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Smoking Behavior and Exposure to Tobacco Toxicants During 6 months of Smoking Progressively Reduced Nicotine Content Cigarettes

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Abstract

Background—Recent federal legislation gives the FDA authority to regulate the nicotine content of cigarettes. A nationwide strategy for progressive reduction of the nicotine content of cigarettes is a potential way to reduce the addictiveness of cigarettes, to prevent new smokers from becoming addicted and to facilitate quitting in established smokers. We conducted a trial of progressive nicotine content tapering over 6 months to determine the effects on smoking behaviors and biomarkers of tobacco smoke exposure and cardiovascular effects.

Methods—135 healthy smokers were randomly assigned to one of two groups. A research group smoked their usual brand of cigarettes followed by 5 types of research cigarettes with progressively lower nicotine content, each smoked for one month. A control group smoked their own brand of cigarettes for the same period of time.

Results—Nicotine intake, as indicated by plasma cotinine concentration, declined progressively as the nicotine content of cigarettes was reduced. Cigarette consumption and markers of exposure to carbon monoxide and polycyclic aromatic hydrocarbons, as well as cardiovascular biomarkers remained stable, while urinary 4-(methylnitrosamino)-1-(3-pyridyl)-1-butanol (NNAL) excretion decreased. No significant changes in biomarkers of exposure or cardiovascular effects were observed in controls.

Conclusions—Our data support the proposition that the intake of nicotine from cigarettes of smokers can be substantially lowered without increasing exposure to other tobacco smoke toxins.

Impact—These findings support the feasibility and safety of gradual reduction of the nicotine content in cigarettes.

Introduction

In June, 2009 the US government passed HR 1256, the Family Smoking Prevention and Tobacco Control Act that grants the Food and Drug Administration (FDA) the power to regulate tobacco products [1]. This legislation gives the FDA the authority to control the

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Disclosure of Potential Conflicts of Interest
Dr. Benowitz is a consultant to several pharmaceutical companies that market medications to aid smoking cessation and has served as a paid expert witness in litigation against tobacco companies. Dr Hall has received material support for an ongoing clinical trial from Pfizer. The other authors have no conflicts to declare.

nicotine content of cigarettes. A nationwide strategy for the progressive reduction of the nicotine content in cigarettes has been widely discussed as a potential way that would result in a cigarette that does not sustain or result in addiction and/or aid smoking cessation [2–6].

We have shown in prior research that when smokers smoke single cigarettes with differing nicotine content the nicotine intake per cigarette is proportional to the nicotine content of the cigarettes, without evidence of compensation [7]. Furthermore we have previously reported on a small uncontrolled clinical trial of 20 smokers who smoked cigarettes of their usual brand, then cigarettes of progressively lower nicotine content, each for one week [8]. That trial confirmed that the nicotine intake declined progressively as the nicotine content of cigarettes was lowered. Measurement of carbon monoxide and tobacco smoke carcinogens indicated minimal or no compensation, suggesting that gradual reduction of the nicotine content of cigarettes is no more hazardous than smoking regular nicotine cigarettes. We also observed in that study that 25% of smokers quit smoking after the taper, despite having expressed no desire to quit on entry into the study. The data suggested that the degree of nicotine dependence can be lowered without increasing exposure to tobacco smoke toxins using RNCs.

Limitations of our prior RNC clinical trial included a relatively small number of subjects and a brief duration of the tapering at each yield level. There is concern among some tobacco researchers that over the long term smokers will attempt to obtain the nicotine that they crave by increasing the frequency and depth of inhalation. We now present data from a longer duration study, with nicotine yield tapering at monthly intervals, and which included a larger number of subjects as well as a control group of smokers smoking their own cigarettes. The full study is a two year study with an initial 6 month nicotine tapering phase followed by 6 months of smoking the lowest nicotine content cigarettes and then a one year follow up without research cigarettes. In this paper we present data on the 6 months of progressive tapering.

Methods

Overview of Study Design

This was a 2 year, two-arm, randomized, unblinded study in which smokers smoked their usual brand of cigarette for a baseline period of two weeks and then were randomly divided into a control arm and a research arm. The control group smoked their usual brand of cigarettes throughout the study. The research (RNC) group smoked five types of progressively lower nicotine content cigarettes. The first four levels of RNC were smoked for 4 weeks each. The lowest nicotine content cigarette was smoked for 6 months. Thereafter, all subjects were followed for an additional year after returning to smoking cigarettes of their choosing (or quitting). The study was not blinded because we wanted to simulate a real world regulatory situation in which the nicotine content of cigarettes is progressively decreased with the knowledge of the smoker. The present analysis focuses on the first six months of the study during which the nicotine content of cigarettes was tapered.

Subjects

Smokers were recruited by newspaper advertisements looking for smokers interested in a reduced nicotine cigarette study. Subjects were determined not to be interested in quitting smoking in the next six months. Inclusion criteria included being between the ages of 18 and 70, being healthy based on medical history and screening blood tests, smoking 10 or more cigarettes per day for the past year and having an expired carbon monoxide levels of 25 ppm or a saliva cotinine level of 100 ng/ml or more at the screening visit. Exclusion criteria

included pregnancy or lactation, current use of smokeless tobacco, pipes or cigars, and alcohol or drug dependence.

