AJCN. First published ahead of print June 4, 2014 as doi: 10.3945/ajcn.113.071589.

Climate change mitigation and health effects of varied dietary patterns in real-life settings throughout North America[1–4]

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ABSTRACT

Background: Greenhouse gas emissions (GHGEs) are a major consequence of our dietary choices. Assessments of plant-based compared with meat-based diets are emerging at the intersection of public health, environment, and nutrition.

Objectives: The objective was to compare the GHGEs associated with dietary patterns consumed in a large population across North America and to independently assess mortality according to dietary patterns in the same population.

Design: Data from the Adventist Health Study 2 (AHS-2) were used to characterize the differential environmental and health impacts of the following 3 dietary patterns, which varied in the quantity of animal and plant foods: vegetarian, semivegetarian, and nonvegetarian. The GHGE intensities of 210 foods were calculated through life-cycle assessments and by using published data. The all-cause mortality rates and all-cause mortality HRs for the AHS-2 subjects were adjusted for a range of lifestyle and sociodemographic factors and estimated according to dietary pattern.

Results: With the use of the nonvegetarian diet as a reference, the mean reductions in GHGEs for semivegetarian and vegetarian diets were 22% and 29%, respectively. The mortality rates for nonvegetarians, semivegetarians, and vegetarians were 6.66, 5.53, and 5.56 deaths per 1000 person-years, respectively. The differences were significant. Compared with nonvegetarians, mortality HRs were lower for semivegetarians (0.86) and vegetarians (0.91).

Conclusions: Moderate differences in the caloric intake of meat products provided nontrivial reductions in GHGEs and improved health outcomes, as shown through the mortality analyses. However, this does not ascertain that diets lower in GHGEs are healthy. *Am J Clin Nutr* doi: 10.3945/ajcn.113.071589.

INTRODUCTION

Climate change is emerging not only as a major environmental and public health issue (1, 2) but also as a threat to food security (3). Paradoxically, although food production is vulnerable to the effects of climate change, the food system itself is a significant contributor to global warming, both globally and in the United States (4, 5). Worldwide, agriculture accounts for at least one-fifth of total anthropogenic greenhouse gas emissions (GHGEs)[5], whereas the aggregate global food sector contributes up to 29% (6). It is now evident that the environmental footprint of food groups varies widely, with meat and dairy products being responsible for a larger share of natural resource utilization and pollution impacts compared with plant foods (7–10). Livestock production alone accounts for 14–51% of total anthropogenic GHGEs based on a range of conservative and more inclusive assessments (11, 12).

To alleviate the environmental pressure imposed by the modern food system, both the average worldwide consumption of animal products and the intensity of emissions from livestock production must decrease (13–16). Recently, there have been calls for a shift in consumer behavior to adopt diets with a lower carbon footprint as a tool not only for climate change mitigation but also for public health improvements (14, 15, 17, 18). Scenarios of reduced consumption of animal products have been shown to affect both population health metrics and environmental sustainability in simulated data. However, to our knowledge, no studies have yet used a single, nonsimulated data set to independently assess the climate change mitigation potential and health effects of the same dietary patterns. Thus, the aims of this study were as follows: *1*) to quantify and compare the GHGEs associated with various vegetarian and nonvegetarian dietary patterns in a large population across North America and *2*) to assess total mortality according to the same dietary patterns in the same population.

METHODS

Data from the Adventist Health Study 2 (AHS-2) were used to characterize and quantify the dietary patterns assessed. The AHS-2 is a large prospective cohort study of Seventh-day Adventists spread throughout the United States and Canada (19). Dietary intake was assessed by a self-administered food-frequency questionnaire of 210 food items including fruit, vegetables, legumes, grains, oils, dairy, fish, eggs, meat, beverages, and commercially prepared products such as dietary supplements, dry cereals, and vegetarian protein products. Dietary patterns were determined according to the reported combined intake of all meats, including

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[2] Presented at the symposium "Sixth International Congress on Vegetarian Nutrition" held in Loma Linda, CA, 24–26 February 2013.

