Published in final edited form as:
Tob Regul Sci. 2016 April ; 2(2): 166–175. doi:10.18001/trs.2.2.7.

Differences in cigarette design and metal content across five countries: results from the International Tobacco Control (ITC) Project

Rosalie V. Caruso, MS [Research Technologist],
Department of Health Behavior, Roswell Park Cancer Institute, Buffalo, NY.

Brian V. Fix, MA [Senior Research Specialist],
Department of Health Behavior, Roswell Park Cancer Institute, Buffalo, NY.

James F. Thrasher, Ph.D.,
University of South Carolina, Department of Health Promotion, Education, and Behavior, Columbia, SC.

K. Michael Cummings, Ph.D., MPH [Professor],
Department of Psychiatry and Behavioral Sciences, Medical University of South Carolina, Charleston, SC.

Geoffrey T. Fong, Ph.D. [Professor],
Department of Psychology, University of Waterloo, Waterloo, ON, Canada.

W. E. Stephens, Ph.D. [Senior Research Fellow],
Department of Earth and Environmental Sciences, St. Andrews University, Scotland, UK.

Richard J. O'Connor, Ph.D. [Associate Professor]
Department of Health Behavior, Roswell Park Cancer Institute, Buffalo, NY.

Abstract

Objectives: The current study examines physical cigarette design characteristics and tobacco metal content of cigarettes obtained from 5 countries to determine how these properties vary for cigarette brands, both within and across countries with different dominant manufacturers.

Methods: Cigarette packs were collected from International Tobacco Control Policy Evaluation Survey (ITC) participants in the U.S., the U.K., Mauritius, Mexico, and Thailand. Cigarettes were assessed for physical and design properties (eg, ventilation, pressure drop, rod density, weight) by published methods, and for metal content (As, Cd, Ni, Pb) by X-ray fluorescence spectrometry.

Correspondence : Dr. O'Connor; Richard.oconnor@roswellpark.org.

Human Subjects Approval Statement
Research protocols received ethics approval from the University of Waterloo and Roswell Park Cancer Institute and from IRBs in each of the participating countries.

Conflict Of Interest Statement
RJO is a member of the Tobacco Products Scientific Advisory Committee, U.S. Food and Drug Administration. KMC has provided expert testimony on behalf of plaintiffs in cases against the tobacco industry. JFT and GTF have provided expert testimony on behalf of governments in legal proceedings involving the tobacco industry. WES, RVC, and BVF declare they have no conflicts.

Results: Significant differences in cigarette design and toxic metal concentrations were observed between countries and between manufacturers within countries. Filter ventilation, which is strongly predictive of machine-measured tar and nicotine levels, varied most widely across countries. Ni and Cd were highest in Thailand (2.23ug/g and 1.64ug/g, respectively); As was highest in Mexico (0.29ug/g) and Pb was highest in the U.K. (0.43 ug/g).

Conclusions: Parties to the FCTC should consider the adoption of uniform product standards related to cigarette design, emissions, and tobacco content that would reduce population health risks.

Keywords

Cigarette design; metals; policy

INTRODUCTION

Worldwide, tobacco use causes more than 5 million deaths per year, with current trends showing that tobacco use will cause more than 8 million deaths annually by 2030, 80% of which will occur in low-and middle-income countries.[1,2] In order to address this public health issue, the World Health Organization (WHO) Framework Convention for Tobacco Control (FCTC) was adopted in 2003 to establish international guidelines for tobacco product regulation, packaging and labeling, advertising, tax and price, and education and public awareness.[3]

No final guidelines for tobacco products have been issued for Articles 9 and 10 of the FCTC, which focus on the regulation of tobacco products and the provision of information about the contents of tobacco products; however, "partial guidelines"[4] have been issued along with calls for additional research by countries on tobacco products. Biennial meetings of the Conference of Parties (COP) aim to update FCTC guidelines, and at COP-6 in 2014, interest was expressed in "scientific evidence on specific cigarette characteristics of interest, including slim/super slim designs, filter ventilation, and innovative filter design features including flavour-delivering mechanisms such as capsules, to the extent that those characteristics affect the public health objectives of the WHO FCTC".[5]

Metals have been an emergent concern for the COP, and the WHO Study Group on Tobacco Product Regulation (TobReg) noted in 2013 that "priority should be given to the development by TobLabNet [WHO Tobacco Laboratory Network] of standardized testing methods for the measurement of … cadmium and lead content in tobacco." [6] We have previously reported that cigarettes vary in concentration of metals that cause cancer and other detrimental health effects.[7] The metals most commonly identified as being of concern are arsenic (As), cadmium (Cd), lead (Pd), and nickel (Ni), all of which are known or suspected human carcinogens (IARC). Between 1–20% of tobacco metal content is reflected in smoke, depending on smoking parameters.[8] The remainder is partitioned into the cigarette ash or is trapped by the filter,[8] which may have negative post-consumer environmental implications,[9] particularly for aquatic life.[10] Of course, the primary concern is not exposure from an individual cigarette, but cumulative exposure over years of smoking, especially given that heavier metals like Cd and Pb do not clear quickly from the body. Data from recent longitudinal studies show that Cd exposure is associated with smoking-related cancer mortality, and 9% of lung cancer cases in smokers may be attributable to Cd exposure.[9]

