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ORIGINAL INVESTIGATION

Cigarette Rod Length and Its Impact on Serum Cotinine and Urinary Total NNAL Levels, NHANES 2007–2010

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ABSTRACT

Introduction: Research suggests that smokers of slim, long, or ultralong cigarettes may have a perception of reduced harm from their own brand. This study compared serum cotinine and urinary total 4-(methylnitrosamino)-1-(3-pyridyl)-1-butanonol (NNAL) levels among smokers of regular-sized (68–72 mm), king-sized (79–88 mm), and long (94–101 mm) or ultralong (110–121 mm) cigarettes.

Methods: Nationally representative data from the 2007–2008 and 2009–2010 National Health and Nutrition Examination Survey were analyzed for 3,699 current smokers aged ≥20 years. Biomarker levels were summarized using geometric means (GMs). Multivariate linear regression analyses were performed to assess the effect of cigarette rod length on log-transformed serum cotinine and creatinine-adjusted urinary total NNAL levels.

Results: The GM of serum cotinine level was higher among smokers of long/ultralong cigarettes (263.15 ng/ml) compared with smokers of regular-sized (173.13 ng/ml) or king-sized (213.79 ng/ml) cigarettes. Similarly, the GM of creatinine-adjusted NNAL levels was higher among smokers of long/ultralong cigarettes (0.48 ng NNAL/mg of creatinine) compared with smokers of regular-sized (0.34 ng NNAL/mg of creatinine) or king-sized (0.33 ng NNAL/mg of creatinine) cigarettes. After adjusting for potential confounders, mean cotinine and NNAL levels were both significantly higher among smokers of long/ultralong cigarettes compared with levels observed in smokers of either regular-sized or king-sized cigarettes. However, no significant differences were observed between smokers of regular-sized and king-sized cigarettes in mean levels of cotinine or NNAL.

Conclusions: Significantly elevated tobacco biomarker levels were observed among smokers of long/ultralong cigarettes compared with smokers of regular-sized or king-sized cigarettes. This underscores the need to educate the public about the dangers of all tobacco products.

INTRODUCTION

Cigarette design and engineering have evolved over the last several decades to keep up with changing social, psychological, health, and political climates. Apart from design features such as modifications of tobacco blend, filter, and vents, which were made to modify the quality and/or quantity of smoke yielded from the cigarette, the tobacco industry has also introduced other design features tailored to appeal to certain population niches. These include modifications in tipping color, packaging, flavoring, circumference, and changes in cigarette rod length (Bansal-Travers, Hammond, Smith, & Cummings, 2011; Carpenter, Wayne, & Connolly, 2005; Carpenter, Wayne, Pauly, Koh, & Connolly, 2005; Cook, Wayne, Keithly, & Connolly, 2003).

Within the United States, cigarette brands are sold in various cigarette rod length categories, namely regular-sized (68–72 mm), king-sized (79–88 mm), long (94–101 mm), and ultralong (110–121 mm) cigarettes (FTC, 2012). Several studies have assessed the effect of various physical attributes of cigarettes, such as vents, filters, menthol, and smoke yield on cotinine and tobacco-specific nitrosamines (Hecht et al., 2005; Jones, Apelberg, Tellez-Plaza, Samet, & Navas-Acien, 2013; Joseph et al., 2005; Melikian, Djordjevic, Chen, Richie, & Stellman, 2007; Sarkar, Wang, & Liang, 2012). However, to date, no study has assessed the effect of cigarette rod length on tobacco biomarker levels. This is important because design features such as length and circumference of cigarettes may influence perception of harm by smokers. A recent study showed that longer length cigarettes were often perceived by smokers to be attractive and of high quality. (Borland & Savvas, 2013).

Therefore, to fill this gap in knowledge, this study compared serum cotinine and urinary total 4-(methylnitrosamino)-1-(3-pyridyl)-1-butanonol (NNAL) levels among smokers of

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regular-sized, king-sized, and long/ultralong cigarettes using nationally representative data from the 2007–2008 and 2009–2010 National Health and Nutrition Examination Surveys (NHANES) (CDC, 2007).

