Pharmacology Biochemistry & Behavior, Vol. 31, pp. 93–96. © Pergamon Press plc, 1988. Printed in the U.S.A. 0091-3057/88 $3.00 + .00

Carbon Monoxide Exposure From Commercial Brand Cigarettes Under Controlled Smoking Conditions

LINDA L. WEINHOLD,[1] MAXINE L. STITZER AND JOHN E. YINGLING

Department of Psychiatry & Behavioral Sciences
The Johns Hopkins University School of Medicine, Baltimore, MD 21224

Received 28 September 1987

WEINHOLD, L. L., M. L. STITZER AND J. E. YINGLING. *Carbon monoxide exposure from commercial brand cigarettes under controlled smoking conditions.* PHARMACOL BIOCHEM BEHAV **31**(1) 93–96, 1988.—Carbon monoxide (CO) exposure from ultralow-, low- and high-CO delivery commerical cigarettes was examined under controlled smoking conditions. Seven chronic smokers of mid- to high-CO delivery commercial cigarettes served in the experiment. CO level increases of 2.10, 5.76 and 7.38 ppm were obtained from ultralow-yield (1.6 mg CO delivery), low-yield (5.9 mg CO delivery) and high-yield (14.3 mg CO delivery) cigarettes, respectively. Subjects achieved significantly higher increases in CO levels from both low- and high-yield cigarettes than from ultralow-yield cigarettes, but increased levels of CO from low- and high-yield cigarettes were not different from each other. The data suggest that degree of CO absorption by the lungs during a short period of time may limit increases in CO levels obtained from high-yield cigarettes.

Carbon monoxide Cigarettes Cigarette smokers Smoking topography

THE Federal Trade Commission's (FTC) machine method of determining nicotine, tar and carbon monoxide (CO) deliveries of commercial brand cigarettes has revealed that cigarettes with a broad range of smoke constituent characteristics are available to consumers. Previous studies have employed both basal body burden (i.e., afternoon levels not immediately postsmoking) and acute increases in CO level (i.e., post- minus presmoking) to determine how cigarette constituent yields affect biological exposure. In general, body burden measures of expired breath CO obtained from smokers who have not switched brands (3–5) and smokers who have switched brands (6) have revealed no significant differences in expired breath CO associated with cigarette CO delivery. In these studies, however, smoking behaviors, including cigarettes smoked per day, have been free to vary and may have been an important determinant of levels from cigarettes with different CO deliveries.

In contrast to chronic ad lib smoking, acute measures following a single cigarette more closely approximate the FTC method of determining cigarette CO delivery and eliminate some of the smoking behavior changes which may be confounded with cigarette CO delivery during chronic ad lib smoking. In one study, subjects who showed no difference in body burden expired CO levels after chronic smoking (6) showed a four-fold difference in increased levels of CO when they smoked single cigarettes with high- (>15 mg) versus very low- (1–3 mg) CO yields. Thus, increased levels of CO following a single cigarette, in contrast to basal body CO measures, appear to more closely approximate the relative between-brand CO exposures predicted by FTC testing information.

The effects of individual differences in smoking behaviors on increased levels of CO can be further reduced by employing puff and respiratory control procedures. Instrumentation in our laboratory, as previously described (10), allows for control and on-line measurement of: puff volume, puff duration, interpuff interval, inhalation volume and lung exposure time. The present investigation was conducted to measure the effects of cigarette CO delivery on acute biological exposure to CO for subjects under controlled smoking conditions. Subjects smoked high-, low- and ultralow-CO yield cigarettes while puffing intensity (i.e., puff volume, puff number and interpuff interval) and respiratory involvement (i.e., inhalation volume, inhalation duration and lung exposure duration) were controlled across trials. The purpose of the study was to determine whether relative CO exposure levels measured in human subjects under these controlled puffing conditions would approximate relative exposures predicted by cigarette yield characteristics derived from smoking machine procedures.

