Sensitivity of the Federal Trade Commission Test Method to Analytical Parameters

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INTRODUCTION The Federal Trade Commission (FTC) test method for determining the tar, nicotine, and carbon monoxide yields of commercial cigarettes was designed to characterize and compare brands. Relevance to human smoking was a consideration in choosing the test method, but the principal objective was to select a method that provided the most accurate and reproducible result. Relevance to human smoking was addressed by using intermittent puffing and by choosing puff volume, puff duration, puff frequency, and butt length based on observations of human smokers. Accuracy and reproducibility were addressed by selecting a single set of smoking conditions, demanding narrow tolerances for variation in the conditions, and standardizing everything from cigarette selection, to the smoking environment, to the laboratory analytical chemical methods.

Requirements associated with producing a standard method tend to conflict with those associated with maximizing relevance to the human situation. Bradford and colleagues (1936) recognized from the beginning that humans smoke cigarettes in different and varying ways, but a standardized procedure requires that variables be set and controlled. For practical purposes, only one set of conditions could be selected.

At least two factors have led to an increased concern about the relevance of the FTC test procedure. First, FTC results increasingly have been viewed as a measure of human exposure and therefore health risk. The problem is compounded by the assumption that even a small difference in FTC results signifies a meaningful difference in human exposure. Second, a much greater variety of cigarettes is available today. They range from nonfilter and filter cigarettes similar to those available when the method was adopted, to increasingly popular products with very low FTC yields. Behavioral research has demonstrated that low-yield products are consistently smoked differently than are higher yield products (Kozlowski et al., 1989).

This chapter reviews the nature of the FTC test procedure and the influence of changes in its specifications on yields. Smoking parameters likely to be different for humans from FTC machine smoking are emphasized.

STANDARD MACHINE SMOKING The quantities of tar, nicotine, carbon monoxide, and other constituents in cigarette smoke are measured using smoking machines. One or more cigarettes are smoked by a machine, the constituents of interest are collected in a suitable trap, and the contents of the trap are chemically analyzed. The quantity in the trap is divided by the number of cigarettes smoked to compute a yield (or delivery) per cigarette. In the case of the FTC procedure, the particle phase of the smoke is collected on glass fiber (Cambridge) filters, and the gas phase (passing through the filter) is collected in gas sampling bags. Carbon monoxide is measured in the gas sampling bags. The filter is weighed to yield a measure of total particulate matter (TPM) and is analyzed for nicotine and water content. Tar (or nicotine-free dry particulate matter) is computed by subtracting the weights of nicotine and water from the weight of TPM.

The principal reason for using smoking machines is to maximize the reproducibility of results (DeBardeleben et al., 1991). This is particularly important for quality control and product comparison and is essential for interlaboratory comparisons. However, machine smoking is limited in that it provides results accurate only for the specific set of smoking conditions employed by the machine.

Smoking parameters used in the FTC procedure are based largely on empirical observations of smokers reported by Bradford and colleagues (1936). They suggested a nominal 35-mL ("mL" is used interchangeably in the literature with "cc") puff volume of a 2-second duration taken once per minute to a 23-mm butt length. Current FTC smoking conditions (Federal Trade Commission, 1994) specify a puff volume of 35 ± 0.5 mL, a puff duration of 2.0 ± 0.2 seconds, and a puff frequency of 1 per 60 ± 1 second. Butt length is specified as 23 mm for nonfilter cigarettes and the length of filter overwrap plus 3 mm for filtered cigarettes. The international standard method (Thomsen, 1992) ISO 3308 currently uses the same conditions but requires more stringent tolerances. Puff volume is 35 ± 0.25 mL, puff duration is 2.0 ± 0.05 second, and puff frequency is 1 per 60 ± 0.5 second.

Machine-smoking parameters are only one of several conditions that have been specified to constitute standard FTC testing. Other conditions include the number and manner of selection of cigarettes to be tested, cigarette conditioning (see below), the smoking environment, and the methods and instrumentation used. FTC testing specifies the analysis of 100 cigarettes selected at random from two packages purchased at each of 50 geographical locations throughout the United States. Cigarettes must be conditioned at 60 percent relative humidity and 24 °C for at least 48 hours before smoking and must be smoked in a room maintained under the same conditions. Smoking is performed using a Phipps and Bird 20-port linear smoking machine, thus specifying by default that "restricted" rather than "free" (butt end closed rather than open to the atmosphere between puffs) smoking be performed. Finally, the air flow across the cigarettes must be reproducible and controlled to control the rate at which the cigarette burns between puffs.

The introduction of cigarettes with ventilated filters has made it necessary to pay additional attention to the depth to which the cigarette is inserted into the holder. The cigarette must be inserted sufficiently deep to hold it firmly for the smoking process but not so deep as to occlude the ventilation holes.