METHODS

Data Sources

We merged data from the NHANES 2007–2008 and 2009–2010 waves. NHANES is a household interview and examination survey that uses a complex, multistage probability sampling design to select participants from the noninstitutionalized U.S. population. Overall interview response rates were 78.4% (2007–2008) and 79.4% (2009–2010). Our analyses were restricted to respondents who were above 18 years old, were current smokers, and had provided information on the outcomes of interest, that is, length of cigarette currently smoked. Thus, our final analytic sample included 3,699 smokers aged ≥20 years.

Measures

All respondents who at the time of the survey reported smoking cigarettes everyday or on some days (including the past 5 days) were considered current smokers. Among smokers, the length of the cigarette currently smoked was asked. Categorical responses were “Regular (68–72 mm)” (n = 588), “King (79–88 mm)” (n = 1,855), “Long (94–101 mm)” (n = 1214), or “Ultralong (110–121 mm)” (n = 42). Within the analysis and throughout the article, long and ultralong cigarettes were merged into one category. Smokers were also asked the number of days in which they smoked during the past 30 days and the smoking intensity on the days they smoked (as measured by the number of cigarettes smoked per day or CPD). In addition, smokers were asked to indicate the time from awakening to taking their first cigarette.

Other covariates assessed included the following: age (18–24, 25–44, 45–64, and ≥65 years); gender (male or female); race/ethnicity (non-Hispanic White, non-Hispanic Black, Hispanic, or other race, including multiracial); educational attainment (<12 years, =12 years/General Educational Development Certificate, or >12 years); Poverty index ratio (<federal poverty level or ≥poverty level); body mass index (underweight: <18.5, normal weight: 18.5–24.9, overweight: 25–29.9, and obese: ≥30); presence of any smoker in household as proxy for secondhand smoke exposure (≥1 smoker vs. none); marital status (married or living with partner, widowed, divorced or separated, or never married), and tobacco use pattern (cigarette-only smokers vs. cigarette plus use of any other tobacco product such as pipes, cigars, snuff, or chewing tobacco products).

Serum Cotinine–Urinary Total NNAL

Serum cotinine, a major metabolite of nicotine and a valid marker for tobacco use (Benowitz, 1996), was measured by isotope dilution–high-performance liquid chromatography/atmospheric pressure chemical ionization tandem mass spectrometry (ID HPLC-APCI MS/MS).

NNAL, a metabolite of 4-(methylnitrosamino)-1-(3-pyridyl)-1-butanone and major component of tobacco and tobacco smoke (Hou et al., 2012), was measured by using liquid chromatography linked to tandem mass spectrometry (LC/MS/MS). Because urinary total NNAL was assayed with random urine samples and not 24-hr samples, correction for variability in urine output was made by adjusting urinary NNAL concentrations based on urinary creatinine levels (expressed as nanograms of urinary total NNAL per milligram of creatinine).

Statistical Methods

Tobacco use characteristics among smokers were assessed by cigarette rod length, including CPD, average number of cigarettes smoked in the past 30 days (product of CPD and average number of days in which respondent smoked cigarettes in the past 30 days), and level of nicotine dependence. Nicotine dependence was measured using the Heaviness of Smoking Index, a 6-point scale calculated from the number of cigarettes smoked per day (1–10, 11–20, 21–30, and >30 cigarettes) and the time to first cigarette after waking (≤5, 6–30, 31–60, and >60 min) (Heatherton, Kozlowski, Frecker, Rickert, & Robinson, 1989). Scores of 0–1 were categorized as low nicotine dependence, 2–4 as moderate nicotine dependence, and 5–6 as high nicotine dependence.

