Original investigation

Socioeconomic Disadvantage and Other Risk Factors for Using Higher-Nicotine/Tar-Yield (Regular Full-Flavor) Cigarettes

Stephen T. Higgins PhD^{1,2}, Ryan Redner PhD^{1,3}, Jeff S. Priest PhD^{1,4},
Janice Y. Bunn PhD^{1,4}

¹Vermont Center on Tobacco Regulatory Science, University of Vermont, Burlington, VT; ²Departments of Psychiatry and Psychological Science, University of Vermont, Burlington, VT; ³Rehabilitation Institute, Southern Illinois University, Carbondale, IL; ⁴Department of Medical Biostatistics, University of Vermont, Burlington, VT

Corresponding Author: Stephen T. Higgins, PhD, Department of Psychiatry, University of Vermont, UHC Campus, Rm 3100B Old Hall, 1 S Prospect St, Burlington VT 05401, USA. Telephone: 802-656-9614; Fax: 802-656-9628; E-mail: Stephen.Higgins@uvm.edu

Abstract

Introduction: Use of machine-estimated higher nicotine/tar yield (regular full-flavor) cigarettes is associated with increased risk of nicotine dependence. The present study examined risk factors for using full-flavor versus other cigarette types, including socioeconomic disadvantage and other risk factors for tobacco use or tobacco-related adverse health impacts. Associations between use of full-flavor cigarettes and risk of nicotine dependence were also examined.

Methods: Data were obtained from nationally representative samples of adult cigarette smokers from the US National Survey on Drug Use and Health. Logistic regression and classification and regression tree modeling were used to examine associations between use of full-flavor cigarettes and educational attainment, poverty, race/ethnicity, age, sex, mental illness, alcohol abuse/dependence, and illicit drug abuse/dependence. Logistic regression was used to examine risk for nicotine dependence.

Results: Each of these risk factors except alcohol abuse/dependence independently predicted increased odds of using full-flavor cigarettes ($p < .001$), with lower educational attainment the strongest predictor, followed by poverty, male sex, younger age, minority race/ethnicity, mental illness, and drug abuse/dependence, respectively. Use of full-flavor cigarettes was associated with increased odds of nicotine dependence within each of these risk factor groupings ($p < .01$). Cart modeling identified how prevalence of full-flavor cigarette use can vary from a low of 25% to a high of 66% corresponding to differing combinations of these independent risk factors.

Conclusions: Use of full-flavor cigarettes is overrepresented in socioeconomically disadvantaged and other vulnerable populations, and associated with increased risk of nicotine dependence. Greater regulation of this cigarette type may be warranted.

Implications: Greater regulation of commercially available Regular Full-Flavor Cigarettes may be warranted. Use of this type of cigarette is overrepresented in socioeconomically disadvantaged and other vulnerable populations and associated with increased risk for nicotine dependence.

Introduction

Passage of the Family Smoking Prevention and Tobacco Control Act (2009) gives the US Food and Drug Administration (FDA) regulatory

authority over nicotine content levels in tobacco products.^{1,2} While the legislation prohibits the FDA from eliminating nicotine completely, it allows the agency to establish maximal levels. That

authority creates the opportunity to eventually require that nicotine exposure levels from cigarettes fall below the threshold necessary to produce nicotine dependence, although greater understanding of the relationships between nicotine content, yield, and dependence risk will be necessary to achieve that goal.^{3,4} Hence, increasing understanding of the relationships between nicotine exposure from cigarette use and dependence risk is of greater importance than ever to support evidence-based tobacco regulation.

The present study was conducted to systematically follow-up on a recent report demonstrating that use of commercially available, machine-estimated higher nicotine/tar yield (ie, regular full-flavor) cigarettes is associated with increased risk of nicotine dependence compared to lower nicotine/tar yield (light) cigarettes in nationally representative samples of US smokers.⁵ In that study, the odds of nicotine dependence were greater among users of regular full-flavor compared to lower nicotine/tar yield cigarettes even after adjusting for sociodemographic and other smoking characteristics. This relationship was generally graded across differing nicotine/tar yield cigarettes, discernible across two definitions of nicotine dependence, and observed among adult and adolescent smokers.

Worth clarifying is that commercial higher and lower nicotine/tar yield cigarettes have the same nicotine content, but the latter are engineered through ventilation and other design features to dilute the smoke and reduce toxin exposure compared to the former. There is broad scientific consensus that users of machine-estimated lower nicotine/tar yield cigarettes commonly engage in compensatory smoking by blocking the ventilation holes or altering their smoking topography in order to achieve desired nicotine blood levels thereby undermining the goal of reducing health impacts by lowering toxin exposure.⁶ However, what is less well recognized is that compensatory smoking is typically partial with regard to nicotine exposure, with meta-analysis suggesting that compensation is typically about 75%.⁷ If that average 25% difference between higher and lower yield cigarettes in nicotine exposure levels is sufficient to result in differences in nicotine dependence risk, the implications are substantial as nicotine dependence is considered to be the main contributor to the emergence and persistence of chronic smoking.^{8–10} Put differently, greater risk of nicotine dependence may be an important but overlooked adverse impact of using machine-estimated higher versus lower nicotine yield cigarettes.

