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Limitations to potential uses for data based on the machine smoking of cigarettes: cigarette smoke contents

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Abstract

It has been suggested that cigarette smoking could be made less hazardous by reducing the concentration of toxic smoke constituents relative to the concentration of nicotine. This study has shown that the tar/nicotine (T/N) ratio changes significantly in response to changes in smoking conditions. Consequently, it is not clear that the amount of tar per unit nicotine absorbed by smokers would be less if the T/N ratio to smoking machines was decreased. In fact, this study demonstrates that just the opposite might occur, particularly when ultra-low tar cigarettes are smoked. However, even though the T/N ratio can be increased by 50 per cent or more by intense smoking, the maximum T/N ratio for ultra-low cigarettes was still less than that found under any condition for the middle tar cigarettes which were tested.

Studies of smoke absorption in volunteer subjects have demonstrated that published cigarette yields are poor predictors of smoke absorption. Results reported here from a non-volunteer random selection of smokers support this conclusion for long-term users of a particular brand. With respect to switchers, a 12 per cent decrease in smoke absorption was found for those who voluntarily switched to a low tar cigarette in contrast to those who have always smoked this type of brand.

Figures for smoke constituents are sometimes misused by investigators and often misinterpreted by smokers. Based on the questionnaire responses reported here, smokers rate high tar (18 mg) brands as about twice as hazardous as low tar (3 mg) brands. In this survey, 32 per cent of smokers reported switching to a low-tar brand based on this belief. Part of the explanation for a quantitative association of tar yield with risk to health in the smokers mind may lie in their perception of the numbers for tar and nicotine which appear on every package of Canadian cigarettes. Fifty-one per cent of those who responded felt that these numbers represent the most that can be inhaled from a cigarette.

7.1. Introduction

Inhalation of tobacco smoke increases the relative risk for many pathological conditions depending on amount smoked. Those who smoke fewer cigarettes per day have a reduced relative risk with the maximum benefit accruing to those who stop smoking altogether.[1] Since cigarette smoking and drug dependence have many features in common,[2] there are numerous individuals who cannot quit and will continue to smoke in spite of the consequences. It is for this reason that governments or government agencies in a number of countries, including Canada, have encouraged the development of 'less hazardous' tobacco products.[3] In this context, 'hazard' has and continues to be implicitly equated with 'contents', i.e. cigarettes producing smoke with lowered concentrations of tar and other toxic compounds having a reduced potential hazard in comparison with other brands. Unfortunately, the potential health benefit from switching to low yield cigarettes is not realized by many smokers.[4] Most will obtain the amount of nicotine required for 'satisfaction' independent of the stated yield.[5–7]

There are a number of simple manoeuvres which smokers can use to obtain more nicotine from a cigarette. For example, the nicotine 'content' of an ultra-low tar cigarette ($\leq$1 mg) can be increased as much as 19-fold simply by blocking the ventilation holes found on this type of cigarette.[8] Even when the holes are not blocked, 'contents' may be increased to levels several times those published by government agencies by taking larger puffs of longer duration more frequently.[9]

Since some compensation for nicotine has been reported in most brand switching studies,[6,7,10–12] it has been suggested that cigarette smoking could be made less hazardous by reducing tar and other toxins relative to nicotine.[13] In the United Kingdom the average sales-weighted tar/nicotine (T/N) ratio of cigarette brands has declined from 15.5 in 1972 to 11.5 in 1982.[14] The reasons for this decline are unclear since it has not been part of health policy to officially encourage such a change, for good reasons. A policy to reduce tar yields while maintaining nicotine at current levels assumes that nicotine is neither harmful nor gives rise to harmful by-products. In addition, such a policy also assumes that a reduction in the T/N ratio to smoking machines will be reflected in a decrease in the amount of tar per unit nicotine absorbed by smokers. We have investigated this latter aspect by determining how the T/N ratio changes in response to differences in smoking intensity and type of cigarette. Based on our results the cautionary notes which apply to the use of tar and nicotine yields separately[15] apply to the T/N ratio as well.

