

# Cadmium, lead, and thallium in smoke particulate from counterfeit cigarettes compared to authentic US brands

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## Abstract

Smoking remains the leading cause of preventable disease in the United States. Exposure to tobacco smoke leads to cancer, heart and lung disease, and addiction. The origin of the tobacco and cigarette manufacturing practices of counterfeit cigarettes are unknown. Because toxic metals are incorporated into the tobacco lamina during cultivation, the ambient metal content of the soil could produce significant differences in metal levels in both the tobacco and smoke of counterfeit cigarettes. We compared mainstream smoke cadmium, thallium, and lead deliveries from counterfeit and authentic brands. Mainstream smoke levels of all three metals were far greater for counterfeit than the authentic brands, in some cases by an order of magnitude. Significant differences still existed even after normalizing mainstream smoke metal levels with nicotine delivery; the counterfeits typically delivered much higher levels of all three analytes. Our findings, based on 21 different counterfeit samples, suggest that counterfeit cigarettes potentially result in a markedly greater exposure to toxic heavy metals than authentic brands, even after correcting for differences in nicotine intake. In view of the unknown health risks associated with inhaling higher levels of toxic metals, it is prudent to minimize exposure to toxic substances whenever possible.

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*Keywords:* Tobacco; Cigarettes; Smoke; Lead; Cadmium; Thallium

## 1. Introduction

Although smoking has declined in the United States over the last 20 years, 2004-based estimates indicate that 20.9% (44.5 million) of the US adult population are current smokers (CDC, 2005a). It has been suggested that cigarette smoking causes approximately 440,000 premature deaths

per year and is the leading cause of preventable disease in the United States (CDC, 2002). Tobacco-related disease originates from the biological consequences of repeated inhalation exposure to numerous toxic constituents in cigarette smoke, which are produced by pyrosynthesis or liberated during combustion. Tobacco smoke has toxic (Chiba and Masironi, 1992; Stohs et al., 1997), genotoxic (Husgavfel-Pursiainen, 2004), mutagenic (Demarini, 2004), and carcinogenic properties (Eyre et al., 2004), and has been linked to adverse pregnancy outcomes (Källén, 1999; Lee, 1998; Little et al., 2004). There are five major classes of carcinogens in tobacco smoke (Fowles and Dybing, 2003). Some of these, such as tobacco-specific nitrosamines and polycyclic aromatic hydrocarbons, have been carefully studied, contributing to a strong weight of evidence for associated health risks (Hecht, 1999), while toxic metals and metalloids constitute one of the more understudied

*Abbreviations:* CDC, Centers for Disease Control and Prevention; FTC, Federal Trade Commission; GC, gas chromatograph; ICP-MS, inductively coupled plasma-mass spectrometry; IARC, International Agency for Research on Cancer; ISO, International Organization for Standardization; LOD, limit of detection; NNSP, nicotine-normalized smoke particulate; QFP, quartz filter pad; SRMs, Standard Reference Materials.

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major carcinogenic chemical classes in tobacco smoke. Cadmium and lead are present in tobacco smoke and contribute substantially to cancer risk indices (Fowles and Dybing, 2003). Cadmium is a Group I carcinogen and lead has recently been elevated from a Group IIB to a Group IIA carcinogen (IARC, 2004; Smith et al., 1997, 2003). Several metals, including cadmium, are also significant contributors to toxicological noncancer indices of health risks for respiratory and cardiovascular diseases such as peripheral artery disease (Fowles and Dybing, 2003; Navas-Acien et al., 2004). Thallium may be teratogenic at high levels (Hall, 1985; Léonard and Gerber, 1997; Mulkey and Oehme, 1993; Parker and Scheck, 1981). Monovalent thallium is known for its neurotoxicity (Mulkey and Oehme, 1993).

A cigarette's design features influence smoke particulate mass transport through the tobacco rod and filter; thus cigarettes are characterized according to machine-smoked tar delivery categories described as full flavor, light, and ultra-light. Published cadmium, thallium, and lead smoke levels and tar deliveries from a number of US cigarette brands demonstrate that mainstream smoke particulate heavy metal concentrations correlate well with filter ventilation designs (FTC, 2004; Pappas et al., 2006). Tobacco grown in soils with higher available cadmium and lead levels has correspondingly higher levels in the tobacco lamina (Adamu et al., 1989; Lugon-Moulin et al., 2006; Mulchi et al., 1992) and in the smoke particulate (Bache et al., 1985). Thus, cigarette brands with similar tar deliveries could yield markedly different smoke particulate levels of heavy metals depending on where the tobacco was grown and filter ventilation.

