Human Smoking Patterns

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INTRODUCTION It has been established that human exposure to tobacco smoke constituents does not reflect package yield characteristics of cigarettes as determined by Federal Trade Commission (FTC) smoking machine methods. This chapter describes some reasons for this discrepancy by examining features of human smoking behavior and how smoking behavior interacts with cigarette yield characteristics. The chapter is divided into four sections. The first section describes the topography of cigarette smoking; the second identifies the parameters of smoking topography that influence smoke exposure; the third shows that human smoking patterns are dynamic rather than static; and the fourth draws conclusions about the relevance of the FTC methodology to human smoking patterns.

HOW DO HUMANS SMOKE?

The first behavioral aspect of smoking involves holding the cigarette. When smoking low-yield cigarettes (nicotine yield < 0.9 mg), smokers may knowingly or unknowingly block some or all the filter vents with their fingers or lips. Blockage of these vents increases the density of mainstream smoke that enters the mouth from the cigarette rod because the opportunity for air to be drawn into the smoke stream via the vents is reduced. Vent blocking essentially can turn a low-yield cigarette into a high-yield cigarette. Over the past 10 years, Dr. Lynn Kozlowski has performed a series of studies in which cigarette butts were assessed for vent blocking. He obtained these butts from public access places such as shopping malls. From his butt analyses, he estimated the extent to which smokers in the United States engage in vent blocking. In one study (Kozlowski et al., 1988), the incidence of partial or complete vent blocking of ultralow-yield cigarettes (0.1 to 0.4 mg of nicotine) was 58 percent. In a more recent study, Kozlowski and colleagues (1994) collected butts of so-called "light" cigarettes (0.5 to 0.8 mg of nicotine yield) and found that 53 percent of the butts showed evidence of some degree of vent blocking. Vent blocking can be detected by looking at the filter stain: Cigarettes that are not vent blocked have a dark stain in the middle of the filter toe with a visible white ring surrounding the stain (i.e., "bulls-eye" pattern); cigarettes that are vent blocked have filter stains that encompass to varying degrees not only the middle of the filter toe but also the periphery.

What are other features of smoking behavior? The smoker draws on the cigarette, inhales the smoke into the lungs, then exhales. Drawing or puffing parameters that can be measured include the size of the puff (puff volume), the duration of the puff, and the interval between puffs. Inhalation parameters that can be measured include the amount of air that is mixed with the smoke as it is inhaled into the lungs (inhalation volume, also referred to as inhalation depth), the duration to peak inhalation, and any breath holding that occurs. Exhalation parameters include exhalation volume and duration. These smoking parameters can now be measured with technologies that have been developed over the past 20 years. Puffing parameters can be measured with a plastic flowmeter, which is attached to a pressure transducer; this system measures pressure differences between two points in the flowmeter as the cigarette is puffed. Respiratory parameters can be measured with noninvasive respiratory inductive plethysmography. Essentially, the degree of movement of the chest and abdomen after calibration procedures is directly proportional to volumes of smoky air inhaled and exhaled. Thus, smoking is a complex behavior with a number of discrete, measurable elements.

WHICH HUMAN SMOKING BEHAVIORS DETERMINE SMOKE EXPOSURE?

It is important to identify which specific elements of smoking behavior influence smoke exposure to focus on relevant parameters of the FTC testing procedures vs. human smoking comparison. Stitzer, Zacny, and other colleagues over the past several years have conducted three studies (Zacny et al., 1986 and 1987; Weinhold and Stitzer, 1989) that have examined the relative importance of various smoking topography parameters in determining smoke exposure. Smoke exposure is measured by determining the amount of carbon monoxide (CO) and nicotine absorbed from smoking a single cigarette—these parameters are called CO boost and nicotine boost, respectively.

In these studies, smokers were trained to puff and inhale the cigarette in a standardized fashion. The procedure of the standardization is simple: The computer involved in the measurement of smoking topography parameters can be programmed to beep when a specified level of a smoking parameter has been reached. The investigator programs the computer to give the smoker feedback as to when to (1) stop puffing (this controls puff volume), (2) stop inhaling (this controls inhalation volume), and (3) start exhaling (this controls breath-hold duration). After practice with this biofeedback system, the smoker is able to reproduce a given smoking pattern that includes a fixed puff volume, inhalation volume, and breath-hold duration.