METHOD

Subjects

Two female and five male subjects served in the experiment, mean age, 38.28 (range, 23–47 years old). All subjects

[1]Requests for reprints should be addressed to Linda L. Weinhold, National Institute on Drug Abuse, Addiction Research Center, P.O. Box 5180, Baltimore, MD 21224.

were cigarette smokers (mean years smoking, 21.71, range, 10–37); mean number of cigarettes smoked daily, 39.28 (range 25–60). Their usual brand of cigarettes delivered from mid- to high-yields of tar, nicotine and carbon monoxide as determined by the FTC method (2), with mean values of 15.38 mg tar, 0.98 mg nicotine and 13.98 mg carbon monoxide, respectively. Subjects were recruited by newspaper advertisements and paid $5.00 per hour for participation in the experiment.

Cigarettes

Subjects smoked ultralow- (Carlton), low- (Vantage Ultra-Lights) and high- (Camel filter) yield cigarettes during daily smoking sessions. Average smoke constituents of Carlton, Vantage Ultra-Lights and Camel filter cigarettes were reported by the FTC (2) to be: tar 1.3 mg, 4.7 mg, 15.6 mg, nicotine 0.11 mg, 0.43 mg, 1.07 mg and carbon monoxide 1.6 mg, 5.9 mg, 14.3 mg, respectively. Variability (standard deviations) in smoke constituents of Carlton, Vantage Ultra-Lights and Camel filter cigarettes were reported by the FTC (2) to be: tar 0.05 mg, 0.1 mg, 0.15 mg, nicotine 0.005 mg, 0.01 mg, 0.015 mg and carbon monoxide 0.1 mg, 0.1 mg, 0.15 mg. Cigarettes were stored under refrigeration and maintained at room temperature 15 min prior to smoking sessions.

Apparatus

Smoking was recorded by an Apple IIe computer which received input from behavioral monitoring equipment. A miniature flowmeter cigarette holder was used to measure puffing parameters. Negative oral pressure activated a pressure sensitive switch for puff duration measurement. A small orifice in the flowmeter provided a differential pressure proportional to flow rate which was amplified and integrated to yield the puff volume measure. The flow meter-Apple IIe system was calibrated daily by using a 60 ml syringe to withdraw eight 50 ml puffs of smoke from a Marlboro Flip-Top Box cigarette.

Respiratory activity was measured by a Respitrace Calibrator through two plethysmograph belts worn by the subject. This commercially available instrument (Respitrace Corp) detects gross abdominal and chest movement. The resultant biphasic analog output was sampled through an analog/digital converter by the Apple IIe computer that calculated the desired measures. Prior to each trial, the Respitrace-Apple IIe system was calibrated by having subjects rebreath into 800 ml capacity Spirobags.

Procedures

Each subject participated in six daily laboratory smoking sessions consisting of four trials per day. Subjects were seated in a well-ventilated, enclosed room containing a television set and monitoring equipment. For each trial, subjects received one prelit cigarette which was smoked through the flowmeter holder.

To facilitate consistent baseline CO levels, deprived subjects (abstinent from cigarettes for at least 30 min) smoked one high-yield cigarette under ad lib conditions during the first trial of each daily smoking session. Comparative assessment of increased levels of CO obtained from ultralow-, low- and high-yield cigarettes was conducted during trials two through four. Order of cigarette yield was counterbalanced across dosage and subjects. All trials were sequenced so that at least 25 min elapsed between the last puff from a prior cigarette to the first puff from a subsequent cigarette. Subjects did not smoke between trials.

Smoking was conducted either under ad lib or controlled conditions on an every-other-day basis. During ad lib trials subjects were instructed to smoke freely and the experimenter left the session room. Data from ad lib trials are not presented in this report.

Controlled trials consisted of eight puff-respiratory cycles. A verbal cue signaled puff onset (at 45 sec interpuff intervals). Feedback for puff volume, inhalation volume and lung exposure time was provided by the Apple computer which summed volume measures in real time and emitted a beep when pre-set parameters were reached. Subjects were trained to continue drawing on the cigarette until the first beep (set to obtain 50 ml puff volume), then inhale the smoke and continue to the second beep (set to obtain 25 percent vital capacity inhalation volume), finally to hold the smoke in their lungs to the third beep (set to obtain 12 sec lung exposure duration, LED) prior to exhaling the residual smoke.