Historically, thallium content associated with agricultural products has been of limited concern because of its naturally low levels in the environment (Tremel and Mench, 1997). The few reported thallium levels in tobacco and mainstream smoke particulate were also low (Krivan et al., 1994; Pappas et al., 2006). However, mining and industrial activities in some areas have polluted agricultural irrigation water, resulting in dramatic increases for thallium and other metals in some agricultural products (Cheng, 2003; Xiao et al., 2004a,b). Because tobacco products originate from many different geographical areas, determining thallium levels has become more important.

Analyses of 47 counterfeit tobacco products seized in the UK from 2002 through early 2004 revealed that cadmium and lead levels were often markedly higher than in comparable domestic UK tobacco products. The metals in the counterfeit cigarettes were consistent with tobacco products grown with phosphatic fertilizer or possibly sludge as a soil amendment (Stephens et al., 2005), as has also been reportedly used for some tobacco crops produced in Tanzania (Semu and Singh, 1996).

The prevalence of counterfeit cigarettes in the United Kingdom in 2000–2001 was estimated at 5%. This estimate increased to 15% in 2003–2004 (HM Customs and Excise, 2003–2004). A US General Accounting Office (GAO) report cited Alcohol Tobacco and Firearms (ATF) and Bureau of Immigration and Customs Enforcement (ICE)

investigations as evidence that smuggling of counterfeit cigarettes into the United States has become a significant problem, but stated further that no studies have been done to determine whether counterfeit cigarettes pose any additional health risks compared to genuine brand cigarettes (GAO, 2004). We therefore studied how selected toxic metal levels in mainstream smoke particulate from counterfeit cigarettes confiscated in the US compared to the corresponding authentic brands. We report the cadmium, thallium, and lead mainstream smoke particulate phase levels from 21 counterfeit cigarette samples confiscated in multiple seizures by the US Department of Homeland Security, the Bureau of Immigration and Customs Enforcement, and the Federal Bureau of Investigation. Because of high metal background in the smoke collection materials, we limited our analyses to three metals, excluding several other metals of interest after extensive acid leaching procedures failed to achieve sufficiently low blank levels.

## 2. Materials and methods

### 2.1. Cigarette samples and storage

In 2003, we purchased authentic cigarette brands at various retail outlets in the greater metropolitan area of Atlanta, Georgia, USA. Known counterfeit samples were provided by other federal agencies from ongoing law enforcement activities. The samples were assigned unique identification numbers and logged into a database. The samples were placed in plastic bags in their original packaging and stored at  $-70^{\circ}\text{C}$  until tested. Only authorized personnel had access to the samples. We examined microscopic physical characteristics and compared tobacco filler chemical fingerprints with those from authentic brands to confirm that the cigarettes received from law enforcement agencies were counterfeit.

### 2.2. Sample, standard, and blank preparation and analysis

Method details, including cigarette preparation, smoking conditions, particulate collection, acid-leached 44-mm quartz filter pad (QFP) preparation (QM-A, Whatman, Florham Park, NJ, USA), standards, filter blank preparation, and metals analysis were previously described (Pappas et al., 2006). Briefly, QFPs were leached in two steps with dilute hydrochloric acid and nitric acid ( $\text{HNO}_3$ ), then rinsed, and dried prior to use. Five cigarettes were smoked per QFP under FTC smoking conditions (35-mL puff volume, 2-s puff, and 60-s puff intervals). QFPs were digested overnight with 20.0 mL  $\text{HNO}_3$  at  $120^{\circ}\text{C}$ , followed by cooling, addition of 5.0 mL 35% hydrogen peroxide, and further digestion for 1 h at  $50^{\circ}\text{C}$ . Samples were diluted to 50.0 mL with ultrapure water. 250- $\mu\text{L}$  aliquots were diluted with 1 mL internal standard (1.25  $\mu\text{g/L}$  Ir in 2% v/v  $\text{HNO}_3$ ) prior to analysis.

### 2.3. Quality control procedures

Recovery quality control was evaluated as previously described with high and low QFP spikes included with each digest batch (Pappas et al., 2006). Recovery results were graphically tracked for acceptability according to Westgard rules with SAS<sup>®</sup> version 9.1 (SAS Institute, Cary, NC, USA).