Standardization has produced a remarkably reproducible procedure given that the process involves the combustion of highly processed and packaged plant material. This is illustrated by the data shown in Table 1. Individual laboratories typically generate results with a precision of ±5 percent (relative standard deviation) or better for tar, nicotine, and carbon monoxide yields of high-tar products. Interlaboratory agreement is generally within 4 and 8 percent of the mean, depending on the constituents and number of cigarettes considered. Precision and interlaboratory agreement as a percentage of the mean are poorer for very-low-delivery (e.g., 1 mg tar) products, but the absolute error is similar. The procedure is sufficiently reproducible to allow rounding of FTC results for tar and carbon monoxide to the nearest whole milligram based on a difference between brands of only 0.1 mg (0.4 mg or less reported as <1 mg or below detection limit of the method, 0.5 mg or more rounded up to 1 mg, 1.04 mg rounded down to 1 mg, etc.). Results for nicotine are rounded to the nearest tenth mg. Those with 0.05 mg or greater are rounded up, whereas those with 0.04 mg or less are rounded down, as above.

INFLUENCE OF SMOKING PARAMETERS

Each parameter specified in the FTC testing procedure influences the yields of tar, nicotine, and carbon monoxide. Restrictive tolerances specified for acceptable puff volume, puff duration, and so forth are required to allow comparison of similar products and to allow interlaboratory comparability. Parameters such as cigarette conditioning prior to smoking are specified to accommodate the realities of laboratory measurements: in this case, that the cigarettes are likely to be analyzed after long periods of cold storage. Minor variations in any of these parameters can result in detectable differences in yields. Realistic (comparable with human smoking practices) variations also can result in large differences in yields.

Darrall (1988) has reported a systematic study of the influence of smoking parameters on yields of tar, nicotine, and carbon monoxide. Puff durations of 1.6 seconds and 2.3 seconds produced essentially the same yields for very-low-tar (≤4 mg) cigarettes and almost indistinguishable yields for higher tar products (Table 2). No clear trend toward increasing or decreasing yields was noted. Changing puff volume from 35 to 40 mL produced a small but generally consistent increase in tar and nicotine (Table 3). Low-tar products yielded 1 to 3 mg more tar and 0.1 to 0.3 mg more nicotine at 40-mL puff volumes than at 35-mL puff volumes. Higher tar products increased yield by 2 to 5 mg of tar and 0.1 to 0.5 mg of nicotine. The increases, although small, still may be larger than would be found using the standard FTC method because the investigator in Darrall's study (1988) smoked at 2 puffs per minute, thus increasing the number of puffs per cigarette. Larger changes in puff volume produce larger changes in yields. Browne and colleagues (1980) reported that particulate matter yield increased from 29 mg to 55 mg for a U.S. blend experimental cigarette when the puff volume was changed from 17.5 mL to 50 mL under otherwise standard conditions. Carbon monoxide yields were 9 mg and 20 mg for puff volumes of 17.5 mL and 50 mL, respectively.

Table 1

Collaborative study of tar, nicotine, and carbon monoxide yields of 2R1[a], A-2[b], and A-3[b] cigarettes

Cigarette	Laboratory	Cigarettes/Port	Number of Ports	Yield (mg/cigarette), Average ± Standard Deviation		
				Tar	Nicotine	Carbon Monoxide
2R1	1	4	24	36.6 ± 0.7	2.41 ± 0.06	23.1 ± 0.8
	2	5	16	35.0 ± 1.2	2.42 ± 0.07	24.9 ± 1.6
	3	4	5	36.5 ± 1.6	2.12 ± 0.14	23.5 ± 0.9
	4	5	20	35.6 ± 0.6	2.49 ± 0.14	—
A-2	1	4	16	12.5 ± 0.2	0.92 ± 0.02	15.3 ± 0.3
	2	5	16	12.9 ± 0.8	0.96 ± 0.02	16.3 ± 1.0
	3	5	5	12.9 ± 0.5	0.89 ± 0.03	17.0 ± 0.4
	4	5	20	13.0 ± 0.7	0.97 ± 0.07	—
A-3	1	6	8	1.3 ± 0.1	0.11 ± 0.01	2.3 ± 0.1
	2	5	16	1.3 ± 0.2	0.21 ± 0.03	2.4 ± 0.5
	3	5	5	1.4 ± 0.2	0.19 ± 0.01	2.3 ± 0.3
	4	5	20	1.6 ± 0.3	0.17 ± 0.04	—

[a] *University of Kentucky reference nonfilter cigarette.*

[b] *National Cancer Institute "Nicotine Series" experimental nonfilter cigarette.*

Table 2
Influence of puff duration on machine yields

Brand (FTC tar)	Yield (mg/cigarette)[a] Tar 1.6 Seconds	Tar 2.3 Seconds	Nicotine 1.6 Seconds	Nicotine 2.3 Seconds	Carbon Monoxide 1.6 Seconds	Carbon Monoxide 2.3 Seconds
B (1 mg)	2	2	0.3	0.3	1	1
D (4 mg)	8	7	0.8	0.7	10	8
E (6 mg)	12	10	0.8	0.8	15	12
G (9 mg)	15	14	1.4	1.3	15	12
K (13 mg)	23	22	2.1	2.1	19	17
T (15 mg)	25	27	2.2	2.4	27	24
X (25 mg)	38	39	3.6	3.7	22	20

[a] 35-mL puff, 30-second interval.

