Associations of physical activity and dietary macronutrient changes with smoking abstinence

Kate E. Worwag[1], Janet Audrain-McGovern[2], Meghan L. Butryn[3], Erica M. LaFata[4]

AFFILIATION
1 Department of Clinical and Health Psychology, University of Florida, Gainesville, United States
2 Department of Psychiatry, Perelman School of Medicine, University of Pennsylvania, Philadelphia, United States
3 Center for Weight, Eating, and Lifestyle Science, Drexel University, Philadelphia, United States
4 Oregon Research Institute, Springfield, United States

CORRESPONDENCE TO
Kate E. Worwag. Department of Clinical and Health Psychology, University of Florida, Health Professions, Nursing, Pharmacy Building, 1225 Center Dr, Gainesville, FL 32603, United States
E-mail: kworwag@ufl.edu
ORCID iD: https://orcid.org/0009-0008-4555-9971

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ABSTRACT

INTRODUCTION Research on lifestyle modification interventions for smoking cessation often focuses on physical activity and calorie restriction, with little research exploring whether dietary macronutrient modifications may relate to smoking abstinence. The current study examined associations between changes in physical activity, energy intake, and macronutrient intake with smoking abstinence. It was hypothesized that increases in physical activity duration, added sugar intake, and saturated fat intake would be associated with higher rates of successful abstinence.

METHODS We conducted a secondary longitudinal analysis of a randomized controlled trial conducted at the University of Pennsylvania, Philadelphia, from September 2016 to February 2021. Adults seeking smoking cessation received an 8-week intervention and completed the Automated Self-Administered 24-Hour Dietary Assessment Tool (ASA24) and the 7-day Physical Activity Recall at baseline, end-of-treatment, and at follow-up at 26 weeks. Logistic regression models tested whether changes in energy and macronutrient intake (saturated fat, added sugar, fiber, and protein) and physical activity duration were associated with smoking abstinence (yes, no for 7-day point prevalence abstinence, confirmed by carbon monoxide test) at each visit.

RESULTS A total of 325 adults (59.1% Black) showed increases in protein intake from baseline to follow-up that were significantly associated with improved abstinence rates ($p=0.009$), and increases in saturated fat were associated with lower abstinence rates, with the results in our sample however, not reaching statistical significance ($p=0.085$). Changes in physical activity and energy intake were not significantly associated with smoking abstinence ($p>0.198$). When relative contributions of each predictor were compared, macronutrients (particularly increases in protein) explained the greatest amount of variance in abstinence.

CONCLUSIONS The present findings show that increases in protein intake were significantly associated with improved abstinence rates, while increases in saturated fat were associated with a trend towards lower abstinence rates. This highlights the importance of further investigating macronutrient intake in relation to abstinence adherence, particularly in individuals who identify as Black.

CLINICAL TRIAL REGISTRATION: The study is registered on the official website of ClinicalTrials.gov
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INTRODUCTION

Tobacco use is the leading cause of preventable death worldwide, with an expected 400 million tobacco-related deaths projected between 2010 and 2050[1]. Approximately 68% of individuals who smoke want to quit, yet fewer than one in ten successfully do[2]. Evidence-based smoking cessation interventions often include a combination of psychological approaches, self-management techniques, and pharmacological interventions. Yet, long-term abstinence rates range from 6.5–34.6%, showing a need for additional interventions to improve long-term outcomes[3]. Physical activity (PA) and dietary changes have been previously explored as possible adjunctive smoking cessation treatments due to their low cost and accessibility[3].

Associations between PA and smoking abstinence

Studies suggest that PA is an effective acute intervention for smoking cessation as it reduces uncomfortable symptoms (e.g. cravings, withdrawal) that may arise after a quit attempt[4-7]. Daniel et al.[4] demonstrated that 5 minutes of moderate-intensity exercise resulted in immediate, yet short-lived (i.e. lasting 10 minutes) reductions in the desire to smoke and tobacco withdrawal symptoms. When looking at long-term effects (e.g. six months post-cessation), most studies find null effects of PA on smoking abstinence[8,9]. However, the high attrition rates and poor treatment adherence make it difficult to draw conclusions. To our knowledge, two randomized controlled trials in women found higher[10] or equivalent[11] abstinence rates at the end of treatment, as well as 3- and 12-months following treatment in a PA + Nicotine Replacement Therapy (NRT) group and cognitive behavioral therapy (CBT) + NRT group, respectively, compared to controls. Thus, further exploration is warranted to understand the long-term role of PA as an adjunctive intervention component for smoking cessation.

