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Cigarette Design Features: Effects on Emission Levels, User Perception, and Behavior

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Abstract

Objectives—This paper describes the effects of non-tobacco, physical cigarette design features on smoke emissions, product appeal, and smoking behaviors – 3 factors that determine smoker's exposure and related health risks.

Methods—We reviewed available evidence for the impact of filter ventilation, new filter types, and cigarettes dimensions on toxic emissions, smoker's perceptions, and behavior. For evidence sources we used scientific literature and websites providing product characteristics and marketing information.

Results—Whereas filter ventilation results in lower machine-generated emissions, it also leads to perceptions of lighter taste and relative safety in smokers who can unwittingly employ more intense smoking behavior to obtain the desired amount of nicotine and sensory appeal. Filter additives that modify smoke emissions can also modify sensory cues, resulting in changes in smoking behavior. Flavor capsules increase the cigarette's appeal and novelty, and lead to misperceptions of reduced harm. Slim cigarettes have lower yields of some smoke emissions, but smoking behavior can be more intense than with standard cigarettes.

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Conflict of Interest Statement
Nothing to declare.

Conclusions—Physical design features significantly impact machine-measured emission yields in cigarette smoke, product appeal, smoking behaviors, and exposures in smokers. The influence of current and emerging design features is important in understanding the effectiveness of regulatory actions to reduce smoking-related harm.

Keywords

smoking; cigarette design; filter type; filter ventilation; cigarette user perception and behavior; cigarette emissions

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Exposure to tobacco smoke is an important risk factor for many severe diseases, including cancer, heart disease, and chronic lung disease.[1] Smoker's exposure to tobacco smoke and the related health risks are determined by the levels of toxic smoke emissions and smoking behavior, notably the intensity with which cigarettes are smoked. Product appeal and addictiveness lead to smoking initiation and continuation. Therefore, the World Health Organization Framework Convention on Tobacco Control (WHO-FCTC) encourages participant nations to regulate cigarette attractiveness, toxicity, and addictiveness.[2,3]

Modern cigarettes are carefully designed to increase their attractiveness to consumers by reducing negative experiences (eg, throat irritation), increasing positive experiences (eg, optimized draw resistance and mouth feel), appealing to new users and specific target groups, and fostering the perception of less personal risk.[3] For instance, perceptions of a "lighter" feel and taste of smoke from cigarettes with highly ventilated filters increase palatability and/or reduce perception of risk.[4–6] Design characteristics such as filter ventilation also may affect nicotine delivery and sensory cues, which are critical factors in the determination of smoking satisfaction,[7,8] psychological reward,[9] and craving reduction.[10] Finally, many new products have been marketed or are being researched by the global tobacco industry, with claims that they lower toxicants, for instance, with more efficient filters.

Typical cigarette design components and parameters are tobacco filler-related (eg, tobacco blend, type and amounts of additives used, tobacco weight) and non-tobacco cigarette features (eg, cigarette paper, filter type, filter ventilation, and cigarette rod dimensions (circumference, length).[11] Novel design features include innovative filter elements such as flavor-delivering capsules and selective filtration. These design features can affect tobacco smoke composition, sensory properties, smokers' perceptions and behaviors, thereby, determining exposures and related risks. Whereas tobacco is the main source of smoke constituents, cigarette design and components, such as the paper and the filter, modulate use behavior and the smokers experience by influencing smoke properties and how the tobacco burns.

The influence of tobacco blend on smoke constituents has been reviewed and summarized in several seminal publications.[12,13] This review focuses on non-tobacco cigarette characteristics (eg, cigarettes with an ever-smaller circumference [slim, super-slim, ultra-slim], and crushable cigarette filter flavor capsules). Specific cigarette characteristics including slim/super-slim designs, filter ventilation and innovative filter design features are recognized by the WHO-FCTC in current partial guidelines for implementation of Articles 9 and 10 as important factors with the potential to affect public health: "Product design features are used by the tobacco industry to develop strategies making products more attractive to different segments of society, an approach known as market segmentation."[14] Examples are targeting and increasing smoking initiation in women and vulnerable populations such as youth.[15,16]

The goal of this review is to provide a broad overview of filter ventilation, filter additives, such as those designed to reduce concentrations of toxicants or introduce flavor chemicals in the mainstream smoke, and cigarette dimensions. Each design feature is discussed in terms of delivery of toxic emissions as measured by machine smoking, user perception, and use behavior.

