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Influence of cigarette circumference on smoke chemistry, biological activity, and smoking behaviour

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ABSTRACT

Cigarettes with reduced circumference are increasingly popular in some countries, hence it is important to understand the effects of circumference reduction on their burning behaviour, smoke chemistry and bioactivity. Reducing circumference reduces tobacco mass burn rate, puff count and static burn time, and increases draw resistance and rod length burned during puff and smoulder periods. Smoulder temperature increases with decreasing circumference, but with no discernible effect on cigarette ignition propensity during a standard test. At constant packing density, mainstream (MS) and sidestream (SS) tar and nicotine yields decrease approximately linearly with decreasing circumference, as do the majority of smoke toxicants. However, volatile aldehydes, particularly formaldehyde, show a distinctly non-linear relationship with circumference and increases in the ratios of aldehydes to tar and nicotine have been observed as the circumference decreases. Mutagenic, cytotoxic and tumorigenic specific activities of smoke condensates (i.e. per unit weight of condensate) decrease as circumference decreases. Recent studies suggest that there is no statistical difference in mouth-level exposure to tar and nicotine among smokers of cigarettes with different circumferences. Commercially available slim cigarettes usually have changes in other cigarette design features compared with cigarettes with standard circumference, so it is difficult to isolate the effect of circumference on the properties of commercial products. However, available data shows that changes in cigarette circumference offer no discernible change to the harm associated with smoking.

1. Introduction

Although cigarette rods are generally cylindrical in shape they can, and have, been made in a variety of lengths and circumferences. Reasons for adopting different dimensions include cost, marketing objectives and government regulations. However changing the cigarette dimensions may affect the smoke formation and transport processes within the cigarette rod which in turn could affect the yields of both mainstream (MS) and sidestream (SS) smoke (Norman, 1999). There are also potential changes to the composition of the smoke which can affect its specific biological activity, which is the activity per unit weight of the smoke or one of its components such as nicotine. Understanding these relationships is important both when interpreting chemical and biological assays associated with circumference changes and in understanding smoker behaviour or smoker perception studies.

Although experimental cigarettes have been made with circumferences ranging from as low as 10 mm up to 70 mm (Perfetti and Norman, 1986; Luke, 1986; Norman et al., 1988; Lewis, 1989; White and Perfetti, 1992), the dimensions of commercial products are limited by cigarette manufacturing machine constraints, product performance standards and consumer acceptability. Traditional king size cigarettes have circumferences of 24–25 mm, while slimmer styles of cigarette can have circumferences that range from 14 to 24 mm. While the nomenclature is not standardised, cigarettes with circumferences between 22 and 24 mm are often termed “slim”, those between 19 and 22 mm are referred to as

Glossary and abbreviations: BAT, British American Tobacco; MLE, Mouth level exposure; HCI, Health Canada Intense smoking regime; MS, Mainstream (smoke); NFDPM, Nicotine-free dry particulate matter; SS, Sidestream (smoke); TPM, Total particulate matter.

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demi-slims and those in the range 14–19 mm are termed "super slim". There are also a few "wide" cigarettes on the market with circumferences of 27–28 mm, which are considerably larger than traditional king size cigarettes. Cigarettes of different circumference can be made with or without filters and are generally found commercially in lengths of 80–85 mm, 90–100 mm and 120 mm.

Reduced circumference cigarettes have been marketed for well over sixty years. Early examples include the plain end and filter versions of the Homa cigarette brand which were first produced by the Iranian Tobacco Company in the early 1950s and 1960s, respectively, and had circumferences of 19.75 mm (Reemstma, 1987). In 1973 Lugton (1973) described a large number of commercial brands from around the world including Players No 6 Filter, marketed as a lower cost alternative brand in the UK with a total length of 66 mm and a circumference of 23.2 mm, as well as plain-end cigarettes from Kenya with even lower circumferences: 21.9 mm for King Stork, 20.8 mm for Crescent and Star and 18.1 mm for Ten Cents. Samfield (1991) described an Egyptian brand, King George V from the mid-1950s, with a circumference of 17.4 mm.

In the US, Virginia Slims with a circumference of 23 mm and a length of 100 mm were introduced in 1968, and the first brand marketed as a "super slim", Capri, was launched in 1987 and had a circumference of 17 mm.