[3] Supported by Loma Linda University School of Public Health, Department of Nutrition, McLean Fund for Vegetarian Nutrition Research.

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[5] Abbreviations used: AHS-2, Adventist Health Study 2; CO_2e, CO_2 equivalents; GHGE, greenhouse gas emission; LCA, life-cycle assessment.

doi: 10.3945/ajcn.113.071589.

fish. Vegetarians rarely or never consumed meats (<1 time/mo), semivegetarians consumed meats >1 time/mo but <1 time/wk, and nonvegetarians consumed meats at least 1 time/wk (20).

A life-cycle assessment (LCA) methodology was implemented to calculate GHGE intensities of the foods consumed by the AHS-2 subjects (21). LCA is being increasingly applied in assessments of the agri-food sector and specific food products (22–24). SimaPro 7.0 software (25) was used to calculate the GHGEs with global warming potential [carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O)] by following the Traci 2 life-cycle impact assessment methodology with a 100-y horizon. An attributional approach was used to allocate emissions and to avoid "double-counting" of ecologic impacts (26), and a sensitivity analysis was performed to quantify the uncertainty of the calculations under given assumptions (27). When calculating the CO_2 equivalents (CO_2e) of items that were either a main product or a byproduct of an industrial process, system extension was performed when feasible; otherwise, mass allocation was performed.

The CO_2e embodied in the 210 foods in the questionnaire were estimated by implementing LCAs and on the basis of published GHGE values. The LCA of 50 foods was based on current cost and return studies for the production of fruit, vegetables, cereals, legumes, and nuts in California (28). The assessments of 6 food items widely consumed by Adventists, including tofu, meat analogs, and breakfast cereals, were based on data directly provided to us by manufacturers. In addition, 23 complex foods were modeled in SimaPro by using recipe information and the food ingredients to estimate their corresponding GHGEs. Emissions data from the literature were obtained for the production of bananas, tomato juice, cashews, sesame seeds, and coconut (26). The GHGEs were estimated for 48 processed products, fish, baked products, cured meats, beverages, and breakfast cereals on the basis of published energy input estimates (29), which were then converted into CO_2e (30). The GHGEs for red meats, poultry, and dairy products were derived from the literature (31, 32). For 66 foods for which data were not available, proxy values were used (*see* Supplemental Material under "Supplemental data" in the online issue). The boundaries for the LCA were defined as follows: plant foods (farm to wholesaler or farm gate); soy-based meat analogs, texturized soy protein, and tofu (farm to factory gate); dairy and other processed products (farm to point of purchase); beef, pork, and poultry [farm to the final meat producer gate; hamburger meat (farm to wholesaler gate)].

Univariate analyses were conducted for each of the demographic factors to assess normality of the data and to test the assumptions of parametric and nonparametric statistical tests. Taken into account were age, sex, race, and dietary pattern (vegetarian, semivegetarian, and nonvegetarian). To compare the individual demographic characteristics of interest, Pearson's chi-square *P* value was computed to determine whether or not the dietary patterns were significantly different. The product-sum method was used to compute dietary GHGEs at the individual level, and mean daily GHGEs were then calculated according to dietary pattern, adjusted to 2000 kcal. Means with SDs were derived for continuous data, and a nonparametric *t* test or ANOVA was used to compare means between dietary patterns.

Age-, sex-, and race-standardized mortality rates were computed by dietary pattern, and tests for differences were conducted by using a nonparametric Wilcoxon-Mann-Whitney test against the nonvegetarian group. Analyses of mortality were conducted by using Cox proportional hazards regression with attained age as the time variable and left truncation by age at study entry. The HRs for all-cause mortality were adjusted for age, race, sex, smoking, alcohol use, exercise, sleep, personal income, education, marital status, geographic region, menopause, and hormone therapy. This mortality analysis replicates that conducted by Orlich et al (33). All analyses were performed by using SAS version 9.3 (TS1M2), revision 13w18 (SAS Institute).