### 2.4. Nicotine deliveries

Nicotine measurements were performed as previously described (Calafat et al., 2004). Briefly, glass-fiber filter pads were used to collect the mainstream smoke particulate matter from five cigarettes. The nicotine was extracted from the particulate matter using 50 mL of 2-propanol containing a known amount of *trans*-anethole (100 mg/L) as internal

standard. The extract was analyzed for total nicotine content using a gas chromatograph equipped with a flame ionization detector. The ratios of the nicotine-to-anethole peak areas were compared to known standard solutions to determine unknown concentrations.

### 2.5. Statistical methods

Two-tailed Student *t*-tests were performed with Excel® software (Microsoft, USA). Differences were considered statistically significant when  $p < 0.05$ .

## 3. Results

### 3.1. Particulate cadmium, lead, and thallium levels

All counterfeit brands contained higher levels of cadmium in the mainstream smoke particulate than the authentic brands (Fig. 1). The mean particulate cadmium levels in the mainstream smoke from authentic Marlboro® brands for different varieties exhibited the expected

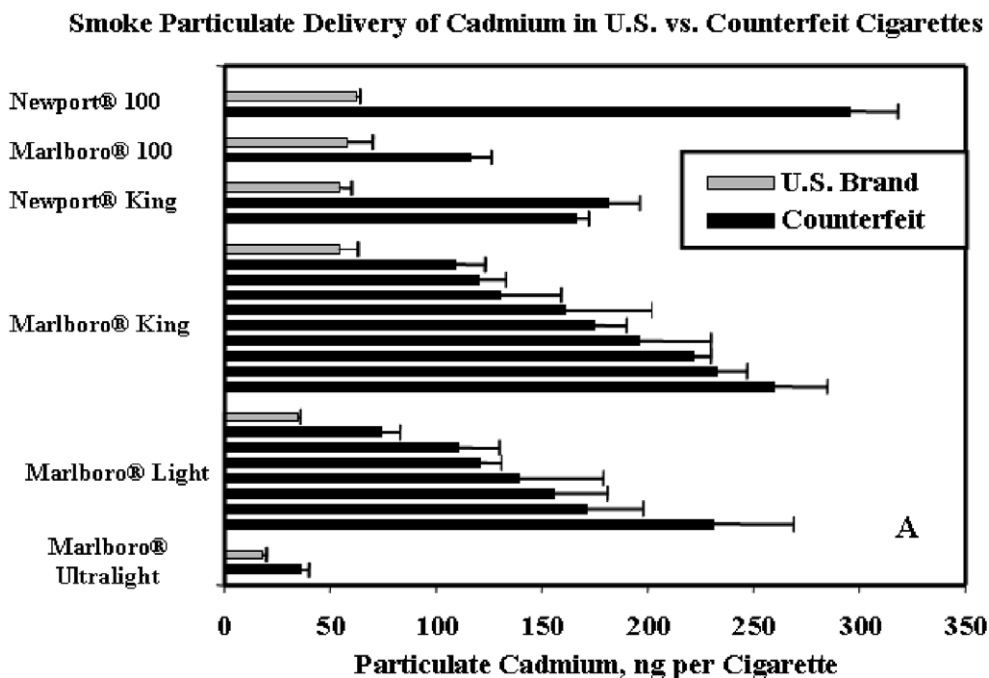


Fig. 1. Mean particulate cadmium levels (with standard deviation bars) in mainstream smoke particulate for counterfeit and authentic US brand cigarettes.