Two hundred and thirty-eight smokers were screened for participation. One hundred and thirty-nine subjects met entry criteria and completed the baseline assessment. The reasons for subject exclusion included cotinine levels < 100 ng/ml (45%), drug or alcohol abuse (35%), history of fainting, poor veins or health issues (20%). Four subjects who completed the baseline screening declined to participate.

One hundred and thirty-five subjects were randomized to RNC or control groups in blocks of 10 subjects. The number of subjects studied was limited by the supply of research cigarettes Twenty-one subjects randomized to the RNC group withdraw between weeks 2 and 6 of study initiation, during which time they were smoking the highest level nicotine research cigarette.

Subjects withdrew primarily because they did not like the taste of the research cigarettes. Because the subjects did not experience any nicotine tapering, these 21 subjects were replaced. Another 11 subjects withdrew during the tapering phase (5 in the control group and 6 in the RNC group) and were not replaced. A total of 53 subjects in the RNC and 50 subjects in the control group completed the tapering phase of the study. Of the 26 subjects who quit in the research group 17 quit due to not liking the cigarettes, 7 relocated, 2 became ill and 1 was a no show. Of the 5 who quit in the control group 1 subject died unexpectedly, 2 relocated and 2 were no shows.

Study Protocol

Subjects were studied in a community-based clinic. Visits were scheduled bi-weekly, at which time cigarettes were dispensed; expired carbon monoxide (CO), height, weight and blood pressure were measured; blood and urine samples were collected; and questionnaires were administered. Subjects were instructed to smoke their cigarettes as desired, but not to smoke any other type of cigarette and not to use other forms of tobacco or nicotine medications. Subjects were also told that if they did smoke cigarettes other than study cigarettes that they should report such lapses to the research staff, and that there would be no penalty with respect to remaining in the study.

Plasma samples were assayed for concentrations of nicotine and cotinine (the proximate metabolite of nicotine) and for selected cardiovascular biomarkers. The following biomarkers were selected as predictors of coronary heart disease risk: white blood cell count, hemoglobin, LDL and HDL cholesterol and serum fibrinogen. Urine samples were assayed for concentrations of 4-(methylnitrosamino)-1-(3-pyridyl)-1-butanol (NNAL), a metabolite of the carcinogenic tobacco specific nitrosamine, 4-(methylnitrosamino-1-(3-pyridyl)-1-butanone (NNK) and metabolites of four polycyclic aromatic hydrocarbons (PAH) found in tobacco smoke. NNAL and the PAH metabolites are biomarkers of exposure to common tobacco smoke carcinogens.[9]

Questionnaires were administered at the end of each of the 4 week tapering intervals and included a report of smoking behavior over the previous four week period, Profile of Mood Scale[10], the Minnesota Nicotine Withdrawal Scale[11], the Fagerström Test for Nicotine Dependence[12] (FTND) and a cigarette acceptance questionnaire.[13] The cigarette acceptance questionnaire uses items with 7 point ratings that cluster into seven scales: satisfaction, similarity to usual brand, psychological reward, aversion, respiratory sensations, craving and perceived strength. A self efficacy questionnaire [14], the Prochaska Stages of Change questionnaire [15] and the the CESD Depression Scale,[16] were administered on the milestone visits – baseline, 3mo, 6mo,1 year and 2 year. The self-

efficacy questionnaire is a 14 item instrument that asks about the confidence of smokers in their ability to resist smoking in various high risk situations. The Stages of Change questionnaire assesses the early stages of movement toward quitting smoking, including precontemplation (no intention to quit within the next 6 months), contemplation (seriously considering quitting in the nest 6 months) and preparation. Subjects were paid for participation. Written, informed consent was obtained from each subject. The study was approved by the Institutional Review Board at the University of California, San Francisco.

Cigarettes

The reduced nicotine content (RNC) cigarettes were manufactured by Philip Morris Tobacco Company by blending very low nicotine tobacco with tobacco containing higher amounts of nicotine. Very low nicotine tobacco was produced by a super critical extraction method. The paper and filters and weight of tobacco in the research cigarettes were similar to that of a Marlboro cigarette. The target nicotine content per cigarette were 12 mg, 8mg, 4mg, 2mg and 1 mg, to allow for a 50% reduction in nicotine dose at each step between 8 mg and 1 mg. These five levels were selected so that at the end of tapering, the maximum systemic nicotine intake could be expected to be 0.2 mg per cigarette or less, based on bioavailability calculations that have been described previously.[2] The lowest level of nicotine availability was based on an estimate of the threshold level of nicotine to maintain nicotine addiction. The characteristics of the research nicotine cigarettes, as well as the subjects' usual brand of cigarettes, are presented in Table 1. Data on the extent of ventilation of the cigarettes were not available. The cigarette filters were perforated with two rows of perforations, similar to those found in the filter of a Marlboro Light cigarette. Cigarettes were stored at 55 degrees F until shortly before they were dispensed to the subjects.