7.2. Potential uses for the tar/nicotine ratio

Monitoring the properties of cigarette smoke

It is clear that the average T/N ratio of cigarettes produced in the UK has decreased since 1972. Since major cigarette manufacturers are multinational it is reasonable to ask whether this trend is isolated to the UK or whether the shift to lower T/N ratios has been more widespread. In 1969 the T/N ratio for all 78 Canadian brands whose yield exceeded 10 mg was 14.5[16,17] which decreased by 9 per cent to 13.2 as of October 1986. These Canadian values or the corresponding sales-weighted estimates cannot be compared with the results from the UK for the following reasons.

While it has been agreed internationally that cigarettes be tested by taking a puff of 35 ml over a period of 2 seconds once a minute, there is no such agreement as to when smoking is to stop. For example, in Canada cigarettes are smoked to a length of 30 mm or to within 3 mm of the filter overwrap when the filter-plus-overwrap is less than 27 mm.[17] This choice for a standard butt length has several important consequences. To begin with, in 1986, 76 brands or close to 70 per cent of all Canadian brands could be smoked to a butt length which was shorter than the standard. This percentage has decreased somewhat from 1978, but still represents a clear majority of Canadian cigarettes (see Fig. 7.1). As a result, for regular length cigarettes (72 mm) with short filters as much as 20 per cent of the available tobacco is not smoked when tested by Canadian standards. Consequently, a direct comparison of yields or average yields is not possible.[17] Also, it is not possible to directly compare T/N ratios for brands of Canadian cigarettes with those available in other countries.

In a study of the relationship of T/N ratios as a function of the amount of unsmoked tobacco the following relationship emerged:[18]

$$\text{T/N ratio} = 20.1 - 0.328x + 0.00598x^2$$

where x is the length of the unsmoked tobacco column (mm). This relationship was highly significant, explaining 98 per cent of the variation in T/N ratios for 10 brands of cigarettes whose standard tar yields ranged from 8 to 18 mg. This study was carried out in 1978 and so the consequence of such a relationship can only be discussed in relative terms. For example, when cigarettes in the 1978 study were smoked to within 3 mm of the filter-plus-overwrap which is the effective US standard,[17] the T/N ratio was 19.2. Under Canadian standard conditions this ratio was 17.4 for a decrease of about 9 per cent. Thus, the T/N ratio depends on the amount of tobacco left unsmoked during testing or, in the case of smokers, how much tobacco is discarded. This source of variation in the T/N ratio has serious implications for the prediction of the amount of tar absorbed based on levels of plasma nicotine.[12]

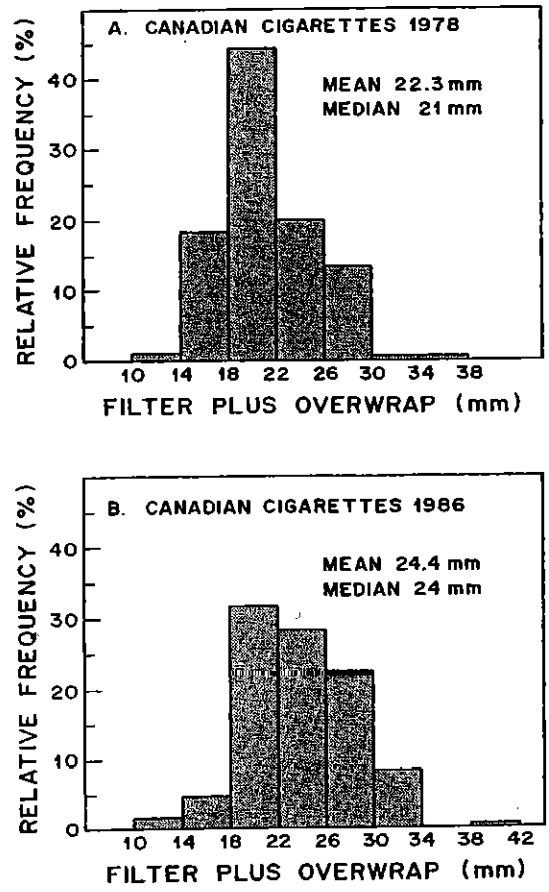

Fig. 7.1. Average, median and distribution of length of filter-plus-overwrap for all Canadian cigarette brands available in 1978 and 1986.