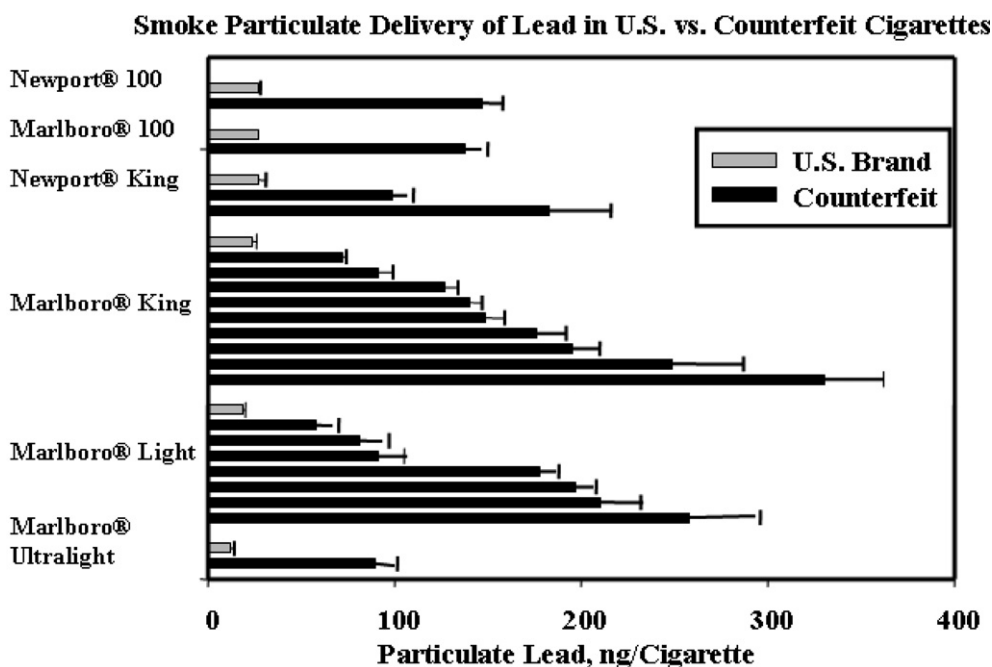


Fig. 2. Mean particulate lead levels (with standard deviation bars) in mainstream smoke particulate for counterfeit and authentic US brand cigarettes.

relationship, in which smoke particulate cadmium levels are in the order full flavor 100 > full-flavor king size > light > ultralight. The same relationship was apparent for mainstream particulate lead (Fig. 2) and thallium (Table 1). As in the case of cadmium, the mean smoke particulate levels of thallium and lead from the counterfeit brands were without exception higher than in the comparable authentic brand.

Mean smoke particulate cadmium levels from counterfeit cigarettes were 2.0–6.5 times higher than the authentic brands and the differences were all statistically significant ( $p < 0.05$ ). Mean smoke particulate thallium levels from counterfeit cigarettes were 1.4–4.9 times higher than the authentic cigarettes. The thallium level differences between counterfeits and the corresponding authentic cigarette brands were statistically significant for all but the two lowest delivery counterfeit Marlboro® light brands ( $p = 0.1$ ,  $p = 0.06$ ), which also had much larger relative standard

deviations. Mean smoke particulate lead levels from counterfeit cigarettes were 3.0–13.8 times higher than the authentic brand cigarettes. Particulate lead levels also showed statistically significant differences from the respective authentic cigarettes.

### 3.2. Particulate cadmium, lead, and thallium levels normalized to nicotine delivery

Nicotine deliveries for authentic and counterfeit cigarettes were 0.5–1.5 mg/cigarette (Table 1). Some nicotine delivery levels in the counterfeit cigarettes were not consistent with the authentic labeled brand variety. For example, the mean nicotine delivery in mainstream smoke for the counterfeit Marlboro Ultralight cigarette was 0.9 mg/cigarette, higher than expected for an ultralight cigarette and a value that would typically be associated with light-branded cigarettes. Moreover, the nicotine deliveries for many counterfeit Marlboro Light cigarettes were higher than the authentic full-flavor Marlboro brand.

In order to more closely match the exposure to metals from these cigarettes, we normalized their deliveries with the mainstream smoke nicotine deliveries. This assumes that individuals smoke a particular brand in such a manner to achieve a target nicotine dose by varying how they smoke, i.e., by changing average puff volume, puff frequency, and/or inhalation depth, smoke residence time, etc. The normalized mainstream smoke heavy metal deliveries from authentic and counterfeit cigarettes are shown in Figs. 3 and 4 and Table 1. After normalization to nicotine, the within-brand, between-variety differences for the mainstream smoke particulate thallium and lead levels for the authentic Marlboro and Newport cigarettes were no longer statistically significant. The same was true for nicotine-normalized smoke particulate (NNSP) cadmium levels, with the exception of the Marlboro® light compared with Marlboro® ultralight ( $p = 0.04$ ).

In most cases, the nicotine-normalized heavy metal levels in the smoke from the counterfeit cigarettes remained significantly higher than those in authentic cigarettes of the same brand and variety. Smoke particulate cadmium levels normalized to nicotine for the counterfeit Marlboro® ultralight, one of the counterfeit Marlboro® light cigarettes and one of the counterfeit Marlboro® king full flavor cigarettes were no longer significantly different from the respective authentic brands ( $p = 0.31$ ,  $p = 0.4$ ,  $p = 0.15$ , respectively). Excluding these exceptions, the NNSP cadmium levels of the counterfeit brands were 1.1–5.7 times those of the respective authentic brands.

