

Toxic metal and nicotine content of cigarettes sold in China, 2009 and 2012

Richard J O'Connor,¹ Liane M Schneller,¹ Rosalie V Caruso,¹ W Edryd Stephens,² Qiang Li,^{3,4} Jiang Yuan,³ Geoffrey T Fong^{4,5,6}

¹Department of Health Behavior, Roswell Park Cancer Institute, Buffalo, New York, USA

²Department of Earth & Environmental Sciences, University of St Andrews, Fife, UK

³Chinese Centers for Disease Control and Prevention, Beijing, China

⁴Department of Psychology, University of Waterloo, Waterloo, Ontario, Canada

⁵Ontario Institute for Cancer Research, Toronto, Ontario, Canada

⁶School of Public Health and Health Systems, University of Waterloo, Waterloo, Ontario, Canada

Correspondence to

Dr Richard J O'Connor, Department of Health Behavior, Roswell Park Cancer Institute, Elm and Carlton Streets, Buffalo, NY 14263, USA; Richard.Oconnor@roswellpark.org

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ABSTRACT

Background Metals of primary health concern can accumulate in the tobacco plant and contribute to smokers' exposures to carcinogens, a significant cause of the millions of smoking-related deaths in China each year. These exposures are due to the smoker's addiction to nicotine.

Objective This study sought to explore toxic heavy metal and nicotine concentrations in the tobacco of Chinese cigarette brands purchased in 2009 and 2012, as well as its regional variation.

Methods Cigarette packs for this study were purchased from seven Chinese cities in 2009 and 2012, and 91 pairs of cigarettes were matched based on UPC for comparison. Ten cigarette sticks were randomly selected from each pack and tested using polarised energy dispersive X-ray fluorescence (XRF) for arsenic (As), cadmium (Cd), chromium (Cr), nickel (Ni) and lead (Pb) concentrations. Nicotine analysis was conducted following Coresta's Recommended Method N°62. Data analysis was conducted using SPSS, encompassing descriptive statistics, correlations and generalised estimating equations to observe changes in brand varieties overtime.

Findings On average, from 2009 to 2012, As, Cd, Cr and Pb concentrations have decreased in Chinese tobacco. Of the seven cities where the cigarette brands were purchased, only four cities showed significant differences of the selected metals from 2009 to 2012. However, there was no significant change in the tobacco nicotine content from 2009 to 2012.

Conclusions Tobacco in Chinese cigarettes purchased in seven geographically disbursed cities contains consistently high levels of metals, including carcinogens like Cd. One source may be the improper use of fertilisers. These numbers should be monitored more carefully and regulated by health officials.

INTRODUCTION

Cigarette smoking in China results in about 140 million deaths per year.¹ These deaths can ultimately be traced to repeated toxicant exposures overtime, including nitrosamines, polycyclic aromatic hydrocarbons, volatile organic compounds and metals.^{2–3} Tobacco grown in soils with high metal concentrations (whether due to natural variation, fertilisers, atmospheric deposition or pollution)⁴ may have a higher metal content depending on uptake and retention by plants, which is controlled by various factors including soil pH.^{5–6} Metals of primary health concern with respect to tobacco include arsenic (As), cadmium (Cd), chromium (Cr), nickel (Ni) and lead (Pb).⁷ Four of these (As, Cd, Cr (VI) and Ni) are known to be carcinogenic

to humans.⁷ Pb is a class 2B carcinogen which also affects the nervous system and the neurodevelopment in youth.^{8–9} As and Cd exposures are also associated with cardiovascular and renal toxicities,^{8–9} and may act as cocarcinogens.^{10–12} Cd, Pb and Ni accumulate in tissues and fluids after smoking,^{6–13–16} and both active and passive smoking are major sources for Cd and Pb exposure in the US population.^{15–18} Prior research has shown that the tobacco grown in China shows elevated levels of Pb and Cd compared with tobacco grown elsewhere.^{19–21} In the current study, we examine the concentration of heavy metals in tobacco from a selected sample of 2009 and 2012 Chinese cigarettes to determine if any changes in tobacco metal content over various brands occurred during that time period, as well as to explore regional variations in cigarette metal content within China.