RESULTS

The characteristics and energy intake of the study population according to dietary pattern are presented in **Table 1**. Mean daily intakes according to dietary pattern in percentage of energy intake and in servings per day from each food group are shown in **Table 2**. Meats and plant foods contributed 6.5% and 77% of energy, respectively, in the nonvegetarian diet, whereas they contributed 1% and 88% and 0% and 91% of energy, respectively, in the semivegetarian and vegetarian diets. Plant foods constituted the greatest number of servings for all 3 dietary groups. Compared with semivegetarians and vegetarians, nonvegetarians consumed ∼5 times more meat and ∼2 times more dairy and eggs, respectively. The daily GHGEs estimated for each of the dietary patterns are shown in **Table 3**. From this, the mean annual GHGEs were calculated as 1113, 872, and 788 kg CO_2e for nonvegetarians, semivegetarians, and vegetarians, respectively. With the nonvegetarian diet as reference, the mean percentage change in total GHGEs and change in annual emissions were −29.2% and −325 kg CO_2e for the vegetarian and −21.6% and −241 kg CO_2e for semivegetarian diets, respectively. The relative food group contribution to GHGEs for the 3 dietary patterns is shown in **Figure 1**. As expected, the overall pattern of food emissions reflects the underlying differential consumption of meats and plant foods. Except for meat and plant foods, the proportional contribution to GHGEs from dairy and eggs and other foods was comparable across the 3 diets.

TABLE 1
Sample participant characteristics and daily energy intake according to dietary pattern

	All participants	Nonvegetarian	Semivegetarian	Vegetarian	*P*[1]
n (%)	73,308	35,383 (48.3)	11,197 (15.3)	26,728 (36.5)	
Age (y)	56.8 ± 13.8[2]	55.5 ± 13.4	58.0 ± 14.2	58.1 ± 14.0	<0.01
Sex, female [*n* (%)]	48,203 (67.8)	23,329 (65.9)	7689 (68.7)	17,185 (64.3)	<0.01
Race, black [*n* (%)]	19,780 (27.0)	12,381 (35.0)	3438 (30.7)	3961 (14.8)	<0.01
Total energy (kcal)	1693.1 ± 764.5	1677.3 ± 783.6	1644.8 ± 773.3	1734.2 ± 732.7	<0.01

[1] Proportions were compared by using Pearson's chi-square, and means were compared by using ANOVA.
[2] Mean ± SD (all such values).

TABLE 2
Daily food intake according to dietary pattern[1]

	All participants	Nonvegetarian	Semivegetarian	Vegetarian	P^2
n (%)	73,308	35,383 (48.3)	11,197 (15.3)	26,728 (36.5)	
Percentage of energy					
Meat[3]	5.0 ± 5.7	6.5 ± 5.9	1.4 ± 2.2	0.0 ± 0.0	<0.01
Plant foods[4]	83.9 ± 13.2	77.2 ± 13.4	87.8 ± 9.9	91.1 ± 8.9	<0.01
Dairy/eggs[5]	11.6 ± 9.4	14.4 ± 9.4	10.2 ± 8.8	8.3 ± 8.3	<0.01
Beverages[6]	1.8 ± 4.9	2.8 ± 6.1	1.1 ± 3.6	0.7 ± 2.8	<0.01
Other foods[7]	0.3 ± 1.2	0.1 ± 0.8	0.3 ± 1.0	0.5 ± 1.6	<0.01
Servings/d per person[8]					
Meat[3]	0.69 ± 0.76	0.90 ± 0.78	0.18 ± 0.27	0.00 ± 0.00	<0.01
Plant foods[4]	14.74 ± 5.68	13.01 ± 5.17	15.59 ± 5.60	16.67 ± 5.66	<0.01
Dairy/eggs[5]	1.97 ± 1.52	2.39 ± 1.53	1.74 ± 1.41	1.48 ± 1.37	<0.01
Beverages[6]	6.66 ± 4.36	6.63 ± 4.48	6.58 ± 4.48	6.72 ± 4.13	<0.01
Other foods[7]	2.46 ± 2.12	2.49 ± 2.14	2.26 ± 2.07	2.51 ± 2.11	<0.01