Serum cotinine and urinary NNAL concentrations are presented using geometric means (GM) with 95% confidence intervals (95% *CI*) because of the skewness of the data. To assess the effect of cigarette rod length on cotinine and NNAL concentrations of smokers, multivariate linear regression models were fitted adjusting for age, sex, race/ethnicity, educational level, poverty index ratio, body mass index, presence of smoker in household, marital status, tobacco use pattern, and CPD. In the regression analyses, cotinine and NNAL were transformed to the natural log scale to assume a normal distribution. Results of the regression analysis are presented as unadjusted and adjusted β coefficients. The level of statistical significance was set at $p < .05$. All analysis were weighted and performed with STATA 11.0 (StataCorp., 2009).

RESULTS

Population Characteristics

Smokers of king-sized cigarettes represented slightly more than half (53.0%) of the overall smoker population, whereas smokers of long/ultralong cigarettes and regular-sized cigarettes constituted 31.5% and 15.4% of the smoker population, respectively. The distribution of the study population by selected sociodemographic characteristics and cigarette rod length is detailed in Table 1. A higher percentage of smokers in the ≤24 and 25–44 age groups were smokers of king-sized cigarettes (63.5% and 57.8%, respectively), with long/ultralong cigarettes used by 55% of the older respondents (≥65 years). Moreover, a higher percentage of females were smokers of long/ultralong cigarettes in comparison to males (40.8% vs. 23.4%, respectively, $p < .001$).

Tobacco Use Characteristics by Cigarette Rod Length

The proportion of low-nicotine-dependent smokers was lower among smokers of long/ultralong cigarettes (38.7%) compared with smokers of regular-sized (55.0%) or king-sized cigarettes, whereas a higher proportion of long/ultralong cigarette smokers had moderate or high nicotine dependence compared with

Table 1. Distribution of Sociodemographic Characteristics of Smokers by Rod Length of the Cigarette Currently Smoked, NHANES 2007–2010 (*N* = 3,699)

		Regular-sized cigarettes (68–72 mm)	King-sized cigarettes (79–88 mm)	Long (94–101 mm)/ ultralong (110–121 mm) cigarettes	
Characteristics	Number, *n*	% (*n*)	% (*n*)	% (*n*)	*p* Value
Age, years					
≤24	403	18.8	63.5	17.6	<.001
25–44	1,573	18.3	57.8	24.0	
45–64	1,334	11.8	46.2	42.0	
≥65	389	8.7	36.27	55.0	
Sex					
Male	2,020	18.9	57.7	23.4	<.001
Female	1,679	11.6	47.6	40.8	
Race/ethnicity					
White, non-Hispanic	1,843	14.3	55.1	30.6	<.001
Black, non-Hispanic	849	2.9	54.7	42.4	
Hispanic	846	34.5	43.0	22.4	
Other race, non-Hispanic	161	20.4	45.2	34.4	
Education level					
<12 years	1,375	17.9	47.7	34.4	.110
=12 years/General Educational Development Certificate	1,091	14.6	54.9	30.4	
>12 years	1,231	14.2	55.5	30.3	
Poverty index ratio					
Below federal poverty level	1,141	16.7	47.4	35.9	.096
At or above federal poverty level	2,208	14.4	55.0	30.7	
Body mass index					
Underweight: <18.5	123	10.3	48.2	41.5	.215
Normal weight: 18.5–24.9	1,225	13.5	56.2	30.3	
Overweight: 25–29.9	1,176	16.9	54.6	28.5	
Obese: ≥30	1,140	16.6	48.1	35.3	
Presence of smoker in household					
Yes	2,104	11.0	48.4	40.5	<.001
No	1,576	20.8	59.0	20.2	
Marital status					
Married/Living with partner	1,930	18.1	50.6	31.3	.003
Widowed/divorced/separated	948	11.3	50.6	38.1	
Never married	818	13.0	61.3	25.7	
Tobacco use patterns					
Cigarettes only	3,597	14.9	53.1	31.9	.024
Cigarettes combined with any other tobacco product	102	31.8	48.9	19.3	
Cigarette smoked per day					
1–10	2,138	18.2	54.4	27.4	.080
11–20	1,162	12.4	51.9	35.7	
21–30	207	11.3	53.2	35.5	
>30	165	10.3	48.8	40.9	
Overall	3,699	15.4 (588)	53.0 (1,855)	31.5 (1,256)	