The International Tobacco Control (ITC) Policy Evaluation Project, an international cohort survey of tobacco use, was designed to gather evidence on the impact of FCTC policies and other evidence relevant to future FCTC policies in order to promote strong evidence-based approaches to tobacco control.[11,12] In its work, the ITC Project has also investigated how tobacco products have evolved in relationship to policy changes, and how product design features relate to how products are perceived and used by participants.[7] Novel methods for obtaining packs of cigarettes from survey participants have allowed examination of cigarette design features and prevalence of tax avoidance.[7,13–16] We have also examined the relationship between cigarette design features and smokers' perceptions of product risks and tobacco use behaviors, finding that perceptions about the lightness and smoothness of a smoker's own brand were significantly related to not only the light/mild brand descriptor, but also to the filter ventilation level of respondents' usual brand, cigarette length, and filter density.[7]

Cigarette design and the composition of tobacco are major contributors to smoke emission characteristics, including those that influence human exposure to toxins in smoke. Metals are useful in that they are present in tobacco prior to smoking the products, whereas many other important toxins, such as the PAHs, are generated by the combustion process. Design factors influence the proportions of toxins in the smoke aerosol. This study examines cigarette design and tobacco metals as 2 independent but easily measured proxies of human exposure because comparable metrics for assessing smoke emissions from systematically sampled products across countries are not available on any useful scale except, possibly, for tar, nicotine and carbon monoxide. The current study examines physical cigarette design characteristics and tobacco metal content of cigarettes obtained from ITC survey participants in the U.S., the U.K., Mauritius, Mexico and Thailand to determine how such properties vary within and across countries with different dominant manufacturers. Consequently, there may be both intra-country and inter-country differences, especially in brands that are local rather than multinational.

METHODS

Sample Collection

Participants in this study come from the International Tobacco Control (ITC) surveys in the United States, United Kingdom, Mexico, Thailand, and Mauritius. As with the ITC Surveys in all 22 countries, these ITC surveys were prospective cohort surveys of probability samples of adult smokers (≥ 18 years) (nationally representative in all countries except for Mexico, which was representative of 7 cities in Mexico),[17] designed to evaluate the psychosocial and behavioral effects of tobacco control policies.[18] Research protocols received ethics approval from the University of Waterloo and Roswell Park Cancer Institute and from IRBs in each of the participating countries. Participants in the U.S. and U.K. were surveyed over the phone, through random digit dialing, whereas participants in Mauritius, Thailand, and Mexico were surveyed face-to-face. The surveys included questions on demographics, participants' beliefs about cigarettes, smoking behavior, brand information, and quitting behavior.

In each country, a subset of survey participants was invited to take part in an optional supplemental data collection to examine cigarette and smoker characteristics, building on prior work using supplemental sample collection to address related research questions.[7,19] Upon completing the main survey, eligible participants were invited to submit a pack of their usual brand of cigarettes, 5 of their smoked cigarette butts, and 2 saliva samples (data related to the saliva and butt samples will be reported elsewhere). Eligible subjects were those who smoked daily, at least 5 cigarettes per day, primarily used factory-made cigarettes, and had a usual brand. Participants received the equivalent of U.S. $25 for their time and effort. For U.S. and U.K. participants, sample collection kits were mailed to survey respondents who agreed to take part, and were returned by postal mail. In the remaining countries, participants who agreed to take part were given a kit, and a time was arranged to retrieve the completed sample within 48 hours. The number of kits returned ranged from 148 in Mexico to 365 in the U.S.

Cigarette Analysis

Cigarette packs that were collected from participants were catalogued, kept in −20°C storage until testing, and conditioned for 48 hours to 22°C and 60% relative humidity prior to testing for physical characteristics. Fifty packs from each country were randomly selected for physical design testing, which was conducted as described in prior publications.[14] Five sticks were selected from every pack for measurements, including cigarette length and diameter, filter weight and length, and tobacco rod length and weight. Tipping paper length was also measured, as well as the presence or absence of ventilation holes. Ventilation and pressure drop were assessed using a dedicated instrument (KC-3, Borgwaldt-KC, Richmond VA). Per-cigarette tobacco weight and moisture content were determined as the average of 5 sticks using a halogen moisture analyzer (HR-83, Mettler-Toledo, Columbus, OH). Manufacturer information was coded from cigarette packages.

A second random selection of 50 packs from each country, different than the packs tested for design characteristics, was tested for metal concentration. Ten sticks were chosen at random from each selected pack, placed in polypropylene zip-top bags with code numbers, and sent to the University of St. Andrews, Scotland for analysis. To quantify metal concentrations, the tobacco was removed from the cigarettes and dried for 48 hours before being pulverizing to powder in a Rocklabs benchtop mill using a tungsten carbide pot. Pellets were pressed from the powder at 20 tons pressure. Polarized energy dispersive x-ray fluorescence (XRF) was used to measure the concentrations of 25 elements (Mg, Al, Si, P, Cl, S, K, Ca, Ti, Cr, Mn, Fe, Ni, Cu, Zn, As, Br, Rb, Sr, Zr, Nb, Cd, Sn, Ba, Pb) in these pellets in accordance with an established method[15] using a Panalytical Epsilon 5 XRF with Gd X-ray tube.

Data Analysis

Data analysis was completed using SPSS Version 21.0 (IBM; Armonk, NY). Analysis of Variance (ANOVA) was used to examine mean differences in cigarette design parameters by country. In markets with more than one major manufacturer (U.S., U.K., and Mexico), we also examined differences by manufacturer within country. Metal concentrations are reported in micrograms per gram of tobacco (dry weight) for 4 metals of focus in this study (As, Cd, Ni, Pb) by country and manufacturer, and compared using ANOVA.