Predicting tar absorption

In 1976 as part of a butt length study a convenience sample of over 5000 cigarette butts was collected at multiple commercial locations at various times in the Canadian provinces of Ontario and Newfoundland. Although this data is not current, it does suggest that there is considerable variability in the amount of tobacco discarded by smokers (Fig. 7.2). This variability is not considered when T/N ratios are used to determine an index of tar absorption (TI). This index is given by:[12]

$$\text{TI(Nic)} = \text{Plasma nicotine} \times \frac{\text{Tar yield of cigarette}}{\text{Nicotine yield of cigarette}}$$

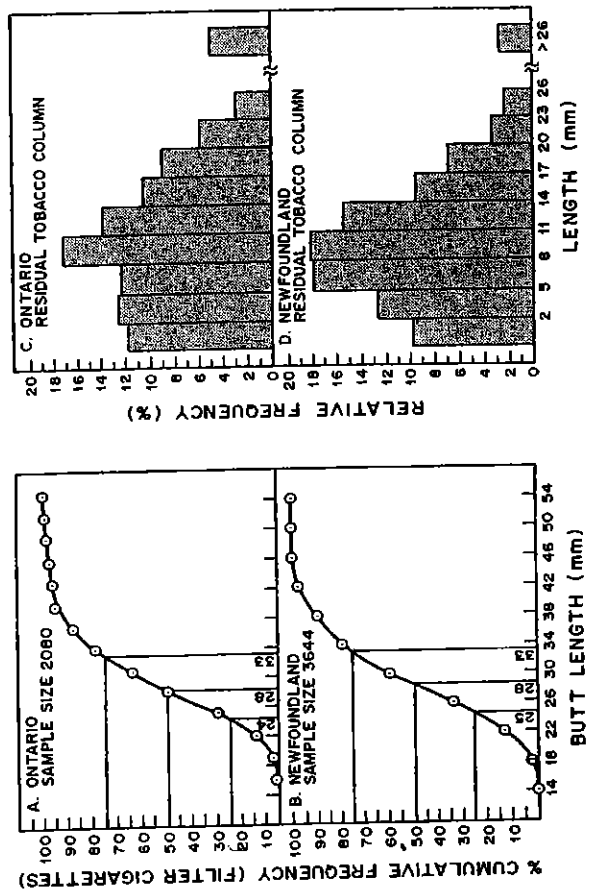

Fig. 7.2. Cumulative distribution of the lengths of discarded cigarette butts collected in a convenience sampling from two Canadian provinces. Frequency distribution of the length of the residual tobacco column from the same cigarette butts.

Assuming an average plasma nicotine of 38.3 ng/ml for middle tar smokers,[12] a range of values for residual column length of from 1 to 26 mm (Fig. 7.2) and the relationship of the T/N ratio to column length noted above, the corresponding values for TI range from a high of 758 ng/ml to a low of 598 ng/ml, a difference of 21 per cent. A decrease in TI of 27.3 per cent has been reported for non-low tar smokers who switched to low tar cigarettes.[12] Even after allowing for variations in butt length, T/N ratios may change considerably depending on how a cigarette is smoked.