The purpose of the present study was to examine whether use of these higher yield or full-flavor cigarettes is overrepresented in populations known to be more vulnerable to (1) cigarette smoking generally or (2) the adverse health effects of smoking (ie, health disparities). Early reports on use of different nicotine/tar yield cigarettes noted substantial differences in preferences by socioeconomic and sociodemographic differences,^{11,12} but, to our knowledge, there has been little subsequent scientific attention to such differences and no examination of associations with risk for nicotine dependence other than the report described above.⁵ Lower socioeconomic status in the United States and most other developed countries is among the most robust predictors of cigarette smoking, being associated with higher prevalence of cigarette smoking, heavier smoking, higher rates of nicotine dependence, lower intentions to quit, lower success rates in quitting smoking, smoking during pregnancy, and higher rates of smoking-related morbidity and mortality.^{13–17} Understanding factors underpinning this increased vulnerability to smoking and associated adverse consequences is an important goal in efforts to improve population health and reduce health disparities.^{18,19} Of course, those with lower socioeconomic status are not the only population subgroup at increased risk for cigarette smoking and associated adverse

consequences. For example, male sex, younger age, race/ethnicity, alcohol use disorders, illicit drug use disorders, and mental illness are each independent risk factors for cigarette smoking.¹⁴ Hence, the present study also included examination of whether use of full-flavor cigarettes was overrepresented in these other vulnerable population subgroups as well. We hypothesize that use of machine-estimated high nicotine/tar yield cigarettes is overrepresented in socioeconomically disadvantaged and other vulnerable populations of smokers and associated with increased risk for nicotine dependence.

Methods

Data Source

The National Survey on Drug Use and Health (NSDUH) is a nationally representative survey of the US noninstitutionalized population aged at least 12 years that measures prevalence and correlates of drug use.²⁰ Detailed descriptions of survey procedures have been provided for each of the survey years.^{21–23} We used the most recent 3 years at the time the study was conducted and opted to combine across survey years for purposes of increased sample sizes for examining relations within population subgroups. Only individuals aged at least 18 years were included in the present study so that participants were likely of legal age to purchase cigarettes and hence better able to express a brand preference. Across each of the survey years, NSDUH recruitment was completed using a multistage area probability sample design in which a predetermined number of participants were randomly recruited by address within each state. Respondents completed computer- and audio-assisted structured interviews. Respondents were selected from the civilian noninstitutionalized population, including group homes, shelters, and college dormitories. Individuals on active military duty, in residential drug treatment programs, in jail, or homeless without residence are excluded from participation in the NSDUH. The present study included 114 426 adult respondents interviewed during 2011 ($N = 39\,133$), 2012 ($N = 37\,869$), and 2013 ($N = 37\,424$). Annual weighted response rates were 74.4%, 73.0%, and 71.7% for the 2011, 2012, and 2013 surveys, respectively. Data were weighted during analysis to adjust for the differential probability of both selection and response.

Current smoker status was defined as smoking all or part of a cigarette within the 30 days preceding the interview and at least 100 cigarettes lifetime. Educational attainment was defined as less than high school, high school only, some college, or a 4-year college degree or more. Poverty status (living below or at/above the federal poverty line) was defined using poverty thresholds published by the US Census Bureau. The six racial/ethnic categories used in the survey were mutually exclusive. Persons identified as Hispanic might be of any race while persons identified as White, Black, Asian, American Indian/Alaska Native, or Other were all non-Hispanic. The category “Other” included Native Hawaiians or Other Pacific Islanders and individuals endorsing two or more races. Any mental illness was defined as having a mental, behavioral, or emotional disorder in the past 12 months, excluding developmental or substance use disorders. To assess the presence of any mental illness, respondents aged at least 18 years answered a series of 14 questions that made up two scales measuring psychological distress (Kessler-6) and disability (World Health Organization Disability Assessment Schedule). Scores on these two scales were used to determine any mental illness status based on a statistical model developed from clinical interviews that assessed disorders based on criteria in the Diagnostic and Statistical Manual of

Mental Disorders (DSM-IV). Past year alcohol and illicit drug abuse/dependence diagnoses were also based on DSM-IV criteria. Note that the vulnerable populations investigated in the present study were not intended to be representative of all those at increased vulnerability to cigarette smoking, but instead represented those subgroups included in the NSDUH that are known to be at increased risk.¹⁴

Cigarette Type

Smokers in the NSDUH were asked to indicate the type of cigarette they usually smoke. More specifically, they were asked “During the past 30 days, what type of cigarettes did you smoke most often?” Respondents selected one of four options: full flavor, medium, light, or ultralight. For purposes of the present project, responses were dichotomized into use of full-flavor (FF) versus lower (L) estimated yield cigarette types. This was done to focus on the highest estimated yield, which in the earlier study on this general topic⁵ was associated with the greatest dependence risk and to limit the number of cigarette types considering that we were examining eight different risk factors.

Nicotine Dependence

NSDUH respondents who reported current smoking were assessed for nicotine dependence using two measures. (1) They answered the first item on the Fagerström Test for Nicotine Dependence (FTND): “How soon after waking do you smoke your first cigarette?”²⁴ Respondents who reported smoking within 30 min after waking are classified as nicotine dependent in the NSDUH. (2) They also completed the Nicotine Dependence Syndrome Scale (NDSS), which is a 17-question validated multidimensional assessment of nicotine dependence that includes questions of smoking-related mood changes, craving, feelings of control, and smoking patterns.⁸ Each question on the NDSS is scored from 1 to 5, with higher scores indicating greater severity. A respondent is classified as nicotine dependent in the NSDUH if the average across questions is at least 2.75. The 17-item NDSS in this study sample had a reliability coefficient (Cronbach’s alpha) of .89. Inclusion of both measures provides an indication of the generality of the any relationships observed with cigarette type across two valid methods of assessing nicotine dependence used in tobacco research.

Statistical Methods

Sample-adjusted frequencies and 95% confidence intervals (CIs) were generated across all respondents at least 18 years of age. Variables of interest were determined based on previously identified socioeconomic and sociodemographic independent predictors of current smoking, including educational attainment, poverty status, age, sex, race/ethnicity, past year mental illness, alcohol abuse/dependence, and illicit drug abuse/dependence.¹⁴

Associations of these risk factors with preference for FF cigarettes versus L were examined. For each risk factor, weighted, univariate logistic regression by current smoking status was used to determine which variables would be included in subsequent multivariable models for current smokers. Multiple logistic regression was then used to analyze preference for FF cigarettes by current smoking status, using all variables from univariate logistic regression that significantly predicted FF preference for current smokers. PROC SURVEYLOGISTIC in SAS (SAS Institute, Cary, NC) was used to conduct these analyses, relying on maximum likelihood estimation and the Fisher scoring algorithm. Variances were estimated using Taylor series linearization.