RESULTS

Cigarette Design Parameters

Table 1 shows mean values for the main cigarette design characteristics by country, which are all significantly different across countries ($p < .001$). The packs collected from survey participants in the U.S. and U.K had higher average measurements on all design features except rod density compared to cigarette packs collected from participants in Mexico, Thailand and Mauritius. Cigarette packs collected from Mexico had the highest mean ventilation level across brands (30.0%), while cigarette packs from Thailand had the lowest levels (7.5%). The ventilation rates for the U.S., U.K. and Mexico were all individually different from both Thailand and Mauritius. The U.S. had a much higher mean cigarette length, most likely attributable to a higher number of 100mm cigarettes; US brands also had longer tipping papers, longer filters, and greater tobacco weight. UK brands had substantially lower rod density than brands from other countries. Mauritius brands had the lowest filter density, and Thai and Mauritius brands had the lowest pressure drop. Correlations among cigarette design characteristics overall can be seen in Table 2.

The packs randomly selected reflected the existence of a dominant manufacturer in each country: Philip Morris in the United States (33.1%); Imperial Tobacco in the United Kingdom (48.8%); Philip Morris International in Mexico (62.2%); Thailand Tobacco Monopoly (TTM) in Thailand (89.0%); and the British American Tobacco Group (BAT) in Mauritius (92.7%). Data comparing manufacturers within countries can be found in Table 3. [Mauritius and Thailand are omitted, since the vast majority of packs were from a single manufacturer (BAT and TTM, respectively).] Within the US and UK, many of the cigarette design features differed significantly between cigarette manufacturer ($p \leq .05$). In Mexico, only cigarette pressure drop and rod density were significantly different by manufacturer ($p \leq .026$).

To examine the interplay between ventilation and other design parameters, we grouped cigarettes by their ventilation status. Unventilated cigarettes (< 2% to allow for measurement error) formed their own category (N = 14). Among the ventilated cigarettes (N = 223), we split at the median (20%) into low (N = 112) and high (N = 111) groups. There were no packs in the U.K., Mexico, or Mauritius that were unventilated. Of course ventilation differed significantly between groups ($p < .001$) with non-ventilated cigarettes averaging 1.5%, low ventilation averaging 6.7% and high ventilation averaging 35.2%. Non-ventilated cigarettes had longer cigarette lengths (92.5mm) than both the low (83.9mm) and high (86.8mm) vent groups ($p = .027$), with longer lengths for tipping paper length (30.3mm vs. 26.5mm and 28.1mm) ($p = .004$), tobacco length (68.2mm vs. 62.2mm and 63.4mm) ($p = .014$), and filter length (24.0mm vs. 21.6mm and 23.4mm) ($p = .029$) as well. Per-cigarette tobacco weight was heaviest in the non-ventilated group (0.7882g; $p = .005$).

Metal Concentration

Differences by country for each metal were statistically significant when analyzed by the anti log of each average metal concentration ($p \leq .002$; Figure 1). Ni and Cd were highest in Thailand (2.2ug/g and 1.61ug/g, respectively). As was highest in Mexico (0.27ug/g); and Pb was highest in the U.K. (0.33 ug/g). Table 4 presents correlations among the concentrations of the metals. The differences of each metal by manufacturer within country were also analyzed, again with Thailand and Mauritius omitted for lack of variability as shown in Table 5. Significant differences were found in Ni concentrations across manufacturers in each the U.S. ($p < .001$), U.K. ($p < .001$) and Mexico ($p = .014$). As and Pb concentrations were significantly different between manufacturers in only Mexico ($p < .001$ and $p = .027$, respectively), while Cd levels were significantly different across manufacturers in both the U.K. ($p = .035$) and Mexico ($p < .001$).

DISCUSSION

We observed significant differences between countries and manufacturers within countries, in patterns of cigarette design and toxic metal concentrations which is consistent with previous studies.[14, 20] This is not necessarily surprising since different markets have differing regulatory requirements, consumer preferences, and supply chains. The UK is the only country in the group of 5 countries studied that had an upper limit on machine-measured smoke emissions. All of the UK brands had filter ventilation, and a lower average tobacco rod density than the other 4 countries, likely in response to this regulatory requirement. Interestingly, cigarettes in Mexico had greater average ventilation compared to both the U.S. and U.K.[21] A number of potential explanations can be hypothesized. Daily smokers in Mexico consume comparatively few cigarettes per day[22,23] (6–7 vs. about 15–16 in the U.S.**)**, leading to a high frequency (>60%) of zero scores on the Heaviness of Smoking Index (an indicator of dependence);[24,25,26] prevalence of nondaily smoking is also very high (~50%). This may reflect a preference for less harsh tasting products among Mexican smokers. A shift toward multinational brands[17], which may be more likely to include ventilation than the national brands that have been losing market share, could also explain the greater proportion of ventilated products in that market.