Nearly all the NNSP thallium levels were significantly higher than the corresponding authentic variety (Table 1). Only the mean NNSP thallium levels from two counterfeit Marlboro® light cigarettes ( $p = 0.07$ ,  $p = 0.07$ ), one counterfeit Marlboro® king size full-flavor cigarettes ( $p = 0.06$ ), and one counterfeit Newport® king size full-flavor cigarettes ( $p = 0.05$ ) were not significantly different from the respective authentic brands. Excluding these

Table 1  
Smoke particulate thallium level and nicotine delivery

| Cigarette                   | Thallium levels $\pm$ SDs <sup>a</sup> (ng/cigarette) | Nicotine levels (mg/cigarette) | Thallium/nicotine levels $\pm$ SDs <sup>a</sup> (ng/mg) |
|-----------------------------|---|--------------------------------|---|
| <i>Newport® 100</i>         |   |                                |   |
| Authentic                   | 2.22 $\pm$ 0.06                                       | 1.2                            | 1.9 $\pm$ 0.05  |
| Counterfeit                 | 5.39 $\pm$ 0.14                                       | 1                              | 5.4 $\pm$ 0.1   |
| <i>Marlboro® 100</i>        |   |                                |   |
| Authentic                   | 2.08 $\pm$ 0.30                                       | 1.1                            | 1.9 $\pm$ 0.3   |
| Counterfeit                 | 4.08 $\pm$ 0.21                                       | 1.3                            | 3.1 $\pm$ 0.2   |
| <i>Newport® King</i>        |   |                                |   |
| Authentic                   | 2.04 $\pm$ 0.21                                       | 1.2                            | 1.7 $\pm$ 0.2   |
| Counterfeit 1               | 4.69 $\pm$ 0.26                                       | 1.4                            | 3.4 $\pm$ 0.2   |
| Counterfeit 2               | 3.42 $\pm$ 0.50                                       | 1.4                            | 2.4 $\pm$ 0.4   |
| <i>Marlboro® King</i>       |   |                                |   |
| Authentic                   | 1.61 $\pm$ 0.14                                       | 1.1                            | 1.5 $\pm$ 0.1   |
| Counterfeit 1               | 2.40 $\pm$ 0.29                                       | 1                              | 2.4 $\pm$ 0.3   |
| Counterfeit 2               | 3.03 $\pm$ 0.35                                       | 1.3                            | 2.3 $\pm$ 0.3   |
| Counterfeit 3               | 3.25 $\pm$ 0.18                                       | 1.9                            | 1.7 $\pm$ 0.1   |
| Counterfeit 4               | 3.34 $\pm$ 0.20                                       | 0.8                            | 4.2 $\pm$ 0.2   |
| Counterfeit 5               | 4.19 $\pm$ 0.77                                       | 0.9                            | 4.7 $\pm$ 0.9   |
| Counterfeit 6               | 4.67 $\pm$ 0.32                                       | 1.3                            | 3.6 $\pm$ 0.2   |
| Counterfeit 7               | 5.49 $\pm$ 0.10                                       | 1.3                            | 4.2 $\pm$ 0.1   |
| Counterfeit 8               | 6.49 $\pm$ 0.65                                       | 1.5                            | 4.3 $\pm$ 0.4   |
| Counterfeit 9               | 7.04 $\pm$ 0.23                                       | 1.4                            | 5.0 $\pm$ 0.2   |
| <i>Marlboro® Light</i>      |   |                                |   |
| Authentic                   | 1.18 $\pm$ 0.10                                       | 0.8                            | 1.5 $\pm$ 0.1   |
| Counterfeit 1               | 1.90 $\pm$ 0.43                                       | 1.8                            | 1.1 $\pm$ 0.2   |
| Counterfeit 2               | 2.53 $\pm$ 0.61                                       | 0.9                            | 2.8 $\pm$ 0.7   |
| Counterfeit 3               | 3.13 $\pm$ 0.17                                       | 0.9                            | 3.5 $\pm$ 0.2   |
| Counterfeit 4               | 3.20 $\pm$ 0.18                                       | 0.9                            | 3.6 $\pm$ 0.2   |
| Counterfeit 5               | 3.22 $\pm$ 0.44                                       | 1.2                            | 2.7 $\pm$ 0.4   |
| Counterfeit 6               | 5.25 $\pm$ 0.69                                       | 1.3                            | 4.0 $\pm$ 0.5   |
| Counterfeit 7               | 5.82 $\pm$ 0.20                                       | 1.2                            | 4.9 $\pm$ 0.2   |
| <i>Marlboro® Ultralight</i> |   |                                |   |
| Authentic                   | 0.70 $\pm$ 0.04                                       | 0.5                            | 1.4 $\pm$ 0.1   |
| Counterfeit                 | 1.01 $\pm$ 0.10                                       | 0.9                            | 1.1 $\pm$ 0.1   |

