A NEW METHOD FOR ASSURING ALVEOLAR-EQUILIBRATED
BREATH ALCOHOL SAMPLES

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SYNOPSIS

Reproducibility is one of the most important figures of merit in breath alcohol analysis. A number of papers have already stressed the important role of the liquid layers covering the conducting airways of the respiratory system. During inhalation these surfaces are deprived of alcohol. This can only be resubstituted by equilibrated alveolar air during exhalation. This paper describes the application of a mathematical lung model on the problem of dynamic gas exchange in the respiratory system. As a result, quantitative relationships for assuring alveolar-equilibrated samples and their use in analytical instruments are demonstrated.

INTRODUCTION

In recent years breath alcohol analysis has become more widespread in several European countries. The reason for this is not only attributable to the speed and ease of application of this method compared with blood alcohol tests but also to some of the major improvements made in the analysis technique. The latest generation of instruments, based primarily on the principle of infra-red absorption, can now achieve analysis results under in vitro conditions, which match the reproducibility of blood alcohol analysis using the Widmark or ADH methods. If a comparison is made with the in vivo reproducibility of successive breath tests, then, at times, a great deterioration in the reproducibility will be noticed. Today every instrument is equipped with devices which monitor the expiration and which are, thereby, intended to guarantee the validity of the breath sample provided. However, the criteria used in this respect (e.g. minimum sample volume or minimum expiration time) are inadequate to encompass all the variable physiological factors which can influence the concentration of alcohol excreted. The dominating influence of the amount of ventilation before and during the giving of a sample on the breath alcohol concentration has been recognized for many years (Jones, 1982; Slemeyer, 1982; Wright et al., 1975). However, a method of measuring and checking the extent of these interference factors was not available.

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The following is a report of an attempt to find a new means by which the dynamic processes of the ethanol-gas exchange in the lungs can be taken into consideration.

I. Monitoring the Exhalation of the Sample

To be accepted as proof of the intoxication of a driver, strict requirements must be fulfilled by the method of analysis with respect to accuracy. When analyzing blood alcohol, the statistical certainty of the results may be increased by performing repeated measurements of one homogenous sample. Multiple analysis of the same sample, however, in breath analysis cannot be expected to improve the evidential validity since its composition is very much dependent on the type of breathing both before the test and while the sample is being provided.

As early as 1914 (Krogh & Lindhard, 1914) described the time course of the CO₂ concentration in the air expelled from the lungs. Their studies led to a curve in which 3 phases are clearly recognisable: an initial delay time due to the dead volume (I); a rise phase (II); and the formation of the so-called alveolar plateau (III); the last being characterized by the fact that the slope of the CO₂ concentration becomes less as the more air is expired, because the proportion of alveolar air constantly increases (Figure 1).

The first attempts to make use of this phenomenon to analyse the ethanol content in the breath were based on the assumption that the amount of this substance exhaled would be proportional to the amount of CO₂. This is why the first breath alcohol analyzers constructed by Harger, Lamb, and Hulpieu (1938) and Jetter and Forrester (1941) also determined the CO₂ concentration in the breath parallel to that of ethanol. By comparing the measured value with a limit value of CO₂ to be found in the end-expiratory air, the proportion of deep-lung air and, therefore, the alveolar ethanol concentration were calculated. The error inherent in this method reflected the assumption that the CO₂ concentration would be the same for all subjects irrespective of their physiological conditions.

Greenberg and Keater (1941), and Borkenstein and Smith (961) used a different technique. They added a device to their instruments which only provided the last part of the breath sample for the analysis. This method was then further improved by insisting upon a minimum volume without which the sample would not be accepted as valid.
When the first electronic breath analyzers appeared, using the principle of infra-red absorption, the length of time of the exhalation was monitored instead of the volume. In order to guarantee an adequate flow of breath, the pressure drop was measured at a nozzle (Harte, 1971; Grambow et al., 1980). The minimum values for FLOW and TIME had to be selected so that even people with vital capacities well below average could also achieve the requirements. Subjects with greater vital capacities were therefore able to fulfill these conditions although their breath samples did not contain deep-lung air. In such cases considerable inconsistencies were recorded in successive breath tests.

II. The Influence of Ventilation

The criteria mentioned above only take into account minimum volume and time requirements for a breath test, but not the dynamic conditions of the exchange of gas within the lungs. Experience has shown that an increased ventilation rate (hyperventilation) prior to the test will result in a flatter slope of the breath alcohol concentration (Figure 2a).

The opposite effect, that is, a steeper, faster rate of rise (Figure 2b) will be noticed following hypoventilation before the test. Here, the point in time when the measurement is stopped is relatively unimportant because the changes in the concentration towards the end of the exhalation are only very small. In the case of hyperventilation it is impossible to decide upon a time for the measurement at which the sample adequately approaches the alveolar equilibrated concentration. Both with hyper- and hypo-ventilation the fixed time and volume criteria are too unreliable.

III. Effects in the Upper Respiratory Tract

Studies of the pulmonary gas exchange have shown that the conditions for the transfer of ethanol from the blood into the alveoli are extremely good. However intense the ventilation may be, the reduction of this concentration will only be negligible (Slemeyer, 1980 a). The important influences are to be found in the upper respiratory tract where the conditions for diffusion and vaporization are very poor. Here the inhalation of alcohol-free air leads initially to a great reduction of the surface concentration. The alcohol loss can only be replaced by back-diffusion from the saturated air exhaled from the alveoli. This means that alcohol is removed from the exhaled air until the
equilibrium concentration is once again attained on the surface of the respiratory tract. In addition to this are the ventilation-dependent temperature influences on the distribution of ethanol in the breath and blood.

