Exhaled Carbon Monoxide Level as an Indicator of Cigarette Consumption in a Workplace Cessation Program in Taiwan

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Background: Smoking cessation programs are critical to the safety and health of workers. Exhaled carbon monoxide (CO) is an effective indicator of smoking in clinics and hospitals. Its application in the community and workplace, however, remains limited. This study assessed whether exhaled CO concentration can be used as an objective indicator of the amount of daily cigarette consumption among smokers in the workplace in Taiwan.

Methods: A total of 150 workers from a chemical manufacturer in Taiwan were included; there were 27 nonsmokers and 123 current smokers. The number of cigarettes smoked daily by each subject was reported, and exhaled CO concentration was measured in each subject using the Micro CO meter (Micro Medical Ltd, Chatham, Kent, UK).

Results: Exhaled CO levels were associated with the number of cigarettes consumed daily, with a correlation coefficient of 0.73 ($p < 0.01$) and an adjusted R-square (simple linear regression model) of 0.44. The mean exhaled CO level of nonsmokers was 4.2 ppm (95% confidence interval, 3.3–5.1). A reading of > 6 ppm had a sensitivity of 84% and specificity of 85% in detecting workplace smoking.

Conclusion: Exhaled CO level can be used as an objective, noninvasive indicator to determine the smoking status of an individual in the workplace. [*J Formos Med Assoc* 2006;105(3):210–213]

Key Words: cigarette, exhaled carbon monoxide, smoking cessation, workplace

Despite the fact that smoking is associated, both etiologically and prognostically, with numerous diseases, the prevalence of smoking remains high in Taiwan, with adult smoking prevalence at 45.9% and 6.2% for males and females, respectively.[1] Consequently, the implementation of effective smoking cessation programs is very important; such programs require a valid and convenient method of monitoring smoking status to assess program effectiveness. In addition, demonstration of the immediate and potentially harmful consequence of smoking by using a portable device might increase a smoker's compliance with the cessation program.[2]

Some methods for distinguishing smokers from nonsmokers, such as the measurement of nicotine, cotinine, or thiocyanate levels in the plasma or urine, are either invasive or time consuming.[3] Exhaled carbon monoxide (CO) level is well correlated with blood carboxyhemoglobin level;[4–6] it has also been reported to be highly correlated with smoking status, and measuring exhaled CO level using a portable and noninvasive CO monitor has been widely adopted for assessing individuals' smoking status.[2,3,7]

The Tobacco Hazards Prevention Act was promulgated in Taiwan in 1997, and a series of smoking cessation programs were implemented both

officially and privately.[8,9] Questions regarding daily cigarette consumption are often asked throughout the course of such programs. However, many smokers deny or under-report their real cigarette consumption, making it impossible to obtain an accurate assessment.

Smoking cessation programs are especially important in the workplace, particularly in chemical manufacturing, due to the additional safety concerns. Smoking behavior in the workplace is often subjected to additional restrictions compared to that in the community, usually for safety reasons. Workers tend to smoke less during working hours than during other activities. This might affect the exhaled CO level measured in the workplace.

The objective of this study was to evaluate the feasibility of using exhaled CO monitoring to assess the smoking status among workers in a chemical manufacturing plant, as part of a workplace smoking cessation program.

Methods

In 2003, a smoking cessation program was conducted in a chemical manufacturing plant employing 300 workers in Taiwan. A total of 150 workers were recruited to participate in the program. Among them, 27 were nonsmokers and the other 123 were current smokers. A nonsmoker was defined as an individual who had not smoked for at least 1 year before the study, and a smoker was defined as an individual who had smoked regularly in the past 1 year. Worksite smoking prohibition at the chemical manufacturing plant had been a company policy enforced since 1997, and workers were only allowed to smoke in designated smoking areas outside of buildings. All subjects were informed of the purpose of the study, and they were reassured that the results would be kept confidential to encourage accurate reporting of smoking history. They were asked about their medical and smoking histories. Exhaled CO level was measured in parts per million (ppm) using a Micro CO meter (Micro Medical Ltd, Chatham, Kent, UK). Prior to the study, the CO meter was calibrated with a mixture of 50 ppm CO in air. Subjects were asked not to smoke for at least 1 hour before CO measurement. Subjects were instructed to exhale completely, inhale fully, hold their breath for 15 seconds, and then to exhale rapidly into a disposable mouthpiece, from which the reading of CO level can be directly obtained. The measurement was performed twice. There was no passive smoking in the workplace, and the mean ambient CO concentration during the study period was 0.4 ppm (as detected in the nearby monitor station).

Statistical analysis

All statistical analyses were conducted using SAS version 8.2 (SAS Institute Inc, Cary, NC, USA). Descriptive summary statistics, Spearman's correlation analyses, and simple linear regression model were used to evaluate the relationship between exhaled CO level and the amount of daily cigarette consumption. The CO concentration giving the optimum sensitivity and specificity was selected as the cut-off point for differentiating smokers from nonsmokers using a two-by-two table.

Results

The age, weight, and height of subjects in the smoking and nonsmoking groups are shown in Table 1. All subjects were male. According to their medical records, none of the subjects had any significant respiratory or cardiovascular diseases. The mean amount of daily cigarette consumption (± standard deviation) among the current smokers was 14.7 ± 7.5 cigarettes/day. Exhaled CO levels were detectable in all subjects. Table 2 shows

Table 1. Age, body weight and height of subjects*

	Smokers (*n* = 123)	Nonsmokers (*n* = 27)
Age, yr	39.8 ± 6.0	43.7 ± 7.6
Weight, kg	71.7 ± 10.6	67.9 ± 8.2
Height, cm	167.9 ± 6.7	165.3 ± 5.4

*All subjects were male, and none had any significant respiratory or cardiovascular diseases. Data presented as mean ± standard deviation.