<sup>a</sup> SD = standard deviation.

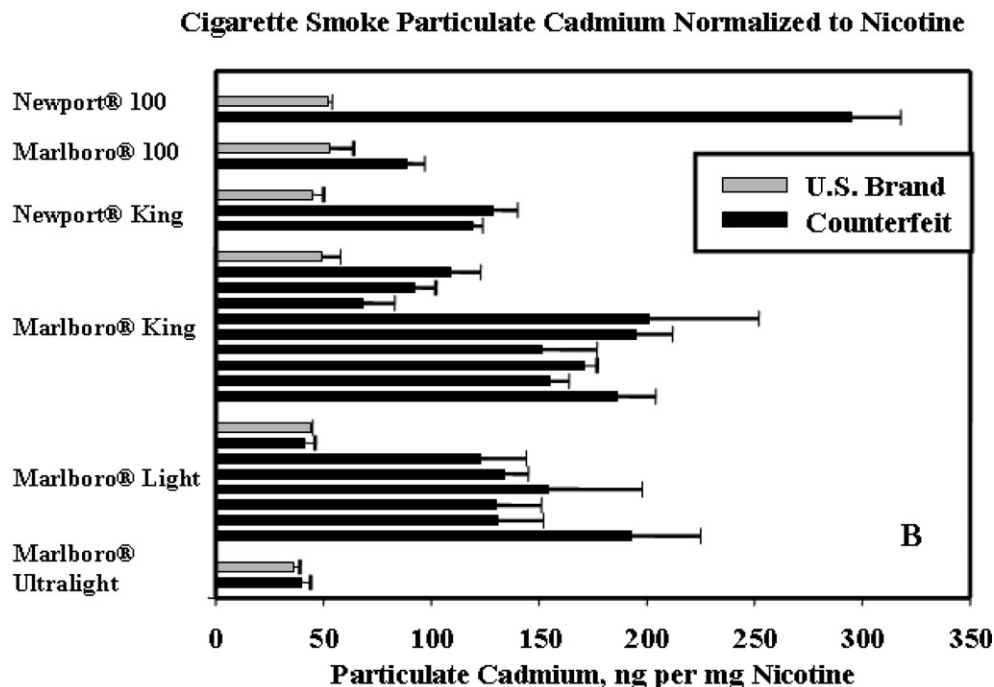


Fig. 3. Mean particulate cadmium levels (with standard deviation bars) in mainstream smoke particulate for counterfeit and authentic US brand cigarettes normalized to nicotine delivery.

