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Observations on the Specificity of Breath-Alcohol Analyzers Used for Clinical and Medicolegal Purposes

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ABSTRACT: This paper deals with the application of three kinds of breath-alcohol analyzer for clinical and medicolegal purposes. The limited specificity for analyzing ethanol in expired breath has given misleading information with potential serious consequences. Three different methods of alcohol analysis are reported: semiconductor sensing (Alcotest 7310), electrochemical fuel cell (Alcolmeter SM-1), and infrared (IR) absorptiometry (IR Intoximeter 3000). Methanol could not be distinguished from ethanol with any of these breath-test instruments. When nonspecific techniques of ethanol analysis are used, the results must be considered with caution when interfering substances expelled in breath cannot be excluded.

KEYWORDS: criminalistics, breath-alcohol testing devices, blood, alcohol, ethanol, methanol, interference, specificity, forensic and clinical practice

In the course of conducting field trials with various instruments for analyzing ethanol in breath, it sometimes occurred that the results were significantly greater than blood-alcohol concentration (BAC) determined directly. These anomalous breath-instrument readings could not be attributed to technical faults with the equipment used or to inaccurate calibration with air-alcohol-vapor standards. The use of a breath-alcohol analyzer at a clinic for detoxification of alcoholics also gave a result that turned out to be completely different from the clinical laboratory report after analysis of a blood specimen [*1*].

The breath-testing devices involved used three different physicochemical principles for the determination of ethanol: (1) electrochemical oxidation with a fuel-cell sensor (Alcolmeter SM-1), (2) infrared (IR) absorptiometry (IR Intoximeter 3000), and (3) semiconductor resistivity (Alcotest 7310). None of these techniques can claim complete specificity with ethanol as the analyte.

This article gives examples of real-life situations when the limited specificity for analyzing ethanol with some widely used breath-testing instruments has given incorrect and misleading information. The results obtained with nonspecific methods of breath-ethanol analysis must be considered with caution in medicolegal work and in clinical medicine for example, the diagnosis of gross intoxication or ethanol-induced coma.

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Case Report 1

The Swedish police apprehended a 44-year-old man suspected of driving under the influence of alcohol. A blood specimen was taken and sent to our laboratory for quantitative determination of ethanol. According to the accompanying police report, the man was stopped in a traffic control, his breath smelt of alcohol, and his gait was unsteady when he was asked to leave his car. A breath-alcohol screening test was made at 1:32 p.m. with Alcotest 7310 (Drägerwerk AG, Lubeck, West Germany), and the result was 0.27-g/210-L breath; a second test made 6 min later showed 0.26 g/210 L.

The official Swedish method for forensic science analysis of ethanol in blood at the time involved enzymatic oxidation with yeast alcohol dehydrogenase (ADH) (Boehringer Mannheim, Scandinavia AB, Sweden). The mean result from four independent determinations on aliquots taken from the same pool of whole blood was 0.0 g/dL w/v. A backup gas chromatographic (GC) method of analysis confirmed the ADH result. Because of the total disagreement between the result of breath analysis reported by the police and the forensic science laboratory analysis of blood, a new investigation was made. Again the ADH method gave 0.0 g/dL w/v BAC, but a more detailed examination of the GC trace showed a large peak at the retention time of methanol. This finding was immediately reported to the police, but the man had been found dead at his home about 24 h after the drunk-driving incident. The autopsy report gave the cause of death as methyl alcohol poisoning. The concentration of methanol in heart blood was 0.24 g/dL w/v, femoral vein blood 0.16 g/dL w/v, and urine 0.38 g/dL w/v. Only trace amounts of ethanol were present in the body fluids.

The yeast ADH enzyme is highly selective for ethanol as substrate and methanol is not oxidized under the assay conditions used; this explains the zero BAC result. The laboratory technician responsible for the GC method recorded only the report from an electronic integrator which was set at the retention time of ethanol. Indeed, the purpose of the GC analysis was to confirm the concentration of ethanol by an independent technique; it was not meant as a general screening test for other low molecular weight volatiles. Moreover, this particular case was submitted to our laboratory as a routine drunk-driving investigation and there was no evidence or suspicion of abuse of narcotic drugs or solvents.