Note. All data were weighted to account for the complex survey design.

either regular-sized or king-sized cigarette smokers (Table 2). Similarly, the proportion of daily smokers was significantly higher among long/ultralong cigarette smokers (92.1%) compared with smokers of regular-sized (72.7%) or king-sized (84.6%) cigarettes (Table 2).

The mean CPD among long/ultralong cigarette smokers (15.4) was significantly higher compared with that among smokers of regular-sized (11.4) or king-sized cigarettes (13.7) ($p < .05$ for both). Similarly, the average number of cigarettes smoked in the past 30 days among long/ultralong cigarette smokers (452.7) was significantly higher compared with the number among smokers of regular-sized (314.8) or king-sized (395.2) cigarettes ($p < .05$ for both).

Cotinine/NNAL Associations With Cigarette Rod Length

Within the bivariate analyses, serum cotinine concentrations were higher among smokers of long/ultralong cigarettes (GM: 263.15 ng/ml) compared with smokers of either regular-sized

Table 2. Tobacco Use Characteristics by Cigarette Rod Length Among Adults Aged ≥20 Years, NHANES 2007–2010 (*N* = 3,699)

Characteristics	Regular-sized cigarettes (68–72 mm), *n* = 588	King-sized cigarettes (79–88 mm), *n* = 1,855	Long (94–101 mm) or ultralong cigarettes (110–121 mm), *n* = 1,256
Heaviness of smoking index[a], % (95% CI)			
Low	55.0 (42.6–67.5)	49.9 (44.6–55.3)	38.7 (34.4–42.9)
Moderate	36.7 (26.6–46.8)	41.2 (36.4–46.0)	48.7 (43.9–53.4)
High	8.3 (3.3–13.2)	8.9 (5.7–12.0)	12.7 (9.6–15.8)
Smoking frequency, % (95% CI)			
Some days	27.3 (19.6–35.0)	15.4 (11.8–18.9)	7.9 (5.0–10.7)
Daily	72.7 (65.0–80.5)	84.6 (81.1–88.2)	92.1 (89.3–95.0)
Average number of cigarettes smoked per day			
Mean (*SD*)	11.4 (9.6)	13.7 (10.8)	15.4 (10.9)
Median (range)	10.0 (1.0–50.0)	10.0 (1.0–95.0)	15.0 (1.0–95.0)
Average number of cigarettes smoked in the past 30 days[b]			
Mean (*SD*)	314.8 (300.9)	395.2 (333.5)	452.7 (330.8)
Median (range)	240.0 (1.0–1500.0)	300.0 (1.0–2850.0)	390.0 (1.0–2850.0)
Proportion of smokers concurrently using other non-cigarette tobacco products[c], % (95% CI)	6.0 (3.1–9.0)	2.7 (1.3–4.1)	1.8 (0.8–2.8)

Note. All data were weighted to account for the complex survey design. CI = confidence interval.
[a]A 6-point scale calculated from the number of cigarettes smoked per day (1–10, 11–20, 21–30, and >30 cigarettes) and the time to first cigarette after waking (≤5, 6–30, 31–60, and >60 min). Scores of 0–1 are categorized as "low nicotine dependence," 2–4 as "moderate," and 5–6 as "high."
[b]Calculated by multiplying the average number of cigarettes smoked per day by the self-reported number of days in which the respondent smoked cigarettes in the past 30 days.
[c]Including cigars, pipes, snuff, or chewing tobacco.