It should be noted that machine-based cigarette smoke emissions do not translate directly to actual human exposure as they do not account for individual use behaviors. Whereas machine smoking follows standard puffing regimens, consumers show large inter-individual and inter-brand differences in smoking behavior. Thus, we also address changes in actual smoking behavior, including smoking topography, in our assessment of the effect of a cigarette design feature on actual human exposure, and biomarkers of exposure.

Based on the summarized evidence, we provide specific recommendations for science-based regulatory measures on cigarette physical design characteristics. In addition, we identify important knowledge gaps where more research is needed to inform regulatory decisions. We also note when the physical characteristics of cigarettes have complex, and sometimes, opposite effects on multiple outcomes.

METHODS

Data Sources

Between June 2015 and December 2015, we searched the literature primarily using the PubMed database and the SciFinder search tool that retrieves data from Medline and CAplus databases. We included relevant articles cited in publications obtained through the database research. In addition, we searched tobacco manufacturers' websites and tobacco document repository research websites, as well as blogs and news articles. Non-peer-reviewed sources were included, as they can provide data not (yet) present in scientific literature, such as new trends in cigarette filters. Internal research conducted by the industry can reveal targeted efforts to modulate nicotine delivery and produce specific sensory characteristics to establish brand and sub-brand identity and enhance product consumer appeal.

Data Selection, Extraction, and Synthesis

We searched for product design related data, marketing information, as well as commentary on filter ventilation, new filter types, and slim cigarettes. We refined our search by focusing on toxic emissions, marketing approaches including any health claims, use behavior and perception, and any specific regulations relevant to these products.

We performed the search by using a combination of initial keywords for cigarette/smoking, with all relevant keywords for cigarette physical design features (specialty filters, filter additives, filter capsules, filter ventilation, cigarette geometry, slim cigarettes), and all relevant keywords for emissions, marketing, taste, target-groups, behavior, and others, followed by the snowball method. There were no restrictions on date, language, or geographical region.

Filter and Paper Ventilation

To yield cigarettes with low tar deliveries, ventilation holes have been introduced in the cigarette filter with the aim of diluting the cigarette mainstream smoke.[12] The amount of filter ventilation refers to the percentage of smoke that is diluted by air during a puff and is defined as the amount of air entering the cigarette through the portion of tipping paper that does not overlap the tobacco rod.[17,18] The amount of ventilation or dilution depends on the porosity of the plug wrap, the extent of tipping-paper perforation or porosity, and the location of the perforations.[19] The amount of filter ventilation ranges from about 10% in some full-flavored varieties to 80% in machine-measured very low delivery brands.[20]

Effect on emissions—Under experimental machine-smoked conditions, higher ventilated cigarettes have lower absolute yields but also less complete combustion, because of reduced oxygen flow to the smoldering coal, resulting in relatively larger amounts of higher molecular weight, and less oxidized compounds.[17] Both particulate delivery and vapor- or gas-phase deliveries are reduced, generally in direct proportion to the level of ventilation when the cigarette is machine smoked with the filter vents unblocked.[19] However, the effects of ventilation on the yields of smoke compounds are not entirely due to dilution of the smoke, but also to different molecular formation and decomposition processes taking place. Whereas all emission levels are reduced linearly in mainstream smoke with filter ventilation, some are reduced to a higher extent than others.[21] When highly ventilated cigarettes are machine smoked under more intense conditions (larger puff volume, vents blocked), which are a better approximation of human smoking behavior (see section 3.3), their emission levels can equal or exceed emission levels in less ventilated, full-flavor cigarettes machine smoked under less intense International Organization for Standardization (ISO) conditions with the filter vents unblocked.[22]

Compared to unblocked vents, increases of 2- to 7-fold in transfer of flavor compounds from tobacco filler to smoke are observed when filter vents are partially or completely blocked, even without an increase in puff volume.[23] The tar or other toxicant-to-nicotine ratio can increase at high levels of ventilation,[24,25] increasing the potential for higher exposures of a smoker who titrates for nicotine levels.[26]

