Breathalyzer and Kitagawa-Wright Methods of Measuring Breath Alcohol

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Brit. med. J., 1964, 1, 9-15

A small proportion of ethyl alcohol which is absorbed into the blood is excreted in the breath. Alcohol in alveolar air is in equilibrium with that in pulmonary capillary blood, and this physiological fact allows the results of breath analysis to be used as an indicator of blood-alcohol levels. The partition ratio of alcohol between air and blood is such that 1 part of alcohol is present in air for every 2,100 parts in blood, at a temperature of 34° C. This temperature is chosen because it is the mean temperature of breath issuing from the mouth. At higher temperatures there is proportionately more alcohol in the air, so that as breath passes from the lungs at 38° C. into the cooler respiratory passages some alcohol condenses on the mucosal surfaces. Instruments which measure breath-alcohol concentration have been based on these figures of 1:2,100 and 34° C., and give their results in terms of blood-alcohol levels.

The "breathalyzer" is such an instrument. It was invented by Borkenstein in 1954 in Indiana (Borkenstein, 1956), and has been used in an increasing number of states in the U.S.A. and in other countries. It is portable and can be operated from electrical mains supply or from a car battery; it collects alveolar air, measures a given volume at a fixed temperature, above the temperature of breath, bubbles it through a dilute solution of potassium dichromate in 50% sulphuric acid, and by means of a built-in colorimeter with twin cells and a null-reading galvanometer measures the degree of reduction of the (yellow) dichromate by the alcohol. The result is obtained directly on a scale in terms of blood-alcohol concentration. The breathalyzer has undergone minor changes in design since 1956 and a model is currently manufactured in Geneva.¹

The manufacturer also produces small self-sealing plastic bags which allow alveolar air to be collected and stored for subsequent analysis in the breathalyzer. These Etzlinger bags are made of laminated plastic and incorporate a polythene flap valve which renders them self-sealing. The subject blows into the bag through a fine-bore drinking-straw and the first part of the breath escapes alongside the straw. When the bag is pulled smartly from the straw the valve operates and the last part of the breath (300-400 ml. of alveolar air) is trapped in the bag. The sample may be stored at ambient temperature until it is analysed in a breathalyzer, perhaps 12 to 24 hours later, and a label is incorporated in the bag for recording the name and other details.

Since the temperature of the breath falls from mouth temperature (34° C.) to ambient temperature in the bag, water and alcohol vapour condense on the walls and it is necessary to heat the bag to a temperature above 34° C. immediately before analysis.

Escape of alcohol vapour or of water-alcohol mixture in fluid form is reduced to a low level by the inner layer of plastic, which is of low permeability.

The air is delivered into the breathalyzer through a small glass connecting tube by squeezing the bag between the palms of the hands. The connecting tube must also be preheated above 34° C. to prevent condensation.

The other instrument which is reported here is the Kitagawa-Wright breath alcohol detector,² the result of combined development work in Japan and Britain (Kitagawa and Wright, 1962). It is a portable instrument, operated from mains supply, which collects deep-lung air and, like the breathalyzer, measures a given volume at a fixed temperature, above the temperature of breath. It pumps the air through a detector tube (the size of a clinical thermometer) which is packed with a constant weight of silica particles coated with anhydrous chromic acid. The chemical reaction is similar to that of the breathalyzer; part of the yellow column of anhydrous chromic acid is reduced to a grey-blue colour and the length of the colour change is measured on an illuminated digital reader which reads directly in units of blood-alcohol concentration.

In view of renewed interest in chemical tests for alcohol in the body, which is reflected in the provisions of the Road Traffic Act, 1962, we undertook a trial in June 1962 to establish the precision of breathalyzer results and their correlation with blood-alcohol levels. At the same time we studied the results obtained from samples of breath collected in breathalyzer bags, half of which were analysed immediately and half after 24 hours. Urine alcohol was also estimated. The Kitagawa-Wright detector was not then available.

This trial has already been reported (Begg, Hill, and Nickolls, 1963). It was found that the Nickolls (1960) modification of the macro-Cavett method of blood-alcohol analysis yielded closely reproducible results (S.D. 4.10 mg./100 ml.), and the reproducibility of the breathalyzer readings was not much poorer (S.D. 6.93 mg./100 ml.) and was thought to be good enough for medico-legal purposes. The correlation between breathalyzer readings and venous blood alcohol (0.956) was good. The breathalyzer readings, however, tended to be higher than the venous blood-alcohol levels 30 minutes after the end of the alcoholic drink, and lower than the blood levels after longer intervals. Breath-alcohol levels reflect the arterial blood content, and this would be expected to exceed the venous blood content during the phase of intestinal absorption of alcohol and

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² Now produced commercially by the Minerva Detector Co., Ltd., Twickenham, Middlesex, as the Hermes alcohol analyser.

its diffusion into the tissues. Therefore some of the comparisons of breath and blood analysis were not strictly fair.

