Nicotine Yield From Machine-Smoked Cigarettes and Nicotine Intakes in Smokers: Evidence From a Representative Population Survey

Martin J. Jarvis, Richard Boreham, Paola Primastesa, Colin Feyerabend, Andrew Bryant

Background: The relevance of nicotine yields from machine-smoked cigarettes for quantifying smokers’ nicotine intakes and exposure to cigarette toxins has been called into question. However, most studies of the relationship between nicotine yield and nicotine intake have been on relatively small and unrepresentative samples and have included few smokers of “ultra-low” brands (i.e., those yielding around 1 mg of tar and 0.1 mg of nicotine). Methods: We examined the relationship between salivary cotinine (a major metabolite of nicotine) concentrations and nicotine yields of machine-smoked cigarettes in a nationally representative sample of 2031 adult smokers of manufactured cigarettes surveyed in the 1998 Health Survey for England. We used standard linear regression techniques to examine associations and two-sided tests of statistical significance. Results: Cotinine concentrations varied widely between smokers at any level of nominal brand nicotine yield. On average, cotinine levels were slightly lower in smokers of lower nicotine-yielding brands, but these smokers differed in terms of sex, socioeconomic profile, and cigarette consumption. After we controlled for potential confounders, nicotine yield from the brand smoked accounted for only 0.79% of the variation in salivary cotinine concentrations. Nicotine intake per cigarette smoked, as estimated from salivary cotinine level, did not correspond with machine-smoked yields at any level of nicotine yield. Nicotine intake per cigarette was about eight times greater than machine-smoked yields at the lowest deliveries (1.17 mg estimated nicotine intake per cigarette from brands averaging 0.91 mg from machine smoking). Conclusions: Smokers’ tendency to regulate nicotine intake violates potential health gains from lower tar and nicotine cigarettes. Current approaches to characterizing tar and nicotine yields of cigarettes provide a simplistic guide to smokers’ exposure that is misleading to consumers and regulators alike and should be abandoned. [J Natl Cancer Inst 2001;93: 134–8]

Tar and nicotine yields of machine-smoked cigarettes have been declining for many years. In the U.K., the so-called “tar reduction programme” (1) was initiated in the early 1970s through voluntary agreements between government and the tobacco industry when tar yields were around 20 mg per cigarette. More recently, a limit of 12 mg per cigarette to be achieved by 1997 was set by European Union directive (2). Sales-weighted tar yield now stand at around 10 mg and nicotine yields at 0.85 mg. Whether low-yield cigarettes offer any real benefits has come under challenge, with concerns that the numbers are misleading and that they may offer reassurance to health-aware smokers and hence deter them from quitting altogether (3–6). Studies of smokers using their own preferred cigarette brand (own brand) (7–13) have found little relation between nicotine yields and nicotine intake, pointing to the overriding importance of smokers’ tendency to regulate their nicotine intake by modulating puffing and inhalation in response to variations in yield. However, some commentators (14, 15) have suggested that compensation may be roughly half way between complete and absent, implying some public health gain from lowering yields.

Studies of the relation between brand yield and smoke intake (16–18) have frequently been on small and unrepresentative samples and have included few smokers of “ultra-low” brands (i.e., those yielding around 1 mg of tar and 0.1 mg of nicotine). Many of these studies were conducted in the 1980s at a time when yields were considerably higher than now (7–11). We report on a large and representative sample of smokers surveyed in 1998 and examine the relation between nicotine yield of self-selected cigarette brands and nicotine intake as indexed by saliva cotinine concentrations. Cotinine is a major metabolite of nicotine and is considered to be a valid measure of nicotine intake (19–21). Since the half-life of cotinine is 16–20 hours, a spot sample provides a good measure of nicotine intake over the previous 2 or 3 days (19).