After filter ventilation, cigarette paper porosity (ie, the paper wrapped around the tobacco, not the filter tipping paper described above) is a common technique to reduce smoke yields.[27] Porosity (permeability of the paper to oxygen and smoke gases) affects the burn rate, puff count, and the amount of tobacco burned per puff. The porosity of the paper is controlled by the size (void volume) of the openings (pores) created by the bonded structure of cellulose fibers and calcium carbonate. Paper porosity can affect taste, delivery, and smoke dilution variability.[28–30] Paper porosity influences the burn temperature of the cigarette. As porosity increases, coal temperature decreases,[31] and the cigarette burns faster due to an increased static burn rate. The result under machine smoking conditions is more tobacco burned between puffs (resulting in sidestream smoke), fewer puffs, and a reduction in nicotine, tar and CO yields.[27,32,33] Very volatile smoke constituents such as CO also readily diffuse through porous wrapper lowering their deliveries relative to less volatile constituents.[32] For B[a]P, delivery decreases as paper porosity increases and the decreases are directly related to lesser amounts of tobacco being consumed in puffing and more being burned in the inter-puff interval.[19]

Filter ventilation and increased paper porosity also can increase the concentration of nicotine in its unprotonated (un-ionized) form, which has higher bioavailability in smoke because it reaches the brain more rapidly than nicotine in its protonated (ionized) state.[34–36] Although both smoke pH and un-ionized nicotine concentration increase with increasing tip ventilation, the precise mechanisms are poorly understood.[24,37,38]

Perception of reduced harm—Filter ventilation in lower-yield cigarettes leads to perceptions of smoke tasting lighter and being less irritating than regular cigarettes, which powerfully supports the misperception that tar and nicotine intake are reduced.[4,6,39] Even those smokers who agree with the notion that "light" cigarettes do not reduce harm in general sometimes believe that they reduce their own exposures because of their sensory experiences.[6] Consequently, filter ventilation changes users' sensory responses to cigarette smoke and can affect consumer perceptions of the relative harm.

It is important to note that despite the removal of descriptors such as "light," "mild," and "low tar," many smokers continue to believe or rationalize that lower-yield cigarettes are less harmful.[40,41] The fact that manufacturers substitute strength descriptors with terms such as "smooth" or "fine" and pack colors to suggest "lightness" or "smoothness" may contribute to sustaining this misperception.[42–44] However, sensory experiences that the smoke of low-yield cigarettes is smoother on the throat and chest can lead to perceptions of reduced harm independent of such cigarette pack design elements.[4–6,45]

Perception of draw—"Perception of draw" is the amount of perceived effort caused by the draw resistance of the cigarette needed to inhale a enough smoke from the cigarette. Substantial amounts of research were conducted by the tobacco industry showing that perception of draw for cigarettes with ventilated filters can be improved by increasing smoke levels of nicotine, volatile aldehydes, ammonia and some other constituents and additives.[7] Perception of draw is proposed as one of the major determinants of puff duration and volume.[46–50] Whereas a higher draw resistance makes smoking more difficult, too little draw resistance is related to insufficient perceived chemosensory "impact," a combination of factors such as throat hit, harshness, and flavor. Given that chemosensory impact drives smokers' perception of satisfaction, insufficient perceived chemosensory impact received in the mouth and upper respiratory tract (throat hit) will cause a smoker to increase puff intensity until the feeling of adequate draw is achieved. Analysis of smoking machine-based emissions show that increases in smoking intensity generate more dramatic increases in the levels of many toxicants, including nicotine and acetaldehyde, in the smoke of low-yield cigarettes compared to regular cigarettes.[51,52] Together, data suggest that increased filter ventilation in "lower-delivery" cigarettes can lead to smokers' dissatisfaction due to reduction in perception of draw, but smokers respond to this perception by smoking with more intensity.

Compensatory Smoking Behavior

Filter ventilation, and subsequent smoke dilution with air, results in compensatory smoking behaviors, such as drawing larger puffs, inhaling more deeply, and blocking filter vents to prevent smoke dilution.[53] Such changes occur because most smokers seek to optimize their nicotine intake, which is associated with the perceived chemosensory impact, to achieve rewarding sensations and to avoid the aversive sensations associated with nicotine withdrawal.[54,55] This is particularly true for highly ventilated cigarette brands,[56] where compensation is high (around 80%) and will result in smokers obtaining almost as high nicotine levels when switching from higher yield to lower yield cigarettes.[25,55] Thus, filter ventilation allows for “elasticity” of use, meaning that the design characteristic of filter ventilation allows smokers to adjust their puffing behavior and obtain their desired amount of nicotine and sensory satisfaction. It also presents a major problem in the measurement of the actual nicotine and tar delivery of a specific cigarette brand. Elasticity varies across and within cigarette brands, with more elastic varieties appearing to have the greatest market share.[56] It should be noted, however, that substantial reductions in smoke nicotine yields through the use of very low nicotine tobacco, as opposed to filter ventilation, do not lead to compensatory smoking behavior.[57]