Associations between diet and smoking abstinence

Prior research shows that dietary choices are significantly impacted by smoking cessation. Multiple recent studies show that ultra-processed foods, especially those high in refined carbohydrates and saturated fat, activate the same dopaminergic pathways implicated in drug dependence[12-14]. For example, Volkow et al.[14] demonstrated that both drug cues and energy-dense foods recruit the dopamine motive system, driving heightened motivation, cue-reactivity, and compulsive reward seeking across substance and food addiction phenotypes. Complementing this, Kenny[12] reviews evidence that excessive intake of hyperpalatable foods induces neuroadaptive changes in mesoaccumbens dopamine circuits similar to those observed in drug addiction, suggesting shared molecular and systems-level mechanisms between overeating and substance use disorders. Together, these findings highlight that individuals who quit smoking may experience increased sensitivity to rewarding foods not merely as a behavioral substitution, but due to shared dopaminergic mechanisms underlying reward, craving, and withdrawal across nicotine and hyperpalatable food reinforcement. Thus, individuals often consume more foods high in calories, fat, and sugar post-cessation[15]. While research has examined this heightened period of reward sensitivity[16,17], few studies have explored whether changes in dietary intake are associated with smoking cessation outcomes.

In addition to the heightened sensitivity to rewarding foods after quitting, certain macronutrients may play a more stabilizing role during cessation. Protein and fiber, in particular, have been shown to increase satiety and support more stable post-meal glucose responses, which may help counter the increased hunger, cravings, and weight-gain concerns that many individuals experience after stopping smoking. Protein also provides amino acid precursors (e.g. tyrosine and tryptophan) that contribute to dopamine and serotonin synthesis, offering a plausible biological pathway through which higher protein intake could modulate reward sensitivity and withdrawal-related mood fluctuations[18]. These characteristics make protein and fiber theoretically relevant 'protective' macronutrients to consider when examining dietary changes during smoking cessation.

Most studies have explored associations between dietary intake and smoking cessation in relation to calorie restriction, yet results remain mixed[19-22]. A very low-calorie diet was associated with both increased cigarette use and reduced the ability to resist smoking[20,22], and with decreased abstinence rates[19-22]. Overall, it appears calorie restriction is not consistently effective for smoking cessation.

Beyond energy intake, significant reductions in carbohydrates have shown promising early evidence for smoking abstinence, especially when participants achieve ketonuria, which has been hypothesized to decrease the urge to smoke[23]. Further, two studies have observed that the administration of 12 g of glucose resulted in acute improvements in nicotine withdrawal symptoms for up to 32 minutes[24,25]. These preliminary data highlight the potential role of macronutrient-related dietary changes for smoking cessation. However, existing literature has only minimally explored how intake of added sugar or other macronutrients like saturated fat, protein and fiber may be related to long-term outcomes for smoking abstinence.

The current study

Prior studies demonstrate that PA reduces cravings for rewarding foods and that intake of reinforcing foods relates to engagement in PA[26,27]. PA may also influence abstinence through its effects on reward circuitry, as acute bouts of exercise have been shown to reduce cue-reactivity and modulate dopaminergic signaling in ways that parallel reductions in both food- and drug-related reward sensitivity[5,6,27,28] Thus, exploring the effects of changes in PA and dietary intake on tobacco abstinence may provide additional context needed to inform future smoking cessation interventions. The present study builds upon prior literature in three novel ways. First, this study explores whether changes in macronutrient intake are associated with successful smoking abstinence. Second, this article compares the relative contributions and potential interactions of PA and dietary intake on smoking abstinence. Lastly, this study examines the relationship between changes in macronutrient intake and smoking abstinence at the longest follow-up time point in the literature: 26 weeks post-cessation.