Subjects and Methods

The Health Survey for England is an annual survey designed to generate a representative sample of the population living in private households in England. With the use of the Postcode Address File as the sampling frame, a stratified random sample of households is identified. Adults and up to two children in eligible households are interviewed, and then a nurse visits to take biologic measures (including blood pressure and blood and saliva specimens). In 1998, a sample of 12 446 households was identified, containing 23 085 eligible respondents; 74% of the households approached cooperated with the survey interview, and in 62% all eligible persons were interviewed and agreed to the nurse’s visit. Smoking habits were ascertained at the interview, and saliva samples were collected by the nurse for determining cotinine levels, usually about a week after the interview. In 1998, of the total of 17 240 adults in cooperating households, 15 908 (92%) were interviewed, 13 586 (79%) saw a nurse, and 13 240 (77%) gave a saliva sample. The survey methodology has been fully described previously (22). Participants in the survey provided informed consent to the interviewer, and ethical approval was obtained from all local research ethics committees in the U.K.

Smoking habits. Smoking habits were ascertained by individual interview with the use of a computer-aided schedule. Those aged 16–17 years (and some aged 18–19 years) were given a self-completion booklet to ensure greater confidentiality. Current cigarette smokers responded “yes” to the question “Do you smoke cigarettes at all nowadays?” and included those who subsequently reported smoking fewer than one cigarette per day. Smokers of filter or plain (but not own-rolled) cigarettes were asked which brand of cigarette they usually smoked. The interviewer checked the brand named against a list of brands currently available in the U.K. At the nurse’s visit, a further question about smoking was asked: “Can I ask, do you smoke cigarettes, cigars, or a pipe at all these days?” Only those reporting smoking cigarettes at both the initial interview and the nurse’s visit were included as current cigarette smokers in our analyses.

Affiliations of authors: M. J. Jarvis (Imperial Cancer Research Fund [ICRF] Health Behavior Unit), P. Primastesa, Department of Epidemiology and Public Health, University College London, U.K.; R. Boreham, National Center for Social Research, London; C. Feyerabend, A. Bryant, Medical Toxicology Unit, New Cross Hospital, London.

Correspondence to: Professor Martin J. Jarvis, ICRF Health Behavior Unit, Department of Epidemiology and Public Health, University College London, 2–16 Torrington Place, London WC1E 6BT, U.K. (e-mail: martin.jarvis@ucl.ac.uk).

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Saliva sample. The nurse attempted to collect a saliva sample from all adults by asking them to keep a dental roll in their mouths until it was saturated and then to replace it in the sample tube.

Tar, nicotine, and carbon monoxide yields of different cigarette brands. Yields of tar, nicotine, and carbon monoxide from machine-smoked cigarettes were supplied by the Laboratory of the Government Chemist, Teddington, U.K., and were derived with the use of standard International Standards Organisation methodology (23–25) from samples of cigarettes purchased over the period January 1998 through December 1998 (Laboratory of the Government Chemist survey 42). Yields were determined with the use of a Filtrona 20 channel linear smoking machine model SM400. The methodology was essentially the same as that specified by the U.S. Federal Trade Commission protocol (3), with a minor difference in the way butt lengths are calculated. When a respondent reported smoking a brand that had been available in 1997 but was no longer on sale in 1998, the yields from survey 41 (January 1997 through December 1997) were used instead.

Cotinine assay. Cotinine was assayed by a widely applied gas chromatographic method (26). Regular internal quality controls were run to ensure comparability and reliability of results over time (27).

Statistical analysis. The association between nicotine yield from brand-named cigarettes from machine smoking and saliva cotinine concentrations was examined with the use of standard linear regression techniques. In multiple regression analyses, potential confounders (age, sex, body mass index, educational qualifications, occupational class, unemployment, car ownership, and housing tenure) were forced into the model, and the increment in variance explained by entering brand nicotine yield was then examined. All statistical tests were two-sided.

RESULTS

Cigarette smoking prevalence at interview was 28.3% in men and 27.0% in women. The great majority of female smokers (93%) smoked manufactured cigarettes, but 26% of men who smoked reported that they smoked own-rolled cigarettes, for which machine-smoked yields are not available.