Filter ventilation and the resulting compensatory smoking behaviors can negate potential reductions in exposures when smoking low-yield cigarettes.[53,58–60] Instead, smokers who believe that they are smoking a product that has lower delivery of harmful emissions may actually increase their exposures. For instance, Strasser et al[59] estimated that those smokers who block filter vents increase their exposure to cigarette smoke components by 30%, and Hammond et al[56] showed that smokers who were switched to a “low-yield” cigarette increased their total smoke intake per cigarette by 40%. Despite the popularity of low-yield cigarettes, switching from higher yield cigarettes did not lead to a concomitant reduction in smoking-related disease, likely due to changes in smoking behavior.[61] Smokers of “light” cigarettes perceived themselves as less addicted, were more likely to have ever made a quit attempt than regular smokers, and had stronger quit intentions but less confidence in their capacity to quit in the future.[5]

Trends in Filter Designs

When first introduced, many cigarette filters were only cosmetic;[62] however, cigarette filters now represent an important design tool to promote a novel smoking experience (eg, Camel Crush) or lowering of select smoke components such as volatile organic compounds. Cigarette filters can be constructed with cellulose acetate, paper, or a combination of these materials,[19] but crimped cellulose acetate fiber (“tow”) is used in approximately 90% of all filters.[63] Specialized filters continue to emerge from cigarette material suppliers, suggesting that there is consumer demand or that manufacturers see them as a way to distinguish their brand. For instance, the Hauni Maschinenbau company offers 18 filter types on their website differing in visual effect, filtration properties, taste enhancement, and interactivity.[64] Another company, Essentra Filter Products, also has a wide range of different filters in different product ranges, for example, sensory (capsules, flavor thread, direct application on filter), earth tones (faster degradation in the environment), performance (high filtration efficiency, also selective removal eg specific vapors) and visual differentiation ("…*use visual appearance to indicate a flavor, a particular product attribute, a brand logo or indeed just to visually differentiate your brand*").[65]

Filter Additives to Reduce Smoke Emissions

Historical examples of novel filter technologies include platinum and silica gel to selectively reduce smoke components such as carbon monoxide and formaldehyde.[19,65,66] For example, platinum and palladium reportedly reduce CO.[67,68] Another example of selective filtration is molecularly imprinted polymers using nicotinamide as a template on a silica surface for the adsorption of tobacco-specific nitrosamines in mainstream cigarette smoke.[69] This technology reportedly reduced levels of tobacco-specific nitrosamines up to 41% while tar levels remained unchanged.[69] Information on reduced smoke emissions in commercial products using these technologies as filter additives was not located.

Carbon as a filter additive to reduce volatile organic chemicals—Perhaps the most studied filter additive is activated carbon (charcoal) to remove volatile chemicals.[70,71] Carbon (charcoal) filters reduce smoke levels of semi-volatiles and vapor phase compounds and provide some reduction of non-volatiles.[72] Lower molecular weight compounds with significant amounts in the vapor phase (eg, phenol, cresols, hydroquinone) are reduced more by charcoal filtration than are compounds of higher molecular weights with significantly lower volatilities (eg, B[*a*]P, tobacco-specific nitrosamines (TSNAs)).[70] Charcoal filters do not typically reduce low molecular weight gases in smoke.[72] However, charcoal coated with a mixture of metallic oxides is reportedly effective in removing acidic gases.[19]

The amount of charcoal, smoking machine conditions (ie, smoking intensity), and the age of the charcoal filter affect the degree of reduction of volatile chemicals.[70] Different amounts of synthetic high-activity carbon spheres were used in the filter of experimental cigarettes with various combinations of treated tobacco, alternative filter ventilation technology, and cigarette circumference (17– 24.6 mm; details on the effect of cigarette geometry are explained in section 5).[73] Tar and many volatile smoke components' yields from larger circumference (21 and 24.6 mm) cigarettes decreased as the carbon load increased, with reductions leveling off for the 2 highest charcoal loadings. The greatest reductions were seen in isoprene, acetaldehyde and acetone emissions, and smaller reductions for pyridine, formaldehyde, and styrene. Interestingly, in contrast to the cigarettes with the larger circumference, tar yields increased and hydrogen cyanide (HCN) and 1,3-butadiene yields did not change significantly in slimmer 17 mm cigarettes as carbon loading increased.[73]