(GM: 173.13 ng/ml) or king-sized (GM: 213.79 ng/ml) cigarettes. Similarly, creatinine-adjusted urinary NNAL concentrations were higher among smokers of long/ultralong cigarettes (0.48 ng NNAL/mg of creatinine) compared with those who smoked regular-sized (0.34 NNAL/mg of creatinine) or king-sized (0.33 ng NNAL/mg of creatinine) cigarettes (Table 3). After adjusting for potential confounders within the linear regression analyses, serum cotinine concentrations were significantly elevated among smokers of long/ultralong cigarettes compared with levels observed in smokers of regular-sized ($\beta = 0.60$, $p = .003$) or king-sized cigarettes ($\beta = 0.25$; $p < .001$). Similarly, creatinine-adjusted urinary NNAL levels were significantly higher among smokers of long/ultralong cigarettes compared with levels observed in smokers of either regular-sized ($\beta = 0.38$, $p = .006$) or king-sized cigarettes ($\beta = 0.26$; $p = .001$) (Table 3). No significant differences in serum cotinine or urinary NNAL concentrations were noted between smokers of regular-sized and king-sized cigarettes.

Cotinine/NNAL Association With Dual Smokeless and Combustible Tobacco Use

Sensitivity analyses were performed to assess the relationship between tobacco biomarker levels and tobacco use patterns. Serum cotinine concentrations were higher among respondents who reported combined use of cigarette plus snuff or chewing tobacco ($n = 40$; GM = 279.2) compared with exclusive cigarette smokers ($n = 3{,}597$; GM = 223.46) or those who smoked cigarettes concurrently with cigars or pipes ($n = 60$; GM = 157.57). Similar results were observed for creatinine-adjusted NNAL levels among combined users of snuff or chewing tobacco plus cigarettes versus exclusive cigarette smokers versus concurrent smokers of cigarettes and cigars or pipes (0.75 ng vs. 0.38 vs. 0.34 ng NNAL/mg creatinine, respectively). After adjusting for potential confounders, average NNAL levels were significantly higher ($p = .003$) among combined cigarette plus snuff or chewing tobacco compared with exclusive cigarette smokers, whereas no significant differences were observed in mean cotinine levels between these groups.

Finally, although not a direct aim of our research, stratifying the analysis by sociodemographic characteristics indicated variations in measured cotinine and NNAL concentrations, with the later found to be higher among those older, White-non Hispanic, of lower educational status, and below the federal poverty level (Tables 3 and 4).

DISCUSSION

Analysis of the merged 2007–2010 NHANES datasets indicated that smokers of long/ultralong cigarettes had significantly higher levels of serum cotinine and urinary NNAL compared with smokers of either regular-sized or king-sized cigarettes. Several factors may account for these findings. First, the higher tobacco content in long/ultralong cigarettes—approximately 18% higher than king-sized cigarettes (American Tobacco, 1967)—may be associated with a correspondingly higher exposure to tobacco smoke under the assumption that the entire cigarette is smoked. Thus, smokers of long/ultralong cigarettes

Table 3. Serum Cotinine and Urinary Total NNAL by Cigarette Rod Length and Other Selected Characteristics Among Adults Aged ≥20 Years, NHANES 2007–2010 (*N* = 3,699)