By December 1962 the Kitagawa-Wright breath alcohol detector was available, and changes had been made to the breathalyzer and the bags after discussions with the designer and the manufacturer; it was therefore decided to carry out a further trial. The breathalyzer changes were the result of experience in the previous trial, and included improvements to the galvanometer and to the movement of the light carriage in the colorimeter, and the provision of a Vernier scale on the pointer. In the previous trial the readings from plastic-bag samples tended to be lower than the direct breathalyzer readings. Dr. J. P. Bull suggested that the "dead air space" within the breathalyzer might be largely responsible, and this space was therefore reduced to a minimum in the revised model. In order to flush the remaining dead space more adequately with alcoholic air the volume of the Etzlinger plastic bags was increased from approximately 300 ml. to 400 ml.

Design of Trial

The trial carried out during December 1962 to March 1963 included the improved Etzlinger model of the breathalyzer, the larger bags, and the Kitagawa-Wright apparatus, and was designed to assess the reproducibility of breath-alcohol estimations by the three methods and to compare them with blood-alcohol results. An effort was made in this trial to ensure that comparisons between breath and venous blood were made only at times when the arteriovenous alcohol difference was minimal—that is, when the peak of the blood-alcohol curve was clearly past and the slope was descending slowly. In this phase the arteriovenous alcohol difference is less than 1 mg./100 ml.

Eighteen healthy males under the age of 40 were given a dose of 70° proof spirits, diluted 1 in 2 with water. Three subjects were allotted to each of six dosage groups: the doses were 0.38 g., 0.50 g., 0.63 g., 0.85 g., 1.04 g., and 1.25 g. of alcohol per kg. body weight, taken on an empty stomach over a period of time convenient to each subject. For a 70-kg. man these doses ranged from 3 fl. oz. (84 ml.) to 9.75 fl. oz. (277 ml.) of 70° proof spirits.

About 30 minutes after the end of the drink two breath samples were taken for analysis in the Kitagawa-Wright apparatus (at 27½ and 32½ minutes), two in the breathalyzer (at 26 and 34 minutes), and two in plastic bags (at 30 minutes) for analysis next day. Similar samples were subsequently taken every 30 minutes. When two successive mean readings by the Kitagawa-Wright method were each less than the previous mean reading—that is, 30 minutes before—the post-absorptive decline in the blood-alcohol level was assumed to have been reached and venous blood samples were taken 30, 90, and 150 minutes later. Each blood sample was mixed with dry fluoride-oxalate reagent and was divided into two parts, which were sent under code numbers to the Metropolitan Police Laboratory, where the alcohol content of each part was estimated in duplicate by the Nickolls (1960) modification of the macro-Cavett method. Each Kitagawa-Wright tube was read in duplicate by each of two observers immediately, and again after 24 hours and after seven days. The bags were stored at room temperature (12–25.5° C.; 54–78° F.) and their alcohol content was measured in the breathalyzer the following day, the exact interval varying between 17 and 25 hours. They were heated immediately before analysis; in the first half of the trial this was done in the cupboard of the breathalyzer, but it was noted that the temperature did not rise above 27° C., and in the second half of the trial the bags were heated for 10 minutes in a 50° C. oven.

Results

Three hundred and eighteen breath samples were taken direct into the breathalyzer, and the same number into plastic bags and

into the Kitagawa-Wright apparatus. Readings could not be obtained from some samples for technical reasons, such as excessive leakage from the bag during emptying or breakage of the Kitagawa-Wright tube; in other cases a reading was obtained but was unacceptable because the operating instructions for the instrument had not been fulfilled—for example, the light which indicated complete emptying of the breathalyzer chamber did not appear. Failures from any of these causes numbered 7 (2.2%) for the direct breathalyzer samples, 15 (4.7%) for the breathalyzer bags, and 4 (1.3%) for the Kitagawa-Wright method. These results would undoubtedly have been recognized as false in practical use of the instrument and were excluded from the analysis. No result was excluded merely because it looked discordant.

The use of the early Kitagawa-Wright readings as a screening test to determine the characteristics of the blood-alcohol curve resulted in the first blood specimen being taken 2 hours after the end of the drink in 10 cases, and 2½ hours in 3 cases, 3 hours in 4 cases, and 4 hours in 1 case. There was a tendency for higher alcohol doses to delay the peak of the blood-alcohol curve or to produce secondary peaks, so that the blood specimens tended to be later in the higher dosage groups. The blood-alcohol results ranged from zero to 147 mg./100 ml.

Basic Variability

In previous reports on blood- and breath-alcohol estimations there has been a tendency to refer to the percentage error rather than to the absolute error of the methods, implying that higher values tend to have higher variability. However, the figures from the present trial show no sign of greater variability at higher values, and it is more reasonable to speak of their absolute variability.