The current study includes two primary aims. The first aim is to establish the individual contributions of PA duration and changes in energy and macronutrient intake (at end-of-treatment [EOT] and follow-up at 26 weeks) on smoking abstinence in the current sample. It is hypothesized that increased PA duration (at EOT), added sugar and saturated fat intake (at both EOT and follow-up) will be associated with greater rates of successful abstinence. The second aim is to compare the relative contributions of energy intake and PA, and macronutrient intake and PA on abstinence adherence.

METHODS

The current study reflects a longitudinal secondary data analysis of a larger clinical trial evaluating the efficacy of a behavioral activation intervention for smoking abstinence (R01CA206058; PI: J. Audrain-McGovern). The study was conducted at the University of Pennsylvania between September 2016 and February 2021. For a detailed description of the primary study's procedure, please see Audrain-McGovern et al.[29].

Study procedures

The study took place at the University of Pennsylvania, conducted in accordance with ethical procedures (e.g. informed consent) and Institutional Review Board (IRB) approval. The primary study randomized participants into one of two intervention groups, both of which received transdermal nicotine throughout treatment. The control group received standard CBT-based smoking cessation counseling, while the behavioral activation group built upon this by encouraging daily engagement in reinforcing activities that did not include cigarettes or food (e.g. spending time with family) for the 8 weeks of treatment. In the parent study[29], abstinence did not differ by treatment condition ($p>0.232$) and thus, both groups were combined to increase power.

Measures

Smoking abstinence (EOT, follow-up at 26 weeks)

Primary outcome variable; assessed using a binary abstinence indicator, where participants were classified as either abstinent (high abstinence score) or not abstinent (low abstinence score) at each time point. Abstinence was defined as 7-day point-prevalence abstinence, biochemically verified using expired carbon monoxide (CO <5 ppm) measured at the assessment visit[30,31].

Dietary intake (change from baseline to EOT and baseline to follow-up at 26 weeks)

Kilocalorie and type of macronutrient (added sugar, fiber, saturated fat, protein) intake in the past 24 hours was assessed using the Automated Self-Administered 24-Hour Dietary Assessment Tool (ASA24®) at baseline, EOT and follow-up at 26 weeks. The above-mentioned macronutrients were chosen to maintain a diverse range of dietary factors, while reducing multicollinearity. Added sugar was chosen over total sugar as a better representation of reinforcing foods (e.g. candy compared to an apple). Saturated fat has been specifically studied as a reinforcing ingredient and was therefore selected over monounsaturated and trans-fat[32]. Finally, protein and fiber were chosen as potentially protective macronutrients due to their ability to increase satiety and slow the absorption of carbohydrates in the food.

Physical activity (change from baseline to EOT and baseline to follow-up at 26 weeks)

Physical activity was measured in minutes using the 7-day Physical Activity Recall[33].

Covariates

Sex assigned at birth was coded as a dichotomous variable (male, female). Race and ethnicity were combined due to small cell sizes and recoded as a dichotomous variable (Non-Hispanic White vs All Other Races/Ethnicities). Education was coded as a five-level categorical variable: 1) grade school, 2) some high school, 3) high school graduate or GED, 4) some college or technical school, and 5) college graduate or beyond. Annual household income ($) was coded as a five-level categorical variable: 1) <20000, 2) 20000–35000, 3) 35001–50000, 4) 50001–75000, and 5) >75000. NRT patch use was treated as a dichotomous variable (used vs did not use); original adherence categories (<1, 1–10, 11–24 hours) were collapsed due to low frequencies. Quantitative variables included physical activity duration (minutes/week), total daily energy intake (kcal), and macronutrient intake (g/day of protein, carbohydrates, total fat, and saturated fat).

Statistical analysis

Descriptive statistics were computed for all baseline variables and are presented in Table 1. Categorical variables are reported as frequencies and percentages, and continuous variables are summarized using means and standard deviations, along with observed ranges.

To identify potential confounders, univariable associations between all candidate covariates and smoking abstinence were evaluated using chi-squared tests for categorical variables and t-tests or correlations for continuous variables. Race/ethnicity was significantly associated with abstinence at both time points, and NRT patch use was associated with abstinence at end-of-treatment; therefore, these variables were included in all corresponding multivariable logistic regression models. All analyses were conducted using SPSS v28, with two-sided $\alpha=0.05$. Analyses were conducted using complete-case procedures; participants with missing data on any variables required for a given model were excluded from that model only.