The repeated exposure to these metals can be accounted for by the smoker's addiction to the nicotine in the tobacco. Nicotine is synthesised by the tobacco plant during growth, and is the primary alkaloid in the leaf tissue, making up about 95% of the total alkaloid content.^{22–24} In most cigarettes, a tobacco rod will contain about 10–14 mg of nicotine, but only about 1–1.5 mg of that will actually be absorbed while smoking. There is some evidence that the amount of nitrogen supplied to the plant during growth impacts the tobacco plant's nicotine content.^{24–25} Nitrogen is naturally found in soil and is one of two primary nutrients in fertilisers.²⁴ The use of fertilisers is mainly to yield the greatest amount of growth; however, their improper use can negatively affect the environment.²⁴ The current study sought to examine levels of metals of health concern and nicotine in cigarette tobacco obtained on the Chinese market in 2009 and 2012.

METHODS

Cigarette packs analysed for this study were purchased by field workers from seven Chinese cities (Beijing, Changsha, Kunming, Shanghai, Shenyang, Guangzhou and Yinchuan) in 2009 and 2012 at three large retail stores in each city (total n=2052; 2009, n=907; 2012, n=1145). Packs were shipped to the Tobacco Research Laboratory at Roswell Park Cancer Institute (RPCI), where they were catalogued and stored unopened at -20°C until analysis. The physical and design characteristics of a selected 197 cigarette packs were tested in accordance with the International Organization for Standardization (ISO) 3402:1999 after being conditioned for a minimum of 48 h at $22\pm 2.0^{\circ}\text{C}$ and



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60±2.0% relative humidity in an environmental chamber. From this larger set, 91 pairs of cigarettes were matched based on Universal Product Code (UPC) to compare the 2009 and 2012 data. Cigarette physical and design characteristics were assessed and are reported elsewhere.²⁶ Ten cigarette sticks were then selected randomly from each pack, placed in polypropylene zip-top bags with code numbers, and sent to the University of St. Andrews, Scotland for quantitation of trace elements using polarised energy dispersive X-ray fluorescence (XRF). Tobacco extracted from each cigarette was dried for 48 h, then pulverised to a powder in a Rocklabs bench top mill using a tungsten carbide pot. Pellets (6 g) were pressed from the powder under 20 tons pressure. The heavy metals and other trace 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) were analysed quantitatively using an Epsilon 5 XRF with a Gd X-ray tube. A more complete description of methods, including limits of detection, can be found in previously published papers.^{27–28} The tobacco nicotine content was conducted in-house using gas chromatographic analysis with nitrogen-phosphorous detection, generally following CORESTA's Recommended Method N° 62 with methyl tert-butyl ether as the extraction solvent and quinoline as the internal standard.²⁹ Duplicate samples were run for each brand.

Statistical analysis of data was conducted using Statistical Package for the Social Sciences V21.0 (IBM; Armonk, New York, USA). The metals and average tobacco rod nicotine were characterised using descriptive statistics and analysed for correlations. Changes as a function of time were assessed within subjects using generalised estimating equations (normal distribution, log link function and exchangeable working correlation matrix except where otherwise specified). Intraclass correlations were used to determine the repeatability of the nicotine analyses, and these values were compared with those of Kentucky Reference cigarettes using a one-sample t test.

RESULTS

Figure 1 displays mean concentrations for As, Cd, Cr, Ni and Pb in micrograms per gram cigarette tobacco. As and Pb concentrations showed a strong correlation (Pearson Correlation=0.844; $p<0.001$), but levels of the other metals were not significantly intercorrelated.

In terms of change in metal concentration from 2009 to 2012, mean concentrations of As ($D=-0.06$ µg/g of tobacco; $t(89)=2.014$, $p=0.047$), Cr ($D=-0.15$ µg/g of tobacco; $t(89)=2.002$, $p=0.048$) and Pb ($D=-0.45$ µg/g of tobacco; $t(89)=3.762$, $p<0.001$) decreased on average (Figure 1). Figure 2 gives a

Figure 1 Mean concentrations (mg/g tobacco) of metals in cigarette tobacco, 2009 and 2012.

depiction of selected brands' metal concentrations in both 2009 and 2012—2A shows the Cd levels and 2B shows the Pb levels. The Beijing brand seemed to have a great decrease in Pb and Cd from 2009 to 2012, while most of the other brands had only small changes in their metal concentrations between the 2 years, if any at all.