Analytical Chemistry

Plasma nicotine and cotinine were measured by gas chromatography with nitrogen-phosphorous detection.[17, 18] Urine concentrations of NNAL (free plus conjugated) and polycyclic aromatic hydrocarbon metabolites, including 2-naphthol, 1,2 and 3+4 hydroxyphenanthrenes, 1-hyroxypyrene, and 2-hydroxyfluorene,were measured by liquid chromatography-tandem mass spectrometry (LC-MS/MS).[19] [20] Cardiovascular biomarkers were assayed by enzyme immunoassay using commercial kits.

Analysis of Compensation

Compensation was defined as the degree to which proportional changes in a subject's intake of a smoke constituent make up for the proportional change in the machine-determined yield of cigarette content of that constituent. As we have described previously, compensation can be expressed mathematically as: $C = 1 - \{[\log(\text{marker } 2) - \log(\text{marker } 1)] / [\log(\text{yield } 2) - \log(\text{yield } 1)]\}$[21]. In the present study we computed compensation using plasma cotinine concentrations as the marker of nicotine intake and the machine determined nicotine yields of usual cigarettes and reduced nicotine content cigarettes. For example, assume that a smoker smokes a cigarette at baseline with a nicotine yield of 1.0 mg and compensation is assessed while smoking a RNC cigarette with a yield of 0.4 mg. Assume the plasma cotinine concentrations at baseline and while smoking the RNC cigarette are 256 ng/ml and 131 ng/ml, respectively. Using the equation above, $C = 1 - \{[\log 131] - [\log 256] / [\log 0.4] - [\log 1.0] = 0.27$. Thus compensation is estimated to be 27%.

Statistical Analysis

Because measurements for each individual were correlated over time, a repeated measures model was constructed for each of the major variables. A mixed effects regression analysis was performed using PROC MIXED in SAS (version 9.2). Measurements at baseline, 3

months, and 6 months were modeled as a function of time and study arm, using time by study arm interactions to assess intervention effects. Models were examined with and without adjustment for age, gender, race/ethnicity and use of menthol cigarettes. Because results were unchanged, unadjusted data are presented. Least square means and 95% confidence intervals were computed within each study arm at each of the three time points. Differences in mean values were computed for each pair of time points within each study arm, as well as the difference between the study arms with respect to each time point comparison; p-values and 95% confidence intervals for the differences were constructed using the Bonferroni adjustment to account for 3 time point comparisons. Variable values for total NNAL, polycyclic aromatic hydrocarbon metabolites and several of the cardiovascular biomarkers were log-transformed to achieve approximate normality, and the analyses were performed on the natural logarithm of the values. Geometric means and corresponding ratios are reported for log-transformed variables.

All data for the 103 participants who completed the first six month period of the study were included in the primary analysis. Dropouts were excluded from the analysis because they had missing data for many or most of the visits. Because several subjects had stopped smoking at various time points the analyses were repeated omitting observations on non-smoking visits (n=6). For individuals who reported not smoking for the previous 24 hours, having stopped smoking was defined biochemically as having a plasma cotinine concentration of less than 10 ng/ml. Analyses that excluded observations when subjects were not smoking did not alter the results so all analyses that are presented include all observations.

At various times 11 subjects in the RNC group reported non-compliance with the research cigarettes – that is, they had smoked some commercial cigarettes in the previous 4 weeks. The analyses were performed both including and excluding these subjects.

Another sensitivity analysis was performed in which data from those subjects who dropped out during the RNC taper phase (5 in the control group and 6 in the RNC group) were included, carrying forward their measurements from the last visit before they dropped out. This analysis examined cigarettes per day, plasma cotinine and expired CO. Urine samples from dropouts for measurement of NNAL or PAHs were not retained, so these measures were not part of the sensitivity analysis.

Results

Demographic and baseline smoking data

Demographic data and baseline smoking data for subjects in the two treatment groups as well as for dropouts are shown in table 2. The FTND score was significantly higher for dropouts compared to those who completed the study; they did not differ significantly with respect to cigarettes per day. Among retained subjects, the research and control groups did not differ significantly with respect to either FTND or cigarettes per day. Other characteristics were similar across groups.

Cigarette Consumption

Average cigarette consumption increased by an average of 3 cigarettes per day in the control group comparing week 26 vs baseline (Figure 1A, Table 3). Cigarette consumption was unchanged in the RNC group between baseline and week 14, but decreased significantly by 4 cigarettes per day between weeks 14 and 26. There were significant differences between the two treatment groups comparing cigarettes per day at 26 weeks to baseline and to 14 weeks. The findings were similar for RNC smokers who were or were not compliant, and when dropouts with data carried forward were included (data not shown for the latter).