Of the total of 3678 self-reported current cigarette smokers at initial interview who participated in the nurse’s visit, 3496 (95%) confirmed to the nurse that they were still smoking cigarettes. We here report on 2031 respondents who reported smoking a manufactured cigarette brand with known yields and for whom a measured cotinine concentration was available. Of these, 868 (42.7%) were men and 1163 (57.3%) were women. Losses to the sample were due to smoking own-rolled cigarettes (n = 542), inadequate saliva volume (n = 685), and missing data on type of cigarette smoked, brand smoked, or brand yield (n = 238). Respondents with inadequate saliva volume were significantly older and were more likely to be female, but they did not differ in terms of brand tar and nicotine yields, cigarette consumption, or socioeconomic status. The preponderance of women in the final sample is mainly due to the higher proportion of smokers of own-rolled cigarettes among men. The mean time between the initial interview and the nurse’s visit was 8 days, and 75% of the respondents were seen within 2 weeks.

As shown in Table 1, smokers displayed a preference for higher nicotine-yielding brands; 59.8% smoked a brand yielding more than 0.75 mg of nicotine, 35.2% smoked a brand yielding between 0.4 and 0.75 mg of nicotine, and only 5% smoked a brand yielding less than 0.4 mg of nicotine. Smokers of higher and lower nicotine-yielding brands differed in several respects. Smokers of lower nicotine-yielding brands tended to be older and were more likely to be female. They were better educated, were less likely to live in rented housing or to have a manual occupation, and were more likely to own a car. They were also somewhat lighter smokers, as shown by the mean daily cigarette consumption and by the proportion who smoked fewer than five cigarettes per day.

The association between nominal brand nicotine yield (measured in milligrams per cigarette) and cotinine concentration (measured in nanograms per milliliter of saliva) is illustrated in Fig. 1. At any given yield, there was a wide variation in cotinine concentrations between subjects. This was so whether subjects were smoking brands with low or high nicotine yields and shows that, at any level of nominal yield, smokers could, and did, achieve very high nicotine intakes. Overall, there was a small but statistically significant correlation between brand nicotine yield and cotinine (r = .19; P < .001), with nicotine yield accounting for some 3% of the variance in cotinine concentrations. The linear regression coefficients based on all 2031 subjects were as follows: cotinine = intercept 173.5 + 138.7 (95% confidence interval [CI] = 106.8 to 170.6) nicotine yield.

Since smokers of cigarette brands with lower nicotine yields differed from those choosing cigarettes with higher nicotine yields in terms of both demographics and cigarette consumption, we controlled for these potential confounders in multiple regression analyses. We also included a term for body mass index (BMI) in these analyses, since, at any given level of cigarette consumption, higher BMI was associated with lower cotinine concentrations. We conducted these analyses in all subjects combined and also in groups stratified by level of cigarette consumption (Table 2). After we controlled for potential confounders, the slope relating nicotine yield and cotinine concentrations among all smokers combined was shallower (slope = 71.0; 95% CI = 41.3 to 100.6) but remained statistically significant. At each stratum of cigarette consumption considered individually, the slope either failed to reach statistical significance or was only marginally significant. After we controlled for confounders, the incremental proportion of variance explained by nominal brand nicotine yield overall was 0.79%. Since relatively few subjects smoked brands yielding less than 0.4 mg of nicotine, we reanalyzed the re-

<table>
<thead>
<tr>
<th>Table 1. Characteristics of smokers choosing cigarette brands with different nominal nicotine yields as determined by machine smoking</th>
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<tr>
<td>Characteristic</td>
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<td>----------------</td>
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<tr>
<td></td>
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<tr>
<td>Mean nicotine yield, mg</td>
</tr>
<tr>
<td>Mean tar yield, mg</td>
</tr>
<tr>
<td>Mean carbon monoxide yield, mg</td>
</tr>
<tr>
<td>% smoking &lt;5 cigarettes/day</td>
</tr>
<tr>
<td>% male</td>
</tr>
<tr>
<td>Mean age, y</td>
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<tr>
<td>% with degree level education</td>
</tr>
<tr>
<td>% with no educational qualifications</td>
</tr>
<tr>
<td>% unemployed</td>
</tr>
<tr>
<td>% manual occupation</td>
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<tr>
<td>% rented accommodation</td>
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<tr>
<td>% with no car ownership</td>
</tr>
</tbody>
</table>
Fig. 1. Scatterplot relating cigarette nicotine yields and saliva cotinine concentrations in 2031 smokers participating in the 1998 Health Survey of England. Cotinine = 173.5 + 138.7 (nicotine yield); \( r = .19; r^2 = .034 \).