Characteristics	Serum cotinine (ng/ml), geometric mean (95% CI)	Unadjusted urinary total NNAL (ng/ml), geometric mean (95% CI)	Creatinine-adjusted urinary total NNAL (ng NNAL/mg of creatinine), geometric mean (95% CI)
Cigarette length			
Regular-sized cigarettes (68–72 mm)	173.13 (133.92–212.35)	0.39 (0.26–0.51)	0.34 (0.26–0.42)
King-sized cigarettes (79–88 mm)	213.79 (200.19–227.38)	0.38 (0.33–0.42)	0.33 (0.29–0.38)
Long (94–101 mm) or ultralong (110–121 mm) cigarettes	263.15 (248.16–278.14)	0.46 (0.42–0.5)	0.48 (0.42–0.53)
Age, years			
≤24	171.93 (147.06–196.8)	0.32 (0.24–0.39)	0.23 (0.18–0.29)
25–44	202.80 (182.58–223.02)	0.41 (0.35–0.46)	0.33 (0.28–0.38)
45–64	269.05 (251.62–286.47)	0.43 (0.39–0.47)	0.48 (0.43–0.52)
≥65	218.52 (197.01–240.02)	0.40 (0.33–0.47)	0.48 (0.38–0.58)
Sex			
Male	224.31 (206.16–242.45)	0.42 (0.37–0.46)	0.34 (0.3–0.38)
Female	221.63 (205.53–237.73)	0.39 (0.35–0.43)	0.43 (0.38–0.48)
Race/ethnicity			
White, non-Hispanic	237.07 (222.49–251.65)	0.45 (0.41–0.49)	0.45 (0.4–0.5)
Black, non-Hispanic	262.43 (244.87–280.00)	0.35 (0.32–0.38)	0.24 (0.22–0.27)
Hispanic	118.90 (104.10–133.70)	0.25 (0.22–0.29)	0.20 (0.18–0.23)
Other race, non-Hispanic	191.25 (157.43–225.07)	0.32 (0.22–0.41)	0.29 (0.2–0.37)
Education level			
<12 years	237.20 (215.79–258.57)	0.46 (0.40–0.52)	0.43 (0.37–0.50)
=12 years/GED	232.31 (214.73–249.89)	0.41 (0.35–0.47)	0.38 (0.33–0.43)
>12 years	205.12 (186.94–223.30)	0.36 (0.31–0.41)	0.34 (0.30–0.38)
Poverty index ratio			
Below federal poverty level	226.45 (200.51–252.39)	0.45 (0.39–0.52)	0.40 (0.34–0.45)
At or above federal poverty level	224.26 (210.01–238.51)	0.40 (0.36–0.43)	0.38 (0.34–0.42)
Body mass index			
Underweight: <18.5	300.56 (241.78–359.34)	0.53 (0.38–0.68)	0.53 (0.43–0.63)
Normal weight: 18.5–24.9	243.49 (223.69–263.29)	0.39 (0.34–0.44)	0.41 (0.35–0.46)
Overweight: 25–29.9	218.42 (204.11–232.72)	0.38 (0.33–0.43)	0.37 (0.32–0.41)
Obese: ≥30	194.48 (174.08–214.89)	0.43 (0.35–0.51)	0.34 (0.28–0.4)
Presence of smoker in household			
Yes	266.26 (252.42–280.1)	0.49 (0.44–0.54)	0.47 (0.41–0.52)
No	169.38 (156.7–182.07)	0.30 (0.27–0.33)	0.27 (0.25–0.3)
Marital status			
Married/living with partner	223.65 (204.83–242.47)	0.42 (0.37–0.47)	0.39 (0.33–0.44)
Widowed/divorced/separated	253.96 (234.41–273.52)	0.44 (0.39–0.49)	0.47 (0.42–0.52)
Never married	189.86 (172.17–207.54)	0.32 (0.27–0.37)	0.27 (0.22–0.32)
Tobacco use patterns			
Cigarettes only	223.46 (208.81–238.12)	0.39 (0.36–0.43)	0.37 (0.33–0.42)
Cigarettes combined with any other tobacco product[a]	211.15 (144.37–277.94)	0.81 (0.4–1.22)	0.51 (0.33–0.7)
Cigarettes smoked per day			
1–10	167.80 (154.30–181.20)	0.29 (0.26–0.33)	0.26 (0.22–0.30)
11–20	274.80 (260.20–289.30)	0.50 (0.46–0.53)	0.47 (0.43–0.51)
21–30	326.40 (296.50–356.30)	0.57 (0.51–0.64)	0.58 (0.52–0.64)
>30	318.50 (296.10–341.00)	0.73 (0.58–0.88)	0.73 (0.63–0.82)

Note. All data were weighted to account for the complex survey design. CI = confidence interval
[a]Including cigars, pipes, snuff, or chewing tobacco.

may be exposed to more nicotine and tobacco carcinogens, which may explain the higher levels of cotinine and NNAL observed in our study.