Biochemical Exposures

Plasma nicotine and cotinine concentrations declined slightly over 26 weeks in the control smokers, but these changes were not significant. (Figure 1B, Table 3). In RNC subjects average plasma nicotine and cotinine concentrations remained stable for the first 6 weeks, but then declined significantly at 14 and 26 weeks compared to baseline. For plasma cotinine, which is the most stable indicator of daily intake of nicotine, the levels at week 26 were 44% of baseline for all RNC subjects and 30% of baseline in those who complied. Significant interactions were observed in the change in plasma nicotine and cotinine comparing the control and RNC groups. Including dropouts with data carried forward, plasma cotinine was 51% of baseline at 26 weeks ($p < 0.001$)

Expired CO increased by an average of 4 ppm comparing baseline to week 14 for all groups, although the change was significant only for the RNC group (Figure 1C). Changes were not significant when dropouts were included. Urine NNAL remained unchanged during the 26 weeks in the controls, but decreased significantly between baseline and weeks 14 and 26 in RNC subjects. (Table 3). The interaction between control and RNC groups was significant. There were no significant changes in excretion of PAH metabolites.

Compensation

Compensation at various levels of nicotine content is shown in Fig 2. While smoking the 12 mg nicotine cigarette, compensation compared to usual brand averaged 100%. While smoking the 8 and 4 mg nicotine cigarettes, compensation averaged 40 to 60%. While smoking the lowest nicotine content cigarettes, 2 and 1mg, compensation averaged 20 to 40%. As expected compensation at the lowest nicotine levels was greater in those who did not fully comply with smoking RNC than those who did comply.

Cardiovascular Measurements and Biomarkers

Body weight did not change significantly in control and among all RNC subjects. Body weight did significantly increase among compliant RNC smokers, from 81 kg (95% C.I. 71 – 81) at baseline to 83 kg (75, 80) at 26 weeks ($p < 0.0166$). Of note there was no change in body weight in this group comparing baseline to 14 weeks. No significant changes were observed in any group for blood pressure, heart rate, white blood cell count, hemoglobin, HDL cholesterol or fibrinogen.

Subjective Responses

There were no significant time or group-related changes in the total Minnesota Nicotine Withdrawal Score, the total POMS score or the CESD score. There was a significant decrease in the POMS vigor score comparing baseline to weeks 14 and 26 in the full RNC group and between baseline and week 14 in compliant RNC subjects ($p < 0.0166$). There was a significant increase in the POMS confusion score in the full RNC group comparing baseline to weeks 14 and 26 ($p < 0.0166$). Responses to the cigarette acceptance questionnaire indicated that on average the RNC were milder, less satisfying, had lower nicotine effect and were of lesser quality than their usual cigarettes. Overall the RNC were rated as not quite as good as their usual cigarette brand.

Quitting and dependence-related questionnaires

Although subjects did not intend to quit smoking on entry into the study, three subjects did quit smoking after completing the RNC taper. Two were in the RNC and one in the control group. All subjects were in the precontemplation stage on study entry. At 6 months 49% of RNC subjects compared to 86% of control subjects were still in the precontemplation stage, indicating that many more RNC subjects were thinking about quitting ($p < 0.001$).

Comparing baseline and week 26 there were no significant changes in the FTND score, time to first cigarette or in the self-efficacy score in any of the groups. Comparing weeks 14 and week 26 there was a significant decrease in the FTND in the RNC group (mean 5.70 to 5.13, $p < 0.05$). This change was significantly greater in the RNC group compared to the control group, which did not significantly change (control group mean values 5.26 and 5.39 at weeks 14 and 26).

Discussion

The present study replicates the main findings of our previous research with some important differences. The present trial includes a larger number of subjects; nicotine tapering was conducted over a much longer period of time; and a control group of smokers smoking their own brand of cigarettes was added. Consistent with our prior work we find that progressively reducing the nicotine content of cigarettes is associated with a progressive reduction in nicotine intake by the smokers. Thus, while smoking the lowest RNC cigarette plasma nicotine concentration was 22% and cotinine concentration 30% of the baseline value. These reductions are similar to what we observed with a 6 week taper and what was reported by Hatsukami et al with a sudden reduction from usual cigarettes to 0.05 mg nicotine delivery cigarettes [8, 22]. Reducing the nicotine content of cigarettes does not appear to be harmful to smokers as evidenced by no increase in cigarettes smoked per day and no increase in exposure to tobacco smoke combustion products (carbon monoxide or PAHs). Furthermore there was no adverse effect of RNC tapering on selected cardiovascular biomarkers that are associated with future risk of adverse cardiovascular events. As expected, smokers of their usual brand had consistent levels of intake of nicotine and other smoke constitutents over the course of the six months.

An analysis of percent compensation of various RNCs compared to the usual brand shows that smokers compensated nearly completely when smoking a research cigarette with nicotine delivery similar to the usual brand. Partial compensation (40 – 60%) was seen while smoking the middle nicotine content cigarettes and relatively low compensation (20 – 40%) when smoking cigarettes with the lowest nicotine contents.

