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Influence of cigarette filter ventilation on smokers' mouth level exposure to tar and nicotine

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ABSTRACT

Cigarette filter ventilation allows air to be drawn into the filter, diluting the cigarette smoke. Although machine smoking reveals that toxicant yields are reduced, it does not predict human yields. The objective of this study was to investigate the relationship between cigarette filter ventilation and mouth level exposure (MLE) to tar and nicotine in cigarette smokers. We collated and reviewed data from 11 studies across 9 countries, in studies performed between 2005 and 2013 which contained data on MLE from 156 products with filter ventilation between 0% and 87%. MLE among 7534 participants to tar and nicotine was estimated using the part-filter analysis method from spent filter tips. For each of the countries, MLE to tar and nicotine tended to decrease as filter ventilation increased. Across countries, per-cigarette MLE to tar and nicotine decreased as filter ventilation increased from 0% to 87%. Daily MLE to tar and nicotine also decreased across the range of increasing filter ventilation. These data suggest that on average smokers of highly ventilated cigarettes are exposed to lower amounts of nicotine and tar per cigarette and per day than smokers of cigarettes with lower levels of ventilation.

1. Introduction

Cigarette filter ventilation allows air to be drawn into the filter, thereby diluting the cigarette smoke. Filter ventilation also reduces the air flow through the burning coal, the cigarette tobacco rod, and the filter, respectively altering the smoke composition, allowing outward diffusion of gaseous compounds, and improving filter efficiency. As a result, mainstream cigarette-smoke machine yields are reduced (Browne, 1990; Adam et al., 2010). Mainstream smoke yields from machine-smoked cigarettes decrease as ventilation rate increases, when the puffing regimen remains unchanged. However, cigarette yields obtained using standardized machine-smoking methods such as ISO (ISO, 2012), Massachusetts (Commonwealth of Massachusetts, 1997) or Canadian Intense (Health Canada, 2000), do not predict yields produced by human smoking (Jarvis et al., 2001; Nelson et al., 2011; St. Charles et al., 2010). As such, machine-smoking methods do not predict exposure to smoke constituents in smokers. Some have suggested in the literature that smokers of ventilated cigarettes block ventilation holes (Scherer, 1999) or otherwise attempt to increase nicotine yield (Scherer and Lee, 2014; Kozlowski and O'Connor, 2002; Kozlowski et al., 2006). The impact of cigarette filter ventilation on smoke yield under natural smoking conditions merits closer examination.

Cigarette smoke exposure can be assessed using the part-filter analysis method (Shepperd et al., 2006; St. Charles et al., 2009). This methodology estimates the yield of smoke constituents which passed through the cigarette filter into a smoker's mouth by analyzing a portion of the spent filters collected from smokers and comparing these to filter portions obtained from cigarettes that were machine-smoked under known conditions (Shepperd et al., 2006; St. Charles et al., 2009). Since the methodology does not account for exhaled smoke or smoke escaped from the mouth during puffing, the estimates represent the maximum smoke constituent yield to which a smoker could be exposed. This is referred to as mouth-level exposure (MLE).

Previously-published studies have reported significant correlations between smoke constituent MLE and standardized machine-smoked yields (Nelson et al., 2011; Mariner et al., 2011; Ashley et al., 2011, 2014; Hyodo et al., 2013; Shepperd et al., 2009, 2011). Considering the association between machine-smoked cigarette yields and cigarette filter ventilation, MLE to smoke constituents in smokers would presumably correlate to cigarette filter ventilation. The objective of this study was to test this hypothesis by investigating relationships between cigarette filter ventilation and MLE to tar and nicotine in cigarette smokers. The findings presented here are based on data collected during the conduct of two previously unpublished studies performed in the

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United States and previously published studies (Mariner et al., 2011; Shepperd et al., 2011). In these studies, MLE to tar and nicotine from commercially available cigarettes in Australia, Brazil, Canada, Germany, Japan, New Zealand, South Africa, Switzerland, and the United States were assessed in adult smokers.

2. Methods

The design, participants, products, procedures, analytical methods, and data analysis in studies conducted in Australia, Brazil, Germany, Japan, New Zealand, South Africa, Switzerland, and two studies in Canada, were previously described (Mariner et al., 2011; Shepperd et al., 2011). Two previously unpublished studies were performed in the United States by R.J. Reynolds Tobacco Company. One study was initiated in 2007 with subjects participating from March to April 2008 and another study performed from March to June 2013. The two USA studies generally followed methods previously described for a study by Nelson et al. (2011)

2.1. Participants

Adult male and female smokers at least 21 years of age (except in the Canada studies where 19 years was the minimum) who regularly smoked at least 5 cigarettes per day of one of the target brand styles as their usual product for at least 6 months prior to the study (3 months in the USA studies) were recruited locally by market research agencies. The recruitment target was at least 50 participants per cigarette brand style in the Côté et al. (2011), Mariner et al. (2011) and 2013 USA studies. In the 2007 USA study, the targets were 20–40 participants per brand style having $\leq 0.1\%$ share of market and 40-50 participants per brand style having $> 0.1\%$ share of market. In the 2007 USA study, smokers were recruited across the states of California, Illinois, Massachusetts, New Hampshire, New York, Oregon, and Vermont. The smokers in the 2013 USA study were recruited in the states of Alabama, Arizona, California, Minnesota, New Jersey, North Carolina, Oregon, Pennsylvania, Tennessee, Texas, and Washington.