Multiple logistic regression analyses were also conducted within each of the risk factor groups to examine relationships with nicotine dependence, using both the FTND and NDSS as dichotomous outcome measures, while controlling for cigarettes per day and age of smoking initiation. Both cigarettes per day and age of smoking initiation were categorical variables, with cigarettes per day ranging from less than one to more than 35 (seven levels) and age of smoking initiation with four levels: 14 years or younger, 15- to 17-years old, 18 years or older, and nonusers. Odds ratios (with 95% CIs) were generated. Across all tests, statistical significance was defined as $p < .05$ (two-tailed).

Lastly, a Classification and Regression Tree (CART) analysis²⁵ was conducted to examine interrelationships of risk factors in current smokers’ preference for FF cigarettes. CART is a nonparametric procedure for dividing a population of interest into mutually exclusive subgroups based on a dependent variable of interest, such as preference for use of FF cigarettes in the present study²⁶ and, in the process, identifying independent variables with the most explanatory power in accounting for that dependent variable. The process begins by identifying the single most important independent variable for dividing the total sample (parent node) into two groups (child nodes), using a predetermined branching criterion. Nodes are split based on their purity using the Gini impurity function.²⁵ A “pure” node has no variability in the dependent variable. A completely “impure” node has a conditional probability of $p(k|t) = .5$, where k refers to the dependent variable and t refers to the node.²⁷ A splitting or branching criterion “selects the split that has the largest difference between the impurity of the parent node and a weighted average of the impurity of the two child nodes.”²⁶, p. 174 Given the dependent variable was binary, we used the Gini impurity function to split nodes, repeating the process recursively with every subsample, until the subsample reached a minimum size or no further splits could be made. The tree was built using R’s rpart package.^{28,29} We used the classification method in R, given the dependent variable was binary, and included survey weights, given the multistage sampling procedures of the NSDUH. A fully saturated tree was produced initially, and then pruned by selecting the complexity parameter that minimized cross-validation error and setting a minimum sample size in terminal nodes of $n = 1000$.

Results

Logistic Regression Analyses

Each of the eight risk factors was univariately associated with increased odds of using FF cigarettes (Table 1). When each of the risk factors was examined together in a multivariate model, all but past year alcohol abuse/dependence remained significant indicating that they are independent risk factors for using FF cigarettes (Table 1). Odds of using FF cigarettes were inversely related to educational attainment, with the greatest likelihood seen among those with less than a high school education; greater among those living below compared to at or above the federal poverty line; inversely related to age, with odds greatest among those 18–25 years of age compared to those at least 65 years; greater in males than females; greatest odds in Blacks, followed by Native Americans, Other, Hispanic, and Whites compared to Asians; and greater odds among those with past year mental illness or illicit drug abuse/dependence compared to those without those disorders.

As might be expected considering that use of FF cigarettes is associated with significantly greater odds of nicotine dependence

Table 1. Univariate and Multiple Logistic Regression Results with Sociodemographic and Other Characteristics Predicting Use of Full-Flavor (HigherYield Regular) Cigarettes

	Unadjusted model			Final adjusted model	
	<i>n</i> (weighted %)	OR	95% CI	aOR	95% CI
Education					
Less than high school	6767 (20.0%)	4.64**	3.86, 5.58	3.34**	2.76, 4.03
High school graduate	11 320 (36.9%)	2.83**	2.41, 3.31	2.31**	1.97, 2.72
Some college	8268 (28.2%)	2.11**	1.79, 2.49	1.78**	1.51, 2.10
Living in poverty	8174 (22.5%)	2.24**	2.07, 2.43	1.64**	1.52, 1.78
Sex (male)	15 706 (54.2%)	1.59**	1.46, 1.73	1.64**	1.51, 1.79
Age, years					
18–25	14 845 (16.8%)	2.62**	2.13, 3.21	2.15**	1.70, 2.73
26–44	9165 (41.0%)	1.58**	1.28, 1.94	1.43*	1.13, 1.80
45–64	4800 (34.2%)	1.40*	1.14, 1.72	1.26	1.00, 1.59
Race					
Black	3201 (11.9%)	6.91**	4.49, 10.64	5.64**	3.51, 9.07
Latino	3244 (10.6%)	2.66**	1.85, 3.82	1.91*	1.28, 2.85
Native American	708 (0.9%)	3.85**	2.44, 6.08	2.73**	1.66, 4.49
White	20 515 (72.0%)	2.03*	1.40, 2.94	1.88*	1.24, 2.85
Other	1360 (2.6%)	3.03**	1.88, 4.87	2.58*	1.52, 4.39
Any mental illness	8079 (27.2%)	1.25**	1.15, 1.35	1.29**	1.18, 1.42
Alcohol abuse or dependence	5512 (14.3%)	1.25**	1.11, 1.39		
Drug abuse or dependence	3359 (7.5%)	2.17**	1.89, 2.48	1.51**	1.27, 1.80

Data are from adult smokers (age 18+) in the 2011–2013 National Survey on Drug Use and Health ($n = 29\,558$). The reference category for age is at least 65 ($n = 748$ or 7.9%). The reference category for education is college graduate ($n = 3203$ or 14.9%). The reference category for race is Asian ($n = 530$ or 2.0%). “Other” includes multiracial and Hawaiian/Pacific Islander (due to small sample sizes). Adjusted analyses controlled for the influence of each of the other seven independent risk factors for use of high nicotine/tar yield cigarettes; alcohol abuse and dependence was not a significant independent predictor and thus was excluded from the adjusted analyses. aOR = adjusted odds ratio; CI = confidence interval; OR = odds ratio.

