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Evaluation of a Portable Measure of Expired-Air Carbon Monoxide[1]

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There are a variety of independent methods of estimating smoking status; measurement of expired air carbon monoxide has proven to be reliable and convenient. This article describes a new, inexpensive, portable analyzer for measuring expired-air carbon monoxide —the Bedfont EC50. We have compared this analyzer with the standard instrument for measuring expired-air carbon monoxide in 138 normal subjects and found good correlation and agreement. The Bedfont was demonstrated to be better at identifying smoking status, and the relevance of this finding for classification of smokers and nonsmokers by fixed-threshold carbon monoxide levels is discussed. The features of the Bedfont EC50 are particularly appealing for field and clinical use.

INTRODUCTION

Self-reported smoking has previously been shown to be unreliable (13). Therefore, an effective indirect measure of smoking is required for use in a variety of clinical situations such as antismoking clinics, risk factor screening, and outpatient departments.

Smoking levels may be estimated by measuring the components or byproducts of inhaled cigarette smoke in the serum, saliva, or urine, and the biochemical markers thiocyanate (SCN), cotinine, nicotine, and carboxyhemoglobin (COhb) have been used (2, 5, 10, 12, 16). These methods have several disadvantages. They are expensive, in terms of both equipment and laboratory time, invasive, or inconvenient, resulting in subject noncompliance.

The amount of carbon monoxide (CO) in expired alveolar air after breath holding is well correlated with COhb (7, 8) and therefore provides a convenient, noninvasive, rapid measurement of cigarette smoking. The Ecolyzer Series 2000 analyzer (produced by Draeger Ltd., Hemel Hempstead, Hertfordshire) has been the traditional analyzer used for several years (7). The Ecolyzer employs an inbuilt pump to draw expired air across the sensor.

Recently, a new analyzer designed to measure end-expired (alveolar) CO has become available, the Bedfont EC50 analyzer (produced by Bedfont Technical Instruments Ltd., Sittingbourne, Kent.[3]). This analyzer has several advantages—it is small, battery-powered, and therefore easily portable. It also has a digital

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display that is read easily and eliminates observer error due to digit preference. Previously, these features were available in analyzers designed initially for use as measures of ambient CO in an industrial setting; they were subsequently modified to measure expired-air CO (1). The EC50 at a cost of £375 ($895) is considerably less expensive than the Ecolyzer, priced at £2,350, and calibration is required infrequently. The Bedfont samples CO by diffusion from expired air trapped over the sensor in a one-way valve. The Bedfont EC50 features an inbuilt alcohol filter, whereas such a filter is available only as an optional extra for the Ecolyzer.

This article describes a comparison of expired-air CO measurements in a sample of normal subjects using the Bedfont EC50 and Ecolyzer.

METHODS

The subjects were healthy men and women, ages 40–59 years, randomly sampled from the Primary Care Registers as part of the Scottish Heart Health Study (14). Subjects completed a questionnaire that included details of their smoking history. Expired-air CO was recorded using the Jarvis protocol (7) in which subjects are asked to exhale fully, inhale deeply, and hold their breath for 20 sec before exhaling rapidly into a disposable mouthpiece. Readings were obtained with both analyzers, the order being alternated for each subject. Background CO values were obtained for both machines prior to the subject readings with each analyzer. The subject readings were determined by subtracting the background level from the observed reading.

Prior to the start of the study, both analyzers were calibrated with a gaseous mixture containing 50 ppm of CO in accordance with the manufacturers' instructions. In addition, the Ecolyzer required further calibrations as directed in the operating manual. Throughout the study CO levels were measured by four operators—all trained in the technique. During the study the Ecolyzer was used with an alcohol filter. Preliminary investigations showed that neither machine was affected by breath alcohol or by levels of hydrogen likely to be encountered.

RESULTS

Over a 3-week period, expired-air CO readings were collected from 138 men and women, 43% of whom were self-reported smokers. During the study period the EC50 proved reliable and easy to use by both the operator and subject. The Ecolyzer had problems associated with its use due to the need for frequent calibration and the difficulty in reading the scaler display.