Toxic heavy metals were found in the unburned tobacco of cigarettes we obtained from smokers in the 5 different countries. The concentrations of metals found in cigarette tobacco varied between countries and within country by manufacturer. The origin of tobaccos used in cigarettes studied here is not known, although it is expected to differ across markets.[13, 20, 27] Thus, it appears that much of the between-country variation in the concentration of metals in cigarette tobacco is the result of different manufacturers sourcing their tobacco from different locations where metal concentrations in the soil vary. For example, Philip Morris USA (Altria) notes on their website that American cigarettes consist of a blend of 3 main tobaccos—bright, burley, and Oriental—and states that their bright and burley tobacco is grown in the United States, while Oriental tobacco is grown in “several Mediterranean countries” (Philip Morris USA).[28] Japan Tobacco International’s website notes that they obtain tobacco from 40 countries.[29] Different growing practices will combine with geographic variations in metal concentrations in the soil, which will ultimately be absorbed by the tobacco plant during growth. Exploring more about how the levels of metals found in unburned tobacco relate to exposure in humans, and how these metals accumulate over time in humans, should be explored. This kind of research would contribute to the foundation for evidence-based implementation guidelines for Articles 9 and 10 of the FCTC.

Variability in the metal contents of tobacco smoke influences the risk for cancer and non-cancer disease in active smokers. For example, Behera et al[30] show that the concentrations of As, Be, Cd and Ni in mainstream smoke contribute to the risk of cancer while Be, Cd, Hg and Pb contribute to the risk of non-cancer disease in the products they investigated. Of relevance to the present study, these authors found that large variations in cancer and non-cancer risk between 4 popular international cigarette brands purchased in Singapore are due to variations in the metal concentrations in smoke. In that study, design features were not recorded, but the samples with the highest tar and nicotine emissions were also those that posed the highest risks of both cancer and non-cancer disease due to metal levels.

It would be wrong to conclude that type of cigarette design is associated with any significant decrease in disease risks. In fact, recent evidence suggests that design changes such as the addition of filters, ventilated filters, and change in tobacco blend which increased nitrosamine content increased the risks of lung cancer, COPD and heart disease risks of smoking over the last 50 years.[31] Additionally, metal concentrations in tobacco vary in cigarettes across countries and manufacturers, indicating that consumers in some markets shoulder a greater potential disease burden that could be mitigated by changes in growing or blending practices. While we did not assess levels of metals in tobacco paper or filters, non-tobacco components of cigarettes make no significant contribution to overall heavy metal content compared with tobacco.[32]

IMPLICATIONS FOR TOBACCO REGULATION

Cigarette design standardization has largely been ignored in terms of product regulation. Parties to the FCTC should consider moving toward the adoption of uniform product standards related to cigarette design, emissions, and tobacco content that would reduce population health risks. The European Union's 10–1-10 emission standard did not reduce UK smokers' exposure to nicotine and carcinogens because of changes made in filter vents and the use of a flawed measurement strategy to document adherence to the regulation.[33] The high variability observed in design features across countries and manufacturers speak to what could be done with respect to more fully developing the Guidelines for FCTC Articles 9 and 10. TobReg has proposed upper limits on smoke toxicants[34, 35] and in smokeless tobacco products.[36] Given the data on inter-country variability reported here, an updated evidence review on the health impacts of key cigarette design parameters, including blending, seems warranted.[37] Similarly, minimization of carcinogenic and toxic metal concentration in cigarette tobacco via enforceable product standards could reduce metal exposures among smokers, particularly in areas with higher background levels (eg China).[38]

These findings are an example of the broader challenges that must be met to move forward with effective regulation of tobacco products. It is critical to understand the relation between the physical and chemical aspects of cigarettes and other tobacco products that contribute to harm so that regulators may be informed on what features to regulate that would be most effective in reducing harm. Such testing and regulation needs to be robust and not open to manipulation by the industry. Research in this area is essential to create strong FCTC guidelines on tobacco product regulation with the potential for significant advances in decreasing the burden of tobacco use.

Acknowledgments

This work was supported by a grant from the National Cancer Institute (P01CA111236).