The measured nicotine content on duplicate samples was stable (intraclass correlation=0.915, $p<0.001$). The change in average rod nicotine was found to be not statistically significant between 2009 and 2012 (2009: $n=71$, $\mu=19.98$ mg/g of tobacco; 2012: $n=68$, $\mu=19.63$ mg/g of tobacco). As a point of reference, we compared these averages with the tobacco rod nicotine content of 3R4F Kentucky Reference cigarettes (20.5 mg/g of tobacco) and found them to be significantly lower ($p<0.001$). We also found significant correlations between the tobacco rod nicotine content and metal concentrations, with the exception of Cd (Table 1). Higher rod nicotine was positively associated with As and Pb levels, but negatively associated with Ni and Cr levels. In Figure 3, the five cigarette brands with the highest and lowest tobacco nicotine content are shown with their respective concentrations in 2012.

DISCUSSION

The Chinese cigarettes examined in this study contained various heavy metals known to adversely impact health. The average As, Cd and Pb levels in Chinese cigarettes were substantially greater than the range of the means found in the Americas.^{30–33} On the other hand, the Cr and Ni average concentrations appeared to be below that of the range of means. Broadly, the levels seen here for each metal are similar to those previously reported for cigarettes purchased in 2005/2006 and 2007 by O'Connor and colleagues. For comparison, O'Connor and colleagues performed a similar analysis on Chinese cigarette brands purchased in 2005–2006 and 2007 and found that the tested brands averaged 0.78 µg/g As (range 0.3–3.3), 3.24 µg/g Cd (range 2.0–5.4), 0.55 µg/g Cr (range 0.0–1.0) and 2.54 µg/g Pb (range 1.2–6.5).¹⁹ The levels reported here for Cd, Ni and Pb are comparable to those in a prior report by our research group, while the As concentrations were notably lower.

These results highlight the sustained exposure among Chinese smokers to high levels of toxic metals. The high levels of Cd and Pb in Chinese cigarettes can be potentially problematic, given China's high smoking prevalence and per capita consumption, as a significant fraction of Cd and Pb transfers directly into smoke and is correlated with smoking intensity. Furthermore, Cd has a biological half-life of one to four decades and minimal

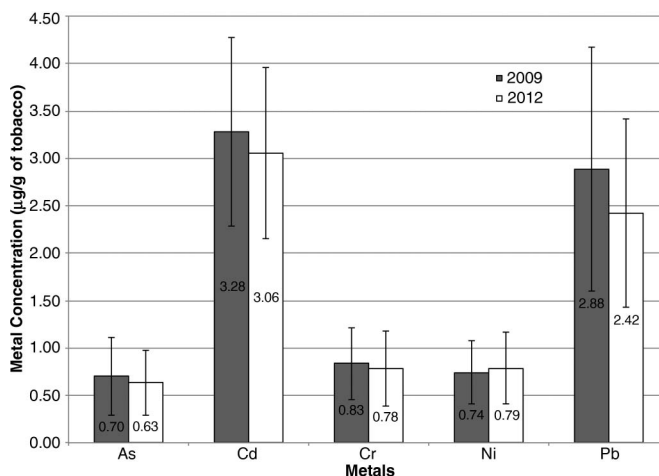


Figure 2 (A) Concentration of Cd in selected cigarette brands, 2009 and 2012. (B) Concentration of Pb in selected cigarette brands, 2009 and 2012.