In 1986 we reported the results of a study of cigarette yields for 10 brands of Canadian cigarettes smoked under 27 different conditions.[9] These were chosen to represent a wide range of smoking behaviours from 'light' to 'intense', where 'light' means a total smoke volume of about 200–300 ml per cigarette and 'intense' about 900–1000 ml per cigarette. Tar and nicotine yields from this experiment were used to determine how T/N ratios vary as a function of smoking intensity and type of cigarette. The results summarized in Fig. 7.3 are typical for non-vented cigarettes and for ultra-light cigarettes whose tar yield is 2 mg or less. For the 10 mg brand

$$\text{T/N ratio} = 11.5 + 0.00276\ V$$

where V represents total volume per cigarette (ml) and for the 2 mg brand

$$\text{T/N ratio} = -0.151 + 0.220\ V + 1.22 \times 10^{-5} V^2.$$

Both regressions are highly significant ($P < 0.005$]. For the ultra-light brand both the linear and quadratic terms are necessary with the quadratic

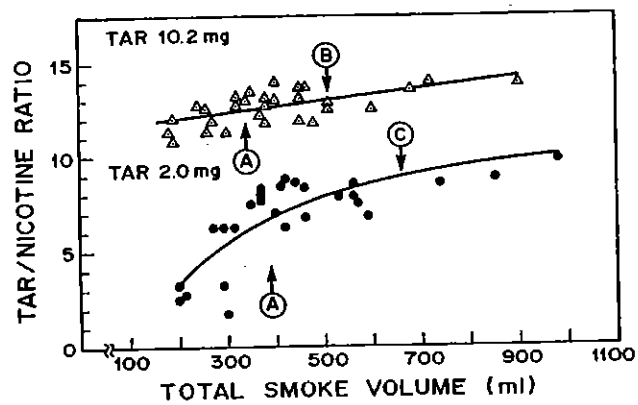

Fig. 7.3. Tar nicotine ratio as a function of the total smoke volume taken for analysis. 'A' represents the volume under standard conditions. 'B' and 'C' the average total volume of inhalation for a middle tar and a low tar cigarette, respectively.[19]

relationship explaining 64 per cent of the variability in T/N ratios. This finding also has implications for potential uses of the T/N ratio.

Multiplication by a constant value for the T/N ratio in the tar index calculation assumes that either individuals obtain the same T/N ratio as the smoking machine or that the smoking behaviour of groups results in an average T/N ratio similar to that found when cigarettes are machine smoked under standard conditions. Neither assumption is likely to be correct. As shown in Table 7.1, allowing for the possibility of differences in smoking intensity the tar index for an average plasma nicotine of 38.3 ng/ml, could be as low as 200 ng/ml for a light smoker of an ultra-light brand or as high as 544 ng/ml for an intense smoker of a middle tar brand.

7.3. Yields as indicators of relative risk to health

Most past studies of smoking behaviour in relation to brand characteristics, including our own,[6,7] have made use of volunteer subjects. For this type of individual, smoking a reduced yield brand appears to result in some decrease in smoke absorption, but not to the extent anticipated based on brand characteristics.[6,7] In order to extend the ability to generalize such findings, we have recently carried out a similar study of smoke absorption, but with a randomly selected non-volunteer sample.

The sampling frame for this experiment was the 1984 tax assessment role for Kitchener, Ontario, Canada (population approximately 145 000). Household addresses were chosen by randomly selecting a page from the assessment role then randomly determining the starting position on that page. A coin toss was used to determine whether to move forward or backward from the starting point until 20 non-commercial addresses had been accumulated. This procedure was repeated 150 times and resulted in the selection of 2891 households.

Table 7.1. Selected values for an index of tar absorption based on variations in the T/N ratio

	Tar index (ng/ml)†	
Smoking intensity*	Middle tar	ultra-low tar
Light (292 ml)	472	200
Standard (350 ml)	478	232
Average‡ (512 ml)	495	303
Intense (970 m)	544	372

*Expressed in terms of total volume of smoke per cigarette.

†The values in the body of this table assume an average of 38.3 ng/ml for plasma nicotine.[12] 'Middle' tar refers to a brand whose nominal delivery exceeds 10 mg. Ultra-low means tar less than or equal to 2 mg.

‡Based on values cited in reference 19, Table 7.2.