The Alcotest 7310 breath-alcohol device used by the police incorporates a semiconductor sensor (Taguchi cell) which is not specific for ethanol. It can respond to both ethanol and nonethanol organic volatiles such as ketones and hydrocarbons. The instrument response does not indicate what volatile substance(s) are being detected and measured and the result obtained by the police was therefore "apparent" blood-ethanol concentration. If the Alcotest device had given an insignificant or zero result and the suspected driver showed obvious signs of inebriation, this might have alerted the police to the possibility of other intoxicating drugs or some medical problem. Hospital treatment might then have been possible, but, without an elevated concentration of ethanol in blood to block the breakdown of methanol, it seems unlikely that the man would have survived.

Case Report 2

Another example of the lack of specificity of breath-testing devices and their failure to distinguish between ethanol and methanol was reported in the *Swedish Medical Journal* [*1*]. This involved tests with an Alcolmeter pocket model device (SM-1) which incorporates a fuel-cell sensor (electrochemical oxidation) for analyzing ethanol. These Alcolmeter devices are widely used as roadside breath-alcohol screening tests and also at surgical emergency units and hospital clinics to monitor blood alcohol among admitted patients [*2*].

A man visited a psychiatric acute ward because he felt depressed and told the physician in charge that he had been drinking heavily for the past seven days and wanted help with detoxification. His breath smelt of alcohol and the result of a test with the Alcolmeter SM-1 was 0.23 g/210 L. He slept the night at another hospital and returned the next morning to the

same psychiatric ward. Breath analysis with the Alcolmeter now showed 0.20 g/210 L. The man denied drinking any alcohol that morning but mentioned that he had vomited and felt generally unhappy. He was admitted to the hospital and a sample of venous blood was taken and sent for toxicological screening analysis. The results were serum-ethanol 0.0 g/dL w/v, serum-methanol 0.304 g/dL w/v, and serum isopropanol 0.0 g/dL w/v. The patient was immediately transferred to an intensive care ward and treated for methanol poisoning with intravenous ethanol and dialysis but he died two days later.

Case Report 3

The third example and the most interesting from the point of view of analytical toxicology was documented during ongoing field trials in Sweden with various evidential breath-alcohol analyzers. Tests were made with a quantitative breath-alcohol instrument IR Intoximeter 3000 (Intoximeters Inc., St. Louis, U.S.). A suspected drinking driver was above the legal BAC limit according to a preliminary roadside breath test and he was therefore taken to a police station and tested with the IR Intoximeter 3000. This device uses IR spectrometry at 3.4 μm for the determination of ethanol. This single wavelength is not specific for analyzing ethanol molecules because methanol, ketones, and volatile hydrocarbons can also absorb IR energy if they are present in the breath at sufficient concentrations.

The result of breath analysis with the IR Intoximeter was 0.345 g/210 L, and a blood sample was taken from the suspect and sent to our laboratory for analysis. The forensic blood-ethanol result by ADH method was 0.212 g/dL w/v (mean of four determinations), which is a poor agreement because this breath-alcohol device is intended for quantitative evidential purposes. The IR 3000 was calibrated with a 2100:1 factor and this implies that the apparent blood-breath ratio of ethanol for this subject is 1290:1.

The same specimen of blood was examined in more detail by headspace gas chromatography-mass spectrometry (GC/MS). An aliquot of whole blood (1 mL) was put into a glass headspace vial and 1.5 g of potassium carbonate was added. The vial was made airtight with a crimped-on aluminum cap and the contents were mixed. The vial was heated in a warm block at 60°C for 20 min, and thereafter, 1 mL of the headspace vapor was removed with a gastight syringe and analyzed by GC/MS. Figure 1 shows the total ion current (TIC) chro-