Source: Darrall, 1988.

Table 3
Influence of puff volume on machine yields

Brand (FTC tar)	Yield (mg/cigarette)[a] Tar 35 mL	Tar 40 mL	Nicotine 35 mL	Nicotine 40 mL	Carbon Monoxide 35 mL	Carbon Monoxide 40 mL
(B) KS-UM-V (1 mg)	2	3	0.3	0.4	1	1
(D) KS-EM-V (4 mg)	7	10	0.7	1.0	8	11
(G) KS-V (9 mg)	14	16	1.3	1.7	12	15
(H) Regular-V (12 mg)	21	21	0.9	1.0	25	25
(K) KS-V (13 mg)	22	24	2.1	2.2	17	17
(O) KS-NV (14 mg)	22	24	2.0	2.3	21	22
(P) KS-NV (14 mg)	24	28	1.6	2.4	18	24
(W) Regular-NF (16 mg)	27	26	2.1	2.4	16	14
(X) Regular-NF (25 mg)	39	44	3.7	4.2	20	21

[a] 2.3-second duration, 30-second frequency.

Key: KS = king size; UM = ultramild (< 4 mg tar); V = ventilated; EM = extra mild (4 to 7 mg tar); NV = nonventilated; NF = nonfilter.

Source: Darrall, 1988.

Puff frequency (Table 4) and filter ventilation (Table 5) were found to have the greatest effect on yields. Decreasing the puff interval from 60 to 40 seconds increased the deliveries of tar, nicotine, and carbon monoxide by 20 to 50 percent on a per-cigarette basis. Using a puff interval of 30 seconds increased deliveries by 40 to 90 percent. Blocking the ventilation system of ventilated filter cigarettes has similar effects for products using a low degree of ventilation and a much greater effect for highly ventilated products. This is particularly important for very-low-delivery (e.g., ≤1 mg tar) products because they typically use highly ventilated filters. Darrall (1988) reported that complete blockage of the filter ventilation of a nominally 4.0-mg tar product resulted in a tar yield of 10 mg (Table 5); nicotine increased from 0.5 to 0.8 mg, and carbon monoxide rose from 4 to 13 mg. Lower yield products employ more highly ventilated filters than in Darrall's (1988) example, and the influence of filter blockage would be expected to be greater for such products.

The importance of filter ventilation to FTC testing is illustrated by the results summarized in Figure 1. Nonfilter, filter (F), and ventilated filter (VF) commercial cigarettes were smoked (see next section, "Influence of Human Smoking Practices") under standard FTC conditions and again under standard conditions but with 23 mm of the butt end taped (FTC+). All cigarettes,

Table 4
Influence of puff frequency on machine yields

	Percentage Increase Over Standard Federal Trade Commission Method							
	40 Seconds				30 Seconds			
	Puffs	Tar	Nicotine	Carbon Monoxide	Puffs	Tar	Nicotine	Carbon Monoxide
Regular (M-H)	28	31	29	26	62	60	49	38
Regular (M-H)	24	33	32	23	52	69	54	42
KS-UM-V (L)	47	55	24	43	90	154	47	67
KS-EM-V (L)	27	31	32	32	52	94	60	64
KS-EM-V (L)	30	21	19	27	69	84	48	79
KS (L)	38	19	19	24	76	54	38	43
KS-NV (L-M)	31	44	35	33	57	62	61	39
KS-NV (M)	26	26	16	16	60	60	32	32
IS-NV (L-M)	38	46	42	39	70	62	58	46

Key: M-H = middle to high tar (23 to 28 mg); KS = king size; UM = ultramild (<4 mg tar); V = ventilated; L = low tar (0 to 10 mg); EM = extra mild (4 to 7 mg tar); NV = nonventilated; L-M = low to middle tar (11 to 16 mg); M = middle tar (17 to 22 mg); IS = international size.

Source: Darrall, 1988.

Table 5
Influence of ventilation on machine yields

		Yield per Cigarette (mg)		
		Percent Blockage		
Brand (ventilation)	Constituents	0	50	100
A (55%)	Tar	3.8	5.9	10.0
	Nicotine	0.46	0.55	0.82
	Carbon monoxide	3.8	6.0	12.7
B (35%)	Tar	9.2	10.6	12.8
	Nicotine	0.90	0.90	0.98
	Carbon monoxide	9.2	10.9	15.2

Source: Darrall, 1988.