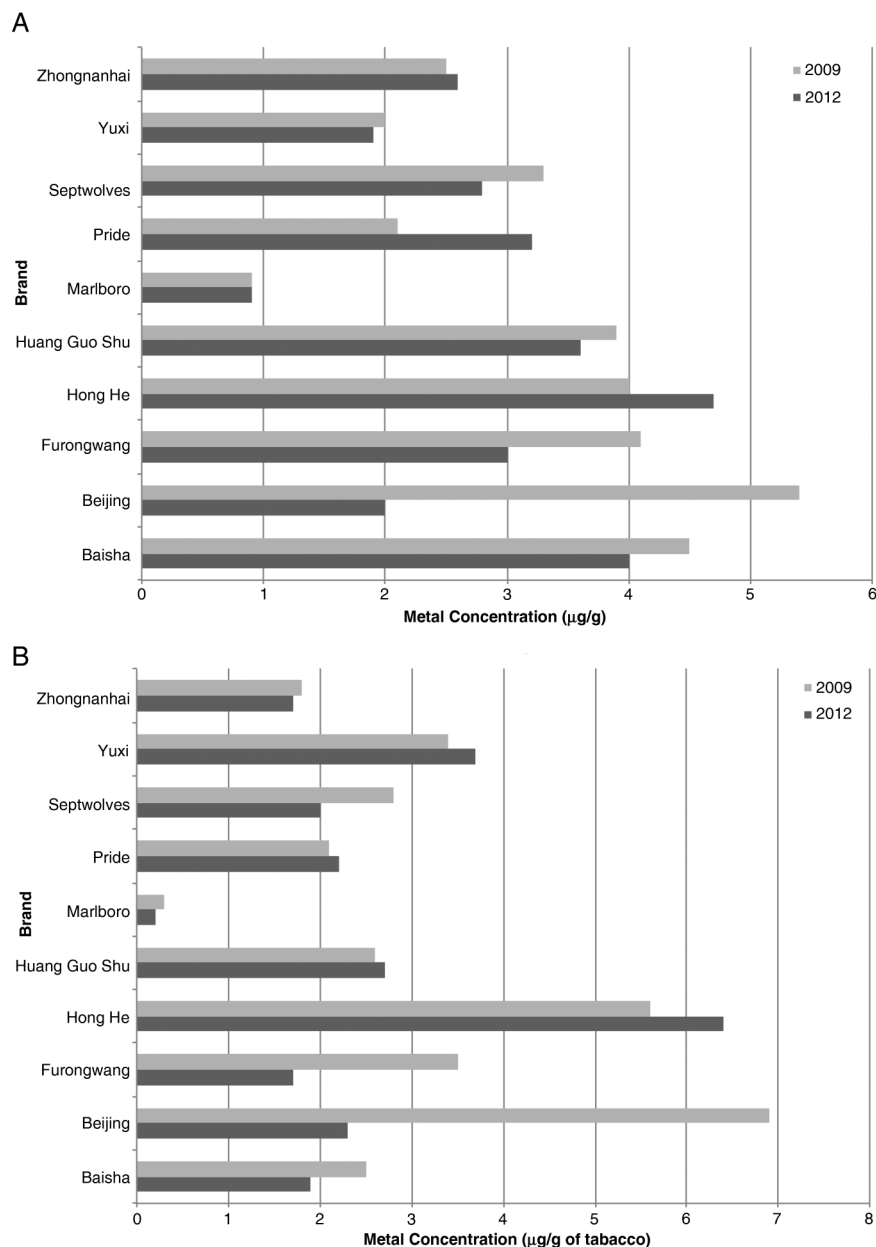


Table 1 Spearman correlation of average tobacco rod nicotine, and the primary metals of interest

	Average rod nicotine	As	Cd	Cr	Ni	Pb
Average rod nicotine	1.00	0.410*	-0.024	-0.223*	-0.310*	0.322*
As	0.410*	1.00	0.182†	-0.255*	-0.313*	0.801*
Cd	-0.024	0.182†	1.00	-0.221*	0.122	0.289*
Cr	-0.223*	-0.255*	-0.221*	1.00	0.248*	-0.222*
Ni	-0.310*	-0.313*	0.122	0.248*	1.00	-0.312*
Pb	0.322*	0.801*	0.289*	-0.222*	-0.312*	1.00