The mean background CO levels and the subject levels for smokers and nonsmokers for the Ecolyzer and the EC50 are given in Table 1. The two estimates of subject CO do not differ significantly when compared by a paired t test and are highly correlated ($r = 0.96$ $P < 0.001$) and show a good level of agreement (see Fig. 1). The line of best fit has a slope of 1.00 and an intercept of -0.60. Both self-reported smokers and nonsmokers fall on the same curve. The relative performance of the machines in discriminating self-reported smoking status is given in Table 2, which shows the percentage of smokers and nonsmokers correctly identified over a range of threshold levels of expired-air CO. The two machines

TABLE 1
COMPARISON OF THE MEASURES OF CARBON MONOXIDE (CO)

	Bedfont EC50		Ecolyzer	
	Mean	SD	Mean	SD
Background CO (ppm)	1.3	1.4	1.7	1.7
Smokers CO (ppm)	24.5	14.2	23.5	16.3
Nonsmokers CO (ppm)	2.7	1.7	2.4	1.9

are broadly similar, but the Bedfont EC50 shows slightly less disagreement with reported smoking.

The relation between reported cigarette consumption and expired-air CO levels for the two machines is given in Fig. 2. A clear dose–response relationship is seen, although there is some overlap in the spread of the observations, particularly at the higher smoking levels.

There is poor correlation between the two measures of background CO (r = 0.11, P = 0.089) and the two populations differ significantly ($P < 0.05$) when compared by paired t test. The difference in background readings between the two instruments is small (mean 0.38 ppm, range −6 to +4) and may result from the several methodological and technical differences between the two machines. A possible major source of the differences in background may arise from the different methods of drawing a sample. The Ecolyzer uses an active pump which

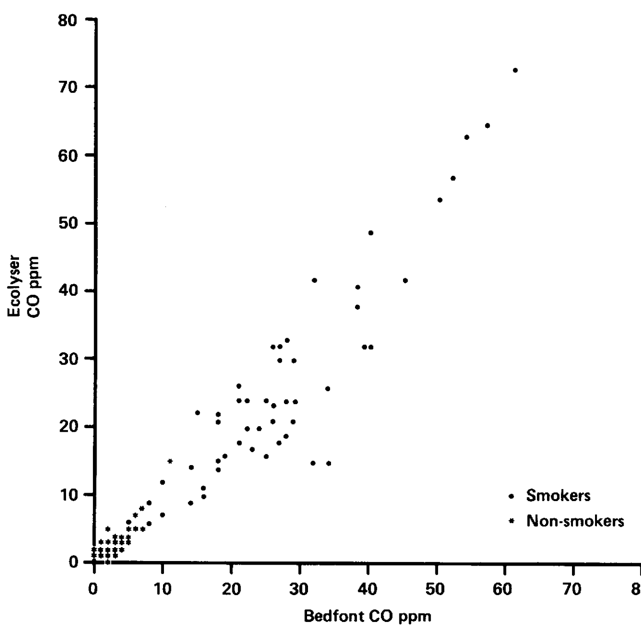

FIG. 1. Comparison of subject expired-air CO by Ecolyzer and Bedfont. (Superimposed points not shown.)

TABLE 2
COMPARISON OF SELF-REPORTED SMOKING AND CLASSIFICATION BY EXPIRED-AIR CARBON MONOXIDE THRESHOLDS

	Bedfont EC50		Ecolyzer	
Threshold CO level ppm	% Smokers correctly identified	% Nonsmokers correctly identified	% Smokers correctly identified	% Nonsmokers correctly identified
0	100.0	0.0	100.0	0.0
4	93.2	88.0	91.5	92.3
8	86.3	98.6	83.0	98.7
12	81.1	100.0	74.5	98.7
16	72.5	100.0	62.6	100.0

continually refreshes the sensor, whereas the Bedfont relies upon diffusion. Thus, there may be a carryover effect from the previous subject reading. However, no such relationship between the previous reading and the background was found, even when the time interval between these readings was small (<10 min).

The EC50 shows a small but significant drop, independent of change in room temperature, during the course of the working day (see Fig. 3). In contrast, the Ecolyzer backround readings show a nonsystematic variation. During the 3-week study period reported here, the single Ecolyzer used was calibrated three times. No adjustment was made to the Bedfont EC50. A change in the calibration or a change of operator caused significant variation in the Ecolyzer background