The reason for incomplete compensation for reduced nicotine delivery from the RNC cigarettes mostly likely relates to the design of the cigarettes, such that the nicotine content is lowered without altering the remainder of the tobacco or altering ventilation. Commercial low yield cigarettes in contrast are low yield primarily because they are highly ventilated; they contain as much nicotine as regular cigarettes [23]. The smoke from such cigarettes is diluted with air and is perceived as less strong than higher yield cigarettes. This signals the smoker to take a larger puff. Another consequence of ventilation is less resistance to draw. In response to a highly ventilated cigarette the smoker inhales smoke more quickly, increases the volume of smoke inhaled and reduces the efficiency of ventilation. Compensation for nicotine is easily accomplished. In contrast the RNC cigarettes used in the present study present the smoker with smoke of a similar strength and resistance to draw independent of the nicotine content, thereby making compensation more difficult.

As was noted in our prior study, switching to RNCs is associated with a significant reduction in urine NNAL, meaning less exposure to the tobacco-specific nitrosamine and lung carcinogen NNK [8]. NNK is formed from nicotine in the presence of nitrites in tobacco, so reducing the nicotine content of cigarettes reduces exposure to NNK. This is seen in the smoking machine-determined yield data presented in Table 1.

As in our prior study, there was no significant change in the total Minnesota Nicotine Withdrawal Scale score. Both of our studies found that RNC subjects gained weight. The

weight gained in the present study(average of 2 kg) was considerably less than the 4 to 5 kg that is reported when smokers quit smoking completely [24], presumably due to some weight controlling effect of even low levels of nicotine. We observed small but significant decreases in vigor and increases in confusion scores on the POMS in during RNC tapering, which are consistent with some degree of nicotine withdrawal.

In the present study three subjects quit smoking, two in the RNC and one in the control group. This is in contrast to our prior study when 20% of RNC smokers quit at the end of 6 weeks of tapering. The difference in quitting may have been due to the design of the present study, which offered an additional six months of low nicotine cigarettes after the end of tapering. Analysis of Stages of Change did indicate that many more RNC smokers were thinking about quitting in the near future compared to controls. There were no significant changes in the FTND, time to first cigarette or in their ratings of self-efficacy in the ability to quit over the course of the study, although FTND did decrease significantly in RNC subjects comparing weeks 14 and 26.

Our study had some limitations that may limit the generalizability of the findings. The number of subjects was relatively small; the subjects were primarily Caucasians and were on average well-educated. The cigarette consumption and baseline cotinine levels were higher than the national average [25]. If anything our subjects might have been more dependent than the typical smokers and would be expected to be more likely to have tried to compensate for lower nicotine availability.

We had a number of subjects (26 %) who dropped out the RNC group, a greater number than dropouts from the control group (9 %). Most of the dropouts from the RNC group did so because they did not like the research cigarettes (63%). Two thirds of the dropouts did so while smoking the 12 mg nicotine research cigarette, indicating that the cigarette quality rather than reduction of nicotine availability prompted dropping out. The cigarettes were several years old and no longer tasted fresh. Another third of smokers dropped out later in the study. It is not clear whether the latter subjects dropped out because of the poor cigarette quality or because of lower nicotine availability from RNC cigarettes. It is possible that some of these dropouts were people who could not tolerate lower nicotine levels such that if a higher nicotine brand were not available (such as would be the case with national regulation), they might have compensated by smoking more cigarettes per day. In contrast to the RNC group, the control group received their usual brand of cigarette, which was newly purchased and was fresh. A sensitivity analysis including late dropouts with data carried forward did not affect results of statistical analysis of changes in cigarettes per day, plasma cotinine or expired CO. Another limitation to generalizability is that our subjects volunteered to smoke cigarettes that might reduce their daily intake of nicotine. This would not be the case with a national policy to reduce the nicotine content of cigarettes.

Compliance with smoking the RNC could not be confirmed. The observation of progressive and substantial reduction in nicotine intake does indicate some level of compliance. Several subjects did report non-compliance, and these subjects demonstrated less of a decline in plasma cotinine levels compared to those who reported compliance. However all of the main findings were observed when RNC data were analyzed without and with exclusion of non-compliant subjects.

In conclusion, our study shows that when the nicotine content of cigarettes is progressively decreased at monthly intervals over 6 months there is a progressive decline in nicotine intake by smokers, with only a small degree of compensation at the lowest nicotine content levels. There was no evidence of increased exposure to tobacco combustion products during RNC tapering over 6 months compared to smoking the usual brand.

Progressive reduction of the nicotine content of cigarettes as a national regulatory policy might have important potential benefits for the population. One is that reduced intake of nicotine is expected to result in a lower level of dependence and a greater likelihood of quitting. Both of our studies with RNC found that some people who had no intention of quitting upon entry into the study had lower levels of questionnaire-determined dependence and either quit spontaneously or were thinking about quitting in the near future after smoking RNC. The ultimate test of the level of dependence is the ability to quit when the smokers tries to do so. The present study was not designed to test this outcome. Another potential benefit is that adolescent novice smokers who initiate smoking the RNC might be less likely to become addicted. Adolescents initiate smoking for social reasons, with friends, and later begin to smoke for pharmacologic reasons related to dependence. Presumably a cigarette with very low nicotine content would be less likely to support the transition from social to dependent smoking, although the threshold level of nicotine to prevent this transition is not yet known.