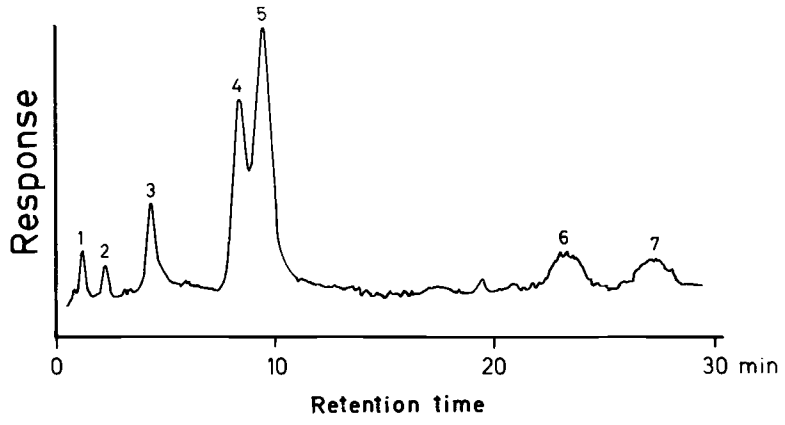

FIG. 1—*TIC chromatogram obtained from analysis of headspace vapor in equilibrium with whole blood from a driver suspected of consuming denatured alcohol. A LKB 2091 GC/MS was used for analysis and Porapak Q was the stationary phase at an oven temperature of 130°C.*

matogram for this analysis. Several other low molecular volatile substances besides ethanol were obviously present in the blood specimen. These peaks were identified from their mass spectra by comparison with standard reference substances. Table 1 gives the principal mass fragments and the percent intensity for the main ion fragments for these chromatographic peaks numbered 1 through 7 in Fig. 1. The option of running mass chromatograms is illustrated in Fig. 2. This mode of operation has the advantage that actual mass fragments within each peak of the TIC trace are displayed as a function of time during the chromatographic run.

TABLE 1—*Principal mass fragments and in brackets their percent intensity obtained from electron impact (70-eV) mass spectra of the GC Peaks 1 through 7 in Fig. 1. These fragment ions were compared with standard reference substances analyzed under the same GC/MS conditions.*

Peak	Substance	Molecular Ion	Base Peak	*m/z*[a]
1	Methanol	32 (60)	31 (100)	29 (30)
2	Acetaldehyde	44 (85)	29 (100)	43 (29)
3	Ethanol	46 (20)	31 (100)	45 (50)
4	Acetone	58 (33)	43 (100)	15 (34)
5	2-Propanol	59 (10)	45 (100)	43 (20)
6	2-Butanone	72 (25)	43 (100)	29 (12)
7	2-Butanol	74 (2)	45 (100)	31 (20)

[a] Next most intense ion fragment.

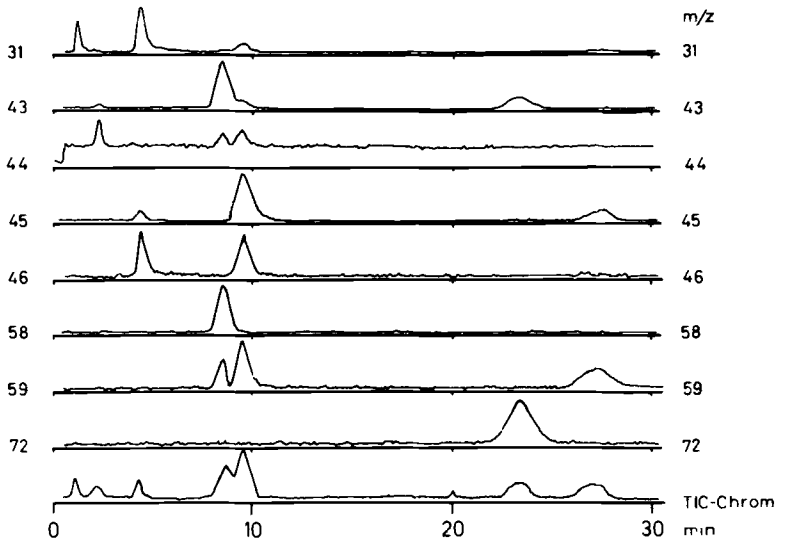

FIG. 2—*Mass chromatograms derived by computer-aided analysis of the peaks identified in Fig. 1. The principal mass fragments within each peak of the TIC chromatogram* (bottom trace) *are shown. Note that the mass fragment* m/z *31 corresponds to the base peak for both methanol and ethanol and this fragment is also present in the spectrum of 2-propanol and 2-butanol although with much weaker intensity.*