Research has also suggested that longer cigarette may be associated with a higher puff volume, which may result in the potential to inhale more smoke with increased exposure to many harmful constituents (Nemeth-Coslett & Griffiths, 1985). Nicotine boost has been shown to increase with higher puff volumes (Zacny, Stitzer, Brown, Yingling, & Griffiths, 1987), and this may account for the higher biomarker levels among smokers of long/ultralong cigarettes. Moreover, the more intense smoking behavior observed among smokers of long/

Table 4. Linear Regression Analyses Assessing the Effect of Cigarette Rod Length on Cotinine and NNAL Concentrations Among Adults Aged ≥20 Years, NHANES 2007–2010 (*N* = 3,699)

		Cotinine, ng/ml (natural log)				Creatinine-adjusted NNAL, ng NNAL/mg of creatinine (natural log)			
	Characteristics	Crude coefficient	*p* Value	Adjusted coefficient[a]	*p* Value	Crude coefficient	*p* Value	Adjusted coefficient[a]	*p* Value
Cigarette length	Regular-sized (68–72 mm)	Referent							
	King-sized (79–88 mm)	0.74	.007	0.36	.110	0.34	.087	0.12	.405
	Long (94–101 mm)/ultralong (110–121 mm)	1.21	<.001	0.60	.003	0.88	<.001	0.38	.006
Age, years	<24	Referent							
	25–44	0.16	.171	0.02	.866	0.33	.010	0.20	.086
	45–64	0.82	<.001	0.32	.019	1.03	<.001	0.56	<.001
	≥65	0.56	<.001	−0.05	.692	0.91	<.001	0.33	.049
Sex	Male	Referent							
	Female	0.02	.827	−0.12	.066	0.35	<.001	0.29	<.001
Race/Ethnicity	White, non-Hispanic	Referent							
	Black, non-Hispanic	0.14	.234	0.26	.031	−0.57	<.001	−0.41	<.001
	Hispanic	−1.44	<.001	−0.83	<.001	−1.22	<.001	−0.62	<.001
	Other race, non-Hispanic	−0.47	.023	−0.19	.307	−0.76	.001	−0.51	.012
Education level	<12 years	Referent							
	=12 years	−0.02	.873	−0.05	.563	−0.05	.636	−0.03	.658
	>12 years	−0.30	.020	−0.19	.076	−0.34	.006	−0.24	.012
Poverty index ratio	Below federal poverty level	Referent							
	At or above federal poverty level	−0.06	.600	−0.08	.250	−0.09	.287	−0.10	.053
Body mass index	Underweight: <18.5	Referent							
	Normal weight: 18.5–24.9	−0.33	.059	−0.12	.403	−0.49	.006	−0.21	.096
	Overweight: 25–29.9	−0.66	.001	−0.32	.019	−0.66	.001	−0.31	.016
	Obese: ≥30	−0.77	<.001	−0.49	.002	−0.75	<.001	−0.44	.004
Smoker in household	Yes	Referent							
	No	−0.99	<.001	−0.45	<.001	−0.92	<.001	−0.40	<.001
Marital status	Married/living with partner	Referent							
	Widowed/divorced/separated	0.36	.006	0.15	.071	0.40	.001	0.12	.090
	Never married	−0.23	.047	−0.13	.225	−0.43	<.001	−0.19	.041
Tobacco use patterns	Cigarettes only	Referent							
	Combined use with other tobacco[b]	−0.41	.305	−0.19	.589	0.14	.530	0.55	.002
Cigarettes per day	1–10	Referent							
	11–20	1.04	<.001	0.74	<.001	1.07	<.001	0.74	<.001
	21–30	1.25	<.001	0.83	<.001	1.35	<.001	0.88	<.001
	>30	1.27	<.001	0.69	<.001	1.54	<.001	0.99	<.001