Smoking Behavior Measures

Through software programming, puff-respiratory cycles were recorded in real time from puff onset (initial negative oral pressure applied to the flowmeter cigarette holder) through exhalation of smoke from the lungs (the lowest potential Respitrace signal following the puff). During the puff-respiratory cycle, the following measures were provided by the flowmeter holder-Apple II system: 1) *puff number*—number of puff onsets, 2) *interpuff interval*—time from puff offset (end of negative oral pressure applied to the flowmeter cigarette holder) to next puff onset, and 3) *puff volume*—integrated differential pressure signal from puff onset through puff offset. The following measures were provided by the Respitrace-Apple II system: 1) *inhalation duration*—time elapsed from puff offset to peak amplitude of Respitrace signal, 2) *inhalation volume*—calibrated value of Respitrace output during inhalation duration, and 3) *lung exposure duration*—time elapsed from inhalation onset through appearance of the minimum amplitude of Respitrace signal concomitant with exhalation offset. Exhalation duration and exhalation volume were recorded but were not included in the data analysis. Table 1 shows target smoking parameter values and average values obtained during the study.

Increases in Levels of Carbon Monoxide (CO)

Two CO samples were obtained from each subject immediately preceding and two min following every smoking trial. Subjects were instructed to invoke a full expiration-inspiration cycle and breath hold. After a twenty sec breath hold duration, subjects expired air into two 1 liter bags. The second 1 liter bag, which contained expired air in proximity to the alveoli, was analyzed for CO content using an Ecolyzer 2000 (Energetics Science, Elmsford, NY). A 20 sec breath hold duration, analysis of the second 1 liter bag for CO and Ecolyzer instrumentation were previously recommended for use in CO collection and measurement (1, 7–9).

Vital Capacity

Vital capacity measures were obtained to grossly assess respiratory status of research subjects and to determine 25 percent vital capacity for inhalation volume values employed during controlled trials. Vital capacity was determined by

TABLE 1

PUFF AND RESPIRATORY MEASURES DURING CONTROLLED SMOKING SESSIONS

	Projected Values	Obtained Values* Nominal CO Dose (mg)† 1.6	(0.1)	5.9	(0.1)	14.3	(0.2)
Number of Puffs	8	8.0	(0.3)	8.0	(0.2)	8.0	(0.3)
Inter-Puff Interval (sec)	45	46.2	(1.0)	45.8	(1.8)	45.2	(2.6)
Puff Volume (ml)	50	51.2	(2.2)	51.0	(3.6)	50.8	(1.6)
Inhalation Volume (ml)	918‡	942.5	(70.5)	903.3	(111.2)	950.7	(115.8)
Lung Exposure (sec)	12	11.4	(1.2)	10.9	(0.7)	11.7	(1.2)
Inhalation duration (sec)	—	2.5	(0.6)	2.7	(0.8)	2.7	(0.9)

*Mean (±s.d.).
†Values reported in FTC, 1985 (±s.d.).
‡Average of 25% vital capacity values for study subjects.

instructing subjects to invoke a forced expiration-inspiration cycle, thereafter fully exhaling into a water spirometer. The process was repeated three times. Of the subjects who served in the experiment, mean vital capacity was 3671 ml with a range of 3100–4600 ml, respectively.

Data Analysis

Two-way (Dose × Time) ANOVAs with repeated measures on both factors were conducted on data obtained during controlled trials. Dose refers to cigarette CO delivery (nominally 1.6, 5.9, 14.3 mg) and time signifies order of cigarette dose presentation. Thus, 2×3 repeated measures ANOVAs were conducted for: 1) three puff parameters (puff frequency, interpuff interval, puff volume), 2) three respiratory parameters (inhalation volume, inhalation duration, lung exposure duration) and 3) expired carbon monoxide increases in levels of CO (post minus precigarette). Where indicated, Tukey post-hoc comparisons were conducted.

RESULTS

Smoking Topography

As shown in Table 1, subject adherence to control feedback systems resulted in obtained smoking parameter values that were very similar to target values. Further, there were no significant differences across cigarette types for puff number, $F(2,12)=0.33$, $p>0.05$, puff volume, $F(2,12)=0.12$, $p>0.05$, interpuff interval, $F(2,12)=0.50$, $p>0.05$, inhalation volume, $F(2,12)=1.89$, $p>0.05$, inhalation duration, $F(2,12)=0.78$, $p>0.05$, or lung exposure duration, $F(2,12)=0.94$, $p>0.05$. Thus, adequate control over smoking behavior was achieved by the biofeedback system.