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

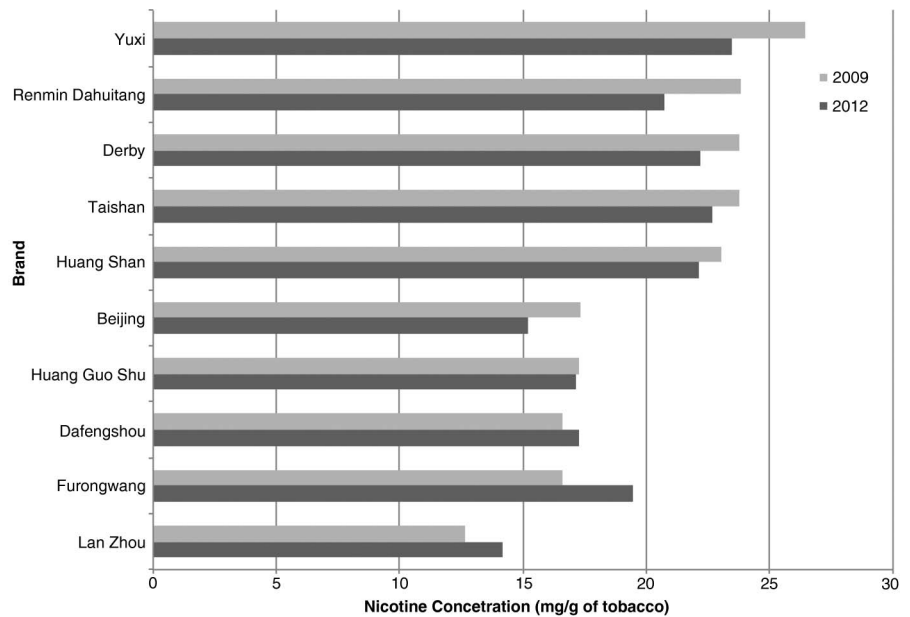
†Correlation is significant at the 0.05 level (two tailed).

excretion through the urinary tract, indicating that the body likely experiences long-term exposures.¹² Metal contamination of agricultural products due to environmental pollution is a broader public health concern in China, particularly for foodstuffs, and recent reports have highlighted high levels of metals in vegetables, rice and fish.^{34–36} So Chinese smokers may be adding an additional metal burden to existing exposures.

Lastly, nicotine, the addictive component of tobacco, is thought to be affected by the plant's supply of nitrogen throughout growth.²⁵ Given that fertilisers are intended to provide nitrogen as well as being a potential source of heavy metal contaminations, the use of fertilisers on tobacco crops may explain the observed correlation between the tobacco rod nicotine and metal content.²⁴ Therefore, the regulation of fertiliser use may act as a means to decrease the amount of heavy metals found within the Chinese tobacco.

We note several limitations of this study. First, we do not have the ability to track the tobacco from growth to sale, although we do know that most of the tobacco grown in China is used

Figure 3 Change in the nicotine concentration of selected cigarette brands, 2009 and 2012.



domestically, and we know in which cities the cigarettes produced and sold in China were purchased. However, we do not know where in China the tobacco was grown. Second, we have measured only the tobacco concentration of metals, not the smoke levels. The transfer rates differ for each metal and can range from 1% to 30%, depending on a number of product and use factors.⁵ Also, we did not explore exposure biomarkers and therefore cannot specifically estimate the health effects caused by the metals in cigarette smoke. Lastly, owing to the lack of availability of additional cigarette sticks because of prior analyses, we were not able to analyse all cigarette pairs for nicotine content.

It is notable that TobReg, the WHO's expert panel on tobacco regulation, has recommended that "regulatory authorities ... consider requiring manufacturers to test cured tobacco purchased from each new agricultural source for levels of arsenic, cadmium, lead and nickel".³⁷ Health officials and regulators in China should develop systems to monitor tobacco metal content and consider establishing upper limits on levels in tobacco as part of a broader effort to mitigate metal contamination of agricultural products throughout China. This should include an in-depth study of the primary sources (e.g. fertilisers, air pollution) of metal enrichment in Chinese tobacco. Precluding trade in tobacco and tobacco products with high toxic metal content could eventually have a positive impact on public health.

What this paper adds

- ▶ Many heavy metals are known carcinogens and exposure via smoking has been identified as a cause of death in smokers. These metals are absorbed through the soil from which the tobacco is grown, and are higher in cigarettes made from tobacco grown in China.
- ▶ We found that levels of toxic metals remain high in Chinese cigarettes. These concentrations should be regulated for the benefit of public health.

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Competing interests None declared.

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