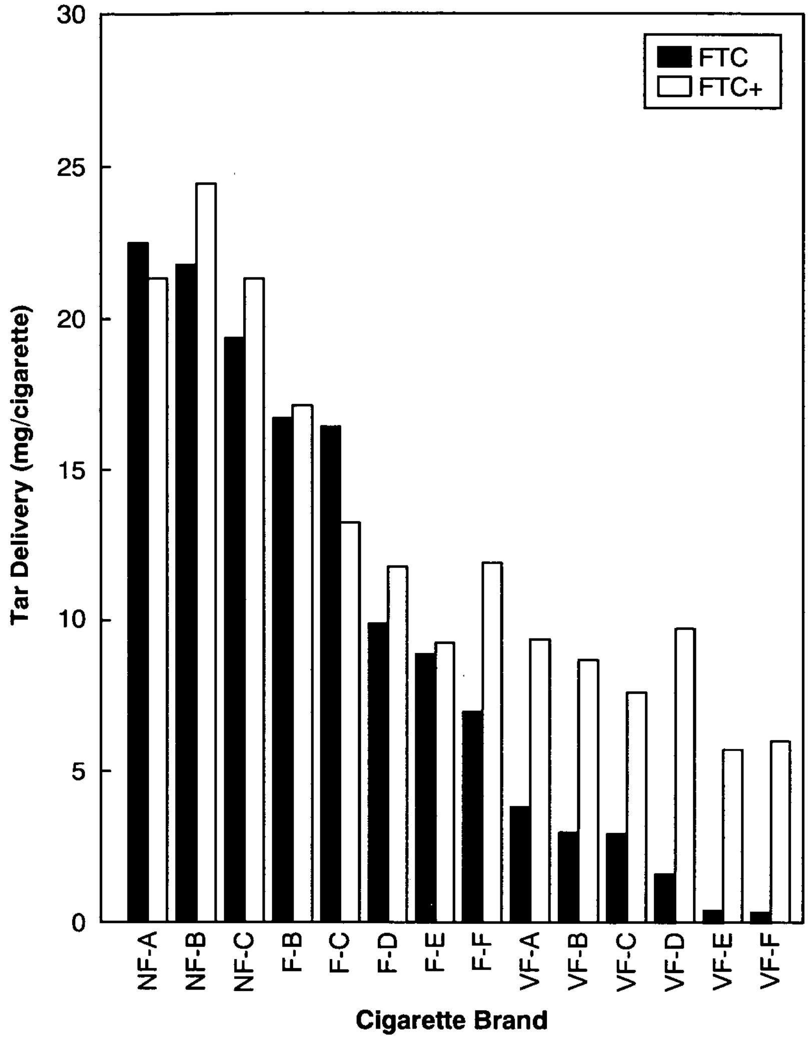
including nonfilter, were taped. Nonfilter cigarettes and filter cigarettes with little or no ventilation were seen to be only slightly affected by the tape. Some effect would be expected for nonfilter cigarettes because taping blocks air flow through the cigarette paper, but the changes observed were barely statistically significant for the experimental design used. The effect on ventilated filter cigarettes (VF-A to VF-F in Figure 1) was significant and major. Products rated as FTC 1 mg tar yielded 5 mg or more of tar when the ventilation was completely occluded. Products rated at 2 to 4 mg of tar delivered up to 10 mg of tar. In the case of brand F-F, the substantial increase in delivery when cigarettes were taped suggested that the filter incorporated ventilation even though it was not obvious from visual inspection. Trends for nicotine and carbon monoxide yields were generally parallel to those for tar.

INFLUENCE OF HUMAN SMOKING PRACTICES

Standardized machine smoking was developed to ensure that differences in yields among cigarettes were caused by the nature of the cigarettes and not by differences in the measurement method. The FTC adopted standardized machine smoking to maximize its ability to discriminate accurately among brands. The FTC test has been successful for this purpose but is accurate only where cigarettes are smoked as prescribed by the method.

The relevance of the FTC test parameters to human smoking practices has been called into question as FTC ratings have increasingly been viewed as a measure of human exposure. This concern is heightened by the increasing popularity of low-tar and ultralow-tar products relying largely on filter ventilation and by a better understanding of compensatory smoking practices. Observation of more recent smoking practice showed that filter ventilation was commonly compromised, puff volume was somewhat greater

Figure 1
Tar yields using standard (FTC) smoking conditions and FTC smoking conditions with tips taped (FTC+)



Key: NF = nonfilter; F = filter; VF = ventilated filter.

Source: Jenkins et al., 1982.

than the standard 35 mL, and a puff frequency of 2 to 3 per minute was more common than was 1 per minute (U.S. Department of Health and Human Services, 1988).

Jenkins and colleagues (1982) surveyed the influence of major changes in smoking parameters on the yields of tar, nicotine, and carbon monoxide by commercial cigarettes. Results are given in Tables 6 through 8.