In the first study (Zacny et al., 1986), an ultralow-yield cigarette was smoked in this standardized fashion, and the number of vents that were blocked was varied. In this way, the effect of vent blocking on smoke exposure could be determined, as measured by CO boost. Either no vents were blocked with tape, 50 percent of vents were blocked, or 100 percent of the vents were blocked. Smokers took eight fixed-volume puffs (60 mL) from the cigarette, inhaled to a certain volume (25 percent of vital capacity), held the breath for a certain duration (10 seconds), and then exhaled. Any differences in CO boost could be attributed to manipulation of vent blocking because other smoking topography parameters were controlled. The authors found a systematic increase in CO boost as a function of number of vents blocked. In a second study, Weinhold and Stitzer (1989) varied the number of puffs (from 8 to 16) taken from a cigarette. CO boost again increased in a linear fashion as a function of number of puffs taken. In a third study

(Zacny et al., 1987), three parameters were systematically manipulated: puff volume (15, 30, 45, and 60 mL), inhalation volume (0, 20, 40, and 60 percent of vital capacity, respectively), and breath-hold duration (0, 4, 8, and 16 seconds, respectively). As puff volume increased, the amount of nicotine and CO absorbed from a cigarette increased in a systematic fashion. However, varying the amount of air mixed with the smoke as it was inhaled (inhalation volume) did not affect nicotine or CO boost; exposure was as great with a shallow inhalation as with a deep inhalation. Breath-hold duration increased CO boost but had no effect on nicotine boost. In summary, the smoking topography parameters that appear to have the larger effect on smoke exposure are vent blocking of low-yield cigarettes and the number and size of puffs taken from any cigarette.

ARE HUMAN SMOKING PATTERNS DYNAMIC OR STATIC?

Much literature indicates that human smoking patterns are dynamic and different from the static FTC smoking method. Puffing parameters change during the course of smoking a single cigarette. Initially, smokers take larger and longer puffs from the cigarette, but as they smoke down the rod, the puffs get shorter and smaller. Interpuff intervals are shortest at the beginning of the cigarette and longest near the end of the cigarette. Smokers engage in activities that can have an influence on smoking topography. Hatsukami and colleagues (1990) developed a portable device that measures number of puffs, interpuff intervals, and puff durations and assessed these parameters in a smoker's natural environment. They found that variables, including mood of the smokers (relaxed vs. stressed) and activities of the smoker (working vs. socializing), influenced smoking topographies. Psychoactive drugs other than tobacco (e.g., stimulants, alcohol, opioids) also can influence smoking topographies. Several investigators have noted changes in smoking topography as a function of alcohol. Keenan and associates (1990) studied smoking topography in alcoholic and nonalcoholic smokers: Alcoholic smokers took more puffs from their cigarettes than did the nonalcoholic smokers, indicating more intensive smoking and suggesting higher exposure levels per cigarette.

Two other examples demonstrate that smoking is a dynamic process. In the first example, Fant and associates (1995) studied smoking deprivation. The number of cigarettes that subjects were permitted to smoke varied from 0 to 11 during a 6-hour period. The number of puffs taken was directly related to the interval between cigarettes and inversely related to the number of cigarettes smoked. In the second example, the authors reviewed studies over the past 15 years that examined smoking topography as a function of cigarette yield. We included only those studies that assessed the smoking of commercially available, as opposed to research, cigarettes. We also arbitrarily defined high-yield cigarettes as having nonventilated filters and an FTC nicotine yield of 0.8 mg or more and low-yield cigarettes as having ventilated filters and an FTC nicotine yield of 0.6 mg or less. Table 1 summarizes the seven studies that fit these criteria. A consistent finding in these studies is that puff volume and puff number are both larger when low-yield compared with high-yield cigarettes were smoked. Overall, it is clear that smoking

Table 1
Studies that assessed smoking topography across different cigarette yields, using commercially available cigarettes