Postsmoking Carbon Monoxide Increases

Figure 1 shows mean CO increases achieved by subjects following controlled smoking trials with ultralow- (1.6 mg CO), low- (5.9 mg CO) and high- (14.3 mg CO) yield cigarettes. These increases were 2.10, 5.76 and 7.38 CO ppm, respectively. There was a significant dose effect of CO yield on CO increases, $F(2,12)=37.66$, $p<0.01$. Subjects achieved significantly larger increases in levels of CO from both low- and high-yield cigarettes than from ultralow-yield cigarettes ($Q>8.32$, $p<0.01$), but CO increases from low- and high-yield cigarettes were not different from each other.

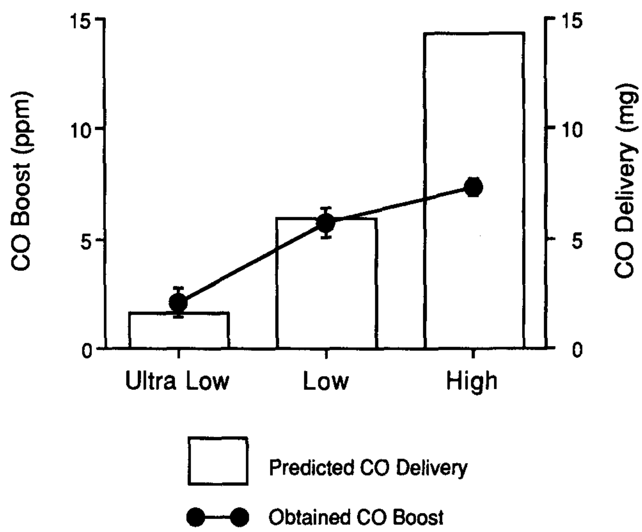

FIG. 1. Predicted CO delivery (per cigarette by FTC machine method) versus obtained CO boost (pre- minus postcigarette expired air) from ultralow-, low- and high-CO delivery cigarettes during controlled sessions.

DISCUSSION

This study used a controlled smoking procedure to examine acute carbon monoxide exposure from commerical brand cigarettes with a wide range of carbon monoxide delivery characteristics. The study showed that increased levels of carbon monoxide (CO) obtained from cigarette smoking were related to the dose delivery characteristics of the cigarette.

Thus, CO level increases of about 2 and 6 ppm were obtained from ultralow-yield and low-yield cigarettes with nominal CO deliveries of 1.6 and 5.9 mg, respectively. The relative extent of acute CO exposure for these two particular cigarette brands was very close to relative exposures as predicted from FTC smoking machine determinations. However, FTC yield information did not accurately predict relative carbon monoxide exposure from high-yield cigarettes (14.3 mg nominal CO delivery) where the observed average increase in CO level of 7.4 ppm was smaller than expected in relation to levels seen after exposure to lower yield cigarettes.

The FTC method of determining yield characteristics is not expected to predict absolute constituent exposure doses from smoking, since individual exposure is affected by a variety of factors including individual differences in smoking behavior (e.g., total smoke dose drawn and inhaled, percent of smoke exhaled), individual differences in the absorption and elimination of smoke constituents and variability in CO delivery across packs of commerical cigarettes. However, it seems reasonable to suppose that yield characteristics should predict relative acute exposure levels obtained from cigarettes with different delivery characteristics. In several studies of regular smokers whose cigarettes span a range of delivery characteristics, there have generally been no major differences noted in chronic exposure levels, particularly for the CO constituent (3–5). This may be explained, however, by increases in the number of cigarettes used and/or the intensity of puffing in low-yield cigarette smokers. When the amount of smoke obtained from each cigarette is controlled, as in the present study, then exposure levels should more accurately reflect yield characteristics.

In the present study, CO increases from the ultralow-yield cigarettes were significantly smaller than from either of the higher-yield cigarette types. This may reflect a very low concentration of CO delivered by cigarettes that utilize extensive filter ventilation to achieve ultralow-yield characteristics. More difficult to explain is the observation that CO obtained from a high-yield brand delivering nominally 14 mg CO was virtually identical to CO increases obtained from a low-yield brand whose nominal delivery was about 6 mg CO in spite of the fact that the amount of smoke drawn from the cigarettes was controlled in the experimental procedure. A possible explanation may lie in the dynamics of CO absorption from the lungs. In the smoking machine determination of CO yield, all the CO available in smoke drawn from the cigarette is measured. Previous research from our laboratory has suggested, however, that human smokers may not absorb all the available carbon monoxide from a smoke bolus. In contrast to nicotine, which seemed to be absorbed within the first few seconds of lung exposure time, carbon monoxide exposure levels were increased by breath holding in an experiment that utilized high-yield cigarettes (10).