In 1975 Dubowski came to the conclusion that 65-70% of the total air exhaled must be discarded before the true alveolar air is present, that is, before a constant alcohol value will be achieved (Dubowski, 1975). This is certainly only correct when breathing has been normal immediately prior to the test. Several studies using a model of a lung with 3 compartments have shown that the same amount of air must be exhaled as was inhaled in order to achieve approximately 90% of the actual alveolar concentration (Slemeyer, 1980 b). For the remaining difference, therefore, sufficient reserves of air must be present, which is not always the case, for example following exaggerated inhalation before a test. The application of these findings for measurement purposes necessitates both the determination of the volume inhaled as well as exhaled. For both technical and hygienic reasons this would be a costly and complicated enterprise.

IV. The Slope Analysis Method

The following describes a procedure which allows the degree to which the equilibrium concentration is approached to be determined. This is done by observing the time course of the concentration and flow rate of a sample during delivery. For this purpose the measured variables are the time-related changes in the breath alcohol concentration (BAC) in relation to the actual measured value and the changes in volume in relation to the volume already provided. The quotient of these 2 variables corresponds to the percentage concentration change divided by the percentage volume change and is to be indicated as the volume-related slope. Following hyperventilation the volume-related slope is still clearly increased even towards the end of the exhalation (Figure 3a), whereas a very fast decay can be recognized following hypoventilation (Figure 3b).

By comparing the actual rate of incline with a limit value $S^*$, one can determine the degree to which the equilibrium concentration is approached. Studies have shown that the application of this technique is largely unaffected by the vital capacity of the individual subject. For practical purposes the limit value $S^*$ is set so that the required approach to the breath alcohol concentration is achieved. This means, however, that the subject will be asked to continue providing sample volumes until the
condition has been fulfilled. The relationship between the degree to which the equilibrium concentration can be approached and the appropriate slope limit value \( S^* \) is such that, for example, to reach 90% of the actual level of intoxication, a slope limit value of \( S^* = 0.15 \) is necessary (Figure 4).

These findings are based on the results of studies which were carried out using measuring devices specially developed for this purpose. The numerical values shown serve as indications as to the quantitative relationships. In principle they can be applied to other measuring devices as long as the dynamic behaviors of the measuring systems both for the concentration and the flow rate are comparable. For the infra-red signal to be able to react quickly to changes in the breath alcohol concentration the volume of the measuring chamber must be as small as possible. In order to calculate the rate of slope one prefers to digitalize the signals and evaluate them by means of a microprocessor rather than using analog divider circuits.

V. Instrumental Application

The findings of the laboratory studies applying the volume-related slope criterion have been taken into account in the development of the ALCOMAT breath alcohol analyzer. Its control program ensures that the exhalation of a sample is continually monitored. In order to provide a valid sample minimum conditions regarding the volume and length of time of exhalation which must be fulfilled. However, these requirements of 1.5 liters and 3 sec can even be met by subjects with obstructive or restrictive respiratory diseases. Also when the volume-related slope becomes less than \( S^* \) the request to provide sample is continued until the flow rate has dropped below a minimum threshold value. The length of time allowed to provide a sample is therefore determined by the subject. Practice has shown that this leads to more complete exhalation than is achieved under fixed time conditions. When the flow rate falls below the minimum value the volume-related slope is checked. If the requirement for an alveolar equilibrated breath sample has been fulfilled the results of the measurement are released. If this cannot be achieved owing to hyperventilation or incomplete exhalation the sample is rejected as invalid.

The effectiveness of this method can be demonstrated if the results of field trials carried out in Sweden are taken as an example. A comparison of the results of 2 successive breath samples taken within 5 min of each other revealed the following:
Eighty-three pairs of values with concentrations between 0 and 0.305% BAC were available for statistical analysis. The mean value of the concentrations was 0.147% BAC. On average, the second breath sample was 0.0014% BAC below the first. The greatest deviation was 0.018% BAC from a first value of 0.251% BAC. From these data I calculated the slope of the regression line as 0.985 and the Y-axis intersection as 0.0037. The correlation coefficient is 0.995 and the standard deviation is 0.00586% BAC for this whole range of concentrations.

CONCLUSION

Experience gained with the ALCOMAT under field conditions has shown that the application of extended criteria for the validity of a sample including a slope analysis enables the influence of ventilation on the excreted breath alcohol concentration to be accounted for. The minimum requirements which must be fulfilled to make a sample valid correspond to the physiological condition of gas exchange in the respiratory system better than has been previously possible. The reliability of test results has been greatly increased by applying this technique thus further strengthening the trust placed in breath alcohol analysis.

REFERENCES


Slemeyer, A. (1982). [Influences of different breathing techniques on breath alcohol concentration.] *Blutalkohol*, 19: 97-102. [In German]

Figure 1. Time course of CO₂ expiration.

Figure 2. BAC as related to ventilation rate.
Figure 3. Volume-related slope applied to extreme cases of hyper- and hypoventilation.

Figure 4. Volume-related slope as related to equilibrium concentration.