Households were visited in the early evening (3–9 p.m.) by trained interviewers. If there were smokers living at that address, one was randomly selected and a request made for either an interview at that time or at some future date. Subjects were asked not to smoke or drink during the interview which lasted at least 15 minutes. At that time a consent form was signed and samples of expired air and saliva obtained.[6] Each subject was paid a total of $5 for participating.

The 2891 addresses surveyed resulted in a sample of 736 participating smokers. Comparisons of sample characteristics such as age, sex, education, levels of cigarette consumption, and type of cigarette smoked with those reported for the province of Ontario[20] did not reveal any major differences.

Numbers for tar and perceived risk to health

Based on questionnaire responses, 47 per cent of 730 subjects stated that they were concerned about the effects of smoking on their health and had tried to lessen the impact in some way (Table 7.2). When probed for specifics, 32 per cent of 441 stated that in order to reduce the impact of smoking on their health they had switched to a lighter/lower/weaker tar brand. It is not too surprising then when subjects were asked to rate the hazards to health of a full flavoured/18 mg brand and a light/3 mg brand, the average score for the 3 mg description was 4.75 while 18 mg was rated as 8.3 (Table 7.3). The extent of the difference between the scores for 3 mg and 18 mg is better determined from the appropriate bar graphs (see Fig. 7.4). The modal value for 3 mg was 3 while the modal value for the 18 mg description was 10. These results indicate that many smokers perceive a quantitative relationship between stated tar yield and risk to health (low tar meaning 'less hazardous'). This finding is one possible explanation for the proliferation of Canadian brands in which the words light and mild

Table 7.2. Tabulation of general health concerns in relation to efforts to reduce smoking related risks*

	Concerned		
Attempted to lessen impact	Yes	No	Totals
Yes	334 (46%)†	72 (10%)	406
No	184 (25%)	140 (19%)	324
Totals	518	212	730

*Response to the questions, 'First. Are you concerned about possible effects of smoking on your health' and 'Have you consciously attempted to lessen the impact of smoking on your health by changing *how* or *what* you smoke in any way'.

†Values are percentages based on 730 responses out of a total sample size of 736.

are part of the brand description (47 per cent of 156 brands). Given the consumers perception of tar numbers, it is unfortunate that in Canada light brands may deliver as little as 4 mg of tar, but as much as 14 mg. Similarly, the range for extra-mild brands is from 0.4 to 12 mg (Table 7.4).

Table 7.3. A summary of the risk to health as perceived by smokers in relation to brand descriptors and tar yields

	Descriptor*				
Grouping	Light	18 mg	Mild	Full flavoured	3 mg
Entire sample	5.38 (690)†	8.30 (605)	5.60 (683)	7.86 (619)	4.75 (632)
Switchers‡					
to low	5.55 (74)	8.86 (72)	5.70 (74)	8.26 (65)	4.92 (74)
to high	5.00 (11)	8.70 (10)	5.64 (11)	8.64 (11)	4.45 (11)
Long-term‡					
low	5.50 (86)	8.47 (83)	5.74 (86)	8.21 (78)	4.86 (84)
middle	4.93 (80)	8.29 (66)	5.44 (82)	7.37 (69)	4.59 (71)
high	5.39 (247)	7.76 (204)	5.54 (240)	7.40 (219)	4.75 (216)

*Responses to the question 'on the same 0–10 scale that we used before where 0 means no health risk and 10 means very serious health risk, what rating would you give a brand described as . . .'.

†Number of responses out of the sample of 736 smokers who participated in this survey.

‡See Table 7.5 for a definition of these terms.

Table 7.4. A comparison of brand descriptors and tar yields of brands of Canadian cigarettes*

Category	Brand designation	Tar yields (mg)			
		No.	Mean	Median	Range
A	Light (s)	28 (18)†	10.7	11	4–14
B	Ultra-light Extra-light	13 (4)	7.6	8	1–11
C	Mild	2 (2)	11.0	11	—
D	Extra-mild Ultra-mild Special mild	30 (23)	6.6	6.5	0.4–12
E	Others	83 (73)	12.8	14	1–18
	All Brands	156 (120)	10.8	11	0.4–18

*List produced by the Canadian Tobacco Manufacturers Council (CMTC) dated June 30, 1986.