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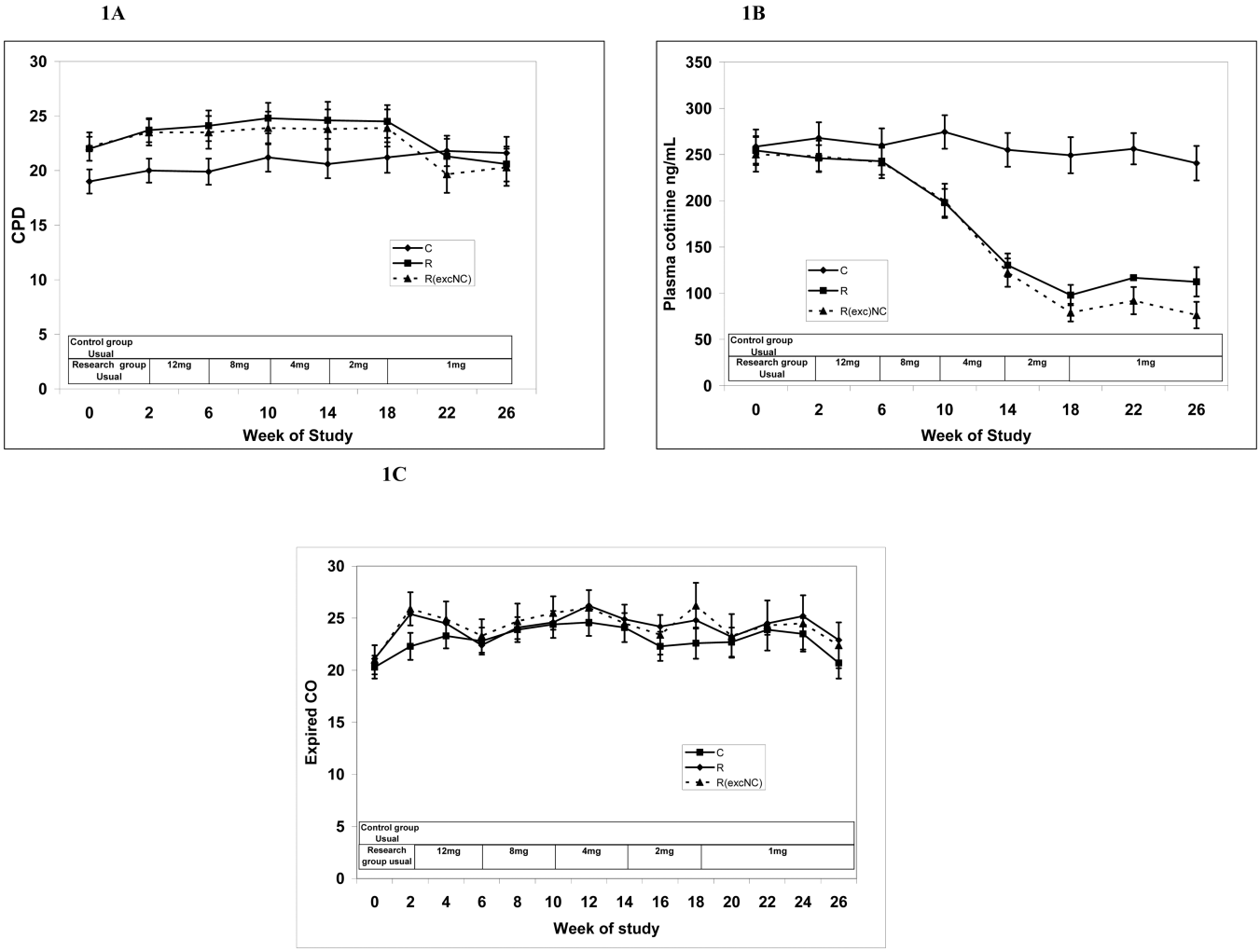

Fig. 1.

A - Mean cigarette consumption over 26 weeks of the study in smokers smoking their usual brand of cigarettes (C, N = 50) or during progressive reduction of nicotine content of cigarettes (R, N = 53). R(excNC) indicates subjects in the RNC group excluding those who did not comply with smoking RNC cigarettes only (N = 42).
The bars represent SEM.

B – Mean plasma cotinine concentration over 26 weeks of the study in smokers smoking their usual brand of cigarettes (C, N = 50) or during progressive reduction of nicotine content of cigarettes (R, N = 53). R(excNC) indicates subjects in the RNC group excluding those who did not comply with smoking RNC cigarettes only (N = 42).
The bars represent SEM.

C – Mean expired carbon monoxide concentration over 26 weeks of the study in smokers smoking their usual brand of cigarettes (C, N = 50) or during progressive reduction of nicotine content of cigarettes (R, N = 53). R(excNC) indicates subjects in the RNC group excluding those who did not comply with smoking RNC cigarettes only (N = 42).
The bars represent SEM.