For each method an estimate has been made of the standard deviation of the process by using the pairs of observations taken on each occasion. The basic variabilities are shown in Table I. The figure given for blood is based upon the variability between readings taken from the two separate parts of the blood as sent to the Police Laboratory, and not upon the duplicate readings from the same part, which gave a lower figure. Only the first reading on each tube of blood was used in the main analysis.

TABLE I.—Basic Variability of Individual Readings

	Standard Deviation (mg./100 ml.)	
	Observed	95% Confidence Limits
Blood	3.66	3.08–4.51
Breathalyzer (adjusted)	7.29	6.55–8.21
(unadjusted)	7.57	6.81–8.53
Bag, 1 day	5.81	5.21–6.56
Kitagawa-Wright	8.37	7.53–9.42
	8.76	7.88–9.86
	10.23	9.20–11.53

Two values are given for the direct breathalyzer samples. The adjusted figure makes allowance for the eight-minute interval between the readings, and gives the variability of an individual reading. No adjustment was necessary for the duplicate bag samples, since they were taken within half a minute of one another. The Kitagawa-Wright figures showed no consistent tendency for the second reading to be lower than the first, so an adjustment for the five-minute interval was not possible.

The standard deviation (S.D.) of the 24-hour bag readings (5.81 mg./100 ml.) is significantly less than that of the direct breathalyzer readings (7.29 mg./100 ml.) ($P=0.01$). The Kitagawa-Wright S.D. (8.37 mg./100 ml.) is not significantly greater than that of the direct breathalyzer samples ($P=0.10$). The variability of the Kitagawa-Wright method is seen to increase if the tubes are kept for a period before reading them.

An analysis of the duplicate readings of the same Kitagawa-Wright tube, based on the immediate readings, showed that on

the average observer B read 1.3 units higher than observer A. This difference is very highly significant, but the absolute value is small enough to be of little practical importance. The standard deviation of the reading process was 1.21 mg./100 ml. for observer A and 1.07 mg./100 ml. for observer B. This difference is just significant ($P=0.05$). It should be noted that this deals solely with the accuracy of the reading process based upon repeat readings of the same tube. The variability is therefore less than that quoted in Table I, which includes other sources of variation.

On the basis of the standard deviations quoted in Table I, it is possible to calculate the range on either side of the "true" value within which 95%, 99%, and 99.9% of the observations would be expected to lie (Table II). The adjusted S.D. has been used in this calculation in the case of the direct breathalyzer samples.

TABLE II.—Estimated Accuracy of Observations

Proportion of Readings	Range (mg./100 ml.)			
	Blood	Breathalyzer	Bag	Kitagawa-Wright
95%	± 7.2	± 14.3	± 11.4	± 16.4
99%	± 9.4	± 18.8	± 15.0	± 21.6
99.9%	± 12.0	± 24.0	± 19.1	± 27.5

Average Readings

Table III shows the average reading obtained by each breath method in terms of the average blood-reading as the unit. The observations have been divided into six groups by blood level in such a way that each group has approximately the same number of observations. Table IV is similar, but shows differences instead of ratios. The keeping of a Kitagawa-Wright tube for a week seems to lead to a shortening of the stain at the lower levels but to a lengthening at the highest levels. The

TABLE III.—Average Readings, the Average Blood Reading Being Taken as the Unit

Blood Level (mg./100 ml.)	No. of Observations	Breathalyzer	Bag, 1 Day	Kitagawa-Wright		
				Immediate	1 Day	7 Days
0-30	9	0.964	0.645	0.307	0.283	0.198
30-40	9	0.747	0.703	0.741	0.673	0.418
40-60	10	0.772	0.755	0.863	0.841	0.630
60-87.5	9	0.831	0.788	1.036	1.056	0.937
87.5-110	8	0.808	0.763	0.959	0.995	0.984
110-145	9	0.872	0.839	1.047	1.091	1.118

TABLE IV.—Differences Between Average Reading and Average Blood Reading (mg./100 ml.)

Blood Level (mg./100 ml.)	No. of Observations	Breathalyzer	Bag, 1 Day	Kitagawa-Wright		
				Immediate	1 Day	7 Days
0-30	9	-3.8	-4.6	-9.0	-9.7	-12.0
30-40	9	-8.9	-10.2	-8.7	-11.1	-19.8
40-60	10	-12.0	-13.0	-7.2	-8.4	-19.3
60-87.5	9	-12.9	-16.0	+3.1	+4.7	-4.1
87.5-110	8	-18.9	-23.3	-3.8	-0.1	-1.1
110-145	9	-15.6	-19.7	+5.7	+11.2	+14.8

calibration of the breathalyzer appears to be definitely low in this experiment. Fig. 1 shows the breathalyzer results plotted against the blood results, together with the regression line. Figs. 2 and 3 give the corresponding information for the plastic bags and for the Kitagawa-Wright method. The bags are seen to give lower readings than the direct breathalyzer samples, and the Kitagawa-Wright apparatus tends to read low for the lowest blood levels (zero readings are often obtained when the blood alcohol is low) and high at the highest levels.