†Values are number of brands based on the CMTC list of March 31, 1983.

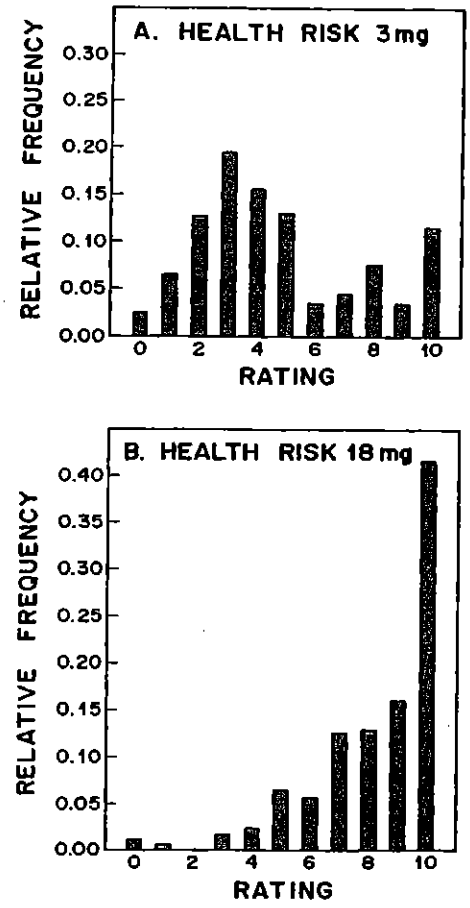

Fig. 7.4. Distribution of risk-to-health ratings for low tar (A) and high tar (B) cigarettes.

Brand characteristics and smoke absorption

To determine if low tar might mean less risk we compared measures of smoke uptake in subjects classified by sex, tar level, and stability of smoking behaviour (brand switchers *v.* non-switchers; see Table 7.5 for a definition of terms). With respect to brand characteristics, the average tar yield for both long-term low tar smokers and those who switched to low tar was 7 mg while the average for long-term high tar smokers was 15 mg. Long-term smokers had smoked their current brand for an average of 6 years (low tar) and 10 years (high tar) while switchers reported smoking current brand for an average of 1.5 years.

Table 7.5. Definition of smoking categories*

Category	Smoke current brand (months)	Previous tar (mg)	Current tar (mg)
1. Switched to low tar brand	≤36	≥13	≤10
2. Switched to high tar brand	≤36	≤10	≥13
3. Long-term low tar smoker	>36	—	≤10
4. Long-term middle tar smoker	>36	—	11, 12
5. Long-term high tar smoker	>36	—	≥13

*In general, 'switch' means change to a brand with a different name. Switching may take place unknown to the smoker if the manufacturer makes a major change.

Since specific contrasts had been decided upon before the experiment, average consumption adjusted values for indicators of smoke absorption were compared by means of simple *t* tests. The contrast of females who always smoked low tar cigarettes with those who switched to low tar was highly significant for both breath CO (52 ppm *v.* 41 ppm; $P<0.001$) and saliva cotinine 320 ng/ml *v.* 259 ng/ml; $P<0.05$). However, females who always smoked low tar cigarettes had higher average results for breath CO than did those who always smoked high tar brands (52 ppm *v.* 43 ppm; $P<0.001$). All other contrasts for the data subdivided by sex were not significant.

When the sex of the smoker is ignored (Table 7.6) the comparison of breath CO for long time low tar smokers with those who switched to low was the only contrast which was significant (49 ppm *v.* 41 ppm; $P<0.001$).