All participants provided informed consent form prior to study enrolment. In total, the number of participants from which filters were obtained was 7534.

2.2. Study products

Twenty-nine commercially available cigarette brand styles were chosen for evaluation in the USA study conducted in 2007. In the 2013 USA study, a total of eleven brand styles of 5 cigarette brands were evaluated and included the four leading brands in the USA. Product selection in the other countries was designed to represent the cigarette market in each of those countries and is described elsewhere (Mariner et al., 2011; Shepperd et al., 2011). In total, data were obtained from 156 different products/brands.

2 .3. Study design

Recruited smokers were screened, and those who were eligible and willing to provide their informed consent to participate in the study were enrolled for participation. Enrolled participants received study instructions and a collection kit for their smoked cigarette samples and answered questionnaires. Participants either supplied their own usual brand-style cigarettes (2007 and 2013 USA studies) or were provided with their usual brand-style cigarettes to smoke during participation (Mariner et al., 2011; Shepperd et al., 2011). Participants were asked to smoke the cigarettes in their normal life settings according to their typical practice and to collect either a minimum of 15 spent cigarettes (Mariner et al., 2011; Shepperd et al., 2011) or, in the USA studies, each spent cigarette smoked in one day from waking up to going to bed (50 spent cigarettes maximum). After completion of the collection period, participants visited their study site, returned the collection kit, and completed a questionnaire. Participants were compensated for their time and travel in those countries where this is customary in research.

2.4. Daily cigarette consumption assessment

In the Australia, Brazil, Canada, Germany, Japan, New Zealand, and South Africa studies, daily cigarette consumption was obtained from the participant self-reported number of cigarettes smoked during the 24 h prior to returning their spent cigarette filter collection. In the Switzerland survey, daily cigarette consumption rate was the number of cigarettes typically smoked in a day as reported by participants during recruitment. For the USA studies, participant daily cigarette consumption was determined from the sum of the number of spent cigarettes collected by the participant and the number of cigarettes the participant self-reported as having smoked but neglected to collect during the collection period.

2.5. Filter analysis methods

The smoked cigarettes collected in the 2007 and 2013 USA studies were analysed by Arista Laboratories, Inc. (Richmond, VA) and Labstat International, ULC (Kitchener, ON, Canada), respectively. The cigarette collection and analysis methods used in the USA studies followed techniques described by Nelson et al. (2011). The collection and analysis methods used in the studies conducted in countries other than the USA are described in detail by Côté et al. (2011) and Mariner et al. (2011). Calibration curves of nicotine yield to nicotine content per filter tip and of tar yield to UV absorbance per filter tip were generated for each cigarette brand style used by participants. Each brand style was machine smoked using 6-10 smoking regimens, and mainstream smoke yields of tar and nicotine were determined using validated, standardized methods. Smoked cigarettes obtained from the calibration procedures and participants were cut to obtain a 10-mm section of the mouth-end portion of the cigarette filters. These filter tips were extracted using methanol with internal standard added (*n*-heptadecane). The extracts were analysed for nicotine by gas chromatography with flame ionization detection and for tar, using high performance liquid chromatography with ultraviolet detection at 310 nm. The mainstream smoke yields from analysis of the filter tips from calibration smoking were used to produce linear regression equations for tar yield per cigarette vs. UV absorbance per filter tip and for nicotine yield vs. nicotine content per tip for each brand style. Tar and nicotine MLE for each participant was estimated using the UV absorbance and nicotine values determined from the filter tips of their smoked cigarettes and the appropriate regression equations from the calibration procedures.

2.6. Measurement of cigarette filter tip ventilation

Filter tip ventilation for the cigarette brand styles were determined using either a C2 instrument or equivalent (Cerulean, Milton Keynes, U.K.) or a QTM 5 module (Cerulean) employing a critical flow orifice. Twenty cigarettes of each brand style were tested and the mean ventilation rate was determined.

2.7. Data analysis

Minitab (version 17, Minitab Ltd., UK) was used for statistical analyses. Data are shown as mean MLE to nicotine and tar per cigarette (cig) and per day, by product and study. The relationships between filter ventilation versus MLE per cig and versus MLE per day were assessed for each study and for all studies (countries) combined using Pearson correlation analysis, with α set at 0.05 (significant) and 0.001 (highly significant).