* $p < .01$, ** $p < .001$.

in the general population of smokers, that same relation is seen in each of these subgroups with greatest odds of using them. Shown in Table 2, for example, are the odds of nicotine dependence among those using FF cigarettes compared to users of cigarettes with lower estimated nicotine/tar yields within each of the risk factor subgroups noted above to have the greatest odds of using FF cigarettes. Odds of nicotine dependence were significantly greater among users of FF compared to L cigarettes in those with less than a high school education, those with annual incomes below the federal poverty level, those 18–25 years of age, those of Black race/ethnicity, and those with past year mental illness or illicit drug abuse/dependence. The increases ranged from 53% to 104% on the time-to-first cigarette measure and from 15% to 72% on the NDSS measure. These increases were significant across both measures in each subgroup except for Black race/ethnicity where significance was reached on the time-to-first cigarette but not the NDSS measure (ie, 13 of the 14 comparisons).

CART Analysis

The CART analysis identified educational attainment as the strongest risk factor for using FF cigarettes, followed by poverty status, sex, age, race/ethnicity, past year mental illness, and past year illicit drug abuse/dependence, respectively. Figure 1 shows a pruned classification tree modeling changes in prevalence of using FF versus L estimated nicotine/tar yield cigarettes associated with various combinations of these seven independent risk factors. The graphic is designed to represent an inverted tree.

The rectangle (node) shown at the top is the root node representing 100% of the adult, noninstitutionalized population of US current smokers. Prevalence rates of using FF versus L cigarettes in the

overall population were 49% versus 51%, respectively. That node is not bolded because prevalence of FF use is less than 50%. The first split of the entire population was based on whether someone was or was not a college graduate. College graduates branched leftward and downward to a terminal node (no further splitting/classification possible). Prevalence of using FF versus L cigarette types among college graduates is 25% versus 75%, respectively, and this node represents 15% of the entire current smoker population. The 85% of current smokers with less than a college education branched rightward and downward to a child node (further classification/splitting possible) with prevalence of FF versus L being 49% versus 51%.

The next branching of the 85% of smokers with less than a college education was based on poverty status. The 21% of smokers with less than a college education and annual incomes below the federal poverty level branched rightward and downward, and for the first time there is a bolded node wherein a majority used FF versus L cigarette types at rates of 61% versus 39%, respectively. The 64% of current smokers with annual incomes at or above federal poverty levels branched leftward and downward with prevalence of FF versus L cigarette type being 45% versus 55%, respectively.

The next branching factor was sex across those with annual incomes at or above the federal poverty level and those with incomes below the poverty level. Among the 64% of current smokers with less than a college education, annual incomes at or above poverty level, females (28%) branched leftward and downward while males (36%) branched rightward and downward. Prevalence of use of FF versus L cigarette types remained well below the majority among females (36% vs. 64%), but not among males where prevalence was 51% versus 49%. Among those with less than a college education and annual incomes below the federal poverty level, the branching

Table 2. Likelihood of Meeting Criteria for Nicotine Dependence on Time-to-First-Cigarette Upon Arising and NDSS Measures Among Adult Users of Full-Flavor Compared to Other Cigarette Types in the 2011–2013 National Survey on Drug Use and Health ($n = 33\,975$)

	Time-to-first-cigarette		Cigarette type	NDSS			
	aOR	95% CI		N	M (SE)	aOR	95% CI
Less than high school education	1.64**	1.34, 2.02	Full flavor	4733	2.82 (0.02)	1.40*	1.13, 1.72
			Other	2637	2.62 (0.02)		
Poverty	1.82**	1.52, 2.19	Full flavor	5591	2.77 (0.02)	1.48**	1.26, 1.74
			Other	3720	2.52 (0.01)		
Age 18–25 years	1.99**	1.79, 2.20	Full flavor	9778	2.60 (0.01)	1.72**	1.56, 1.90
			Other	8333	2.22 (0.01)		
Males	1.90**	1.71, 2.10	Full flavor	9465	2.72 (0.01)	1.54**	1.38, 1.71
			Other	8141	2.46 (0.01)		
Black race	1.53*	1.16, 2.03	Full flavor	2716	2.52 (0.02)	1.15	0.83, 1.59
			Other	1098	2.37 (0.03)		
Mental illness	1.91**	1.62, 2.25	Full flavor	4681	2.93 (0.02)	1.52**	1.27, 1.82
			Other	4182	2.67 (0.02)		
Illicit drug abuse or dependence	2.04**	1.61, 2.59	Full flavor	2309	2.92 (0.03)	1.66*	1.19, 2.32
			Other	1421	2.56 (0.03)		

Means and SEs are derived from the NDSS score and represent average scores across the 17-item instrument. ORs and 95% CIs for NDSS are derived from a dichotomous variable used in the National Survey on Drug Use and Health wherein those with mean scores of 2.75 or greater across items are classified as nicotine dependent. aOR = adjusted odds ratio controlling for cigarettes smoked per day and age of smoking initiation; CI = confidence interval; M = mean; NDSS = Nicotine Dependence Syndrome Scale.

* $p < .01$, ** $p < .001$.

by sex resulted in nodes where the majority of smokers in each used FF versus L cigarette yields. For males that combination of factors resulted in a terminal node comprising 10% of current smokers, with prevalence of using FF versus L cigarette yields being 66% versus 34%, respectively.

Branching continued based on these different risk factor combinations until there was a total of 13 terminal nodes, with prevalence rates of using FF cigarettes varying 2.6-fold from a low of 25% to a high of 66%.