Reference	Number	Low-High Nicotine Yield (mg)	Puff Volume			Puff Number		
			Low Yield	High Yield	*p* Value	Low Yield	High Yield	*p* Value
Bridges et al., 1986	5 vs. 65[a]	0.3-1.1	85.4	52.2	0.05	13.2	10.6	ns
Woodman et al., 1987	10	0.6-1.4	59.5	43.6	0.05	14.0	12.1	ns
Zacny and Stitzer, 1988	10	0.1-1.1	64.7	52.4	0.05	11.3	12.9	ns
Nil and Battig, 1989	15	0.5-0.8	25.7	26.6	ns	17.5	13.7	0.05
Hofer et al., 1991	36[a]	0.1-1.2	44.5	36.8	0.05	15.6	11.1	0.05
Kolonen et al., 1991	10	0.4-0.9	76.9	64.6	0.05	18.7	14.4	ns
Kolonen et al., 1992	8	0.3-1.0	35.6	29.5	0.05	18.5	12.9	0.05
Mean			56.0	43.7		15.5	12.5	
Range			25.7-85.4	26.6-64.6		11.3-18.7	10.6-14.4	

[a] *Cross-sectional study; the sample size in these studies represents each group of smokers studied within a yield category.*

Note: All studies were conducted with filtered, commercial brand cigarettes; low-yield brands were all ventilated and ranged in nicotine yield from 0.1 to 0.6 mg, and high-yield brands were all unventilated and ranged in nicotine yield from 0.8 to 1.4 mg.

Key: ns = not significant.

topography is dynamic and changes in response to several factors, including yield characteristics of the cigarette.

DOES THE FTC METHOD ACCURATELY REFLECT HUMAN SMOKING PATTERNS?

The FTC machine takes 2-second, 35-mL puffs every minute until a certain point has been reached along the length of the cigarette (i.e., filter overwrap plus 3 mm). The length of the cigarette plays a large role in how many puffs are taken by the smoking machine, although porosity of the cigarette paper and tobacco burn rate also play roles. How does the FTC method of smoking compare with how humans smoke cigarettes? A table in the 1988 Surgeon General's Report on smoking (U.S. Department of Health and Human Services, 1988) summarizes results from 32 studies that assessed ad libitum human smoking topography. Table 2 lists the average values, along with the range of puffing parameters observed in each study. Average puff duration across the 32 studies was 1.8 seconds, which is fairly close to the smoking machine value. Human puff volumes tend to be larger than the 35 mL used in standard FTC smoking machine assays. The biggest difference between human and FTC machine smoking parameters was in the rate of puffing. The average interpuff interval in the human studies was 34 seconds, whereas FTC testing used a 60-second interval. Thus, humans took puffs at nearly twice the rate of smoking

Table 2
Published values of common measures of smoking

Reference	Number of Subjects	Puffs/ Cigarette	Interpuff Interval (seconds)	Puff Duration (seconds)	Puff Volume (mL)
Rawbone et al., 1978	12	10	41	1.8	
Rawbone et al., 1978	9	10	35	2.1	43
Woodman et al., 1986	9	13	18	1.9	49
Nemeth-Coslett et al., 1986a	8	8	64	1.8	
Nemeth-Coslett et al., 1986b	8	8	47	1.4	
Nil et al., 1986a	132	13	28	2.2	30
Jarvik et al., 1978	9	10			
Russell et al., 1980	10	11	35		
Ashton et al., 1978	14		24	1.5	
Schulz and Seehofer, 1978	100	11	50	1.4	
Schulz and Seehofer, 1978	218	12	42	1.3	
Henningfield and Griffiths, 1981	8	10	39	1.0	
Stepney, 1981	19	13			38
Bättig et al., 1982	110	13	26	2.1	40
Epstein et al., 1982	63	13		2.4	21
Russell et al., 1982	12	15	26	2.3	40
Gritz et al., 1983	8	9	47	2.2	66
Ossip-Klein et al., 1983	9	8		1.4	
Ossip-Klein et al., 1983	9	12		1.9	
Guillerm and Radziszewski, 1978	8	12	41	1.9	39
Gust et al., 1983	8	9	48	1.6	44
Adams et al., 1983	10		26	1.9	44
Moody, 1980	517	9	26	2.1	44
Nil et al., 1984	20	15	26	1.6	40
McBride et al., 1984	9	16	25	2.1	42
Medici et al., 1985	17	14	19	2.2	43
Burling et al., 1985	24	12	28	1.7	
Nil et al., 1986b	117	13	22	2.1	42
Hughes et al., 1986	46	11		1.6	
Bridges et al., 1986	108	11			56
Puustinen et al., 1986	11	13	22	2.3	44
Hilding, 1956	27	10			
Mean		11	34	1.8	43
Range		8-16	18-64	1.0-2.4	21-66