Table 2. Mean exhaled carbon monoxide (CO) level of subjects with different smoking status

Smoking status	Mean number of cigarettes consumed per day (SD)	Mean exhaled CO level, ppm (95% CI)
Nonsmoker (n = 27)		4.2 (3.3–5.1)
Smoker (n = 123)		
1–10 cigarettes/day (n = 49)	7.4 (2.5)	9.1 (7.9–10.3)
11–20 cigarettes/day (n = 65)	18.0 (2.8)	18.1 (16.5–19.6)
> 20 cigarettes/day (n = 9)	29.1 (5.0)	20.3 (12.4–28.3)

the mean exhaled CO levels of the subjects with different smoking status. The mean exhaled CO level of nonsmokers was 4.2 ppm (95% confidence interval, 3.3–5.1). A CO reading > 6 ppm suggested that the individual might be a smoker with a sensitivity and specificity of 84% and 85%, respectively. There was a significant positive correlation between exhaled CO level and the self-reported amount of daily cigarette consumption ($r = 0.73$, $p < 0.01$, Spearman's test). The regression coefficient in the simple regression model was 0.70 (F value = 97.1, $p < 0.01$, adjusted R-square = 0.44) (Figure).

Discussion

Although many factors might affect exhaled CO level, the most likely cause of high levels of

CO exposure is smoking.[2] The time period between the last cigarette smoked and CO measurement is an important consideration in individual smoking status according to the exhaled CO level. This might explain why the mean exhaled CO level of those consuming 1–10 cigarettes a day was significantly lower than the mean exhaled CO level of those consuming > 10 cigarettes a day in this study. In contrast, there was no significant difference in mean exhaled CO levels between individuals consuming 11–20 cigarettes a day and those consuming > 20 cigarettes a day (Table 2). Those consuming more cigarettes tend to visit the smoking areas and smoke during working hours, which explains their higher exhaled CO levels measured in the workplace. However, because of the limitation of time, individuals who generally smoke > 20 cigarettes a day might not easily smoke more than those who smoke 11–20 cigarettes a day during working hours.

Jarvis et al studied 211 hospital outpatients and reported that the optimal cut-off to differentiate a smoker from a nonsmoker was 8 ppm, with a sensitivity and specificity of 90% and 89%, respectively.[3] Wald et al studied 11,249 men aged 35–64 years attending a medical center for health screening examination and also reported that a cut-off of 1.5% COHb in the blood (which corresponds to an exhaled CO level of approximately 8 ppm) differentiated a smoker from a nonsmoker with a sensitivity of 86% and specificity of 96.6%.[5] In other studies using exhaled CO monitors, a CO level of 10 ppm was used as the cut-off.[10,11] However, our results suggest that such a high cut-off level might reduce the sensitivity of CO monitoring, as a better diagnostic value
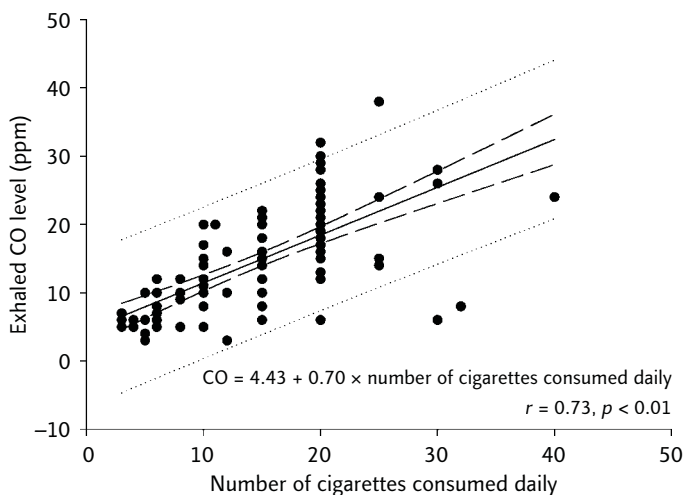

Figure. Correlation between exhaled carbon monoxide (CO) levels and the number of cigarettes consumed daily in 123 current smokers. The dashed lines indicate the 95% confidence interval, and the dotted lines indicate the 95% prediction interval.

CO = 4.43 + 0.70 × number of cigarettes consumed daily
$r = 0.73$, $p < 0.01$

was obtained at a CO cut-off of 6 ppm, in accordance with the work of Middleton and Morice, who also showed that a cut-off level of exhaled CO of 6 ppm detected 94% of smokers and 96% of nonsmokers in a respiratory outpatient clinic.[2] Because smoking behavior in the workplace is different from that in the community, we did misclassify smokers as nonsmokers. Consequently, the sensitivity of the best cut-off point to differentiate smokers from nonsmokers in this study was only 84%.

In conclusion, this study supports a good correlation between exhaled CO level and daily cigarette consumption in the workplace in Taiwan. The exhaled CO monitor can be used to monitor smoking status, and can be combined with a smoking cessation program for health promotion. A reading of > 6 ppm is a good cut-off point that strongly indicates that an individual is a current smoker.

Acknowledgments

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