The relationship between nicotine yield and cotinine concentrations, limiting our consideration to smokers of a brand yielding 0.45 mg of nicotine or more. The regression coefficients adjusted for potential confounders were not substantially changed (cotinine = intercept 148.5 + 87.7 [95% CI = 49.9 to 125.5] nicotine yield, as compared with intercept 164.1 + 71 [95% CI = 41.4 to 100.6] nicotine yield).

Benowitz and Jacob (19) have demonstrated that daily nicotine intake can be estimated from cotinine concentrations on the basis that every 100 ng/mL plasma cotinine at steady state represents a daily intake of 8 mg of nicotine. Since saliva cotinine concentrations are some 20% higher than in plasma (28), 100 ng/mL cotinine in saliva represents a daily intake of about 6.7 mg of nicotine. We used this approximate equivalence to estimate daily intake of nicotine and nicotine intake per cigarette smoked by nominal brand nicotine yield (Table 3). For brands yielding about 0.1 mg of nicotine on machine smoking, the estimated intake per cigarette smoked was 1.07 mg, some 10 times higher. However, because of the small numbers smoking these brands, this estimate is subject to considerable imprecision. From brands with nominal yields of 1 mg, smokers were estimated to take in about 1.4 mg of nicotine per cigarette—still much higher than the level suggested by the numbers. There was only a very slight tendency for smokers of higher nicotine-yielding brands to have higher intakes from each cigarette smoked. Estimated nicotine intake per cigarette was 1.17 mg in smokers of brands yielding less than 0.4 mg of nicotine (average yield = 0.14 mg), 1.22 mg from brands yielding between 0.4 mg and less than 0.8 mg (average yield = 0.57 mg), and 1.31 mg from brands yielding 0.8 or more (average yield = 0.91 mg).

**DISCUSSION**

Our results confirm that machinesmoked nicotine yields of cigarettes are poor predictors of nicotine intake in smokers. Since tar and nicotine deliveries are highly correlated, this indicates that there is little difference, on average, between tar exposure in smokers of low and high nicotine-yielding brands and once more calls into question the magnitude of the potential reduction in health risk obtained by smoking low tar and nicotine brands. With the exception of the Scottish Heart Health Study (12), to our knowledge, our study is the largest reported, and the nationally representative sampling frame and good response rate facilitate generalization to the whole population of smokers of manufactured cigarettes in England. The observed prevalences of cigarette smoking in men and women (28.7% and 27%, respectively) were close to estimates for England from the 1998 General Household Survey (28% and 26%, respectively), confirming the representative nature of the sample (29,30).

We found that, at any given level of nicotine yield, there was wide variation in cotinine concentrations between individuals in the observed level of saliva cotinine. This remained the case after adjustment for cigarette consumption. The factors influencing preferred level of nicotine intake are not well understood, although both socioeconomic circumstances (31,32) and genetic variation in nicotine metabolism (33) may play a part. Within individuals, there appears to be a reasonably stable level of nicotine intake over.

**Table 2.** Linear regression coefficients relating brand name cigarette nicotine yield (by machine smoking) and saliva cotinine: univariate analysis and multivariate analysis after controlling for potential confounders.

<table>
<thead>
<tr>
<th>Cigarette consumption, No. per day</th>
<th>Univariate</th>
<th>Adjusted for potential confounders*</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No. of subjects</td>
<td>Intercept</td>
</tr>
<tr>
<td>0–7</td>
<td>459</td>
<td>32.6</td>
</tr>
<tr>
<td>8–12</td>
<td>493</td>
<td>196.4</td>
</tr>
<tr>
<td>13–17</td>
<td>370</td>
<td>255.7</td>
</tr>
<tr>
<td>18–22</td>
<td>471</td>
<td>304.8</td>
</tr>
<tr>
<td>≥23</td>
<td>238</td>
<td>300.4</td>
</tr>
<tr>
<td>All</td>
<td>2031</td>
<td>177.7</td>
</tr>
</tbody>
</table>

*Adjusted for cigarettes smoked per day within consumption category, age, sex, body mass index, car ownership, housing tenure, unemployment, occupational class, and educational qualifications. The numbers of smokers in the multivariate analysis are lower because of missing data on potential confounders.