Correlations

The correlations between the different methods are shown in Table V. The comparisons of the different breath methods are

based upon all the occasions on which breath readings were taken, but the correlations with blood have inevitably had to be based only upon readings for which blood samples were available. The direct breathalyzer readings show a higher correlation with blood than do the plastic bag and the Kitagawa-Wright methods, but the differences are not quite significant ($0.05 < P < 0.10$ in each case).

Investigations of Additional Features

During the course of the trial it was necessary to make a few modifications of equipment and of technique. About halfway through the trial the cylinder assembly of the breathalyzer was

FIG. 1.—Scatter diagram of individual breathalyzer readings (direct samples) (Y) and mean blood-alcohol readings (X). The thin diagonal is the regression line and the thicker diagonal represents $Y=X$.

FIG. 2.—Scatter diagram of individual breathalyzer-bag readings (Y) and mean blood-alcohol readings (X). The thin diagonal is the regression line and the thicker diagonal represents $Y=X$.

changed; at about the same time a new policy was started of heating the bags before analysis in a 50° C. oven instead of in the breathalyzer cupboard, which had a maximum temperature of 27° C. A new batch of Kitagawa-Wright tubes was also started about halfway through, and for three subjects a different Kitagawa-Wright instrument was used.

In addition, records were kept of the delay between the taking of a bag sample and its analysis, of the total length of reagent material in each Kitagawa-Wright tube, and of the total Kitagawa-Wright pumping-time on each occasion. An analysis was made of these additional features to discover which ones appeared to be important.

This analysis used the statistical technique of multiple regression, first of all removing the variability which could be accounted for by the differences in alcohol doses, ages, and weights of the various subjects and by the time since drinking, and then seeing how much of the remaining variability could be accounted for by the relevant additional features.

The change of cylinder assembly was found to have made no significant difference to the direct breathalyzer readings. The delay in analysing the bags was found to be highly significant ($P < 0.001$), each extra hour of delay adding 2.2 mg./100 ml. to the reading, on the average. This surprising result is discussed later. The delays varied from 17 to 25 hours, with an average of 21.6 hours; the result should not be extrapolated outside this observed range of delays.

The difference between cupboard (27° C.) and oven (50° C.) readings was also found to be significant ($P < 0.01$), provided that the delay was allowed for first. An oven-reading was, on the average, 3.7 mg./100 ml. higher than would have been

expected for a cupboard reading with the same dose, age, weight, time after drinking, and delay before analysis.

With the Kitagawa-Wright readings the pumping-time and the batch of tubes were each found to be highly significant ($P < 0.001$). Each additional minute of pumping-time added about 3.9 mg./100 ml. to the result (and the range of observed pumping-times was considerable: from 1.6 to 10.5 minutes). One batch of tubes gave an average reading 7.8 mg./100 ml. greater than would have been expected from the other batch, under the same conditions.

Which of the two Kitagawa-Wright instruments was used was found to be highly significant ($P < 0.001$), but this could be completely explained by the correlations between instrument used, batch of tubes used, and pumping-time. If batch and pumping-time are allowed for, the significant difference between instruments vanishes.

The total length of material in the tubes failed to show any effect; the amount of variability that could be accounted for by this feature was *less* than would be expected on the average by chance alone.

Mouth-alcohol Effect

Residual alcohol in the mouth will produce a concentration of alcohol in the air of the mouth and upper respiratory passages by equilibration, and, since the concentration of alcohol in the mouth immediately after a drink will be considerably higher than that in the blood, "mouth air" will contain much more alcohol than alveolar air, and alveolar air may pick up alcohol as it is exhaled through the mouth. This will produce spuriously high breath-alcohol readings.

The magnitude and duration of this effect were studied in eight subjects, four of whom had dentures. Each swilled 10 ml. of 70° proof whisky round the mouth for 10 seconds and expelled it without swallowing any. Every five minutes for 30 minutes thereafter they provided duplicate samples of alveolar air in Etzlinger plastic bags, which were analysed in the breathalyzer. The experiments were repeated on the same eight subjects, who on this occasion rinsed the mouth with cold water before filling each bag at 10, 20, and 30 minutes, but did not rinse at 5, 15, and 25 minutes.

Results

The results are shown in Figs. 4, 5, and 6. The readings at five minutes were high and variable, in the range of 38–172 mg./100 ml., but these diminished rapidly, and 15 minutes after the end of the "drink" were within the range 1–8 mg./100 ml. Therefore a breath sample should not be vitiated by the mouth-alcohol effect if it is taken at least 15 minutes after the end of a drink.

The presence or absence of dentures (Fig. 4) has no significant influence on the magnitude or duration of the phenomenon, and rinsing the mouth with water (Figs. 5 and 6) has not made much difference.