References

1. WHO. Report on the Global Tobacco Epidemic, 2008: The MPOWER Package Geneva: World Health Organization; 2008 Available at: http://apps.who.int/iris/bitstream/10665/43818/1/9789241596282_eng.pdf. Accessed October 25 2015.
2. World Health Organization. WHO Report on the Global Tobacco Epidemic, 2011: Warning about the dangers of tobacco Geneva: World Health Organization, 2011 Available at: http://apps.who.int/iris/bitstream/10665/44616/1/9789240687813_eng.pdf. Accessed February 14 2014.
3. World Health Organization. WHO Framework Convention on Tobacco Control 2005 Available at: http://whqlibdoc.who.int/publications/2003/9241591013.pdf?ua=1. Accessed February 14 2014.
4. FCTC/COP4(10). Partial guidelines for implementation of Articles 9 and 10 of the WHO Framework Convention on Tobacco Control Available at: http://www.who.int/fctc/guidelines/Decisions9and10.pdf. Accessed February 14, 2014.
5. FCTC/COP6(12). Further development of the partial guidelines for implementation of Articles 9 and 10 of the WHO FCTC. Report of the working group 18 10 2014 Available at: http://apps.who.int/gb/fctc/PDF/cop5/FCTC_COP5_9-en.pdf. Accessed February 14, 2014.
6. REF: 2 September 2014 Provisional agenda item 4.6 Progress of the validation of analytical chemical methods for testing and measuring cigarette contents and emissions. Available at: http://apps.who.int/gb/fctc/PDF/cop6/FCTC_COP6_14-en.pdf. Accessed February 14, 2014.
7. O'Connor RJ, Caruso RV, Borland R, et al. Relationship of cigarette-related perceptions to cigarette design features: Findings from the 2009 ITC United States Survey. Nicotine Tob. Res 2013 in press.
8. Rodgman A, Perfetti TA. The Chemical Components of Tobacco and Tobacco Smoke, Second Edition CRC Press, Taylor and Francis Group 2013.
9. Moerman JW, Potts GE. Analysis of metals leached from smoked cigarette litter. Tob Control 2011 5;20 Suppl 1:i30–35. 10.1136/tc.2010.040196. [PubMed: 21504922]
10. Slaughter E, Gersber RM, Watanabe K, et al. Toxicity of cigarette butts, and their chemical components, to marine and freshwater fish. Tob Control 2011 5;20 Suppl 1;i25–29. Doi:10.1136/tc.2010.04170. [PubMed: 21504921]
11. The International Tobacco Control Policy Evaluation Project: the ITC Project. Promoting Evidence-Based Strategies to Fight the Global Tobacco Epidemic Version 3-March 2010. Available at: http://www.itcproject.org/sites/default/files/files/ITC%20General%20Brochure%20V5(1).pdf. Accessed September 5 2014.
12. International Tobacco Control Policy Evaluation Project. What is the ITC Project? Last updated: October 24, 2014. Available at: http://www.itcproject.org/node/1. Accessed February 14, 2014.
13. O'Connor RJ, Wilkins KJ, Caruso RV, et al. Cigarette characteristic and emission variations across high-, middle-and low-income countries. Public Health 2010 124;12:667–674. [PubMed: 21030055]
14. Caruso RV, O'Connor RJ. Cigarette design features in low-, middle-, and high-income countries. J Environ Public Health 2012 vol. 2012, Article ID 269576, P1–6. Epub 2012 May 8. doi:10.1155/2012/269576.
15. Stephens WE, Calder A. Analysis of non-organic elements in plant foliage using polarized X-ray fluorescence spectrometry. Analytica Chimica Acta 2004, 527;1:89–96.
16. Fix BV, Hyland A, O'Connor RJ, et al. A novel approach to estimating the prevalence of untaxed cigarettes in the USA: Findings from the 2009 and 2010 international tobacco control surveys. Tob. Control 2014 23 Suppl 1:i61–66. 10.1136/tobaccocontrol-2013-050138. Epub 2013 Aug 22. [PubMed: 23970794]
17. de Miera Juarez BS, Thrasher JF, Reynales Shigematsu LM, et al. Tax, price and cigarette brand preferences: a longitudinal study of adult smokers from the ITC Mexico Survey. Tob Control 2014 3; 23Suppl 1:i80–85. doi:10.1136/tobaccocontrol-2012-050939. Epub 2013 Oct 10. [PubMed: 24114563]

18. Fong GT, Cummings KM, Borland R, et al. The conceptual framework of the International Tobacco Control (ITC) Policy Evaluation Project. Tob Control 2006 15 (Suppl III), iii3–iii11. [PubMed: 16754944]