If excess CO in the lungs is absorbed at a constant rate until equilibrium with the blood concentration is reached, then differences across brands delivering different CO doses per puff may emerge only over longer durations of lung exposure time. The current line of reasoning predicts that measured CO levels would continue to rise over a broad range of lung exposure times when the cigarette delivers a very high CO dose but that CO from lower-yield cigarettes would asymptote more quickly as all the available CO is absorbed. This prediction could be examined experimentally in a study that manipulates breath hold time while holding other smoking behavior parameters constant.

In summary, results from the present investigation indicate that chronic smokers studied under controlled puffing conditions show acute CO increases which are directly related to nominal cigarette CO deliveries, with relative exposure being especially precise at the lower end of the CO delivery range (i.e., for ultralow- and low-yield cigarettes). However, it appears that smokers do not achieve predicted levels of CO exposure from cigarettes with high nominal CO deliveries (CO 14–15 mg and greater). The data suggest that degree of CO absorption by the lungs during a short period of time may limit CO exposure from high-yield cigarettes. These dynamics of CO absorption may in part explain the observation that basal CO levels of chronic smokers is poorly related to cigarette CO delivery. Thus, CO exposure and the hazards associated with it appear to be similar across cigarettes with a broad range of nominal CO yields, with the possible exception of ultralow-yield cigarettes.

ACKNOWLEDGEMENTS

This research was supported by National Cancer Institute grant 5 RO1 CA 3776 and USPHS grant T 32 DA 07209.

REFERENCES

1. Biglan, A.; Magis, K.; Dirocco, A.; Silverblatt, A. First versus second portion of expired air and duration of breath holding in the sampling of expired air carbon monoxide. Br. J. Addict. 81:283–286; 1986.
2. Federal Trade Commission Report. "Tar", nicotine, and carbon monoxide of the smoke of 207 variations of domestic cigarettes. January, 1985.
3. Jaffe, J. H.; Kanzler, M.; Cohen, M.; Kaplan, T. Inducing low tar/nicotine cigarette smoking in women. Br. J. Addict. 73:271–281; 1980.
4. Jaffe, J. H.; Kanzler, M.; Friedman, L. Studies of switching to low tar and nicotine cigarettes. In: Gori, G. B.; Beck, F. G., eds. Banbury reports 3: A safe cigarette. Maine: Cold Spring Harbor Laboratories; 1980:311–323.
5. Maron, D. J.; Fortman, S. P. Nicotine yield and measures of cigarette smoke exposure in a large population: Are lower-yield cigarettes safer? Am. J. Public Health 77:546–549; 1987.
6. Ossip-Klein, D. J.; Epstein, L. H.; Winter, M. K.; Stiller, R.; Russell, P.; Dickson, B. Does switching to low tar/nicotine/carbon monoxide-yield cigarettes decrease alveolar carbon monoxide measures? A randomized trial. J. Consult. Clin. Psychol. 51:234–241; 1983.
7. Wald, N. J.; Idle, M.; Boreham, J.; Baily, A. Carbon monoxide in breath in relation to smoking and carboxyhaemoglobin levels. Thorax 36:366–369; 1981.
8. West, R. J. The effect of duration of breath-holding on expired air carbon monoxide concentration in cigarette smokers. Addict. Behav. 9:307–309; 1984.
9. Woodman, G.; Newman, S. P.; Pavia, D.; Clarke, S. W. Inhaled smoke volume puffing indices and carbon monoxide uptake in asymptomatic cigarette smokers. Clin. Sci. 71:421–427; 1986.
10. Zacny, J. P.; Stitzer, M. L.; Brown, F. G.; Yingling, J. E.; Griffiths, R. R. Human cigarette smoking: Effects of puff and inhalation parameters on smoke exposure. J. Pharmacol. Exp. Ther. 240:554–564; 1987.