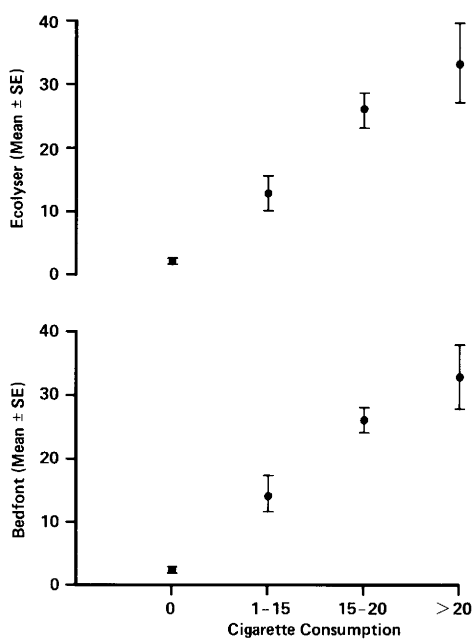

FIG. 2. Relation between expired-air CO and self-reported cigarette consumption.

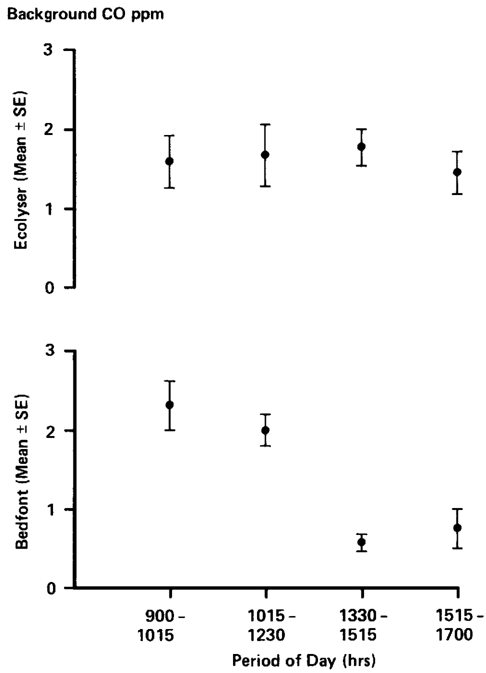

FIG. 3. Relation between background air CO and period of day.

reading ($P < 0.001$) when compared by a one-way analysis of variance. No such variation was seen with the Bedfont readings.

DISCUSSION

The two measures of expired-air CO show a high level of agreement, although the Bedfont shows a better ability to identify smokers at low threshold levels of CO.

The daily variation in background CO recorded by the EC50 is similar to the diurnal variation in indoor and outdoor background CO which has been extensively reported (6, 9). No such pattern is seen with the Ecolyzer. The systematic variation in background CO, thought to reflect road traffic exhaust emissions, demonstrates the unsuitability of using fixed predefined background values that have been used elsewhere (15). Although other causes for the difference in estimation of background CO cannot be excluded, the lack of diurnal variation of Ecolyzer background CO may reflect the imprecision discussed earlier. This slight difference in precision is relatively unimportant when comparing groups of smokers and nonsmokers (see Table 1) but could lead to the incorrect classification of individuals when low thresholds, i.e., 8 ppm, of CO are used to separate smokers and nonsmokers (4, 11, 16). Variation about the threshold value, induced by any inaccuracy or imprecision in the method of measurement, could easily affect allocation of individual smokers and nonsmokers (see Table 2). If 8 ppm is used to distinguish smokers and nonsmokers, the two machines differently allocate three individuals. While this level of disagreement is small, the Ecolyzer's imprecision becomes a particular problem when even lower threshold readings are required, for instance, when groups of relatively infrequent smokers are considered, i.e., school children (3), and in checking compliance at smoking cessation clinics.

CONCLUSION

Estimates of CO levels were obtained from 138 subjects using the Bedfont EC50 and the Ecolyzer. Both measures of expired-air CO showed a clear dose–response relationship with cigarette consumption, were highly correlated, and showed a good level of agreement. The Ecolyzer showed slightly less agreement with reported smoking than the Bedfont EC50 and did not detect the diurnal variation in ambient CO. This may reflect an apparent lack of discrimination that may be a problem near threshold values for classification of individuals as smokers. Though the reported study has a restricted age range, it is probable that the findings are applicable to both younger and older individuals.

The sensor used in the EC50 is highly stable unlike that in the Ecolyzer which requires weekly calibration. Adjustment appears to induce variation in CO readings. The EC50 is insensitive to breath alcohol without the use of the external filters required by the Ecolyzer. These features in combination with the low cost, ease of use, portability, and digital display make the Bedfont EC50 an attractive device for use in large field studies and in other clinical areas.

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