Note. All data were weighted to account for the complex survey design.
[a]The multivariate regression analyses had adjusted R^2 values of 24.6% (cotinine) and 33.0% (creatinine-adjusted NNAL) after adjusting for all factors listed in table.
[b]Including cigars, pipes, snuff, or chewing tobacco.

ultralong cigarettes in our study may also contribute to higher exposure to tobacco smoke and increased levels of tobacco biomarkers including cotinine and NNAL (Joseph et al., 2005; Williams et al., 2011).

The fact that combined users of cigarettes plus smokeless tobacco products had significantly higher levels of NNAL compared with exclusive cigarette smokers demonstrates that persons who use multiple tobacco products may be at increased risk of tobacco-related morbidity and mortality. The high levels of NNAL among smokers who concurrently use smokeless tobacco products may be due to the direct swallowing of tobacco-heavy spittle associated with some smokeless tobacco products and the long duration in which habitual smokeless tobacco users put the tobacco products in their mouths (Hecht et al., 2007). Further research is needed to assess these hypotheses.

Variations in NNAL and cotinine levels were observed by several sociodemographic characteristics including race/ethnicity, sex, age, education level, poverty index ratio, body mass index, and presence of smoker in household. These variations may be due to differences in the pattern and duration of tobacco use or other consumption behaviors that were not assessed (Raunio & Rahnasto-Rilla, 2012; Upadhyaya, Carmella, Guengerich, & Hecht, 2000; Wood, Wewers, Groner, & Ahijevych, 2004). Moreover, the higher levels of NNAL and cotinine among respondents who had ≥1 smoker in the household may indicate an increased exposure to tobacco smoke through passive smoking (Bernert et al., 2010; Vardavas et al., 2013).

Our findings underscore the need for intensified efforts to educate the public through mass-media campaigns that all cigarettes, regardless of length, and all tobacco products are harmful. Other evidence-based interventions such as those outlined in the World Health Organization's MPOWER package may help reduce use of all tobacco products. These interventions include increasing the price of tobacco products, implementing smoke-free laws in workplaces and public places, increasing access to help quitting, and enforcing restrictions on tobacco advertising, promotion, and sponsorship (WHO, 2008). The implementation of these strategies as part of sustained, adequately funded comprehensive tobacco control programs may lower all tobacco use and lead to reduced tobacco-related diseases and death (CDC, 2012).

The strength, and novelty, of this study is the use of a nationally representative dataset to assess the association between cigarette rod length and tobacco-specific carcinogen biomarkers among adult smokers. However, a number of limitations must be noted. First, these analyses did not account for cigarette rod diameter since only a small fraction of cigarettes (mostly ultralong cigarettes) were slim (i.e., 17.1–23.4 mm), whereas the majority were regular width cigarettes (23.5–27.1 mm). A longer, but smaller diameter rod with a longer filter length could yield relatively lower emissions (less tobacco to be consumed) than would be expected otherwise. Second, questionnaires were administered only in English and Spanish, which may have resulted in nonresponse or misresponse among persons who speak other languages. Finally, we limited our analyses to conventional cigarettes and did not include roll-your-own cigarettes or other tobacco products. Further research is needed to confirm the noted associations within case crossover experimental studies.

CONCLUSIONS

Our analyses indicated that smokers of long/ultralong cigarettes had significantly higher levels of serum cotinine and NNAL in comparison to smokers of either regular-sized or king-sized cigarettes. These findings suggest that cigarette rod length, a specific design characteristic, may be directly associated with tobacco-specific carcinogen concentrations among its consumers. This finding indicates the potential of taking cigarette rod length into account by the U.S. Food and Drug Administration under section 904 of the Family Smoking Prevention and Tobacco Control Act as a design characteristic that is directly related to tobacco carcinogen uptake.

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DECLARATION OF INTERESTS

None declared.

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