19. Fix BV, O'Connor R, Hammond D, et al. ITC "spit and butts" pilot study: the feasibility of collecting saliva and cigarette butt samples from smokers to evaluate policy. Nicotine Tob Res, 2010 3;12(3):185–190. Doi:10.1093/ntr/ntp101. Epub 2010 Jan 15. [PubMed: 20081040]
20. Caruso RV, O'Connor RJ, Stephens WE, et al. Toxic metal concentrations in cigarettes obtained from U.S. smokers in 2009: results from the International Tobacco Control (ITC) United States survey cohort. Int J Environ Res Public Health 2013 12 20;11(1):202–217. 10.3390/ijerph110100202. [PubMed: 24452255]
21. Swayampakala K, Thrasher J, Carpenter MJ, et al. Level of cigarette consumption and quit behavior in a population of low–intensity smokers–longitudinal results from the International Tobacco Control (ITC) survey in Mexico. Addict Behav, 2013 4;38(3):1959–1965. 10.1016/j.addbeh.2012.12.007. Epub 2012 Dec 16.
22. Blackford AL, Yang G, Hernandez-Avila M, et al. Cotinine concentration in smokers from different countries: relationship with amount smoked and cigarette type. Cancer Epidemiol Biomarkers Prev 2006 10;15(10):1799–1804. Epub 2006 Oct 4. [PubMed: 17021350]
23. Campuzano JC, Hernandez-Avila M, Jaakkola MS, et al. Determinants of salivary cotinine levels among current smokers in Mexico. Nicotine Tob Res 2004 12;6(6):997–1008. [PubMed: 15801572]
24. Thrasher JF, Osman A, Moodie C, et al. Promoting cessation resources through cigarette package warning labels: a longitudinal survey with adult smokers in Canada, Australia and Mexico. Tob Control 2015 24;e23–e31. 10.1136/tobaccocontrol-2014-051589. [PubMed: 25052860]
25. Thrasher JF, Abad-Vivero EN, Huang L, et al. Interpersonal communication about pictorial health warnings on cigarette packages: Policy-related influences and relationships with smoking cessation attempts. Social Science & Medicine 2015;0.1–9. 10.1016/j.socscimed.2015.05.042.
26. Thrasher JF, Abad-Vivero EN, Moodie C, et al. Cigarette brands with flavour capsules in the filter: trends in use and brand perceptions among smokers in the USA, Mexico and Australia, 2012–2014. Tob Control 2015;0:1–9. doi:10.1136/tobaccocontrol-2014-052064. [PubMed: 25505099]
27. O'Connor RJ, Schneller LM, Caruso RV, et al. Toxic metal and nicotine content of cigarettes sold in China, 2009 and 2012. Tob Control 2014;0.1–5. doi:10.1136/tobaccocontrol-2014-051804.
28. Philip Morris US: an Altria Company. Cigarettes: Making Our Cigarettes 2015 Available at: http://www.philipmorrisusa.com/en/cms/products/cigarettes/manufacturing/default.aspx. Accessed February 14 2014.
29. Japan Tobacco International. Our Company: Facts and Figures Available at: http://www.jti.com/our-company/facts-and-figures/where/. Accessed November 5 2014.
30. Behera S, Xian H, Balasubramanian R. Human health risk associated with exposure to toxic elements in mainstream and sidestream cigarette smoke. Science of the Total Environment 2014;472947–956. Doi:10.1016/j.scitotenv.2013.11.063. [PubMed: 24342102]
31. Thun MJ, Carter BD, Feskanich D, et al. 50-year trends in smoking-related mortality in the United States. N Engl J Med 2013 1 24;368(4):351–364. doi: 10.1056/NEJMsa1211127. [PubMed: 23343064]
32. Wu D, Landsberger S, Larson SM. Determination of the elemental distribution in cigarette components and smoke by instrumental neutron activation analysis. J. Radioanal. Nucl. Chem 1997 217(1) 77–82.
33. O'Connor RJ, Cummings KM, Giovino GA, et al. How did UK cigarette makers reduce tar to 10 mg or less. BMJ 2006 2 4;332(7536):302.
34. Burns DM, Dybing E, Gray N, et al. Mandated lowering of toxicants in cigarette smoke: a description of the World Health Organization TobReg proposal. Tob Control 2008 4:17(2):132–141. 10.1136/tc.2007.024158. [PubMed: 18375736]
35. WHO Study Group on Tobacco Product Regulation Report on the Scientific Basis of Tobacco Product Regulation. WHO Technical Report Series 951 World Health Organization 2008 Available at: http://www.who.int/tobacco/global_interaction/tobreg/publications/tsr_951/en/. Accessed October 25, 2015.

