exhalation.
8. Systematic errors in calibration of instruments used to analyse alcohol in blood and breath.
Figure 1. Venous blood-alcohol and converted breath-alcohol concentration after intake of 0.8 g ethanol/kg body weight (lower part). The upper part of the figure shows changes in apparent blood/breath ratios of alcohol during the metabolism of alcohol. An Alcolmeter eba with 2300:1 blood-breath calibration factor was used for breath testing. Headspace gas chromatography was used for blood-alcohol analysis. EOD = end of drinking.