Discussion

The concentration of alcohol in tissue fluids may be assessed by analysing blood, urine, saliva, or breath. Various chemical methods used for blood, urine, and saliva are known to be precise and reliable, and the choice of one of these fluids for alcohol analysis depends upon other considerations. Blood is used in many countries, but it may be difficult to obtain in an intoxicated, uncooperative individual and may in law be an assault on his person. Urine is more easily collected, but suffers from two disadvantages: the alcohol content is higher than that of blood, by a factor which varies considerably, so that the blood (and therefore the tissue fluid)-alcohol concentration can be calculated only approximately; and, secondly, the urine passed

FIG. 3.—Scatter diagram of the results from the individual Kitagawa-Wright detector tubes (mean of four immediate readings; two readings of each two tubes) (Y) and mean blood-alcohol readings (X). The thin diagonal is the regression line and the thicker diagonal represents $Y = X$.

TABLE V.—Correlations Between Alcohol Estimations

	Breath- alyzer	Bag, 1 Day	Kitagawa-Wright		
			Immediate	1 Day	7 Days
Blood	0.982	0.971	0.972	0.970	0.956
Breathalyzer ..		0.955	0.950	0.954	0.952
Bag, 1 day ..			0.950	0.951	0.946
Kitagawa-Wright, immediate ..				0.997	0.989
Kitagawa-Wright, 1 day ..					0.994

at a particular time reflects the blood-alcohol level during the period of its secretion and not necessarily that obtaining at the time it is voided. Saliva also contains more alcohol than an equal volume of blood, and this ratio too is inconstant (Coldwell and Smith, 1959); in addition, it is difficult to obtain an adequate specimen of saliva from an uncooperative individual, and some intoxicated persons are unable to produce saliva, presumably because of dehydration.

Breath samples are particularly convenient. They do not involve an assault and demand only a limited amount of co-operation from the subject. They reflect the arterial blood-alcohol level at the time of sampling, and this is probably preferable to analysis of venous blood, since the arterial concentration gives a better idea of the rate of entry of alcohol into the tissues of the nervous system. If the accuracy of breath-alcohol measurements were to equal or approach closely that of blood analysis, breath samples would be preferable.

Several conditions must be satisfied before breath can be accepted as a reliable indicator of blood-alcohol levels. Alcohol which lingers in the mouth must not be producing a spuriously high reading, and our studies agree with those of Monnier (1961) and of Lins and Raudonat (1962) in showing that any such effect is negligible 20 minutes after the end of a drink. Dentures do not prolong this mouth-alcohol effect. Further, the chemical test for ethyl alcohol must be specific and should not yield false readings due, for example, to acetone. The chemical reaction in the breathalyzer, which is the reduction of dichromate present in low concentration in 50% sulphuric acid, is not completely specific, but for practical purposes it is satisfactory. Acetone does not distort the measurements even in uncontrolled diabetics; even when moderate amounts of acetone are present in urine the breathalyzer usually gives a zero reading, and in only a few cases gives readings up to 3 mg./100 ml., and even these small readings are probably due to impurities in air or tubing (Martin, 1958). Smith (1951) obtained breath readings not greater than 2 mg./100 ml. in diabetics. Nor is there any reason to suspect that acetone will give significant readings with the Kitagawa-Wright method, since the chemical reaction is similar to that in the breathalyzer. Ether and paraldehyde, however, also react with dichromate, but it is unlikely that they will be excreted in the breath of persons suspected of alcoholic intoxication. The ingestion of ethyl alcohol together with disulfram (tetraethylthiuram disulphide; "antabuse"; "cronetal") produces acetaldehyde in the breath, but Borkenstein and Smith (1961) found this to give no "apparent alcohol" reading in the breathalyzer. The same authors point out that methyl alcohol gives positive readings; if this is suspected a reading should be taken when the chemical reaction in the breathalyzer has proceeded for 10 minutes, in addition to the usual reading at two minutes, and the reading will have doubled if it is due to methyl alcohol; with ethyl alcohol the reaction is complete at two minutes.

Another prerequisite of breath-testing is that the "blank" reading obtained from room air should be negligible. It is readily shown that no colour change takes place when room air is pumped through the Kitagawa-Wright tube. The breathalyzer, as we received it, had a mark behind the zero line, at which to set the indicator before taking a sample; this resulted in the automatic subtraction of about 6 mg./100 ml. from the reading, to allow for the "blank" value. A series of preliminary experiments (Begg, unpublished) showed that with uncleaned glass bubbler-tubes as received from the manufacturer of the breathalyzer the "blank" value was 4.9 ± 3.25 mg./100 ml. (mean $\pm$ S.D.), and with tubes cleaned in acid solution, rinsed and dried, the "blank" was 1.5 ± 1.9 mg./100 ml. (mean $\pm$ S.D.). Fox *et al.* (1963) obtained figures similar to these with uncleaned and cleaned bubbler-tubes. In our previous trial uncleaned glass bubbler-tubes were used and the automatic subtraction of 6 mg./100 ml. "blank" was made; in the present trial cleaned tubes were used, the indicator was pre-set at the zero mark, and a 2 mg./100 ml. "blank" was subsequently subtracted from the reading on the scale.