Discussion

The primary aim of the present study was to assess whether FF cigarette use continues to be overrepresented among socioeconomically disadvantaged and other populations known to be vulnerable to cigarette smoking and tobacco-related adverse health effects as it was in earlier research on differing machine-estimated nicotine yield cigarettes.^{11,12} The results affirm that association demonstrating that lower educational attainment and having an annual income below the US federal poverty level are each independently associated with increased odds of using FF cigarettes compared to those with greater education or higher incomes. Indeed, being a college graduate was the only characteristic that stood alone as a risk profile in the CART analysis. A college education was associated with relatively low rates of using FF cigarettes, with only 25% of smokers with a college education reporting use of FF cigarettes compared to the overall prevalence in US adult smokers of 45%. The present results also demonstrate that use of FF cigarettes within these socioeconomically disadvantaged smoker groups is associated with increased odds of nicotine dependence as has been reported for the general population of adult and adolescent smokers.⁵

The particularly strong association between educational attainment and risk of using FF cigarettes merits underscoring. An almost identical pattern of results was seen in an earlier study examining the association of this same set of risk factors with odds of being a current smoker.¹⁴ Educational attainment was the

strongest independent risk factor in both studies. Compared to college graduates, those with less than 12 years of education were 4.6-fold more likely to be current smokers in the prior study and 3.4-fold more likely to use FF cigarettes in the present study. In both studies, being a college graduate was the only variable that stood alone as a risk profile in the CART analysis. Educational attainment is also a robust independent predictor of successfully quitting smoking, as well as the likelihood of other forms of tobacco use.^{13–17} Unfortunately, the mechanisms underpinning this broad and robust association between educational attainment and various aspects of cigarette smoking and other tobacco use are not yet well understood. A recent study in women of reproductive age examined the possibility that delay discounting or other measures of impulsivity and biases in decision making might mediate the association between educational attainment and vulnerability to smoking.³⁰ Instead of mediation, however, educational attainment, delay discounting rates, and Barrett impulsivity test scores³¹ were each independent predictors of smoking status. Elucidating the mechanisms underpinning educational attainment and smoking risk would represent a substantial advance toward answering the proverbial question of why people continue to smoke despite the well-established and numerous serious adverse health risks of doing so.

Importantly, the present results also demonstrate that, as in the case of risk for being a current smoker,¹⁴ risk for using FF cigarettes is associated with other independent risk factors, including younger age, male sex, minority race/ethnicity, past year mental illness, and past illicit drug dependence. As noted above for socioeconomic status, use of FF versus L cigarettes within each of these population subgroups was associated with greater odds of nicotine dependence even after controlling for smoking rate and age of smoking initiation as was seen previously in the general population of smokers.⁵ The CART analysis illustrates how risk for using FF cigarettes varies in a summative manner related to the number of these risk factors present such that in some subgroups (eg, college graduates discussed above) only one-quarter of smokers use FF cigarettes while in others (eg, males with less than college education and incomes below the

Figure 1. A pruned, weighted classification and regression tree (CART) model in US adult (>18 years of age) smokers of associations between use of full-flavor (FF) versus lower (L) machine-estimated nicotine/tar yield cigarettes and the following seven risk factors: educational attainment, annual income below federal poverty level, race/ethnicity, sex, age, past year mental illness, and past year drug abuse/dependence. Results from a saturated model were pruned using CART analytic software to reduce complexity (R Core Team²⁸). Rectangles (nodes) represent prevalence of using FF or L yield brand cigarettes for the entire population (top-most node) or population subgroups (all others nodes). Nodes also list the proportion of the adult smoker population represented. Nodes wherein the majority uses FF cigarettes are bolded. Using the root node as an example, 49% and 51% of the US population of adult smokers use FF and L brand cigarettes, respectively; because prevalence of use of FF is below 50% the node is not bolded; the root node represents 100% of the US adult smoker population. Lines below nodes represent the binary yes—no branching around particular risk factors and risk factor levels, with subgroups in whom the risk factor/level is present moving leftward and downward and those in whom it is absent moving rightward and downward for further potential partitioning based on additional risk factors/levels. The bottom row comprises terminal nodes (ie, final partitioning for a particular subgroup). Note that minimal terminal node size was set to more than 1000 individuals. Terminal nodes contain the same information as the other nodes.

federal poverty cutoff) as many as two-thirds do so. The CART analysis, with its explicit rank ordering of the relative strength of the risk factors of interest and delineation of risk profiles and associated proportions of the total adult smoker population included in each, provides information beyond that obtained in multiple regression analyses that has the potential to be useful in devising tobacco control and regulatory policy. In terms of more basic scientific implications, the independence of each of the seven risk factors underscores how risk for using FF cigarettes, as well as risk for smoking generally,¹³ is multiply determined and probably not accounted for by any single underpinning mechanism.

The point on multiple determinants notwithstanding, there is broad scientific consensus that cigarette smoking represents a form of drug self-administration with nicotine acting as a primary, centrally mediated, reinforcer that sustains the behavior.^{9,10} As such, it would seem likely that the greater nicotine yield of FF compared to L cigarettes contributes, at least in part, to the preferences that these vulnerable subgroups of smokers study show for the highest

machine-estimated nicotine yield cigarettes. As discussed briefly above, while there is considerable evidence documenting compensatory smoking with L yield cigarettes that results in higher levels of nicotine exposure than would be expected based on their machine-estimated yields, there is also considerable evidence,⁷ including results from rigorous experimental brand-switching studies,^{32–34} that compensation is often partial. That is especially the case when estimated yield differences are large, resulting in differing levels of nicotine exposure corresponding to the different machine-estimated nicotine yields. The greater nicotine exposure associated with using FF cigarettes would also provide a parsimonious account, at least in part, for why their use would be associated with increased odds of nicotine dependence. Of course, the present observational study is not designed to support or refute causal inferences regarding a direct role of the differing estimated nicotine yields in accounting for the observed preferences for FF cigarettes and associated increases in dependence risk in the subgroups of smokers examined. However, the large extant literature on the role of the reinforcing effects of

nicotine in promoting and sustaining smoking and dependence certainly would suggest a high likelihood of at least a partial contribution in that direction.