[1] All values are means ± SDs unless otherwise indicated.
[2] Proportions were compared by using Pearson's chi-square, and means were compared by using ANOVA.
[3] Includes beef, lamb, pork, chicken, and fish.
[4] Includes cereals, legumes, vegetables, fruit, nuts, and soy products.
[5] Includes dairy cheese, dairy milk, and eggs.
[6] Includes bottled water, colas, coffees, herbal teas, and beer.
[7] Includes donuts, cookies, cakes, and added fats such as margarines, olive oil, and butter.
[8] Adjusted to 2000 kcal.

Mortality rates and mortality HRs according to dietary pattern are presented in **Table 4**. Mortality rates (95% CIs) for nonvegetarians, semivegetarians, and vegetarians were 6.66 (6.26, 7.05), 5.53 (4.99, 6.08), and 5.56 (5.24, 5.87) deaths per 1000 person-years, respectively. The mortality rate for nonvegetarians was 20% higher than that for vegetarians and semivegetarians. This trend was also reflected in the mortality HRs adjusted for a wide range of lifestyle factors, with lower risks for semivegetarians (0.86; 95% CI: 0.77, 0.96) and vegetarians (0.91; 95% CI: 0.83, 1.00) in comparison with nonvegetarians.

DISCUSSION

Modeled results suggest that public health and environmental sustainability goals for the food system converge under scenarios of reduced meat consumption (34–37). This research is the first, to our knowledge, to assess and confirm those results by independently quantifying the impact of reduced meat scenarios on both GHGEs and health outcomes in nonsimulated data from a large culturally, ethnically, and geographically diverse population sample in North America. Given that meat intake varies among Adventists, they provide an ideal study population for investigating the differential impacts of dietary choices. Limited confounding attributable to other lifestyle factors produces greater statistical power and makes this cohort particularly suited to test the effect of diet on mortality (33) (Table 4). The observational approach to data collection allowed for a realistic and unique assessment of complete and consistent dietary patterns monitored over an extended time period, as actually consumed by large populations. Comparative analyses have relied on either semirealistic average diets based on national food supply and consumption statistics (4, 38) or on designed diets to model various scenarios of nutritional requirements and GHGE reductions (10, 37). However, designed diets may be markedly different from those consumed on a daily basis by real people, and the particular choice of foods that make up the constructed "ideal" diet may reflect the bias of the researcher. Other approaches to evaluating the impact of reducing or removing meat from the diet have focused on single food exchanges. For example, meat is replaced with soy. However, people do not usually replace meat (and its nutrients) with soybeans only. Thus, ultimately, such approaches are likely to produce assessments that are only theoretical, not grounded in reality, potentially leading to bias in the results and limiting their value to guide policy efforts in real-life settings.

Our assessment indicates that relatively minor differences in the substitution of meat by plant foods in populations who adhere to a spectrum of meatless to low/moderate meat dietary profiles translate into nontrivial reductions in GHGEs. To elaborate, moving from the nonvegetarian to the semivegetarian consumption of meat equates to a difference of 25 g (approximately one-third of a standard serving) of ground beef (39). Moving from the nonvegetarian to the vegetarian consumption of meat equates to a difference of 39 g of ground beef (39). Vegetarians and semivegetarians contribute close to one-third and more than one-fifth, respectively, fewer GHGEs than nonvegetarians. The meat intake of the AHS-2 nonvegetarians was ∼2 times less than that of the average American (40). The observed differences in terms of