A denatured technical alcohol, sold in Sweden under the tradename T-Red®, contains 92% w/w ethanol, traces of methanol, 2% w/w acetone, and 5% w/w 2-butanone. Both primary and secondary alcohols serve as substrates for liver ADH and these reactions are reversible. Ketones can therefore be converted into their respective secondary alcohols by reduction with liver alcohol dehydrogenase. Acetone is the precursor of 2-propanol and 2-butanone is converted into 2-butanol [*3,4*]. One litre of T-Red costs $2.00 and can be bought almost without restriction. One litre of vodka costs $25 and can only be bought from special government-controlled shops with restricted opening times. Abuse of this denatured alcohol (T-Red) is well known among skid-row alcoholics in Sweden, but it was only recently recognized as a problem among drinking drivers [*5*].

Discussion

These brief reports bring out some of the problems arising from lack of specificity for analyzing ethanol with some currently available breath-alcohol instruments. The alleged response to interfering substances is a recurring issue in drinking and driving trials in those countries where breath-alcohol analysis is approved for substantive testing [*6–8*]. Legal questions about the lack of specificity for ethanol could explain, at least in part, why some countries are hesitant to introduce evidential breath-alcohol analyzers for legal purposes as replacement for blood-ethanol analysis by GC. The frequent occurrence of breath volatiles besides ethanol might also explain some of the abnormally low blood-breath ratios of alcohol reported in the literature when nonspecific instruments were used for analysis in large scale field trials [*8*].

Trace quantities of several low molecular volatile agents have been identified in the expired air of normal healthy individuals and analysis of breath could have diagnostic potential in some disease states [*9,10*]. Breath volatiles such as acetone or industrial solvents, mainly hydrocarbons inhaled from the atmosphere, have become targets for defense attack in drinking and driving trials [*6,7*]. Toluene was apparently detected and reported as ethanol in tests with the IR Intoxilyzer 5000 breath analyzer [*11*]. But whether the elevated blood and breath concentrations of toluene was the result of occupational exposure alone or solvent abuse such as sniffing was not elaborated upon. If the breath specimen is not preserved for later confirmatory analysis at a laboratory, the presence of nonethanol interfering substances is hard to disprove. Expert testimony will inevitably depend on various theoretical calculations about the uptake and excretion of solvent vapors through the lungs.

Several recent improvements are evident with regard to the specificity of IR breath-alcohol analyzers. The use of two or more different wavelengths for absorption of IR light can help to establish the presence of elevated concentrations of acetone in breath [*12*]. One of the latest generation of IR instruments uses absorption of IR light at 9.2 μm instead of the usual 3.4 μm [*13*]. The Alcolmeter range of fuel-cell instruments are inherently more specific than either IR or conductivity analysis when interference from elevated concentrations of acetone in breath is suspected [*14*]. But to distinguish ethanol from methanol seems to be a difficult analytical task unless some kind of chromatographic separation step is included [*15*]. Two kinds of GC breath-analyzer have been manufactured and used for legal purposes, but these proved less practical and more difficult to maintain in the field than IR instruments [*16*].

The limited specificity for analysis of ethanol has emerged as a key medicolegal issue and a definite limitation with some of the currently available breath analyzers compared with forensic blood-ethanol determinations by GC. The requirement of duplicate determinations on separate breaths, calibration control checks, and analysis of room air blanks before and after the suspect blows, are necessary scientific safeguards when instruments are used for evidential purposes [*8,17*]. The routine analysis of known strength air-vapor ethanol standards will help to ensure that breath instruments used at different locations are working according to the same specifications of accuracy and precision and that the whole process is

quality controlled. The use of an objective test to confirm an instrument's analytical specificity for ethanol under field conditions might become a mandatory requirement in future quality control programs.

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