It is also important to acknowledge alternative ways for potentially accounting for the observed preferences for FF cigarettes and associated increased odds of nicotine dependence other than a direct effect of greater nicotine exposure. Rather than the relatively greater nicotine yields of FF cigarettes directly increasing the odds of preferring them and developing dependence, smokers who develop nicotine dependence for other reasons may switch brands to higher nicotine yields in order to more effectively avoid withdrawal or switch to lower yields to reduce the severity of their dependence (ie, reverse causation). Brand switching is common among regular cigarette smokers and is associated with changes in biological exposure levels.^{35,36} There is also room for both directions of causality between nicotine yield and preference/dependence risk to contribute to the results observed in the present study.

The findings of the present study have regulatory implications that merit mention, especially when considered in combination with experimental studies on the influence of nicotine levels in cigarettes on dependence risk.^{5,37–40} The present study provides evidence that use of FF cigarettes is overrepresented in subgroups of smokers who are also known to experience a disparate proportion of the burden of tobacco-related morbidity and mortality (eg, economically disadvantaged smokers, racial minorities).^{13–17,41} As evidence along these lines accumulates, policy makers may want to consider regulations that further protect these populations against cigarette advertising and other targeting strategies along with policies that reduce nicotine levels in all cigarettes below levels currently available in commercial FF cigarettes, ideally to a subaddiction level.³ Such regulations have the potential to help reduce the overrepresentation of FF cigarette use in socioeconomically and other vulnerable populations, reduce nicotine dependence levels in those populations, and to reduce the disparities in tobacco-related adverse health impacts that they encounter. Important to underscore is that countering the greater use of FF cigarettes and nicotine dependence risk in vulnerable populations by advocating switching, or adopting policies that encourage transition, to commercially available L yield cigarettes is not a viable option. While doing so may reduce nicotine dependence rates, there is also likely to be sufficient compensatory smoking and attendant adverse health consequences associated with L cigarette use to neutralize any benefits in terms of protection against smoking-related morbidity and mortality.⁶ As mentioned above, the main reason for this problem appears to be that commercially available FF and L cigarettes typically have the same nicotine content, with reductions in estimated yield being achieved through cigarette engineering. Even though compensation is often only partial in terms of nicotine exposure, apparently it is sufficient to sustain compensatory smoking and attendant serious adverse health consequences. A more promising alternative is a policy that reduces the nicotine content of the cigarette to very low levels. Results from experimental studies using very low nicotine content cigarettes suggest that lowering content to 1.0mg/g or below can reduce nicotine dependence with minimal increases in compensatory smoking and attendant increases in biological exposure to smoking-related toxins.^{37–40} That would appear to be a more fruitful direction for tobacco regulators to consider in efforts to protect these vulnerable populations from dependence-producing levels of nicotine exposure.

Of course, protecting socioeconomically disadvantaged and other vulnerable populations from the adverse effects of cigarette smoking

will require improved tobacco control interventions in addition to the improved tobacco regulations discussed above. There is broad and growing recognition of this need as indicated by commentaries from thought leaders and special interest groups,^{19,42} empirical studies on new cessation strategies,^{43–47} and population-specific requests by the National Institute of Health for research proposals on new cessation strategies in socioeconomically disadvantaged populations.⁴⁸ Tobacco control strategies that were sufficient in reducing smoking prevalence among more affluent populations and those without complicating comorbid conditions are clearly falling short with socioeconomically disadvantaged and other vulnerable populations.

The limitation of the present observational study in being unable to support casual inferences was noted above. The exclusion of institutionalized and homeless individuals, those in active military service, and the absence of information on sexual orientation in the NSDUH is also a limitation that was mentioned above. Whether use of FF cigarettes is overrepresented in those important population subgroups will have to be addressed in future studies. Lastly, the study was conducted with an exclusively US sample and thus whether the results can be generalized to other countries with different tobacco regulatory policies will also need to be determined in future studies. These limitations notwithstanding, the present study demonstrates that use of machine-estimated high nicotine/tar yield cigarettes is overrepresented in socioeconomically disadvantaged and other vulnerable populations of US adults and associated with increased risk of nicotine dependence. As such, greater regulation of this cigarette type may be warranted.

Funding

This project was supported by Tobacco Centers of Regulatory Science award P50DA036114 from the National Institute on Drug Abuse (NIDA) and Food and Drug Administration (FDA) and Center of Biomedical Research Excellence award P20GM103644 from the National Institute of General Medical Sciences (NIGMS). The content is solely the responsibility of the authors and does not necessarily represent the official views of NIDA, FDA, or NIGMS.

Declaration of Interest

None declared.

Acknowledgment

We thank Alyssa Noble for assistance with figure graphics.

References

1. Family Smoking Prevention and Tobacco Control Act. <http://thomas.loc.gov/cgi-bin/bdquery/z?d111:HR01256:@@P>. Accessed March 13, 2016.
2. Ashley DL, Backinger CL, van Bommel DM, Neveleff DJ. Tobacco regulatory science: research to inform regulatory action at the Food and Drug Administration's Center for tobacco products. *Nicotine Tob Res*. 2014;16(8):1045–1049. doi:10.1093/ntr/ntu038.
3. Benowitz NL, Henningfield JE. Establishing a nicotine threshold for addiction—the implications for tobacco regulation. *N Engl J Med*. 1994; 331(2):123–125. doi:10.1056/NEJM199407143310212.
4. Donny EC, Denlinger RL, Tidey JW, et al. Randomized trial of reduced-nicotine standards for cigarettes. *N Engl J Med*. 2015;373(14): 1340–1349. doi:10.1056/NEJMsa1502403.
5. Redner R, White TJ, Bunn JY, Higgins ST. Use of high-nicotine/tar-yield (full-flavor) cigarettes and risk for nicotine dependence in nationally