TABLE 3
Embodied food greenhouse gas emissions, adjusted to 2000 kcal, according to dietary pattern

Dietary pattern	*n*	Mean ± SD	Mean percentage change	Change in annual emissions
		kg CO_2e^1/d	*%*	*kg CO_2e/y*
Nonvegetarian	35,383	3.05 ± 1.02	Reference	Reference
Semivegetarian	11,197	2.39 ± 0.78[2]	−21.6	−240.9
Vegetarian	26,728	2.16 ± 0.66[2]	−29.2	−324.9

[1] CO_2e, carbon dioxide equivalent emissions.
[2] $P < 0.001$ (ANOVA for differences in mean kg CO_2e/d between the 3 dietary groups and Dunn's test for post hoc analysis).

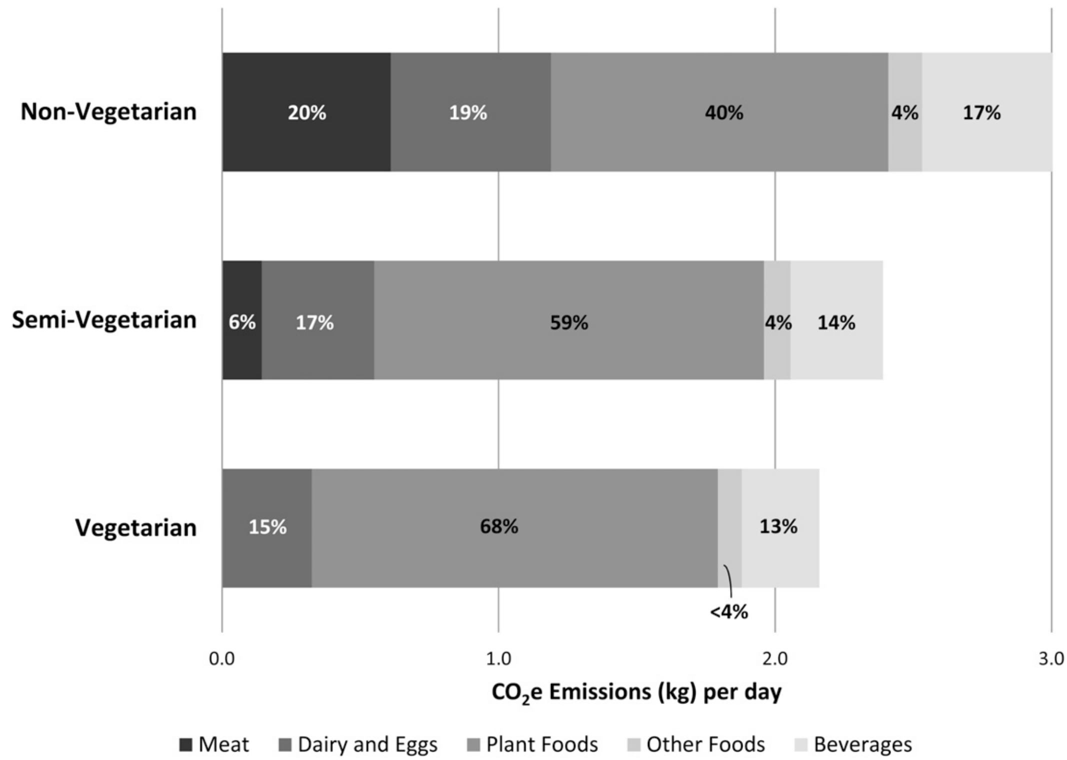

FIGURE 1. Comparison of greenhouse gas emissions (kg CO_2e/d) by major food groups and dietary pattern, adjusted to 2000 kcal. CO_2e, carbon dioxide equivalent emissions.

GHGEs could therefore be greater if compared with the typically nonvegetarian American diet.