Under more intense smoking machine conditions, smoke emissions (tar, nicotine, CO and volatile constituents) were no longer significantly lower in the smoke of some charcoal filtered cigarettes (approximately 45 mg charcoal) compared to cellulose acetate filtered cigarettes.[71] This was attributed to an insufficient amount of charcoal being present. Varieties with higher amounts of charcoal (120 or 180 mg) demonstrated a significant reduction under both intense and non-intense smoking conditions.[71] Similarly, experimental blended tobacco super-slim cigarettes with unventilated carbon filters (15 to 90 mg per filter) were machine smoked under ISO and Canadian Intense conditions.[74] Approximately twice as much carbon was needed to retain about 50% of a smoke component when the super-slim was machine smoked under intense conditions.[74] HCN retention by a standard carbon filter decreases with the age of the cigarette from about 38% at 0 weeks to about 25% retention at 8 weeks.[72]

More intense smoking behavior—The presence of carbon in cigarette filters may affect the levels of some smoke constituents that contribute to the perception of draw, and therefore, lead to changes in smoking intensity. In a study by Rees et al,[75] Marlboro Lights smokers were switched to carbon-filtered cigarettes Marlboro Ultra Smooth and non-carbon Marlboro Ultra Lights for 48 hours each. The study showed that the carbon-containing Marlboro Ultra Smooth was smoked with greater puff volume than both Marlboro Lights (difference in puff volume ranged from 2.4 to 13.6 mL in 2 study groups, overall $p = .006$) and Marlboro Ultra Lights (difference in puff volume ranged from 2.4 to 3.6 mL in 2 study groups, overall $p = .007$).[75]

Filter Flavor Capsules, Granules, and Flavor Threads

Flavor capsules are available in Japan and the United States and have been marketed in several European Union member states.[76] According to industry reports, filter flavor capsules that release a burst of flavor, are a significant growth segment of the market.[77] Capsules typically contain menthol or related flavors such as lemon mint; they are available in many different types of cigarettes, and sometimes 2 differently flavored capsules are present in one filter, as reported in a trade journal.[78] Filters can also contain herbal or botanical granules.[64] Another technology to alter smoke taste and cigarette appearance is a flavored thread inserted into the filter tow. The flavored thread can be colored *"to create a more unique appearance,"*[64] or as a *"visual indicator of taste delivery technology."*[65]

Effect on emissions—Two studies reported on the effects of mainstream smoke of crushable mentholcapsules.[79,80] Both studies observed no change in the yields of particle-phase constituents. Apart from the obvious increases in menthol deliveries, Gordon et al[79] found increases in the yields of several gas phase constituents, notably in 5 VOCs (acetaldehyde, acrylonitrile, benzene, 1,3-butadiene, and isoprene) in the mainstream smoke of Camel Crush brand cigarettes but not in non-menthol cigarettes that had been spiked with menthol. Dolka et al[80] from Philip Morris did not find such increases in gas phase components in cigarette prototypes that varied in machine smoked tar deliveries and filter capsules containing 4.8 mg of menthol or in a market survey of commercial cigarettes with menthol capsules.

User perceptions—A study among smokers in the United States, Australia, and Mexico showed that flavor capsules are most attractive to younger people.[77] Other findings from the study are that use of cigarettes with flavor capsules is growing, that flavor capsules can lead to misperceptions of relative harm, and that use of flavor capsules can differentiate brands.[77] A focus group study among young female non-smokers and occasional smokers showed that they perceived flavor-capsule cigarette very positively.[81] Participants appreciated the novelty and liked the fact that the taste could be switched from ‘normal’ to menthol. Just as research shows that cigarette packs can influence perceptions of appeal, harm and taste, this study suggests features of the cigarette have a similar effect.[81]

Cigarette Length and Diameter, Including Slim and Super-slim Cigarettes

Whereas the usual diameter of a conventional cigarette is 7.5 to 8.0 (circumference 23.6 to 25.1) millimeter (mm), slim varieties can have diameters of 5 or 6 mm (circumference 15.7 to 18.8).[82] Cigarette lengths generally fall into one of 4 categories: a regular 68 to 70 mm unfiltered cigarette; a 79 to 88 mm king-size filtered cigarette; 94 to 101 mm filtered longs, or extra-long cigarettes ranging from 110 to 121mm.[82]