- representative samples of US smokers [published online ahead of print November 7, 2015]. *Nicotine Tob Res.* 2015;18(6):1424–1430.
6. Kozlowski LT, O'Connor RJ, Sweeney CT. *Cigarette Design. Smoking and Tobacco Control Monograph 13*. Bethesda, MD: US Department of Health and Human Services, Public Health Services, National Institutes of Health; 2001:13–38. <http://cancercontrol.cancer.gov/brp/tcrb/monographs/13/>. Accessed June 16, 2015.
 7. Scherer G, Lee PN. Smoking behavior and compensation: a review of the literature and meta-analysis. *Regul Toxicol Pharmacol.* 2014;70(3): 615–628. doi:10.1016/j.yrtph.2014.09.008.
 8. Shiffman S, Waters AJ, Hickcox M. The Nicotine Dependence Syndrome Scale: a multidimensional measure of nicotine dependence. *Nicotine Tob Res.* 2004;6(2):327–348. doi:10.1080/1462220042000202481.
 9. US Department of Health and Human Services. *The Health Consequences of Smoking—Nicotine Addiction*. Washington, DC: United States Public Health Service, Office on Smoking and Health; 1988.
 10. US Department of Health and Human Services. *The Health Consequences of Smoking—50 Years of Progress: A Report of the Surgeon General*. Atlanta, GA: US Department of Health and Human Services, Centers for Disease Control and Prevention, National Center for Chronic Disease Prevention and Health Promotion, Office of Smoking and Health; 2014.
 11. Stellman SD, Garfinkel L. Smoking habits and tar levels in a new American Cancer Society prospective study of 1.2 million men and women. *J Natl Cancer Inst.* 1986;76(6):1057–1063. http://academiccommons.columbia.edu/download/fedora_content/download/ac:174431/CONTENT/Stellman_1986_CPS2Smoking_JNCI.pdf. Accessed March 13, 2016.
 12. Behm I, Sokol NA, Kennedy RD, Rees VW, Connolly GN. Population use, sales, and design: a multidimensional assessment of “light” cigarettes in the United States, 2009. *Am J Public Health.* 2013;103(3):e93–e99.
 13. Higgins ST, Heil SH, Badger GJ, Skelly JM, Solomon LJ, Bernstein IM. Educational disadvantage and cigarette smoking during pregnancy. *Drug Alcohol Depend.* 2009;104(suppl 1):S100–105.
 14. Higgins ST, Kurti AN, Redner R, et al. Co-occurring risk factors for current cigarette smoking in a US nationally representative sample [published online ahead of print February 21, 2016]. *Prev Med.* 2016. doi:10.1016/j.ypmed.2016.02.025.
 15. Kandel DB, Griesler PC, Schaffran C. Educational attainment and smoking among women: risk factors and consequences for offspring. *Drug Alcohol Depend.* 2009;104(suppl 1):S24–S33.
 16. Hiscock R, Bauld L, Amos A, Fidler JA, Munafò M. Socioeconomic status and smoking: a review. *Ann NY Acad Sci.* 2012;1248:107–123.
 17. Reid JL, Hammond D, Boudreau C, Fong GT, Siahpush M; ITC Collaboration. Socioeconomic disparities in quit intentions, quit attempts, and smoking abstinence among smokers in four western countries: findings from the International Tobacco Control Four Country Survey. *Nicotine Tob Res.* 2010;12(suppl 1):S20–S33.
 18. Higgins ST. Behavior change, health, and health disparities: an introduction. *Prev Med.* 2014;68:1–4.
 19. Schroeder SA. American health improvement depends upon addressing class disparities [published online ahead of print March 24, 2016]. *Prev Med.* 2016. doi:10.1016/j.ypmed.2016.02.024.
 20. Center for Behavioral Health Statistics and Quality. *2013 National Survey on Drug Use and Health Public Use File Codebook*. Rockville, MD: Substance Abuse and Mental Health Services Administration; 2014. http://www.icpsr.umich.edu/cgi-bin/file?comp=none&study=35509&ds=1&file_id=1166336&path=SAMHDA. Accessed March 13, 2016.
 21. Substance Abuse and Mental Health Services Administration (SAMHSA). *Results From the 2011 National Survey on Drug Use and Health: Summary of the National Findings, NSDUH Series H-44 (HHS Publication No. (SMA) 12-4713)*. Rockville, MD: Substance Abuse and Mental Health Services Administration; 2012.
 22. Substance Abuse and Mental Health Services Administration (SAMHSA). *Results From the 2012 National Survey on Drug Use and Health: Summary of the National Findings, NSDUH Series H-46 (HHS Publication No. (SMA) 13-4795)*. Rockville, MD: Substance Abuse and Mental Health Services Administration; 2013.
 23. Substance Abuse and Mental Health Services Administration (SAMHSA). *Results From the 2013 National Survey on Drug Use and Health: Summary of the National Findings, NSDUH Series H-46 (HHS Publication No. (SMA) 14-4863)*. Rockville, MD: Substance Abuse and Mental Health Services Administration; 2014.
 24. Heatherton TF, Kozlowski LT, Frecker RC, Fagerstrom KO. The Fagerström test for nicotine dependence: a revision of the Fagerstrom Tolerance Questionnaire. *Br J Addict.* 1991;86(9):1119–1127. doi:10.1111/j.1360-0443.1991.tb01879.x.
 25. Breiman L, Friedman JH, Olshen RA, Stone CJ. *Classification and Regression Trees*. Belmont, CA: Wadsworth; 1984.
 26. Lemon SC, Roy J, Clark MA, Friedmann PD, Rakowski W. Classification and regression tree analysis in public health: methodological review and comparison with logistic regression. *Ann Behav Med.* 2003;26(3):172–181.
 27. Lei Y, Nollen N, Ahluwalia JS, Yu Q, Mayo MS. An application in identifying high-risk populations in alternative tobacco product use utilizing logistic regression and CART: a heuristic comparison. *BMC Public Health.* 2015;15:341.
 28. R Core Team. *R: A Language and Environment for Statistical Computing*. Vienna, Austria: R Foundation for Statistical Computing; 2013. <http://www.R-project.org/>. Accessed March 20, 2016.
 29. Therneau T, Atkinson B, Ripley B. *rpart: Recursive Partitioning. R Package Version 4.1-3*. 2013. <http://CRAN.R-project.org/package=rpart>. Accessed March 20, 2016.
 30. Chivers LL, Hand DJ, Priest JS, Higgins ST. E-cigarette use among women of reproductive age: Impulsivity, cigarette smoking status, and other risk factors. *Prev Med.* 2016. pii:S0091-7435(16)30206-7. doi:10.1016/j.ypmed.2016.07.029.
 31. Patton JH, Stanford MS, Barratt ES. Factor structure of the Barratt impulsiveness scale. *J Clin Psychol.* 1995;51(6):768–774.
 32. Benowitz NL, Dains KM, Hall SM, et al. Progressive commercial cigarette yield reduction: biochemical exposure and behavioral assessment. *Cancer Epidemiol Biomarkers Prev.* 2009;18(3):876–883. doi:10.1158/1055-9965.EPI-08-0731.
 33. Zacny JP, Stitzer ML. Cigarette brand-switching: effects on smoke exposure and smoking behavior. *J Pharmacol Exp Ther.* 1988;246(2):619–627.
 34. Russell MAH, Sutton SR, Iyer R, Feyerabend C, Vesey CJ. Long-term switching to low-tar low-nicotine cigarettes. *Br J Addict.* 1982;77(2): 145–158. doi:10.1111/j.1360-0443.1982.tb01416.x.
 35. Lynch CJ, Benowitz NL. Spontaneous cigarette brand switching: consequences for nicotine and carbon monoxide exposure. *Am J Public Health.* 1987;77(9):1191–1194.
 36. Melikian AA, Djordjevic MV, Chen S, Richie J, Stellman SD. Effect of delivered dosage of cigarette smoke toxins on the levels of urinary biomarkers of exposure. *Cancer Epidemiol Biomarkers Prev.* 2007;16(7):1408–1415. doi:10.1158/1055-9965.EPI-06-1097.
 37. Benowitz NL, Hall SM, Stewart S, Wilson M, Dempsey D, Jacob P. Nicotine and carcinogen exposure with smoking of progressively reduced nicotine content cigarette. *Cancer Epidemiol Biomarkers Prev.* 2007;16(11): 2479–2485. doi:10.1158/1055-9965.EPI-07-0393.
 38. Benowitz NL, Dains KM, Hall SM, et al. Smoking behavior and exposure to tobacco toxicants during 6 months of smoking progressively reduced nicotine content cigarettes. *Cancer Epidemiol Biomarkers Prev.* 2012;21(5):761–769. doi:10.1158/1055-9965.EPI-11-0644.
 39. Hatsukami DK, Kotlyar M, Hertsgaard LA, et al. Reduced nicotine content cigarettes: effects on toxicant exposure, dependence and cessation. *Addiction.* 2010;105(2):343–355. doi:10.1111/j.1360-0443.2009.02780.x.
 40. Hatsukami DK, Hertsgaard LA, Vogel RI, et al. Reduced nicotine content cigarettes and nicotine patch. *Cancer Epidemiol Biomarkers Prev.* 2013;22(6):1015–1024. doi:10.1158/1055-9965.EPI-12-1439.
 41. Jha P, Peto R, Zatonski W, Boreham J, Jarvis MJ, Lopez AD. Social inequalities in male mortality from smoking: indirect estimation from national death rates in England and Wales, Poland, and North America. *Lancet.* 2006;368(9533):367–370.
 42. Rojewski AM, Baldassarri S, Cooperman NA, et al.; Comorbidities Workgroup of the Society for Research on Nicotine and Tobacco (SRNT)