Table 6
Effect of smoking conditions on tar yield

Brand	FTC Rate	Yield (mg/cigarette ± one standard deviation) Low 17 mL, 1 Sec 1 Puff/Min	FTC 35 mL, 2 Sec 1 Puff/Min	FTC+ Tip Taped 35 mL, 2 Sec 1 Puff/Min	Average 45 mL, 2 Sec 2 Puffs/Min	High 75 mL, 3 Sec 3 Puffs/Min	High+ Tip Taped 75 mL, 3 Sec 3 Puffs/Min
VF-A	6.3	1.7 ± 0.3	3.8 ± 0.5	9.4 ± 0.9	11.2 ± 1.3	18.7 ± 3.9	38.2 ± 3.4
VF-B	2.3	0.3 ± 0.3	3.0 ± 0.7	8.7 ± 1.2	7.7 ± 1.4	12.8 ± 2.0	38.3 ± 5.4
VF-C	2.9	0.4 ± 0.4	2.9 ± 0.6	7.6 ± 0.9	8.8 ± 0.6	15.2 ± 1.8	26.4 ± 1.8
VF-D	1.1	.04 ± 0.14	1.6 ± 0.2	9.7 ± 0.8	2.6 ± 0.4	10.4 ± 3.2	35.5 ± 2.8
VF-E	[a]	.03 ± 0.12	0.4 ± 0.4	5.7 ± 0.7	1.5 ± 0.5	0.9 ± 0.9	24.5 ± 2.8
VF-F	[a]	–0.1 ± 0.2	0.3 ± 0.3	6.0 ± 0.5	3.0 ± 0.8	7.5 ± 2.0	23.5 ± 1.8
F-A	16.0	8.4 ± 0.6	18.5 ± 1.2	[b]	33.6 ± 4.3	53.9 ± 2.7	56.6 ± 3.5
F-B	15.4	7.7 ± 0.8	16.7 ± 0.8	17.1 ± 2.0	35.4 ± 3.2	53.3 ± 2.3	55.5 ± 3.1
F-C	16.3	7.9 ± 0.8	16.4 ± 1.4	13.2 ± 0.6	32.9 ± 1.6	44.9 ± 4.5	46.5 ± 7.6
F-D	8.3	3.8 ± 0.5	9.9 ± 0.8	11.7 ± 1.3	17.2 ± 1.5	31.7 ± 1.3	41.7 ± 2.3
F-E	7.3	3.4 ± 0.6	8.9 ± 1.0	9.2 ± 1.0	17.7 ± 1.3	30.9 ± 1.8	39.4 ± 6.9
F-F	7.0	2.6 ± 0.3	7.0 ± 0.6	11.9 ± 2.1	20.3 ± 3.4	28.7 ± 1.7	41.7 ± 5.2
NF-A	20.6	10.1 ± 1.4	22.5 ± 1.0	21.3 ± 1.5	36.2 ± 2.8	60.7 ± 2.2	60.0 ± 3.2
NF-B	24.3	12.6 ± 0.7	21.8 ± 2.6	24.4 ± 3.2	43.9 ± 2.3	65.0 ± 2.1	71.5 ± 4.4
NF-C	24.8	10.7 ± 0.6	19.4 ± 1.1	21.3 ± 1.0	43.7 ± 1.5	65.7 ± 7.6	63.3 ± 4.5

[a] *Below reporting limit.*
[b] *Not determined.*

Key: VF = ventilated filter; F = filter; NF = nonfilter.

Table 7
Effect of smoking conditions on nicotine yield

		Yield (mg/cigarette ± one standard deviation)					
Brand	FTC Rate	Low 17 mL, 1 Sec 1 Puff/Min	FTC 35 mL, 2 Sec 1 Puff/Min	FTC+ Tip Taped 35 mL, 2 Sec 1 Puff/Min	Average 45 mL, 2 Sec 2 Puffs/Min	High 75 mL, 3 Sec 3 Puffs/Min	High+ Tip Taped 75 mL, 3 Sec 3 Puffs/Min
VF-A	.54	.13 ± .01	.40 ± .05	.72 ± .05	1.05 ± .10	1.08 ± .18	2.02 ± .19
VF-B	.32	.10 ± .04	.35 ± .03	.62 ± .07	.68 ± .15	1.11 ± .16	2.04 ± .24
VF-C	.31	.07 ± .03	.25 ± .04	.45 ± .03	.62 ± .10	.82 ± .04	1.23 ± .12
VF-D	.19	.05 ± .01	.19 ± .05	.62 ± .07	.52 ± .05	.84 ± .15	1.53 ± .12
VF-E	.11	.01 ± .01	.05 ± .01	.37 ± .08	.21 ± .03	.42 ± .03	1.08 ± .18
VF-F	.11	.02 ± .01	.06 ± .02	.31 ± .03	.28 ± .08	.52 ± .11	.83 ± .13
F-A	1.04	.56 ± .10	1.09 ± .07	[a]	1.99 ± .17	2.20 ± .18	2.47 ± .17
F-B	1.10	.50 ± .01	.99 ± .02	.80 ± .06	1.92 ± .09	2.16 ± .16	2.29 ± .08
F-C	1.24	.53 ± .05	.94 ± .02	.71 ± .06	1.56 ± .39	2.31 ± .16	2.20 ± .20
F-D	.72	.25 ± .05	.61 ± .02	.68 ± .10	1.15 ± .07	1.81 ± .33	1.90 ± .15
F-E	.71	.31 ± .03	.77 ± .07	.81 ± .09	1.56 ± .22	1.92 ± .05	2.00 ± .12
F-F	.51	.19 ± .04	.40 ± .03	.56 ± .03	1.13 ± .06	1.29 ± .06	1.42 ± .08
NF-A	1.42	.69 ± .05	1.14 ± .05	1.37 ± .07	1.89 ± .16	2.68 ± .21	2.54 ± .20
NF-B	1.52	.70 ± .03	1.04 ± .11	1.16 ± .08	2.62 ± .27	3.61 ± .16	2.75 ± .22
NF-C	1.66	.74 ± .08	1.13 ± .13	1.60 ± .23	3.19 ± .33	3.29 ± .28	3.46 ± .24