Multivariable logistic regression was conducted for both aims, using SPSS v28. All non-dichotomous predictor variables were centered before being added to each model, and unstandardized regression coefficients were reported to allow for interpretations to align with initial measurements (e.g. cal, g). Two models were built for the first aim, one with the outcome variable specified as abstinence (yes, no) at EOT and the second at follow-up at 26 weeks. Race/ethnicity and NRT patch use were added as covariates in block one. Next, the change in PA duration, energy, or macronutrient intake from baseline to the corresponding study assessment was added into block two of three separate models.

To evaluate aim 2, PA duration was added in block three of the two aforementioned logistic regression models with either a change in energy or intake of the four macronutrients specified in block two. This resulted in four logistic regression models to test aim 2, with two models focusing on changes in energy intake and two on changes in macronutrient intake (at EOT and follow-up at 26 weeks). Change in Nagelkerke's R^2 was used to comparatively assess which variables were more associated with abstinence adherence in each model.

The authors note that further information concerning the methods and procedures of the primary study can be found at Audrain-McGovern et al.[29] or at ClinicalTrials.gov (NCT02906787). The secondary analyses pertaining to this article were not preregistered. Materials and analysis code for this study are available upon request.

RESULTS

Sample characteristics

The final sample consisted of 325 treatment-seeking individuals aged 18–65 years who smoked more than five cigarettes a day. All available data from the primary study were used, and no participants were excluded from analyses. Of the participants, 42.2% were women, and the sample was diverse in terms of racial identification, with 59.1% of participants identifying as Black, 35.7% as White, and 5.2% identifying as members of another race. Participants reported substantial variability in smoking behavior, including total cigarettes smoked after the quit attempt (mean=409.0, SD=659.0; range 0–3650). Most participants (90.2%) used nicotine replacement therapy (NRT) for 11–24 hours per day, with smaller percentages reporting shorter or no use. A total of 37 participants (11.4%) did not complete the follow-up at 26 weeks visit. See Table 1 for full sample characteristics.

Abstinence outcomes by race/ethnicity

Race/ethnicity was significantly associated with smoking abstinence at EOT (χ^2[1, 288]= 4.01, p=0.045) and follow-up (χ^2[1, 288]=5.21, p=0.022). At followup, a greater proportion of participants identifying as non-Hispanic White were abstinent compared with those identifying as other races/ethnicities (27.2% vs 16.1%). Among participants who did not complete the 26-week visit (n=37), no significant differences in combined race/ethnicity were observed (p= 0.911).

Associations between PA, energy intake, and dietary macronutrients and abstinence adherence

Among those retained, biochemically verified abstinence rates were 32.6% at end-of-treatment (EOT) and 20.5% at follow-up. Across behavioral and dietary predictors, there were no significant associations between changes in physical activity (PA) duration and higher abstinence at either EOT (adjusted odds ratio, AOR=0.999; 95% CI: 0.997–1.002, p=0.644) or follow-up (AOR=1.001; 95% CI: 0.998–1.004, p=0.449), nor between changes in energy intake and abstinence at EOT (AOR=1.000; 95% CI: 1.000–1.000, p=0.806) or follow-up (AOR=1.000; 95% CI: 1.000–1.001, p=0.198). Similarly, changes in macronutrient intake were not associated with abstinence at EOT (p>0.359). Specifically, changes in added sugar (AOR=0.990; 95% CI: 0.969–1.012, p=0.359), fiber (AOR=1.009; 95% CI: 0.971–1.048, p=0.639), protein (AOR=1.003; 95% CI: 0.994–1.012, p=0.499), and

Table 1. Baseline sample characteristics, secondary analysis of a randomized controlled trial, University of Pennsylvania, September 2016–February 2021) (N=325)