- Treatment Network. Exploring issues of comorbid conditions in people who smoke [published online ahead of print January 17, 2016]. *Nicotine Tob Res.* 2016. PMID:26783291
43. Halpern SD, French B, Small DS, et al. Randomized trial of four financial-incentive programs for smoking cessation. *N Engl J Med.* 2015;372(22):2108–2117.
44. Higgins ST, Solomon LJ. Some recent developments on financial incentives for smoking cessation among pregnant and newly postpartum women. *Curr Addict Rep.* 2016;3(1):9–18.
45. Sigmon SC, Miller ME, Meyer AC, et al. Financial incentives to promote extended smoking abstinence in opioid-maintained patients: a randomized trial. *Addiction.* 2016;111(5):903–912.
46. Loh WY, Piper ME, Schlam TR, et al. Should all smokers use combination smoking cessation pharmacotherapy? Using novel analytic methods to detect differential treatment effects over 8 weeks of pharmacotherapy. *Nicotine Tob Res.* 2012;14(2):131–141.
47. Thompson TP, Greaves CJ, Ayres R, et al. An exploratory analysis of the smoking and physical activity outcomes from a pilot randomized controlled trial of an exercise assisted reduction to stop smoking intervention in disadvantaged groups. *Nicotine Tob Res.* 2016;18(3):289–297.
48. National Cancer Institute. *Improving Smoking Cessation in Socioeconomically Disadvantaged Populations via Scalable Interventions. PAR-16–202.* 2016. <http://grants.nih.gov/grants/guide/pa-files/PAR-16-202.html>. Accessed May 26, 2016.