Mechanics of the Instruments

The convenience of the breath-testing instrument is an important consideration. The mechanics of the instrument should be such that the subject has little difficulty in blowing into it. None of our subjects failed to provide the breath samples when asked, and only occasionally was more than one attempt required. However, it should be emphasized that all subjects remained co-operative, although some were highly intoxicated. In the breathalyzer there is only moderate resistance to be overcome by the expiration. In the Kitagawa-Wright detector the resistance is in three phases and is considerable at the end of the expiration. Some of the second attempts were required on account of this, but experiments on 15 chronic bronchitic and asthmatic patients (who had had no alcohol) showed that, with two exceptions, they had no difficulty in providing the sample, even when their forced expiratory volume (F.E.V.₁) was as low as 0.5 litre and their vital capacity 1.42 litres; one patient had uncontrollable cough whenever she blew, and one man, aged 53, with emphysema, F.E.V.₁ of 0.8 litre, and vital capacity of 3.2 litres was never able to overcome the resistance.

From the operator's point of view, the Kitagawa-Wright detector is by far the easier to work. The subject is simply asked to blow fairly hard into the delivery-tube until the noise of the pump is heard and the light appears. A pre-set volume of initial breath is automatically discarded—in our trial 0.5 litre—and the procedure is fully automatic until pumping ceases and the operator has to remove the detector-tube from its socket for reading. In the case of the breathalyzer the operator has a series of procedures to carry out, and has to tell the subject

FIG. 4

FIG. 5

FIG. 6

FIG. 4.—The decline of the mouth-alcohol effect with time. Each entry represents the mean of eight breathalyzer-bag results, with maxima and minima. The results at five minutes were in the 38–172 mg./100 ml. range. The mouth was not rinsed with water prior to breath-sampling.

FIG. 5.—Mouth-alcohol effect. Showing the effect of rinsing the mouth with water (R) prior to breath-sampling in four subjects without dentures.

FIG. 6.—Mouth-alcohol effect. Showing the effect of rinsing the mouth with water (R) prior to breath sampling in four subjects with dentures.

when to discontinue blowing, so that a varying volume of air is discarded. The procedures are complex and most are concerned with the pre-setting and reading of the colorimeter—operations familiar to laboratory staff but not to untrained persons. Both instruments are portable, but have their limits in this respect. The Kitagawa-Wright detector requires 250 V mains supply in its present form, although we understand that a car-battery model would be possible. The breathalyzer may be operated from mains or from a car battery, but the need for continued accuracy demands that the galvanometer and other fine parts be treated with care, and it is therefore best considered as a laboratory instrument. However, the use of Etzlinger plastic bags in conjunction with the breathalyzer may satisfy the need for a portable means of breath-collection.

Neither instrument provides suitable exhibits for use in a court of law, apart from the analyst's certified readings. The Kitagawa-Wright detector-tube seemed at first to be suitable for this purpose, but the end-point was found to change with storage. Immediately after the exposure to alcoholic air the end-point (the interface between the grey-blue and yellow column) is clear-cut, but after 24 hours the interface is indistinct and there is a tendency for the apparent readings to increase or decrease according as the alcoholic concentration is high or low respectively.

The mechanical and electrical reliability of the instrument employed is a major consideration. The breathalyzer has been in use for nine years and is therefore past the stage of developmental difficulties. Minor mechanical and electrical faults occasionally arise, but they are immediately spotted if the proper procedure is followed—for example, if there is incomplete filling or incomplete emptying of the collecting cylinder the appropriate light signal will not appear, and another breath sample must be taken. Such faults are easily corrected by a trained operator. In this trial the failure rate from technical faults was 2.2% for the breathalyzer, 4.7% for the bags used in conjunction with the breathalyzer, and 1.3% for the Kitagawa-Wright method. The Kitagawa-Wright detector has been produced commercially only for a few months, and the trial reported in this paper employed two prototype models built in the National Institute for Medical Research. Mechanical faults arose on several occasions in the pumping mechanism owing to blocking of the valve beneath the detector-tube socket, and electrical faults occurred in the digital reader. Minor changes in design have been made which should overcome the difficulties. Again, the faults are easily recognized and should not lead to spurious results. Any such instrument which is adopted for medico-legal purposes will require to be subject to strict control of quality and to regular inspection and calibration, and the operators must be adequately trained and supervised. Smith and Lucas (1963) describe the organization of such a scheme for the breathalyzer in Ontario. An efficient acceptance sampling procedure would be necessary for Kitagawa-Wright detector-tubes.