[a] *Not determined.*

Key: VF = ventilated filter; F = filter; NF = nonfilter.

Table 8
Effect of smoking conditions on carbon monoxide yield

		Yield (mg/cigarette ± one standard deviation)					
Brand	FTC Rate	Low 17 mL, 1 Sec 1 Puff/Min	FTC 35 mL, 2 Sec 1 Puff/Min	FTC+ Tip Taped 35 mL, 2 Sec 1 Puff/Min	Average 45 mL, 2 Sec 2 Puffs/Min	High 75 mL, 3 Sec 3 Puffs/Min	High+ Tip Taped 75 mL, 3 Sec 3 Puffs/Min
VF-A	9.0	1.2 ± 0.3	4.1 ± 0.7	12.3 ± 1.5	11.2 ± 0.8	18.8 ± 1.7	34.5 ± 4.7
VF-B	2.9	1.8 ± 0.5	2.1 ± 0.5	8.8 ± 1.6	6.2 ± 1.9	12.9 ± 1.9	26.2 ± 3.2
VF-C	4.8	0.7 ± 0.2	2.1 ± 0.2	8.7 ± 1.2	9.9 ± 1.5	18.7 ± 4.0	27.5 ± 2.0
VF-D	1.2	.06 ± 0.0	1.0 ± 0.1	10.7 ± 0.4	5.0 ± 0.7	6.0 ± 1.7	28.7 ± 2.8
VF-E	1.1	.08 ± .03	0.6 ± .1	10.8 ± 1.4	2.3 ± 0.2	6.2 ± 0.4	21.5 ± 1.6
VF-F	1.3	0.1 ± 0.6	0.7 ± 0.3	8.8 ± 1.1	3.4 ± 0.7	8.3 ± 1.4	23.6 ± 2.1
F-A	14.5	5.8 ± 0.5	15.7 ± 1.8	[a]	25.3 ± 2.4	35.8 ± 2.6	35.5 ± 2.2
F-B	15.5	5.6 ± 1.1	17.6 ± 0.9	16.2 ± 1.0	24.2 ± 1.5	29.8 ± 5.7	33.4 ± 2.2
F-C	16.3	6.9 ± 0.5	13.4 ± 1.2	17.9 ± 1.2	24.2 ± 2.6	29.1 ± 3.2	29.2 ± 3.4
F-D	10.6	3.5 ± 0.5	8.5 ± 0.3	11.5 ± 0.7	13.5 ± 1.7	23.4 ± 2.2	33.3 ± 2.6
F-E	8.1	2.6 ± 0.5	8.8 ± 1.0	10.1 ± 1.7	17.6 ± 1.3	25.1 ± 2.2	25.1 ± 2.4
F-F	10.4	2.5 ± 0.9	9.9 ± 1.2	12.1 ± 1.6	14.6 ± 2.2	22.6 ± 1.7	27.8 ± 3.2
NF-A	12.5	4.5 ± 0.4	11.3 ± 1.0	12.8 ± 2.7	17.6 ± 1.4	25.6 ± 1.0	28.4 ± 1.2
NF-B	16.7	5.9 ± 0.7	12.3 ± 0.8	14.5 ± 1.6	21.7 ± 0.5	30.3 ± 3.1	34.8 ± 0.9
NF-C	16.1	4.6 ± 0.6	11.3 ± 1.2	12.9 ± 0.8	22.9 ± 1.6	31.8 ± 2.7	28.5 ± 5.7

[a] *Not determined.*

Key: VF = ventilated filter; F = filter; NF = nonfilter.