Characteristics	n (%)
Age (years), mean (SD) (range)	45.9 (11.9) (19–65)
Sex	
Male	188 (57.8)
Female	137 (42.2)
Other/prefer not to say	5 (1.8)
Race	
Black	192 (59.1)
White	116 (35.7)
Asian	4 (1.4)
American Indian/Alaska Native	1 (0.3)
More than one race	7 (2.2)
Unknown or not reported	5 (1.5)
Ethnicity	
Non-Hispanic/Latinx	304 (93.5)
Hispanic/Latinx	20 (6.2)
Education level	
Lower than high school	16 (4.9)
High school graduate/GED	101 (31.1)
Some college/technical school	125 (38.5)
College graduate and higher	83 (25.5)
Total cigarettes smoked after quit attempt, mean (SD) (range)	409.0 (659.0) (0–3650)
Typical daily NRT use (hours)*	
Never use	2 (0.8)
<1	13 (5.3)
1–10	9 (3.7)
11–24	222 (90.2)

*Typical daily NRT use refers to the number of hours per day participants reported using transdermal nicotine patch.

Table 2. Association between changes in macronutrient intake from baseline to follow-up at 26 weeks and smoking abstinence at follow-up at 26 weeks, secondary analysis of a randomized controlled trial, University of Pennsylvania, September 2016–February 2021 (N=325)

	B	SE	Wald χ^2	p	AOR	$R^{2§}$	χ^2(df)	p
Constant	-0.39	0.24	2.71	0.100	0.68			
Block 1						0.07	10.08 (1)	0.001
Race+	-1.05**	0.33	10.38	0.001	0.35			
Block 2						0.12	7.64 (4)	0.106
Change in added sugar intake	0.003	0.01	0.04	0.838	0.00			
Change in fiber intake	-0.01	0.03	0.13	0.722	0.99			
Change in protein intake	0.02**	0.01	6.77	0.009	1.02			
Change in saturated fat intake	-0.03	0.02	2.96	0.085	0.98			
Model						0.12	17.72 (5)	0.003

Logistic regression model showing associations of changes in macronutrient intake from baseline to follow-up with 7-day point-prevalence abstinence at follow-up at 26 weeks. B: unstandardized logistic regression coefficient. SE: standard error. AOR: adjusted odds ratio. + Race coded as: Non-Hispanic White (reference) and All other races/ethnicities. § Nagelkerke's R^2. *p<0.05, **p<0.01, ***p<0.001.

saturated fat (AOR=0.997; 95% CI: 0.973– 1.022, p=0.823) were all non-significant predictors of abstinence at EOT.

However, the model was significant at follow-up [$\chi^2(5)$=17.72, p=0.003, Nagelkerke's R^2= 0.12], such that it was able to correctly predict 71.8% of cases. Race was responsible for the greatest variance [$\chi^2(1)$=10.08, p=0.001, Nagelkerke's R^2=0.07], yet macronutrients, particularly protein, added additional explanatory power. Specifically, every additional gram of protein intake beyond the sample mean at follow-up compared to baseline was associated with 2% higher abstinence after controlling for race (AOR=1.02; 95% CI: 1.01–1.03). For example, adding ~12 g of protein per day (about the amount in two eggs) corresponds to an estimated 27% higher odds of abstinence, based on the model's AOR of 1.02 per gram.

A descriptive, but not statistically significant trend (p=0.085) in saturated fat was observed, such that increases in saturated fat were associated with lower abstinence. In the model where all insignificant macronutrients were removed, both race and protein remained significantly associated with abstinence (p=0.002 and 0.042, respectively). The possibility of an interaction between race and protein intake was tested; however, no interaction was observable (p>0.515). No other interactions were tested as no other predictor variables were significant.

The relative contributions of PA, energy, and macronutrient intake on abstinence adherence

Logistic regression revealed that energy intake explained no additional variance beyond race at both EOT and follow-up (Nagelkerke's R^2 change = 0.00). Therefore, PA was more associated, yet not significantly (p>0.518), with abstinence when compared to energy intake (p> 0.867) at both time-points (Nagelkerke's R^2 change = 0.005 and 0.006, respectively). Macronutrients were able to explain more variance in the model than PA. At EOT, the change in Nagelkerke's R^2 was 0.01 for the block with macronutrients (p>0.344), greater than the change of 0.007 for the block with PA (p>0.479). At follow-up, macronutrients (e.g. protein; p>0.024) once again explained a greater amount of variance (Nagelkerke's R^2 change = 0.09) compared to PA (p>0.797; Nagelkerke's R^2 change = 0.001). Overall, there was a greater improvement in the model's overall fit and explanatory power when macronutrients were added, compared to PA. Yet PA was able to explain more variance when compared to energy intake.