Currently, reduced circumference cigarette products are becoming more popular in certain areas of the world. Markets with the highest share of slim products are South Korea, Indonesia, Kazakhstan and Iran where they are predominantly smoked by adult males (Park, 2009). In the European Union, research by the European Commission has shown that the market share of reduced circumference cigarettes grew significantly within a declining EU cigarette market from ~3.6% in 2006 to ~6% in 2012 (EC, 2013). This is consistent with global trends where sales of reduced circumference cigarettes have been reported to have grown ten times faster than the overall market in the past five years (EC, 2013). The lack of association between smoking prevalence rates and market share of slim (<7.5 mm diameter, <23.6 mm circumference) cigarettes has been confirmed by studies of smoking data in up to 96 countries for the years 1996, 2006 and 2012 (Slater, 2016). After accounting for socio-economic and cultural confounding factors, the correlation between smoking prevalence and market share of slim cigarettes for males was only significant (at $P < 0.1$) for one of the years (2012), and, for females, there were no significant correlations for any of the years.

Given the increasing interest in slim circumference cigarettes, this review examines the effects of changing cigarette circumference on cigarette physical properties, burn rates, combustion temperatures, MS and SS smoke chemistry, smoke toxicity and smoking behaviour. In this review we have made use of both peer-reviewed papers published in the open literature as well as unpublished tobacco industry documents, sourced from the Legacy Documents database. Also note that all the unpublished industry documents (except a reference to Mouth Level Exposures on the BAT website) can be easily identified since they include a link to the Legacy website and the link is always preceded by "industry documents" or "legacy".

The review focuses mainly on the effects of circumference change alone, so that the influence of confounding design variables can be avoided. These data are mostly available from experimental studies performed by tobacco industry laboratories in which series of cigarettes with only changes in circumference were designed and tested. However commercial, low circumference cigarettes are designed to be acceptable to smokers and other design features such as levels of filter ventilation, tobacco packing density or paper porosity may also change. It is beyond the scope of this review to assess the interaction of other variables with circumference on, for example, smoke chemistry or bioactivity. However some studies of smoke toxicants from commercial low circumference cigarettes are also reviewed in section 9.3.

Historically, the effects of cigarette rod circumference have been well studied (e.g. Arany-Fuzessery et al., 1982; Gugan, 1966; Muramatsu, 1981; 2005; Resnik et al., 1977; Yamamoto, 1981) with the first investigations, which focused on nicotine yields, dating back to 1936 (Wenusch, 1936). Further research coincided with the commercialisation of lower circumference cigarettes in the 1950s, and with the introduction of the Cigarette Safety Act in the mid-1980s when cigarette circumference was one of the variables studied in attempts to understand ignition propensity of cigarettes. A new phase, currently ongoing, involves analysing market trends towards slimmer cigarettes, as well as research into reduced toxicant prototype cigarettes (Dittrich et al., 2014). In reference to the latter aspect, reducing circumference has been one of a number of cigarette design parameters that have been investigated as a potential route towards harm reduction (Branton et al., 2011a; Branton et al., 2011b; Liu et al., 2011; McAdam et al., 2011; McAdam et al., 2012).

2. Physical properties of the cigarette

Circumference is one of several variables that can be altered during cigarette design and, as will be seen in this review, it has an impact on cigarette physical properties as well as smoke chemistry and bioactivity.

There are two major physical changes that occur when cigarette circumference is reduced. The first, perhaps self-evident, is that at a constant packing density (the density of tobacco in the cigarette rod) and tobacco rod length, the tobacco weight is reduced in proportion to the volume reduction, or cross-sectional area. The second is that resistance to draw, or pressure drop, increases in inverse proportion to the reduced cross-sectional area at a constant volumetric flow. In mathematical terms the pressure drop along a tobacco rod can be described (Schneider and Schluter, 1987) by a modified Kozeny-Carman equation (Carman, 1956). The Kozeny-Carman equation is used in the field of fluid dynamics to calculate the pressure drop of a fluid flowing through a packed bed of solids under lamina flow. For a tobacco rod the equation can be written as:

$$PD = K\left[(\rho_P/\rho_T)^2 \Big/ (1-\rho_P/\rho_T)^3\right] F/A$$
$$= K\left[(\rho_P/\rho_T)^2 \Big/ (1-\rho_P/\rho_T)^3\right] F4\pi \Big/ C^2$$

Where K is an empirical factor related to the tobacco particle shape and tortuosity of the spaces between the particles, F is the flow rate of air drawn through the rod, A is the cross-sectional area of the cigarette, C is the circumference, ρ_P is the packing density and ρ_T is the density of the tobacco shreds.

The equation shows that pressure drop is inversely proportional to the cross sectional area, or square of circumference, and it is also very sensitive to the packing density of the blend, ρ_P. Several authors (Norman, 1999; Hook, 1985) have pointed out that many of the early studies of the effects of circumference change either failed to adequately control packing density (e.g. Wenusch, 1936), or deliberately altered packing density to obtain a constant pressure drop. Since pressure drop affects ventilation into the smoke stream through the paper or filter as well as the filtration of smoke particulate along the rod (Norman, 1999) some of the early studies relating cigarette circumference to other cigarette physical properties and smoke yields may not be reliable.