Effect on Emissions

The mediating effect of cigarette length and diameter on smoke composition depends on the packing density of the tobacco in the tobacco rod, ie, the mass of tobacco filler divided by the volume of the tobacco column.[83] As packing density increases, there is more tobacco mass to burn during puffs and there is a corresponding increase in chemical emissions in mainstream smoke. However, tobacco also filters some smoke constituents as smoke is drawn through the tobacco rod. In one study of cigarettes of different packing densities, machine-smoked to predetermined lengths, nicotine and smoke condensate yields were lower in cigarettes with higher packing density and higher in cigarettes with lower packing density.[84] As the circumference of a cigarette decreases, less tobacco is available for consumption with a corresponding decrease in some smoke emissions) on a total delivery and per puff basis,[72,85] potentially decreasing emissions delivered to the smoker.[82] This phenomenon has been noted for cigarettes with circumferences smaller than the regular 24.8–25.5 mm (eg, 23 mm or less).[13] For example, as circumference decreases from 26 mm to 21 mm the amount of CO per puff decreases about 20% and levels of B[a]P decrease approximately 40%.[72] Machine-smoked nicotine delivery in mainstream smoke decreases from 1.56 mg/cigarette with a cigarette circumference of 26 mm to 1.21 mg/cigarette with a circumference of 23 mm.[12,13,86]

One study reported levels for a large number of smoke constituents for 6 super-slim cigarette varieties sold in Canada (diameter 5.3–5.4 mm; circumference 16.7–17 mm; length 83–99 mm; and tobacco weight 296–371 milligrams (mg)).[87] Compared to a standard size research cigarette, except for formaldehyde, ammonia, and phenols, levels of many chemicals were lower in the emissions of a machine-smoked flue-cured tobacco super-slim cigarette due to reduced quantity of tobacco and reduced puff count.[87] The increase in formaldehyde in slim cigarettes was attributed to an increased circumference to cross-section area ratio that facilitated oxidation reactions by allowing more contact of tobacco with ambient air during a puff, and the higher phenols emissions were attributed to an increased combustion temperature due to the decreased circumference.[87]

Reducing the circumference of cigarettes (of the same length) also increases smoke velocities, ie, it reduces the time for the smoke to pass from the coal to the mouth end of the cigarette (residence time). Super-slim cigarettes, generally defined as having less than a 17-mm circumference, have smoke velocities more than twice that of standard circumference cigarettes.[74] Increased smoke velocities decreases both filtration by the tobacco rod and retention by the filter of particles and vapor, and there is also less time for diffusion of gas phase chemicals through the paper.[74,88] These factors may result in higher levels of smoke emissions. For example, as circumference is decreased, and tobacco weight is held constant, the filter retention of HCN decreases steeply.[38,86]

Increased Appeal and Lowered Harm Perceptions

Length and circumference of cigarettes influence their appeal and affect harm perceptions. Longer and slimmer cigarettes are widely acknowledged to increase perception of stylishness and to generally appeal to women.[81,89] For instance, Philip Morris observed that fashion-conscious female smokers associated slim, long and light-tasting cigarettes with increased femininity; they also observed that the smoking of slim cigarette was associated with weight control.[90] Lorillard’s consumer research also revealed that female smokers of slim 100-mm cigarettes perceived this style as feminine and graceful, as well as milder and longer lasting.[90] Thus, research conducted by the tobacco industry suggests that these characteristics are successful targets for female smokers. One study also showed that smokers often perceived longer cigarettes to be attractive and of high quality.[91] In addition, Ford et al[92] showed that that slim and super-slim cigarettes led to perceptions of lower harm among (mostly) non-smoking adolescents). To reduce the possibility of cigarette appearance misleading consumers, the European Commission’s draft Tobacco Products Directive proposed banning cigarettes <7.5 mm in diameter.[93] However, this ban has not been included in the final Tobacco Products Directive.[94]

More Intense Smoking Behavior

Research where smokers smoked cigarettes of full or partial length suggests that the cigarette length may affect measures of smoking behavior such as puff duration and volume.[47–50] In one study, smoking cigarettes that were full length was associated “satisfaction” than smoking half, quarter, or eighth length cigarettes.[50] Another study compared urinary levels of cotinine and total 4-(methylnitrosamino)-1-(3-pyridyl)-1-butanonol (NNAL), a biomarker of NNK, among smokers of regular-sized, king-sized, and long/ultralong cigarettes using nationally representative data from the National Health and Nutrition Examination Survey (NHANES).[46] Measures of tobacco dependence and smoking intensity (time to first cigarette, number of cigarettes smoked per day, etc.) and tobacco biomarker levels were higher among smokers of long/ultralong cigarettes compared with smokers of regular-sized or king-sized cigarettes.[46]