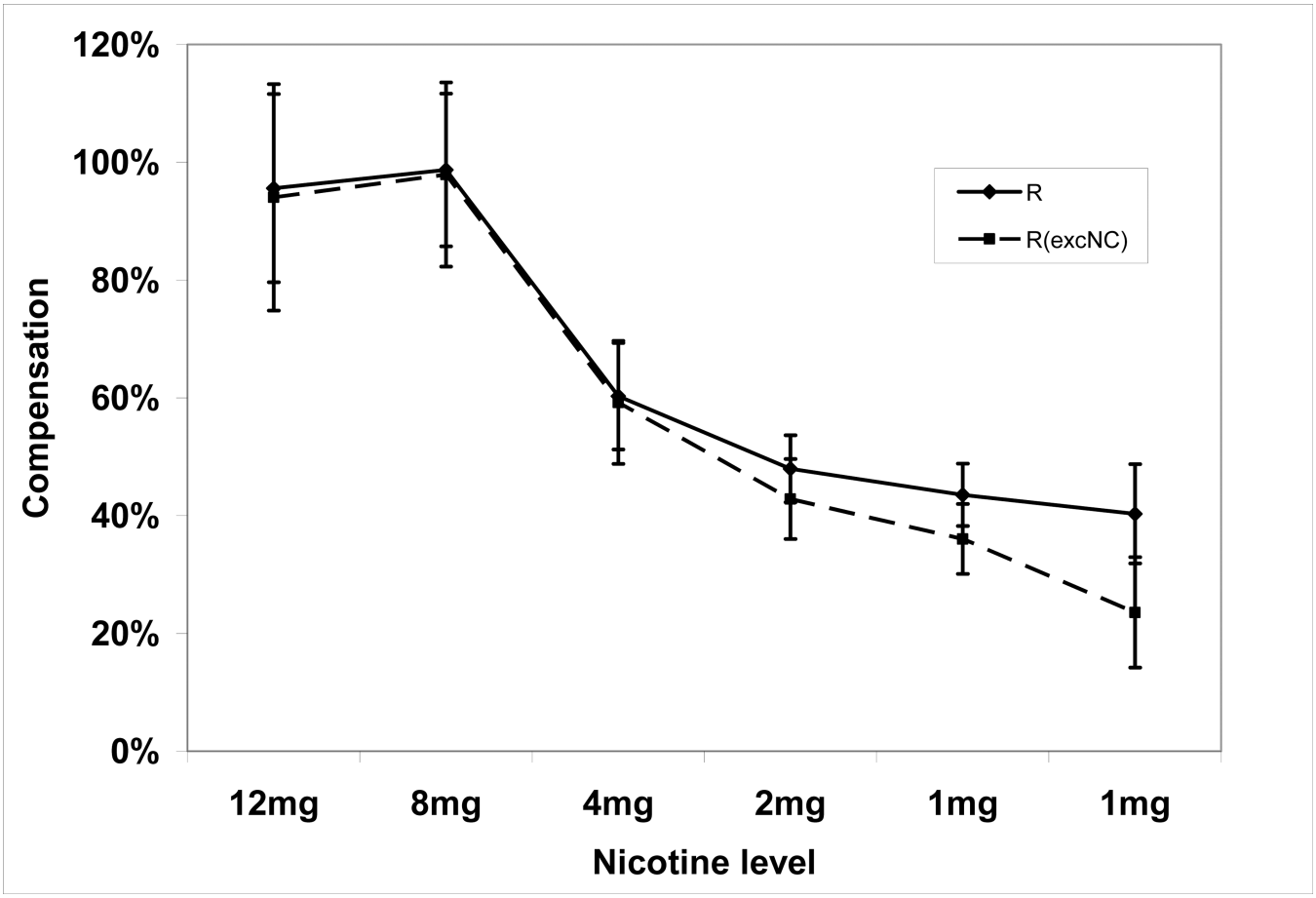

Fig. 2.
Mean percent compensation for smokers during nicotine reduction at different levels of nicotine content. Compensation is calculated based on plasma cotinine levels and machine-determined nicotine yields comparing RNCs to the usual brand.

Table 1

Characteristics of research cigarettes

	Research cigarettes nominal nicotine content				
	12 mg	**8 mg**	**4 mg**	**2 mg**	**1 mg**
Measured nicotine content (mg)	10.3	6.5	3.9	1.7	0.5
Tobacco weight (mg)	636	636	615	626	650
FTC method					
Nicotine (mg)	0.9	0.6	0.4	0.2	0.1
Tar (mg)	11.0	9.9	9.5	9.9	11.0
Carbon monoxide (mg)	11.4	11.5	10.1	10.3	11.9
NNK (ng)	49.3	41.4	42.9	26.1	29.6
NNN (ng)	109.7	79.5	127.7	59.9	52.6

Abbreviation: NM, not measured

*Mean (standard deviation)

Machine testing of research cigarettes using standard U.S. Federal Trade Commission procedures were performed by the U.S. Centers for Disease Control and Prevention.

Table 2

Demographic Comparisons by Group (mean, 95% C.I.)