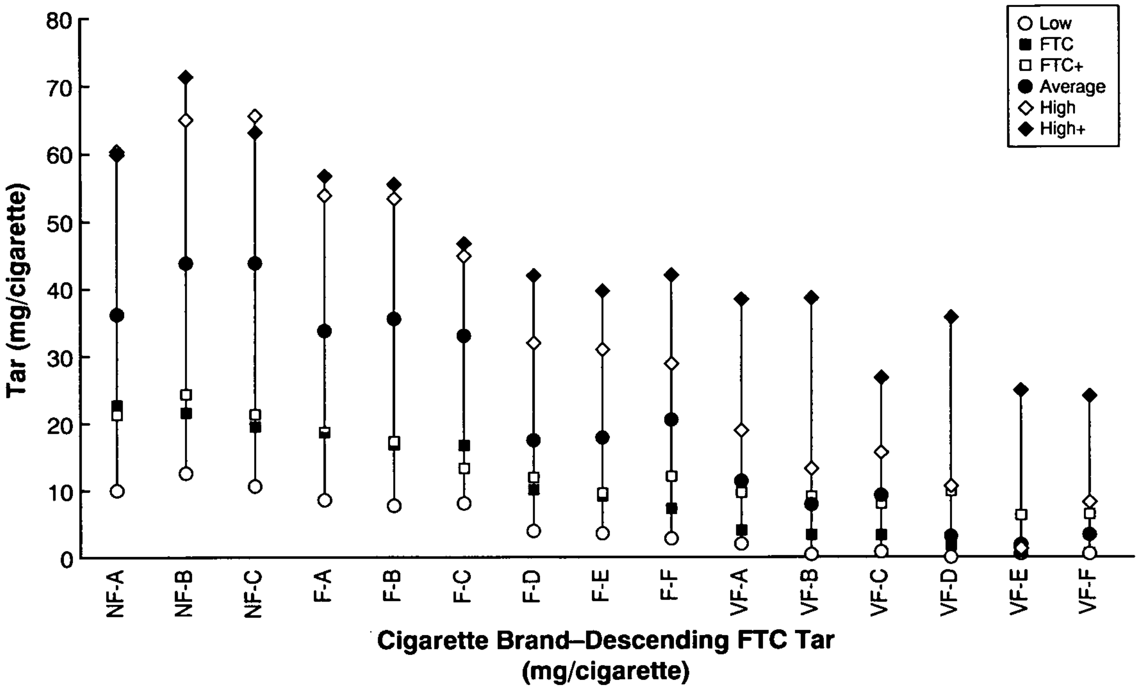
Smoking parameters were chosen to represent less intense smoking (17-mL, 1-second puffs, once per minute), conditions considered to be "average" smoking (45-mL, 2-second puffs, twice per minute) at the time, and extreme ("high") smoking (75-mL, 3-second puffs, three times per minute) conditions. These results were compared with results generated using the standard FTC conditions, FTC conditions with 23 mm of the butt end of each cigarette taped to completely occlude tip ventilation (FTC+), and the extreme conditions with the tips taped (high+). Yields under high+ conditions were viewed as the maximum practical yields of the cigarettes.

The cigarettes chosen for analysis were selected by weight and pressure drop (the differential pressure from end to end when air is drawn through a cigarette at a rate of 1,050 mL per minute [equivalent to a 35-mL puff taken over a 2-second period]) from two cartons purchased locally; they were conditioned and smoked under FTC-specified environmental conditions. The smoke was trapped and analyzed using FTC methods except that carbon monoxide was determined using gas chromatography (Horton and Guerin, 1974) rather than nondispersive infrared spectroscopy. A single-port and a linear four-port Filimatic smoking machine were used rather than the standard 20-port machine, and one to six cigarettes were smoked per port depending on the smoking conditions used. At least four ports of cigarettes were smoked per brand or condition, but the precision of the results remained 2 to 3 times poorer than would be expected using the standard 20-port protocol.

Results for tar deliveries are diagramed in Figure 2. Results for nicotine and carbon monoxide generally parallel those for tar (although carbon monoxide yields are more scattered and less systematically varied). Several observations are apparent. First, the trend toward decreasing yields generally parallels the decrease in FTC yields regardless of the conditions used for most products. Second, products with barely detectable yields of tar measured by the FTC method produce readily detectable quantities of tar when smoked under reasonable conditions. Third, even the lowest FTC tar products can yield 10 to 20 mg of tar under sufficiently aggressive smoking conditions. Products with very low FTC tar yields that depend largely on filter ventilation are those most subject to underestimation of practical yields by the FTC method.

Several investigators have reported on the influence of more relevant combinations of smoking conditions on the yields of tar and nicotine. Table 9 summarizes some of these observations for tar. Rickert and colleagues (1983) reported that increasing the puff volume to 48 mL and decreasing the puff interval to 44 seconds resulted in an increase of approximately 40 to 90 percent in the yield of tar over that found using standard FTC conditions. Using the same conditions but also occluding 50 percent of the filter ventilation resulted in an increase of from 70 to 500 percent depending on the product. Percentage increase in yield tended to correlate inversely with yield of FTC tar; that is, the lower the FTC yield, the greater the percentage increase.