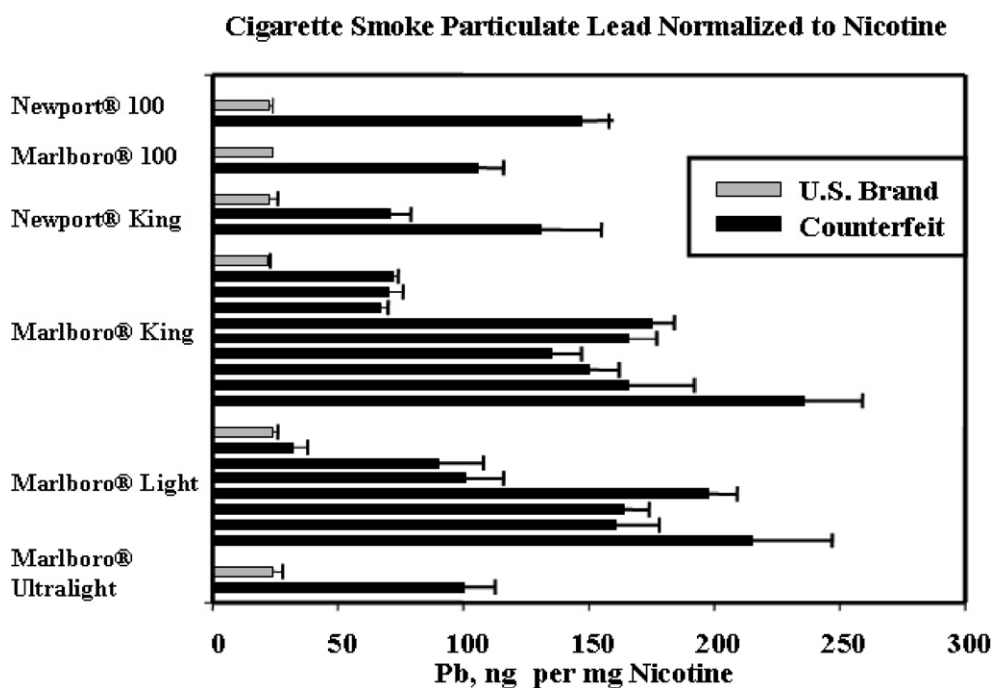


Fig. 4. Mean particulate lead levels (with standard deviation bars) in mainstream smoke particulate for counterfeit and authentic US brand cigarettes normalized to nicotine delivery.

brands, the NNSP thallium levels were 1.5–3.3 times higher than the respective authentic brands.

Except for the counterfeit Marlboro® light with the lowest mean smoke lead level ( $p = 0.054$ ), the mean NNSP

lead levels were significantly higher than the authentic brand. Among the 20 other counterfeits exhibiting a statistically significant difference, the NNSP lead levels were 3.1–10.9 times higher than the respective authentic brands.

#### 4. Discussion

Mainstream particulate cadmium, lead and thallium levels from counterfeit cigarettes were significantly higher than the corresponding levels from authentic commercial cigarettes of the same brand and variety using a standardized machine smoking protocol. In most cases, these findings remained statistically significant when the levels were normalized against nicotine delivery. Compared to authentic brands, the differences in mean smoke particulate cadmium, thallium, and lead levels from the counterfeit cigarettes were significantly larger than any differences we have encountered from authentic US cigarettes manufactured across multiple years and brands (Pappas et al., 2006). In some cases, these counterfeit brands deliver quantities of heavy metals more than an order of magnitude higher than the comparable authentic brands. These data suggest that smokers could receive significantly higher exposures to various toxic and carcinogenic metals from counterfeit cigarettes than from the comparable authentic cigarettes, even when accounting for possible nicotine compensation habits among smokers of different tar delivery group cigarettes (Kozlowski and O'Connor, 2002).

Toxic metal uptake by tobacco plants depends on the levels of these contaminants in the soil, soil amendments (Adamu et al., 1989; Mulchi et al., 1992), and soil pH (Mulchi et al., 1987). Metal absorption for a variety of agricultural products has been shown to be dependent on geographical origin (Anderson et al., 1999; Schwartz and Hecking, 1991). The levels of particulate thallium from counterfeit cigarettes, while elevated relative to the levels from authentic brands, were not as high as might have been expected from tobacco grown in areas highly industrially polluted to the extents described in a few cases in the literature (Cheng, 2003; Xiao et al., 2004a,b). Counterfeit cigarettes seized by the UK Customs and Excise had significantly higher heavy metals content in their tobacco compared to their genuine equivalents (Stephens et al., 2005). These authors thus predicted that smokers of counterfeit cigarettes would be exposed to higher levels of heavy metals. They found that the levels of cadmium in tobacco from counterfeit cigarettes were  $5.0 \pm 2.7$  (mean  $\pm$  standard deviation) times higher than the mean cadmium level found in authentic cigarettes. The levels of lead in tobacco from counterfeit cigarettes were also  $5.8 \pm 3.7$  times higher than from the corresponding authentic cigarette brands. Their study and ours are not directly comparable because of brand differences and the unknown origins of counterfeit cigarette tobacco. Nevertheless, both studies show a remarkable similarity in the magnitude of elevated levels of these metals in the counterfeit over the authentic brands.

Nicotine deliveries from 17 out of 21 of the counterfeit cigarettes were higher than those of the comparable authentic brands; four had lower nicotine deliveries. All of the counterfeit Marlboro Light and Marlboro Ultralight cigarettes had higher nicotine deliveries than the authentic brands. In fact, many of the counterfeit nicotine deliveries

were out of the range expected from their labeled variety. Many of the counterfeits did not have the same filter ventilation as the corresponding authentic brands. However, differences in total delivery did not account for the increased levels of metals in smoke particulate. Our data show that particulate cadmium, thallium, and lead levels from counterfeit cigarettes remain significantly higher in most cases, even after nicotine normalization.