Sources of Error

Estimations by means of laboratory instruments are subject to observer error, and this should be reduced to a minimum. In the Kitagawa-Wright apparatus the collection of breath and its delivery through the detector-tube are automatic and allow no operator variation, but the reading process depends upon precise positioning of the detector-tube and judgment of a colour end-point by the observer. In the present trial, over 300 tubes were read twice by each of two observers immediately after the tube had been exposed to the breath. Although on average observer B gave readings which were 1.3 mg./100 ml. higher than those of observer A, this inter-observer error is negligible for practical purposes. The intra-observer error was also small; the S.D. of the reading process was only 1.21 mg./100 ml. for observer A and 1.07 mg./100 ml. for observer B.

No estimations of inter-observer or intra-observer error are possible with the breathalyzer, but one would expect standard deviations of the same order as those with Kitagawa-Wright tubes, due to slight variations in the setting and reading of the galvanometer and the indicator.

Alcohol Readings

The reproducibility of the readings of alcohol concentration by the various methods studied in this trial appears satisfactory. Blood gave the most reproducible results (S.D. 3.66 mg./100 ml.), followed by the Etzlinger plastic bags (S.D. 5.81 mg./100 ml.), the direct breathalyzer samples (S.D. 7.29 mg./100 ml.), and the Kitagawa-Wright apparatus (S.D. 8.37 mg./100 ml.).

A close correlation between breath and blood estimations should be expected in this trial, since the venous blood was taken when the blood-alcohol level was falling slowly (at a rate of about 13 mg./100 ml./hour) and the arteriovenous difference would be negligible. The correlations between blood estimations and breathalyzer, plastic bag, and Kitagawa-Wright estimations are 0.982, 0.971, and 0.972 respectively, figures which appear satisfactory and which do not differ significantly one from the other. Lereboullet *et al.* (1961) produced results from 131 direct breathalyzer samples which give a correlation of 0.994 with the blood levels; however, the distribution of the alcohol levels quoted in their paper is difficult to understand; a few fixed values in the lower part of the range occur with great frequency, with intermediate values not occurring at all. The correlation of the present results is not of such a high degree, but it is sufficiently high to be of practical value in forensic practice. Examination of the regression equation shows (Fig. 1) that the breathalyzer is reading 13% lower than blood and that a simple recalibration would render this instrument more accurate. The Kitagawa-Wright method (Fig. 3) gives readings which tend to be low compared with blood estimations at low alcohol levels and high at high levels, and the readings appear correct at about 100 mg./100 ml. Recalibration of the Kitagawa-Wright apparatus would not be so easy, especially at the low levels, in the 0–40 mg./100 ml. range, but for forensic purposes this range is of little importance.

Small plastic bags of the Etzlinger type would extend considerably the range of usefulness of the breathalyzer. They are suitable for use "in the field" by police officers, who can easily be trained in their use; in contrast, more prolonged and careful training is required for breathalyzer operators. Several replicate samples of breath may be obtained in bags in the space of one to two minutes, and some of the samples may be given to the suspected person for use in his defence if he so desires. Analysis of triplicate samples, for example, would ensure a considerable measure of accuracy. There is no problem about identification of the sample, since a label is incorporated into the seal of the bag.

The employment of bags would also ensure the economical use of breathalyzers, which could be situated in a large police station or a police laboratory and could serve a series of stations, each supplied with Etzlinger bags. Since seven or eight estimations may be performed on one breathalyzer per hour, 50 or 60 could conveniently be done during the "office hours" of a single day.

The bags are simple to use, both for the subject and the operator. Only a limited amount of co-operation is demanded of the subject in order to obtain an alveolar sample. No special precautions are required during storage or transportation, but pre-heating of the bags immediately before analysis must be adequate. The cupboard inside the breathalyzer, in its present form, is unsatisfactory for this, since it reaches a temperature of only 26–27° C., which is substantially lower than the mouth temperature of 34° C., and our analysis shows that results are more accurate when the bags are heated to a temperature

well above 34° C., so that at no time during the delivery process does the temperature of the breath fall below 34° C. and allow condensation of water and alcohol. However, the cupboard inside the breathalyzer could be raised to a higher temperature by some simple alterations in design which would not interfere with the parts of the instrument used for the alcohol analysis itself.

The degree of accuracy obtained with the bag samples depends upon the inherent accuracy of the breathalyzer as an instrument and upon special factors introduced by the use of bags. The regression equation in Fig. 2 shows that the bag readings are 16% lower than blood readings, whereas the direct breathalyzer samples are 13% low (Fig. 1). The "deficit" of alcohol in the analysis of the bags may be due to loss during storage, to inadequate heating prior to analysis, or to dilution with non-alcoholic air in the dead space of the tube leading into the breathalyzer, or to a combination of these factors. The fact that increasing the time interval between sampling and analysis (within the range 17–25 hours) led unexpectedly to an increase in readings, averaging 2.2 mg./100 ml./hour, suggests that alcohol was not being preferentially lost from the bag, but may have been preferentially retained at the expense of loss of air or water. This may seem inconsistent with the fact that the bags usually give a lower reading than direct breath, but in our previous trial, where some bags were analysed immediately after filling, it was found that the mere process of using a bag, without any delay, led to lower readings than direct breath. The facts are clearly difficult to explain, and we hope to perform a further experiment on this point. The dilution factor has also been reduced to a minimum in the latest Etzlinger model of the breathalyzer, and the larger plastic bag (approximately 400 ml.) ensures moderate flushing of the dead-space. Further enlargement of the bags might introduce breath which is not alveolar in origin.