DISCUSSION

This study found that increases in protein intake from baseline to follow-up were associated with higher rates of smoking abstinence, whereas increases in saturated fat were associated with a descriptive, yet not statistically significant, trend toward decreased abstinence rates. When comparing the relative contributions of changes in PA duration and changes in macronutrient intake to smoking abstinence, increases in macronutrient intake from baseline to follow-up explained the greatest amount of variance in the model, although explained variance was modest overall, consistent with behavioral outcome models. These observational findings suggest that dietary patterns may be relevant correlates of cessation success and merit testing in prospective and experimental designs.

The effects of changes in dietary intake on smoking abstinence

Protein

The exact mechanisms underlying dietary protein intake and its implications for abstinence are unclear, although an interpretation can be gleaned from prior literature. Increases in protein consumption have been shown to stimulate dopamine and serotonin synthesis in rodents[14,18]. These neurotransmitters are involved in symptoms of addiction, including craving and withdrawal, making it plausible that protein intake could influence neural mechanisms related to addiction. Importantly, nicotine use increases dopamine concentration in the nucleus accumbens, and smoking cessation leads to decreases in dopamine that trigger cravings for nicotine[34]. If dietary protein were to increase dopamine synthesis in humans, consuming protein could ameliorate the dip in dopamine and moderate nicotine cravings. Further, increased synthesis of serotonin from protein intake may improve the physical and psychological side effects of nicotine withdrawal, such as enhancing satiety and improving mood[14,34]. Therefore, dietary protein might improve smoking cessation outcomes by balancing neurotransmitters implicated in substance craving and withdrawal. However, future research is needed to explore these potential biological processes and their impact on smoking abstinence and withdrawal symptoms.

Alternatively, an individual who successfully quits smoking may also be the type of person to adopt healthier dietary habits (i.e. increasing protein). Future studies might explore whether protein intake is a proxy for general health behavior change or whether there is a direct implication of protein intake on successful smoking abstinence. Baseline dietary patterns may also shape the magnitude of macronutrient changes, as smokers typically consume fewer fruits and vegetables and more processed foods than non-smokers. Expressing macronutrients as a percentage of total energy intake could clarify whether increases in protein reflect true dietary shifts or changes in energy distribution.

Saturated fat

Given prior research supporting the reward replacement hypothesis[15,29], it was expected that increased intake of reinforcing macronutrients (e.g. sugar, fat) would 'replace' the reward deficit caused by quitting nicotine and therefore improve abstinence outcomes. However, changes in added sugar were not associated with abstinence, and, surprisingly, increases in saturated fat from baseline to follow-up were associated with a descriptive, non-significant trend toward lower abstinence rates. One explanation is that both sugar and saturated fat are proxies for ultra-processed foods (UPFs), yet a broader range of UPFs contain saturated fat[12].

It is also important to note that participants randomized to the behavioral activation intervention were explicitly encouraged to engage in reinforcing activities that did not include food. This instruction may have suppressed what might otherwise be a natural tendency to increase intake of rewarding foods following cessation. As a result, the expected substitution of nicotine reward with highly palatable foods (i.e. the reward-replacement hypothesis) may have been attenuated by the intervention design. This tension between the intervention goals and the theoretical model should be considered when interpreting the null findings for added sugar and the descriptive trend observed for saturated fat.

Given the lack of statistical significance, interpretations for saturated fat remain exploratory. One hypothesis is that increased intake of nicotine and saturated fat could represent a broader pattern of heightened reward sensitivity early in smoking, consistent with evidence linking dopaminergic responses to greater reward seeking[12,15,28,29]. However, this pattern requires confirmation in future work using stronger dietary assessment tools and larger samples.

Understanding the intake of rewarding foods (e.g. those high in saturated fat) also has implications for post-cessation weight gain (PCWG), which is associated with increased energy consumption[12,15,29]. Previous research shows that PCWG is a major barrier to maintaining abstinence and might moderate the relationship between saturated fat and abstinence[29]. Furthermore, metabolic changes accompanying early weight gain, including increased appetite, altered reward processing, and changes in energy balance, may heighten vulnerability to relapse. These mechanisms should be examined in future studies.