Note: Data were taken from the baseline phase (or placebo treatment) of studies involving an experimental manipulation with at least eight subjects. Values are rounded off to the nearest unit and, in some cases, were calculated from other variables or estimated from data presented in figures; missing values indicate that the variable was not measured or was not presented in the published study.

Source: U.S. Department of Health and Human Services, 1988.

machine rates used in standardized testing. Across the 32 studies, there appears to be a large degree of variability in the values (as shown by the range of values listed at the bottom of the table) that is not reflected in the FTC method. The average number of puffs taken per cigarette by human smokers was 11; FTC does not publish the number of puffs taken from a cigarette by the machine. Differences in puffing rates suggest that the FTC method probably underestimates the number of puffs taken from a cigarette by humans.

It is possible to estimate the number of puffs used to determine FTC cigarette yield by having cigarettes machine-smoked in a research laboratory. The authors had a low-yield cigarette brand, Now, smoked according to the FTC method at the Tobacco and Health Research Institute in Lexington, Kentucky. Two hundred cigarettes were smoked; the average number of puffs taken per cigarette was 6.8. This same procedure was repeated with a high-yield cigarette, Camel, and an average of 8.3 puffs was taken. Thus, the machine took more puffs from the high-yield than from the low-yield cigarette, which is at odds with the human data presented in Table 1 in which the opposite occurs. Therefore, there appears to be a discrepancy between the FTC method of smoking and the way humans smoke different-yield cigarettes: Machines tend to puff *less* smoke from low-yield than from high-yield cigarettes, and humans tend to compensate for air dilution by puffing *more* smoke from low-yield than from high-yield cigarettes. Thus, humans smoke low-yield cigarettes in a manner that attenuates machine-determined yield differences.

SUMMARY In conclusion, we have shown that the number and size of puffs are key factors that determine per-cigarette smoke exposure. Vent blocking is another important smoking behavior that can occur with low-yield cigarettes. Human smoking behavior is dynamic, not static. There is between-smoker variability in smoking topography, and there are dynamic changes in response to smoking deprivation, cigarette characteristics, other drugs, and situational determinants. The evidence suggests that the FTC method does not accurately reflect human smoking patterns. The FTC method takes smaller, fewer, and more widely spaced puffs than do humans, on average. The underestimation of puff volume is exaggerated with low-yield cigarettes because people tend to increase both the size and number of puffs drawn from lower, as compared with higher, yield cigarettes, whereas smoking machines decrease the number of puffs drawn while holding puff size constant. In addition, the FTC method does not take into account the important behavior of vent blocking of low-yield cigarettes. Thus, there are important differences between FTC and human smoking that result in the machines underestimating the amount of smoke drawn by humans from low-yield as compared with high-yield cigarettes.

QUESTION-AND-ANSWER SESSION

DR. HOFFMANN: How did you cover half of the ventilation holes?

DR. ZACNY: We did not tape half of the cigarette. We put little pieces of square tape all the way around it, so that approximately half the holes were unblocked.

DR. HARRIS: Why is it that it is not how big a puff they took once it was in their mouths, but how deeply they drag that puff into the lungs?

DR. STITZER: I think the explanation is that the dose of nicotine that is drawn in with the puff is the critical determinant. The amount of air that is breathed in along with it, which is what determines the depth, is how much additional volume of air was breathed in with the smoke. That does not seem to be relevant with nicotine.