Table 7.6. Adjusted levels of cotinine in saliva and CO in exhaled air for a random selection of smokers*

	Salivary cotinine (mg/ml)		
	Low tar	High tar	Average
Switcher	273 (65)†	213 (8)	266 (73)
Non-switcher	297 (77)	302 (200)	301 (277)
Average	286 (142)	299 (208)	
	Breath CO (ppm)		
Switcher	41.3 (78)	38.4 (9)	41.0 (87)
Non-switcher	49.3 (80)	45.6 (219)	46.6 (299)
Average	45.3 (158)	45.3 (228)	

*Adjusted for level of consumption.
†Number of subjects.

When both sex and brand loyalty are ignored long-term low tar and long-term high tar smokers had identical average values for breath CO (45.3 ppm). When smokers were categorized based on brand loyalty alone those who had switched down absorbed on the average 12 per cent less nicotine and 12 per cent less carbon monoxide than did those who had smoked the same brand for more than 3 years. If this finding can be generalized, those who switch down, particularly females, may experience a small but tangible health benefit when compared with those who continue to smoke the same brand. Since there were only 11 smokers who reported switching up, this group has not been included in the analysis.

Interpretation of published tar and nicotine yields

There are a number of well known explanations why smokers absorb quantities of smoke which are different from yields under standard conditions. One possibility which generally has not been considered is if smokers perceive that cigarettes contain a specific amount of tar they might also believe that it is not possible to obtain more from a cigarette than the published value. By this reasoning switching to a lower tar brand should result in a health benefit since it should not be possible to inhale more from the new cigarette no matter how it is smoked. Of the 558 individuals who responded, 51 per cent stated that they believed that the numbers which appear on every Canadian cigarette package represents the *maximum* which can be inhaled from that brand of cigarette (Table 7.7). This is obviously incorrect since the maximum based on human smoking behaviour may be as high as 2½ times the published number or even higher.[8,9] The continued publication and advertising of numbers for tar and nicotine reinforces the idea of fixed cigarette contents and perpetuates this fallacy.

7.4. Conclusions

It has been suggested that the hazards associated with smoking could be decreased by maintaining levels of nicotine while reducing the concentration of other hazardous substances such as tar.[13] This approach is strongly supported by evidence that nicotine is the prime reinforcer of the smoking habit.[2] However, it is not clear how reducing the T/N ratio to smoking machines will result in a health benefit to smokers. This investigation has shown that T/N ratios are clearly dependent upon how cigarettes are smoked. As shown in Fig. 7.3, a T/N ratio of 6.1 to a smoking machine may become 9.7 to the smoker who tries to increase the amount of nicotine from an ultra-light cigarette. Figure 7.3 also demonstrates that even under intensive smoking conditions, the T/N ratio for ultra-light cigarette which

Table 7.7. Smoker's perception of tar values as representing the 'maximum' in relation to tar yield of current brand*

	Tar (mg)		
Perception of numbers	≤10	11, 12	≥13
Represents most	90 (93.8)†	50 (46.1)	143 (143.0)
Can inhale more	95 (91.2)	41 (44.8)	139 (139.0)

*Response to the question 'let's assume for a moment that the tar rating is 10 mg. What does that mean? Is it possible to inhale more than 10 mg tar from each cigarette or does this represent the most you can inhale with this brand?
†Expected values under the hypothesis of independence ($\chi^2 = 0.97$; $P = 0.6165$).

was tested never equalled that of the 10 mg cigarette. For those who will not quit this suggests that there may be some advantage to smoking ultra-light cigarettes provided that the number smoked per day does not increase.

The continued misuse and misinterpretation of cigarette yields indicates that the method of communicating brand characteristics to smokers should be changed. It may be time to acquaint the smoker and researcher alike with the variable nature of yields by publishing a range of values for each brand.[9] A more radical approach would be to stop publishing numbers altogether, replacing them with some other more realistic system. One possibility would be to use colour codes where the colour represents filter tip stain when cigarettes are smoked under a number of conditions.[15] We have investigated this possibility by actually measuring the amount of colour on pads and filters after the deposition of various amounts of tar. The resulting numbers are readily translated by printers so that the colours can be accurately reproduced and used to represent deliveries in terms which smokers may better understand.

Acknowledgements

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