The potential health impact from smoking cigarettes that deliver high levels of toxic metal is not limited to active smokers. In indoor environments, cadmium, lead, and other metals from sidestream smoke are readily available from passive exposure (Chang et al., 2005; Landsberger and Wu, 1995; Wagner et al., 2001). The Third National Exposure Report of the National Health and Nutrition Examination Survey showed that geometric mean serum cotinine levels in children aged 3–11 years (0.110 ng/mL, 95% confidence intervals: 0.076–0.160 ng/mL) were more than twice the geometric mean serum levels of adults age 20 years and older (0.052 ng/mL, 95% confidence intervals: <LOD–0.063 ng/mL). Geometric mean serum cotinine levels in children aged 12–19 years (0.086 ng/mL, 95% confidence intervals: 0.059–0.126 ng/mL) were approximately 65% greater than those of adults age 20 years and older (CDC, 2005b; Pirkle et al., 2005). Cotinine is a biomarker for exposure to tobacco smoke. It is thus likely that children who are environmentally exposed to second-hand tobacco smoke would also have other exposure biomarkers, such as metals. Indeed, an association of elevated blood lead levels with exposure to second-hand smoke has been shown in children aged 4–6 years (Mannino et al., 2003). The association between elevated serum cotinine concentrations and children with elevated blood lead concentrations was apparent without regard to poverty index. Thus, it is probable that exposure of children or adults to tobacco smoke with higher particulate levels of cadmium and lead such as those found in these counterfeit cigarettes could translate to higher heavy metal blood levels.

Because cadmium and lead have long biological half-lives, they accumulate in bone, blood, lung, kidney, and various other organs (Gairola and Wagner, 1991; Musalo-Rauhamaa et al., 1986; Pääkö et al., 1989). Chronic exposure to and accumulation of heavy metals from any source, including tobacco smoke, has a high potential to adversely impact health. Accumulation in various tissues and fluids could result in various metals becoming available at particularly inopportune times, such as during increased calcium resorption from bone. Pregnancy and nursing are two examples of inopportune times for mobilization of these metals with regard to the health of infants and mothers. Whether resorbed from bone or simply present at elevated circulating levels from chronic tobacco smoke inhalation, 7–49% higher lead concentrations were found in the cord blood of infants born to mothers who smoke than to those who are nonsmokers (Rhoads and Levallois, 1997; Rhoads et al., 1999). Among smoking

pregnant women diagnosed with oligohydramnios, and whose gestational durations were only 32–39 weeks, amniotic fluid cadmium concentrations were almost twice as high as those from a second group whose serum cotinine concentrations were less than one fourth as high (Milnerowicz et al., 2000). Smoking has also been associated with four times higher concentrations of cadmium in human milk among smoking mothers than nonsmoking mothers (Milnerowicz and Chmerek, 2005). Thus, prepartum or postpartum maternal exposure to elevated levels of cadmium and lead from cigarette smoke increases exposure to such toxic metals for both mothers and children.

We have shown that levels of cadmium, thallium and lead were elevated in the mainstream smoke particulate of counterfeit cigarettes compared to authentic brands. However, this does not necessarily indicate that all counterfeit cigarettes have elevated levels of heavy metals. This study examined a convenience sample of counterfeit cigarettes that were available from ongoing law enforcement activities. This small sample cannot be used to draw general conclusions about counterfeit cigarettes. In addition, we only examined three of the many metals that occur in tobacco smoke. Depending on geographical location, industrial or mining activities, and agronomic practices, tobacco grown in a given location will have varying amounts of each heavy metal. Thus, it is possible that the levels of different metals may be higher or lower depending on the growing conditions.

Heavy metals constitute just one of many classes of toxic, carcinogenic, and addictive substances in smoke. Differences in other classes of toxic compounds such as volatiles, tobacco-specific nitrosamines, and polyaromatic hydrocarbons, or the bioavailability of nicotine must also be evaluated for the health impacts of tobacco products. Elevated levels of cadmium, thallium, and lead in counterfeit cigarettes do not necessarily indicate that such products bestow additional risk to those already associated with tobacco use. However, elevated levels of heavy metals in both counterfeit and authentic tobacco products merit further evaluation from a public health standpoint.

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