DR. ZACNY: Even with a shallow inhalation, the surface volume of the lungs is pretty huge.

DR. HARRIS: I understand. It is all in that 1.8-second drag on the cigarette.

DR. STITZER: Yes.

DR. HARRIS: Once the smoke is in your mouth, then you can jump up and down; it does not matter.

DR. STITZER: No, once it is in your lungs. Once you have made that inhalation maneuver, because if you just hold it in your mouth, that was the zero inhalation condition.

DR. HARRIS: So, as long as you inhale it, it does not matter how much air goes in with it.

DR. RICKERT: One important point is that you haven't looked at tar. Tar may react differently. Depth of inhalation and volume of inhalation might be more important. Deposition of tar is not nearly as efficient as for water-soluble vapors and gases. In one of the documents that we received from the tobacco industry, there is a study that has been cited by Stitzer, which says that, on 1,631 cigarette butts, only .1 percent were completely blocked. The information that you have provided today suggests that it is somewhere between 53 and 58 percent. What is the reason for the discrepancy?

DR. ZACNY: The reason for the discrepancy is that those 1,600 butts are from only 10 subjects. We had them smoke the ultralow cigarettes for a week and save the butts. We then analyzed the stain patterns.

We were looking at the acute effects of smoking these ultralow cigarettes in the field, and there may be a lower incidence of blocking than what you see when Lynn Kozlowski does his cross-sectional studies—when people have been normally smoking these cigarettes for a long time. Plus, our data were from only 10 subjects.

DR. RICKERT: Do you feel that this blocking is something that we should be concerned about?

DR. ZACNY: Yes.

DR. SHIFFMAN: One of the issues that you raised that we have not discussed much is variability within a given smoker, due to brand switching, for example. Can you give us some quantitative estimates of the degree of variability?

DR. ZACNY: I believe Dr. Stitzer would be the best person to answer this question.

DR. STITZER: In one example, it was shown for deprivation to be 10 to 15 puffs. And that makes quite a big difference when you multiply it by the puff volumes, leading to a substantial difference in cumulative puff volume.

DR. HATSUKAMI: Also, one subject after meals typically took about eight puffs per cigarette, whereas on the telephone, they would take about five puffs from the cigarette.

DR. TOWNSEND: Dr. Zacny, I am a bit confused about the whole blockage question. Is the measure that you used to determine hole blockage just the staining at the mouth end of the filter?

DR. ZACNY: Yes. Different cigarettes have different types of what we call tipping and different types of perforations. The perforations differ largely in the number of holes and the size of those holes.

Those parameters of ventilation, in fact, determine to a large degree the staining pattern in the first place. So, it is possible to make a highly air-diluted cigarette with many ventilation holes that are very small and, in fact, see relatively uniform staining patterns right at the mouth end of the cigarette.

If you are interpreting that as vent blocking, then I think that is probably an incorrect conclusion, because of the design of that specific filter. Filters with large though very few holes will tend to force the smoke to the center of the filter, and you will see that bullet shape right at the mouth end that was shown in one of the slides.

The concern is that not all cigarettes are built in the same way and so that it is probably a bit premature to conclude that there is vent blocking solely on the basis of filter observation.

DR. STITZER: The data that were presented in this talk showed what happened to smoke *exposure* when the vents were experimentally blocked with tape. Dr. Townsend is asking a different kind of question about measurement of blocking in the natural environment.

DR. TOWNSEND: So, these were not with actual subjects, then?

DR. STITZER: They were with natural subjects, but we blocked the vents.

DR. ZACNY: You were talking about the first study when we looked at 50 and 100 percent of hole blocking.

DR. TOWNSEND: I understand. I would like to talk with you some more about this, because we have some data at R.J. Reynolds where we have gone directly to an inhydrin staining test where the saliva on the filter, in fact, stains with inhydrin; therefore, we can visually see how much saliva has gotten up to the vents.

What we have seen in a study with a number of subjects is that the spent butts show some blockage, but it is a very infrequent phenomenon. So, I would like to talk to you further about that. Perhaps we can propose doing some additional studies.

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