Figure 2
Influence of smoking parameters on constituent yield



Key: low = 17-mL puff volume, 1-second duration, 1 puff/minute; FTC = 35-mL puff volume, 2-second duration, 1 puff/minute; FTC+ = same as FTC plus butt end taped; average = 45-mL puff volume, 2-second duration, 2 puffs/minute; high = 75-mL puff volume, 3-second duration, 3 puffs/minute; high+ = same as high plus butt end taped; NF = nonfilter; F = filter; VF = ventilated filter.

Source: Jenkins et al., 1982.

The Rickert and colleagues (1983), Darrall (1988), and Jenkins and colleagues (1982) studies all considered the effect of increasing the puff frequency from one per minute to two per minute. Puff volumes varied from 40 to 48 mL across the studies, but the results were similar. Smoking at two puffs per minute approximately doubled the tar yield for most products tested.

Filter ventilation also has been considered. The Jenkins and colleagues (1982) data illustrated that 100 percent ventilation blockage increased the tar delivery by a factor of 10 to 20 for very low (< 1 mg) FTC tar products if all other smoking parameters were kept constant. Kozlowski and coworkers (1982) reported increases of a factor of 20 to 40 using conditions of 100 percent blockage, a 47-mL puff volume, and a 44-second puff interval for products rated as <1 mg FTC tar. The influence of ventilation blockage was smaller but still important for products rated as 1 to 6 mg FTC tar (2 to 6 times increased delivery compared with that measured using the FTC method without ventilation blockage), was readily detectable for products

Table 9
Influence of "more relevant" smoking parameters on tar yields

	Ratio: Experimental/Standard Tar						
FTC Tar mg/Cigarette	Rickert et al., 1983	Rickert et al., 1983	Rickert et al., 1983	Darrall, 1988	Jenkins et al., 1982	Kozlowski et al., 1982	Jenkins et al., 1982
<1	1.6, 2.0	5.2, 5.6	—	—	3.8, 10.0	19 - 39	14, 20
1- 3	1.6 - 1.9	2.8 - 4.3	—	3.0, 3.0	1.6 - 3.0	—	2.6 - 6.1
4 - 6	1.4 - 1.7	2.1 - 2.9	—	2.0 - 2.7	2.9	—	2.5
7 - 10	1.4 - 1.9	2.0 - 2.6	—	1.8, 1.9	1.7 - 2.9	—	1.0 - 1.7
11 - 15	1.4 - 1.9	1.7 - 2.4	2.1 - 2.3	1.7 - 2.0	—	1.5	—
16 - 20	1.6, 1.7	—	2.0, 2.1	1.6 - 1.9	1.8 - 2.2	—	0.8 - 1.1
>20	—	—	—	1.8	1.6, 2.0	—	1.1, 1.1
NV	—	—	2.0 - 2.3	1.7 - 2.0	1.6 - 2.2	—	0.9 - 1.1
Experimental Conditions							
Puff Volume (mL)	48	48	48	40	45	47	35
Puff Duration (sec)	2.4	2.4	2.4	2.3	2.0	2.4	2.0
Puff Interval (sec)	44	44	31	30	30	44	58
Ventilation Block (%)	0	50	0	0	0	100	100

Key: NV = nonventilated.

rated up to 10 mg FTC tar, and became insignificant for products rated as 15 mg FTC tar and higher. It is conceivable that a higher tar (e.g., > 10 mg) product exists that incorporates a highly ventilated filter. Such a product would be affected by ventilation blockage similar to the way lower tar products are affected.

CONCLUSIONS The FTC procedure for measuring the tar, nicotine, and carbon monoxide yields of cigarettes provides an accurate measure of yield for cigarettes smoked in the specified manner. It serves the purpose of comparing the yields of brands smoked under the same (specified) conditions. The utility of the procedure for measuring human exposure is doubtful because it is unlikely that all brands are smoked in the same way. This is especially the case given the wide variety of products currently available. Results using realistic combinations of puff volume, puff frequency, and filter ventilation blockage suggest that human smoking conditions can produce from two times (nonfilter and standard filter brands) to ten times (low-tar and very-low-tar ventilated filter brands) the yields of tar that are measured by the FTC test. Nicotine and carbon monoxide yields vary similarly.

The current FTC test procedure must continue to be used if there is a need to compare current products with those of the past. New or additional sets of smoking parameters must be adopted if a more accurate measure of human exposure is desired.

QUESTION-AND-ANSWER SESSION

DR. RICKERT: There was a question I had asked earlier today and I wonder if you could answer it. It looks as though you have some information about interlaboratory variation, plus within-lab variation, plus variation over time. If you measure, for example, a 12-mg cigarette—how different would another brand have to be before you would be comfortable in calling it truly different?

DR. GUERIN: Certainly it would have to be more than 10 percent different. I think that it is more like, at that range, about 2 mg different.

DR. RICKERT: So, you would say that, for example, 10 mg would be considered different from one that was 14; but other than that, there would be virtually no difference.

DR. GUERIN: Right.

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