36. WHO Study Group on Tobacco Product Regulation Report on the scientific basis of tobacco product regulation: third report of a WHO study. WHO Technical Series 955 World Health Organization 2009 Available at: http://www.who.int/tobacco/global_interaction/tobreg/publications/tsr_955/en/. Accessed October 25, 2015.

37. The Scientific Basis of Tobacco Product Regulation. Report of a WHO Study Group World Health Organization 2007 Available at: http://www.who.int/entity/tobacco/global_interaction/tobreg/tsr/en/index.html. Accessed October 25, 2015.

38. Zhao Q, Wang Y, Cao Y, et al. Potential health risks of heavy metals in cultivated topsoil and grain, including correlations with human primary liver, lung and gastric cancer in Anhui province, Eastern China. Sci Total Environ 2014470–471:340–347.

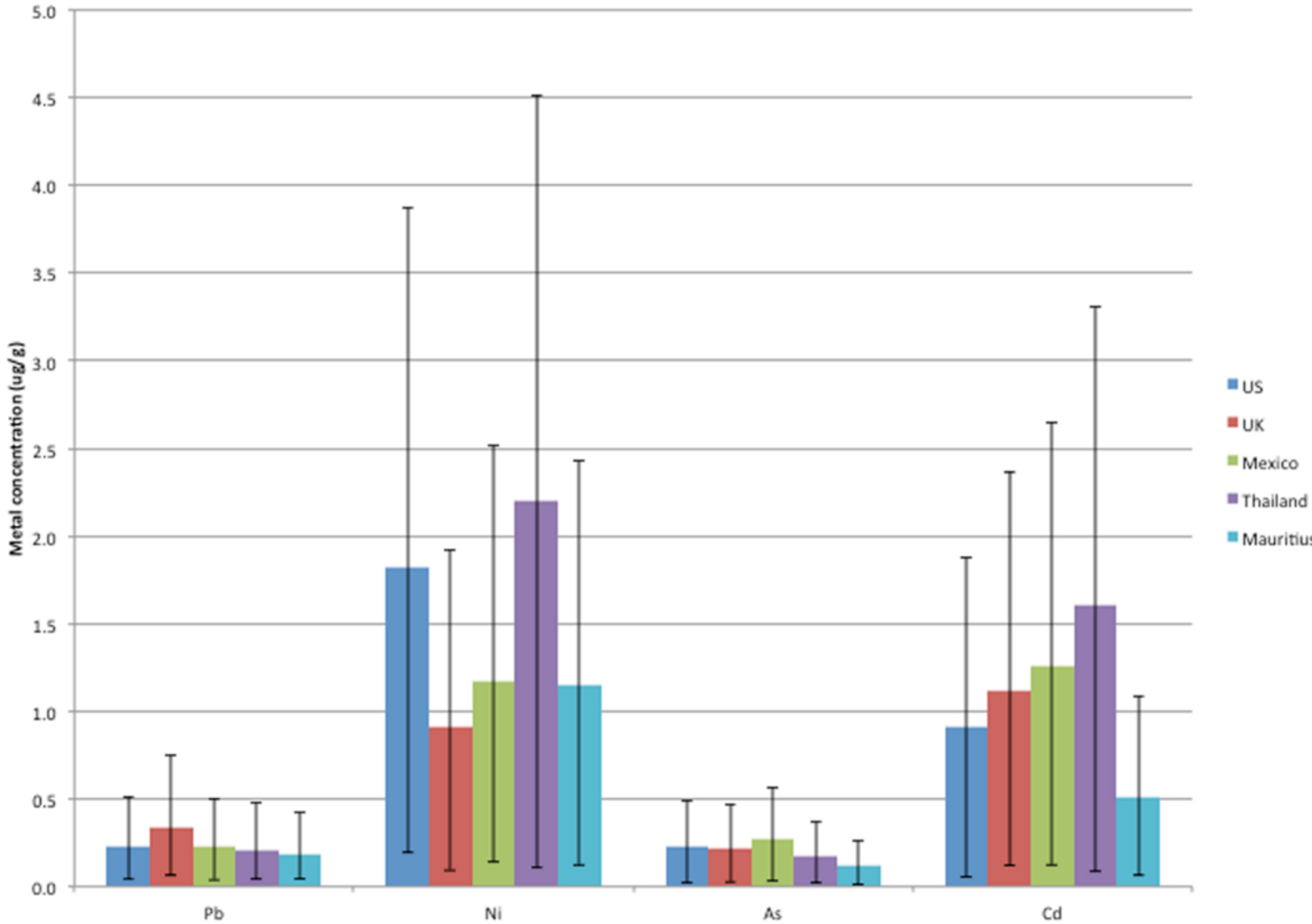

Figure 1:
Metal concentrations by Country (Geometric mean, 95% CI)

Table 1:

Means of cigarette design features by country

		Cigarette Length (mm)	Tipping Paper Length (mm)	Tobacco Length (mm)	Filter Length (mm)	Filter Weight (g)	Pressure Drop (mmH_20)	Ventilation (%)	Tobacco Weight Per Cigarette (g)	Filter Density (mg/cm^3)	Rod Density (mg/cm^3)
United States	Mean	94.4^{a}	32.6^{a}	66.9^{a}	27.6^{a}	0.150^{a}	107.3^{a}	23.4^{a}	0.774	115.8^{a}	246.9^{a}
	Min.	78.7	23.2	56.0	18.8	0.097	83.1	0.3	0.60	101.0	212.9
	Max.	119.1	37.4	87.5	31.7	0.186	142.9	59.8	0.97	133.9	312.5
United Kingdom	Mean	89.9^{b}	28.4^{b}	66.4^{a}	23.9^{b}	0.123^{b}	102.4^{ab}	25.3^{ab}	0.66^{a}	112.6^{ab}	212.9
	Min.	82.4	25.0	56.6	19.7	0.106	76.8	5.9	0.59	58.0	206.0
	Max.	99.2	32.5	74.1	41.8	0.156	123.5	52.7	0.89	132.2	281.5
Mexico	Mean	78.5^{c}	24.0^{c}	60.3^{jb}	19.7^{c}	0.106^{c}	110.5^{ab}	30.0^{ab}	0.66	122.9	258.7^{b}
	Min.	73.0	17.9	56.1	13.9	0.034	89.2	4.4	0.60	37.7	196.8
	Max.	97.7	32.1	73.8	26.9	0.139	150.8	84.0	0.86	148.8	327.6
Thailand	Mean	83.5^{d}	26.7^{d}	63.3^{c}	19.7^{d}	0.105^{c}	93.3^{c}	7.5^{c}	0.70^{ab}	114.0^{ab}	242.7^{a}
	Min.	82.6	24.9	62.2	19.0	0.097	73.8	1.3	0.42	102.5	157.3
	Max.	84.2	27.3	64.2	21.1	0.116	119.9	51.7	0.75	124.0	275.4
Mauritius	Mean	82.8^{d}	26.0^{d}	60.5^{d}	22.0^{c}	0.108^{c}	95.0^{c}	14.0^{c}	0.73^{ab}	105.3	257.4^{b}
	Min.	82.2	25.5	55.7	21.1	0.102	84.6	2.8	0.60	98.3	215.0
	Max.	83.2	31.1	61.2	26.8	0.139	111.8	45.3	0.82	117.1	294.5

All omnibus tests across countries were significant, $p < .001$.

Letter superscripts are Bonferroni results for differences between countries for each individual design characteristic.

Table 2:

Overall Correlations of Cigarette Design Characteristics.

		Cigarette Length	Tobacco Length	Filter Length	Tipping Paper Length	Cigarette Weight	Ventilation	Pressure Drop	Rod Density	Filter Density
Cigarette Length	r	1	.836**	.816**	.889**	.604**	.071	.145*	−.217**	−.108
	p		<.001	<.001	<.001	<.001	.285	.027	.001	.098
Tobacco Length	r		1	.584**	.696**	.618**	.029	.050	−.291**	−.061
	p			<.001	<.001	<.001	.665	.448	<.001	.351
Filter Length	r			1	.891**	.432**	.106	.221**	−.185**	−.228**
	p				<.001	<.001	.109	.001	.004	<.001
Tipping Paper Length	r				1	.516**	.048	.161*	−.213**	−.083
	p					<.001	.469	.014	.001	.204
Per-cigarette Weight	r					1	−.028	−.024	.354**	−.165*
	p						.670	.719	<.001	.011
Ventilation	r						1	.021	.006	.218**
	p							.775	.930	.001
Cigarette Pressure Drop	r							1	.152*	.261**
	p								.021	<.001
Rod Density	r								1	.073
	p									.266
Filter Density	r									1
	p									

* Correlation is significant at the 0.05 level (2-tailed).