DISCUSSION

The available information summarized in Table 1 suggests that consumer perception, behavior, and delivery of smoke emissions are greatly affected by cigarette design characteristics. In addition to influencing human exposures, non-tobacco design characteristics also can enhance product appeal by lowering the barrier to tobacco product initiation by reducing the negative aspects of cigarette smoking, or by enhancing the perception of a safe product. Taken individually, the effects of some of the characteristics are studied in more detail than others. For instance, the effects of filter ventilation have been extensively studied, while there is limited publicly available data on the effects of filter flavors (expect for menthol).

Many physical characteristics of cigarettes have complex, and sometimes opposite effects on multiple outcomes. For instance, filter ventilation reduces per cigarette machine-generated emissions,[17,19,22,23] and leads to perceptions of lighter taste and relative safety in smokers.[4,6,39] Together, these effects change smoking behaviors resulting in similar or higher exposures to toxic and carcinogenic emissions as achieved with higher tar, less ventilated cigarettes. Filter ventilation is the non-tobacco design feature most often recognized for adding "elasticity" to a cigarette.[95] Elasticity is a term that describes how cigarette design allows smokers to obtain their desired amount of nicotine regardless of machine smoke measured yields. Cigarette elasticity is more evident with very low delivery cigarettes than full-flavor varieties.[53–56]

Sufficient levels of filter additives, like charcoal, can reduce emissions of select chemicals in the smoke,[72] yet, removal of certain chemicals can modify sensory cues resulting in changes in smoking behavior. For example, it has been shown that smokers take larger puffs when smoking cigarettes with charcoal filters.[75] Smokers perceive charcoal filtered cigarettes as less risky than cellulose acetate filters,[96] but laboratory research shows that, except for very large amounts of charcoal, typical levels of charcoal are insufficient to substantially reduce mainstream levels of toxic emissions.[71]

Cigarette dimensions present another example of a complex interplay between various components. Thus, slim cigarettes contain less tobacco available for burning and smoking machine data suggest that they can lead to lower overall 'per cigarette' exposures in smokers.[87] However, the same design characteristics that result in lower smoke emission under machine-smoking conditions create appeal for women due to their stylish, attractive, and high quality appearance, and lead to perceptions of reduced harm.[81,89,92] Furthermore, exposures to some constituents including HCN and formaldehyde may not be reduced for smokers of these cigarettes compared to cigarettes with standard circumference.[38,86,87] Although there is some evidence for compensatory behavior among smokers of slim cigarettes,[46,50] more evidence is needed in this area. Many new innovations that could impact user perceptions or reduce smoke emissions have focused on filter technologies. Nontraditional methods of adding flavors such as flavor capsules and flavor threads create appeal through their novelty and brand differentiation.[64,65,77,78] Flavor capsules, for instance, are a significant growth segment for the tobacco industry, and are particularly attractive to young people.[77] In addition to flavor, capsules and threads add a decorative and novel element. Whereas some technologies such as super-slims and charcoal filters have provided encouraging findings by reducing some toxicants,[70,72,87] these gains are frequently offset by increases in other toxicants,[38,86] or changes in use behavior.[75] Therefore, the effects of design changes on all toxicants and smoking behavior need to be assessed for a more complete understanding of the impact on a smoker's exposure and related health risks.

IMPLICATIONS FOR TOBACCO REGULATION

The Conference of the Parties (COP) at its 6th session (Moscow, Russia, October 13–18, 2014) noted slim/super-slim designs, filter ventilation, and innovative filter design features, including flavor-delivering mechanisms such as capsules, as cigarette characteristics of interest, to the extent that those characteristics affect the public health objectives of the WHO FCTC.[97] Based on our review, we advise parties to consider filter ventilation and any other design characteristics that facilitate cigarette elasticity, filter capsules as they increase novelty, and slim cigarettes which are attractive to female smokers as they develop their tobacco regulations as available information indicates that toxic emissions, smokers' perceptions, and use behaviors are greatly affected by these product features.