†Two-sided.
time (4), and it would appear that smokers’ nicotine preferences are the most important factor determining how cigarettes are puffed and inhaled (4). Low-tar cigarettes are not made from low-nicotine-yield tobacco, and indeed the total nicotine content of the tobacco is as high or higher than in mainstream brands (34,35). Low deliveries are achieved primarily through filter ventilation, which dilutes the smoke puffed with air by as much as 83% (34). Smokers can achieve essentially whatever delivery they desire, irrespective of nominal machine-smoked delivery, through taking larger and more frequent puffs and through maneuvers such as blocking ventilation holes with lips or fingers. However, the effort required to puff the necessary volume of smoke increases markedly as machine-smoked yields decrease and may become quite aversive (36). This may explain why so few smokers choose to smoke brands with low nominal deliveries.

The fact that there was some association, albeit weak, between brand nicotine yield and saliva cotinine concentrations and that this persisted in attenuated form after we controlled for cigarette consumption and socioeconomic status could be interpreted as implying that there is a real population benefit to be obtained from shifting to lower deliveries. This interpretation assumes that some element of the observed reduction in intake is causally attributable to lowered yields. While this is a possibility that cannot be unequivocally rejected from our data, we would regard it as unlikely. Smokers are not randomly assigned to brand but self-select on the basis of a number of factors. These factors include cost, brand image, socioeconomic status, and level of nicotine dependence. The last of these is of particular importance. We controlled for cigarette consumption as a proxy for nicotine dependence and found a flattening of the slope relating brand yield and nicotine intake. But cigarette consumption is a weak indicator of nicotine dependence, and more adequate adjustment might have resulted in further flattening of the slope. Our observations indicate that nicotine compensation is at least 80% complete, but they do not rule out the possibility that it may be 100%. A definitive answer to this question would require a time series tracking nicotine intakes in the population as machine-smoked yields decline. Such data are currently lacking. The largest studies of long-term switching are consistent with 100% compensation (37,38).

We estimated nicotine intake per cigarette smoked and found that at no level of nicotine yield did it match machine-smoked deliveries. It was some eight times greater at the lowest deliveries and one and a half times greater at the highest. These estimates are subject to inaccuracies and should only be regarded as approximate. Although cotinine has a half-life of 16–20 hours, there is some diurnal variation, and a single spot sample may not fully represent steady state (19). More significantly, smokers’ self-reports of consumption tend to be inaccurate. Neither of these factors is likely to be of such magnitude as to critically undermine our estimates; in particular, there are no reasons to expect them to operate differentially by brand yield.

We conclude that yields of tar and nicotine from machine-smoked cigarettes provide a very poor guide to smokers’ exposure. Nominal nicotine deliveries are misleading both at the individual level (since intakes vary widely between individuals at any given yield) and for groups (since average nicotine intake per cigarette differs substantially from nominal yields at every level of brand yield). If lower yield cigarettes confer any benefit, it is likely to be through factors such as improved tar-to-nicotine ratio rather than through the absolute level of machine-smoked yields (8). Our findings reinforce the emerging consensus that current approaches to characterizing tar and nicotine yields of cigarettes are simplistic and misleading to consumers and regulators alike and should be abandoned.

**REFERENCES**


(9) Benowitz NL, Hall SM, Herning RI, Jacob P 3rd, Jones RT, Osman AL. Smokers of low-


**Notes**

The Health Survey for England is commissioned by the Department of Health. The 1998 Health Survey for England was carried out by the Joint Survey Unit of the National Center for Social Research and the Department of Epidemiology and Public Health at University College London.

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