Energy intake

Prior research regarding energy intake has largely focused on calorie restriction, and thus, because calorie intake did not significantly change from baseline to follow-up in this sample, it is unsurprising that the change in energy intake was not associated with abstinence outcomes.

The effects of changes in PA on smoking abstinence

While many studies have examined the effects of PA on smoking abstinence, most studies, including the current one, have found null effects at six months post-cessation[8,9,35]. Additionally, the current study made no recommendations to alter participants' PA habits, so the lack of significant findings is not surprising. It is possible that individuals in the behavioral activation condition could have chosen PA as an alternative reinforcing activity, though any changes to PA were not associated with abstinence outcomes. Because the 7-Day Physical Activity Recall is subjective, recall and social desirability bias may have reduced measurement precision. Objective methods (e.g. accelerometry) would permit more accurate estimation of habitual activity and may clarify whether PA contributes to abstinence in the long term.

Association of racial identification with smoking abstinence

In the current sample, participants identifying as non-Hispanic and White were more likely to remain abstinent at follow-up compared to those identifying as other races and ethnicities. No differences in combined race/ethnicity were observed among individuals who did not complete the follow-up at 26 weeks. This pattern may relate to documented disparities in access to cessation resources and the importance of social support for individuals from diverse backgrounds[36].

Limitations

Several study limitations should be acknowledged. First, the ASA24 depends on participants' ability to accurately remember and report their food intake, which can lead to information bias, misclassification of dietary intake, and may not capture all foods consumed (e.g. oil, condiments, or snacks consumed outside of regular mealtimes). Further, examining foods holistically rather than strictly by macronutrient composition may yield additional insight. Rather than coding foods as UPFs, the secondary nature of these analyses only allowed for a proxy of UPFs.

Second, the longest follow-up period in the current trial was 26 weeks, whereas previous studies have reported effects of diet and PA up to 12 months after treatment ends[6,9]. Additionally, 37 participants did not complete the study, and while no significant racial differences were observed, it is possible that other significant differences exist between those who remained enrolled and those who dropped out. Specifically, individuals who were unable to maintain abstinence may be more likely to drop out. Therefore, the present results are only generalizable to adults who have similar treatment-seeking motivations and smoking habits. Using a single 24-hour dietary recall at each time point also introduces substantial intra-individual variability and may not fully represent habitual intake. Multiple recalls or food-frequency questionnaires would provide more stable estimates of the usual diet. Similarly, the self-reported PA measure is vulnerable to recall and social desirability bias.

Finally, as with all observational analyses, the possibility of residual confounding remains despite covariate adjustments. Moreover, because multiple macronutrients were examined across two time points, the study is susceptible to an increased risk of Type I error; corrections for multiple comparisons (e.g. Bonferroni) were not applied due to the exploratory nature of the analyses, and findings, particularly trend-level results, should therefore be interpreted with appropriate caution.

CONCLUSIONS

The current study found that increases in protein intake from baseline to follow-up at 26 weeks were associated with higher rates of smoking abstinence. Increases in saturated fat intake were associated with a descriptive, yet not significant, trend toward lower rates of abstinence, potentially due to increased motivation for reward (e.g. nicotine, UPFs). Finally, when relative contributions of changes in PA, energy, and macronutrient intake were compared, macronutrients (particularly protein) explained the greatest variance in abstinence. These findings suggest that dietary patterns may be relevant to smoking abstinence, but given the observational design, the findings should be interpreted cautiously. Further controlled studies are needed before drawing conclusions about whether altering macronutrient intake can improve cessation outcomes.

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CONFLICTS OF INTEREST
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Ethical approval was obtained from the Institutional Review Board (IRB), University of Pennsylvania (Approval number: 825425; Date: August 2016). Participants provided informed consent.

DATA AVAILABILITY
The data supporting this research are available from the authors on reasonable request.

AUTHORS' CONTRIBUTIONS
KEW: conceptualization, formal analysis, and writing of original draft. JAM: funding acquisition, data curation, supervision. MLB: supervision. EML: conceptualization, supervision. JAM, MLB and EML: reviewing and editing of the manuscript. All authors read and approved the final version of the manuscript.

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