Given the complexity of the interrelatedness of cigarette physical characteristics on human exposures and that these exposures are mediated by smokers' perceptions and behaviors, more work is needed to determine how specific cigarette designs influence key exposure and health outcomes.[98] Evidence suggests selective reduction of some mainstream smoke toxicants is accompanied by an increase in the levels of other toxicants.[99] Thus, it is important to study the interplay between design characteristics to reduce the possibility that product design related policies and regulations bring about unintentional individual and population level effects. When studying the effect of design features on emissions, it is important to consider nicotine yields. Any effects on emissions need to be reported on a per mg nicotine level, as a smoker will inhale sufficient levels of nicotine to optimize their nicotine intake.[54,55] Because free-base nicotine is the most bio-available form, validated methods for measuring free-base nicotine in mainstream smoke would inform efforts to understand the impact of product design changes critical aspects of nicotine delivery to the consumer.

Presently, it is not possible to study these product characteristics individually (eg, slim cigarettes separate from filter ventilation) to assess their relative contributions to emissions, user perception, or changes in use behavior. However, others have used regression models to identify correlations between physical properties and machine smoked yields of tar, nicotine, and CO.[18] Therefore, modeling may be a promising tool when developing risk assessment frameworks that address cigarette design features. The framework should minimally include emissions, as normalized per mg of nicotine; exposure; and impact on perceptions and behaviors of smokers, former smokers, and never-smokers, particularly adolescents. In addition, weighting factors are needed to address the severity of each effect for individual and population health.

The goal of extensive multivariate analysis of the tobacco filler constituents, mainstream smoke emissions (under smoking protocols of varying intensity), and cigarette physical properties is to identify the range and limits of these and other product design variables on targeted mainstream smoke emissions, as well as unintended consequences such as new or increased levels of untargeted constituents. The analysis should include cigarette varieties representative of products on the commercial market.

Other tools to study the perceptions and behaviors of smokers and non-smokers, especially adolescents, include consumer surveys, focus group analyses, and clinical (topography and biomarker analyses) investigations.

Also for consideration is surveillance of exposure and population-level health effects in countries after changes to these product characteristics. Panels of biomarkers provide information on exposure to relevant cigarette toxicants.[100] Clinical studies that include markers of early effects such as inflammation and oxidative stress may inform on health effects related to changes in exposures. *In vitro* tests such as those published using air liquid interface cell models are also promising,[101] as this testing paradigm models the exposure of airways to smoke.

It is important to monitor the tobacco product market for innovations and emerging technologies, in line with FCTC partial guidelines.[2] For example, standard searches of published literature can be enhanced or supplemented with surveillance of industry trade journals and social media, as well as field research. Also, in-depth analyses of information on design features, parameters, and specifications, along with mainstream smoke emissions, when provided by the cigarette manufacturers, can be helpful. This approach would be possible where sufficient regulatory authority exists, and could include checking the results by an ISO 17025 accredited governmental laboratory or independent contract laboratory as part of the regulatory oversight. Under the US Family Smoking Prevention and Tobacco Control Act, manufacturers must report changes to ingredients, additives, components, parts, and materials (eg, change in paper porosity) recognizing that changes to these components could raise different questions of public health over that of a “predicate” product.[102] An example includes specialized filters. The precedent for disclosure of design features includes the European Union, where the Tobacco Products Directive requires manufacturers to provide information on all aspects of a product and use of flavors in filters, including capsules.[94]

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Table 1

Summary of the Effects of Non-tobacco, Physical Design Characteristics on Smoke Emissions, Product Appeal, and Smoking Behaviors

	Effects on		
Design Characteristic	**Smoke Emissions**	**Product Appeal**	**Smoking Behaviors**
Increased Filter Ventilation and Paper Porosity	• Reduced per cigarette machine-generated emissions. • Less complete combustion.	• Perceptions of relative safety and lighter taste. • Modification of sensory cues: less "impact," "mouth feel," "throat hit", reduced perception of draw.	• Compensatory smoking behavior: more intense smoking behavior resulting in similar or higher exposures to toxic and carcinogenic emissions.
Filter Additives Like Charcoal	• Reduced emissions of select but not all smoke components.	• Perceptions of relative safety. • Modification of sensory cues.	• Compensatory smoking behavior.
Filter Flavor Capsules and Flavor Threads	• (Some evidence for) increased emissions of several gas phase smoke components.	• Perceptions of relative safety and novelty, brand differentiation, more appeal (particularly for young people)	• Unknown.
Reduced Circumference "Slim Cigarettes"	• Reduced emissions of select but not all smoke components.	• Perceptions of relative safety and high quality, more appeal (particularly for women).	• (Some evidence for) compensatory smoking behavior.