Characteristic	Control group (*n* = 50)	Research group (*n* = 53)	Drop outs (n=32)
Age, yrs	37.4 (34.4,41.0)	36.6 (33.4,39.2)	36.6 (32,41)
Gender			
Male	31	25	20
Female	19	28	12
Race/Ethnicity (%)			
Caucasian	70	70	78
AA	8	8	0
Asian	10	6	0
Other/mixed	12	16	22
BMI	24.8 (24.5,25.0)	26.3 (26.1,26.6)	25.8 (23.4,28.2)
Education, yrs	15.7 (14.9,16.1)	15.1 (14.6,15.8)	14.5 (9 – 17)
CPD	19.9 (17.9,22.0)	23.4 (21.5.25.4)	24.3 (20.9, 27.8)
Years smoked	21.4 (17.9,24.8)	20.5 (17.5,23.5)	19.9 (15.4,24.5)
Menthol n (%)	5 (10)	6 (11)	3(9)
FTC nicotine (mg)	1.0 (0.9,1.0)	1.0 (0.9,1.0)	1.0 (0.9,1.1)
FTC tar (mg)	11.6 (10.8,12.3)	11.4 (10.6,12.1)	11.8 (10.7, 13.0)
FTND score	5.5 (4.9,6.2)	5.6 (5.2,6.1)	6.5 (5.7,7.4) *

*Significant difference at p< 0.05

Table 3

Smoking behavior and biomarkers of exposure while smoking reduced nicotine cigarettes means

Characteristic	Baseline – Week 2 (usual) Control (n=50) Research (n=53) Research (compliant) (n=42)	Week 14 (4 mg) Control (n=50) Research (n=53) Research (compliant) (n=42)	Week 26 (1 mg) Control (n=40) Research (n=53) Research (compliant) (n=42)	Significant effects p<0.0166 R = RNC C = Control
Cigarettes per day†	19 (17, 21) 22 (20, 24) 22 (19, 25)	21 (18, 23) 24 (21, 27) 24 (21, 28)	22 (19, 25) 20 (17, 23) 20 (17, 24)	W26 vs. W14: R W26 vs. W2: R vs. C W26 vs. W14: R vs. C
Plasma nicotine ng/mL†	17 (14, 20) 15 (13, 17) 15 (13, 17)	18 (15, 21) 10 (8, 11) 9 (7, 11)	16 (13, 19) 7 (5, 10) 4 (3, 6)	W14 vs. W2: R W26 vs. W2: R W14 vs. W2: R vs. C W26 vs. W2: R vs. C
Plasma cotinine ng/mL†	256 (220, 293) 256 (225, 287) 252 (215, 289)	255 (218, 292) 131 (106, 202) 121 (92, 152)	240 (202, 278) 113 (81, 145) 76 (49, 105)	W14 vs. W2: R W26 vs. W2: R W14 vs. W2: R vs. C W26 vs. W2: R vs. C
Expired CO (ppm)†	20 (18,23) 21 (19,24) 21 (18,24)	24 (20,27) 25 (22,28) 25 (21, 28)	20 (18,23) 23 (19,27) 22 (19, 27)	W14 vs W2: R
Urine (pmol/mg creatinine)*				
Total NNAL	1.0 (0.7, 1.3) 1.4 (1.1, 1.7) 1.3 (1.0, 1.6)	0.9 (0.7, 1.2) 1.2 (1.0, 1.5) 1.2 (1.0, 1.4)	0.9 (0.6, 1.2) 0.8 (0.5, 1.1) 0.7 (0.5, 0.9)	W26 vs. W2: R W26 vs. W14: R W26 vs. W2: R vs. C W26 vs. W14: vs. C
Sum of phens	3.5 (2.8, 4.4) 4.0 (3.3, 4.7) 3.7 (3.1, 4.5)	3.5 (2.9, 4.4) 3.8 (3.3, 4.3) 3.5 (3.0, 4.0)	4.0 (3.3, 4.7) 3.9 (3.1, 4.8) 4.0 (3.1, 5.2)	NS
2-naphthol	97 (73, 129) 161 (123, 210) 166 (122, 227)	91 (66, 127) 142 (113, 180) 137 (104, 179)	112 (92, 136) 137 (107, 174) 151 (119, 192)	NS
Sum of fluors	13 (10, 17) 17 (14, 22) 17 (14, 22)	12 (9, 17) 18 (15, 22) 18 (14, 22)	15 (12, 18) 17 (13, 23) 20 (15, 26)	NS
1-hydroxypyrene	1.1 (0.9, 1.5) 1.4 (1.1, 1.7)	1.2 (0.9, 1.6) 1.4 (1.2, 1.6)	1.4 (1.1, 1.6) 1.5 (1.2, 1.9)	NS

Characteristic	Baseline – Week 2 (usual) Control (n=50) Research (n=53) Research (compliant) (n=42)	Week 14 (4 mg) Control (n=50) Research (n=53) Research (compliant) (n=42)	Week 26 (1 mg) Control (n=40) Research (n=53) Research (compliant) (n=42)	Significant effects p<0.0166 R = RNC C = Control
	1.3 (1.1, 1.7)	1.3 (1.1, 1.5)	1.6 (1.2, 2.1)	

*geometric means

†arthimetic mean (95% C.I.)