The bags cannot be used in conjunction with the Kitagawa-Wright breath-alcohol detector in its present form, since this instrument automatically discards the first part of any breath sample which it receives—for example, a fixed volume of 500 ml.

The length of the column of reagent in the Kitagawa-Wright detector tube is apparently irrelevant. Kitagawa (1963) has stated that a correction should be made to the reading to allow for variations in column length (and therefore for density of packing), while Wright (1963) claims that in his experience "it is not, in fact, worth while making the correction," and our results support Wright's view.

However, the time which it takes to pump the alcoholic air through the detector-tube does need investigation; the time ranged from 1.6 to 10.5 minutes, and each additional minute added 3.9 mg./100 ml. to the reading on average. Fifty-one per cent. of the pumping-times fell within two to three minutes, and 88% within two to four minutes.

Summary

Breath-alcohol levels reflect blood-alcohol levels, since an equilibrium exists between pulmonary blood and alveolar air. Three methods of estimating breath alcohol have been studied:

the breathalyzer using samples collected directly, the breathalyzer using samples stored in plastic bags, and the Kitagawa-Wright method.

Various doses of distilled spirits were given to 18 healthy young men and the alcohol content of their alveolar air was measured each half-hour for several hours; using the three methods; venous blood was also analysed chemically for alcohol on three occasions in each subject, by the Nickolls method, at times when the arteriovenous difference would be negligible.

All three methods of breath analysis were suitable for practical use, the readings were reproducible, and they correlated well with blood analysis.

Experiments showed that the error in breath-alcohol readings due to alcohol in the mouth was negligible 15 minutes after the drink.

The merits of breath-alcohol analysis and of the breathalyzer, breathalyzer bags, and Kitagawa-Wright instrument are discussed.

This work was carried out under the auspices of the Medical Research Council's Working Party on the Comparability of Measurements of Breath and Blood Alcohol Content. We are grateful to the members for their encouragement, criticism, and advice, and in particular to Professor E. J. Wayne, Dr. B. M. Wright, and Dr. J. P. Bull. Dr. B. Bronte-Stewart, Director of the M.R.C. Atheroma Research Unit, kindly provided facilities. Generous help was provided by Miss A. G. Galloway, and thanks are due to Mr. Gabriel Donald (Western Infirmary, Glasgow) for photography of the diagrams. The multiple regression analysis was performed by the Mercury computer of the University of London Computer Unit, using a programme devised by Miss C. M. Devine. Miss I. Allen made some of the other calculations. We wish to thank our subjects, students and others, who volunteered so willingly for a tedious task. The members of the Working Party were: Professor E. J. Wayne (Chairman), Dr. J. P. Bull, Dr. Richard Doll, Professor G. C. Drew, Mr. L. C. Nickolls, Dr. E. Rentoul, Dr. R. J. Smeed, Dr. F. G. Tryhorn, Dr. B. M. Wright, and Dr. T. B. Begg and Mr. I. D. Hill (scientific secretaries).

REFERENCES

- Begg, T. B., Hill, I. D., and Nickolls, L. C. (1963). In *Alcohol and Road Traffic*, p. 277. B.M.A., London.
- Borkenstein, R. F. (1956). *Breath Tests to Determine Alcoholic Influence*. Indiana State Police Manual.
- and Smith, H. W. (1961). *Med. Sci. Law*, **2**, 13.
- Coldwell, B. B., and Smith, H. W. (1959). *Canad. J. Biochem.*, **37**, 43.
- Fox, B. H., Lower, J., and Fox, M. W. (1963). In *Alcohol and Road Traffic*, p. 261. B.M.A., London.
- Kitagawa, T. (1963). *Ibid.*, p. 246.
- and Wright, B. M. (1962). *Brit. med. J.*, **2**, 652.
- Lereboullet, J., Amstutz, C., Leluc, R., and Biraben, J. N. (1961). *Rev. Alcool.*, **7**, 81.
- Lins, G., and Raudonat, H. W. (1962). *Dtsch. Z. ges. gerichtl. Med.*, **52**, 242.
- Martin, E. (1958). Quoted by D. Monnier and W. Ruedi. *Rev. int. Criminol.*, 1958, **12**, 141.
- Monnier, D. (1961). *Chroniques internationales de Police*, No. 49.
- Nickolls, L. C. (1960). *Analyst*, **85**, 840.
- Smith, H. W. (1951). *J. Lab. clin. Med.*, **38**, 762.
- and Lucas, D. M. (1963). In *Alcohol and Road Traffic*, p. 189. B.M.A., London.
- Wright, B. M. (1963). *Ibid.*, p. 251.