** Correlation is significant at the 0.01 level (2-tailed).

Table 3:

Mean cigarette design features by dominant manufacturer within US, UK, and Mexico.

Manufacturer^{z}		Cigarette Length		Tipping Paper Length		Ventilation		Per-Cigarette Tobacco Weight		Rod Density		Filter Density	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
US	RJR (N=20)	97.6^{**a}	11.19	33.40^{a}	4.59	33.4^{*a}	10.08	0.80^{**a}	0.07	251.97^{*a}	17.14	109.62^{*}	6.26
	PM (N=14)	88.11	9.34	30.88^{a}	5.38	23.0^{ab}	13.19	0.69	0.05	232.81	11.30	122.30^{a}	3.95
	Other (N=13)	96.40^{a}	5.54	33.16^{a}	3.57	16.8^{b}	16.84	0.81^{a}	0.09	254.15^{a}	27.20	118.44^{a}	9.40
UK	Imperial (N=24)	89.20^{a}	8.02	27.77^{*a}	2.03	17.7^{**}	15.20	0.67^{*a}	0.06	220.64^{*}	9.71	107.87^{*a}	11.13
	JTI (N=13)	87.51^{a}	7.15	27.40^{a}	2.42	32.5^{a}	8.10	0.71^{ab}	0.05	232.49^{a}	11.45	120.18^{b}	6.38
	Other (N=10)	94.29^{a}	7.37	31.11	1.92	34.8^{a}	11.19	0.75^{b}	0.10	236.02^{a}	19.79	115.91^{ab}	8.56
Mexico	PMI (N=28)	78.58_{a}	5.98	24.29_{a}	2.67	34.6_{a}	17.68	0.65_{a}	0.06	250.41^{*}_{a}	19.54	127.03_{a}	20.98
	BAT (N=18)	77.91_{a}	2.47	23.52_{a}	2.97	25.8_{a}	24.80	0.66_{a}	0.02	267.66_{b}	18.44	115.96_{a}	8.04
	Other (N=2)	80.64_{a}	3.07	24.66_{a}	1.25	19.9_{a}	13.45	0.69_{a}	0.14	277.88_{ab}	43.37	132.69_{a}	6.74

* Differences between design feature within that country is significant at the 0.05 level.

** Differences between design feature within that country is significant at the 0.01 level.

z Max sample size for a given design feature tested within that country.

Letter superscripts are Bonferroni results for differences between manufacturers for each individual design feature and country

Table 4.

Metal concentration in tobacco (μg/g) by dominant manufacturer within US, UK, and Mexico.

		Ni				As				Cd				Pb			
	Manufacturer	Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max
US	RJR	2.26 *a	0.42	1.6	2.9	0.22a	0.06	0.1	0.3	0.97a	0.19	0.6	1.3	0.28a	0.17	0.1	0.6
	PM	2.22a	0.40	1.7	3.1	0.27a	0.08	0.1	0.4	0.9a	0.13	0.6	1.1	0.27a	0.14	0.1	0.6
	Other	1.40b	0.57	0.6	2.3	0.24a	0.06	0.1	0.3	0.93a	0.27	0.5	1.5	0.25a	0.11	0.1	0.4
UK	Imperial	0.84 *a	0.21	0.6	1.4	0.27a	0.10	0.1	0.5	1.31 **a	0.28	0.9	1.9	0.53a	0.39	0.1	1.5
	JTI	0.79a	0.22	0.6	1.2	0.23a	0.09	0.1	0.4	1.03a	0.22	0.8	1.4	0.25a	0.15	0.1	0.5
	Other	1.41b	0.59	0.5	2.7	0.19a	0.10	0.1	0.4	1.04a	0.52	0.2	2	0.31a	0.15	0.2	0.6
MX	PMI	1.41 **a	0.47	0.6	2.2	0.23 *a	0.07	0.1	0.4	1.04 *a	0.20	0.7	2	0.23 **	0.09	0.1	0.4
	BAT	0.98b	0.27	0.6	1.4	0.41b	0.07	0.3	0.5	1.97b	0.48	0.7	3	0.31	0.22	0.1	0.8
	Other	1.43ab	1.00	0.3	2.2	0.27a	0.06	0.2	0.3	1.4a	0.35	1.2	2	0.60		0.6	0.6

* Differences between metal concentration within that country is significant at the 0.05 level

** Differences between metal concentration within that country is significant at the 0.01 level

Letter superscripts are Bonferroni results for differences between manufacturers for each individual design feature and country

Table 5:

Overall Correlations of Tobacco Metal Concentrations

		Ni	Cd	Pb	As
Ni	Spearman's rho	1	.130*	−.193**	−.156*
	Sig. (2-tailed)		.041	.010	.016
Cd	Spearman's rho		1	.176*	.379**
	Sig. (2-tailed)			.018	<.001
Pb	Spearman's rho			1	.316**
	Sig. (2-tailed)				<.001
As	Spearman's rho				1
	Sig. (2-tailed)				

*Correlation is significant at the 0.05 level (2-tailed).

**Correlation is significant at the 0.01 level (2-tailed).