In addition to climate benefits, any deliberation focused on reducing the consumption of animal products is of fundamental interest from a public health perspective. Meat-based diets are linked to poor health outcomes (41–43), whereas plant-based diets have positive impacts on human health and life expectancy (20, 44, 45). Our findings are in support of this, with mortality rates 16–17% lower among vegetarians and semivegetarians compared with nonvegetarians (Table 4). In addition, mortality risk across all causes was 9–14% lower among vegetarians and semivegetarians compared with nonvegetarians (Table 4). Given that the HR was adjusted for a number of lifestyle characteristics, including smoking, alcohol use, exercise, sleep, and a range of sociodemographic variables, it is unlikely that the trend observed was intrinsically linked to nondietary lifestyle factors, and hence is relevant to other populations with different lifestyle characteristics. That is, it is reasonable to expect that in a North American, non-Adventist population, a reduction in the consumption of animal products would align with a relative reduction in

TABLE 4
Standardized mortality rates and HRs by dietary pattern for Adventist Health Study 2 participants

	All participants	Nonvegetarian	Semivegetarian	Vegetarian
n	73,308	35,383	11,197	26,728
Time (person-years)	424,512.1	202,364.5	64,709.9	157,437.7
Mean time (y)	5.79	5.72	5.78	5.89
No. of deaths	2570	1154	410	1006
Death rate [deaths/1000 person-years (95% CI)]	6.05 (5.82, 6.29)	6.66 (6.26, 7.05)	5.53 (4.99, 6.08)	5.56 (5.24, 5.87)
P[1]	—	—	0.041	0.001
All-cause mortality [HR (95% CI)][2]	—	1.00 (Reference)	0.86 (0.77, 0.96)	0.91 (0.83, 1.00)

[1] Derived by using 2-sided Wilcoxon-Mann-Whitney test of no difference compared with the nonvegetarian mortality rate.

[2] Adjusted by age (ie, attained age as time variable), sex, race (black or nonblack), smoking (current smoker; quit: <1 y, 1–4 y, 5–9 y, 10–19 y, 20–29 y, or ≥30 y ago; or never smoked), exercise (none; 20, 21–60, 61–150, or 151 min/wk), personal income ($20,000/y, >$20,000–$50,000/y, >$50,000–$100,000/y, or >$100,000/y), educational level (up to high school graduate, trade school/some college/associate degree, bachelor's degree, or graduate degree), marital status (married/common law or single/widowed/divorced/separated), alcohol [nondrinker, rare drinker (<1.5 servings/mo), monthly drinker (1.5 to <4 servings/mo), weekly drinker (4 to <28 servings/mo), or daily drinker (28 servings/mo)], region (West, Northwest, Mountain, Midwest, East, and South), and sleep (4, 5–8, or 9 h/night), menopause [in women; premenopausal (including perimenopausal) or postmenopausal], and hormone therapy (in postmenopausal women; not taking hormone therapy or taking hormone therapy).

mortality risk. It is possible to speculate that some individuals would not opt for plant foods that provide optimum nutrition and instead choose highly processed, high-fat products. However, within the study sample there was a variance in plant food choices, yet favorable health outcomes in comparison with the general population were still observed in previous analyses (45). This variance also shows that individuals were able to autonomously select optimal plant foods across a range of geographic, cultural, ethnic, and socioeconomic environments. Hence, there is reason to assume that this could also occur across other populations.

As with any analysis, care should be taken with regard to outright inferences to the general population, and findings should be understood within a relevant context. It should be noted that the associations between GHGEs and dietary pattern, and mortality with dietary pattern in the wider population, are not directly quantifiable from this analysis and that any inferences made are applicable to Western societies that have adequate access to reduced-meat, or plant-based, food options. The AHS-2 participants are not representative of the US population with respect to certain lifestyle characteristics; however, they are embedded with the rest of the population within the same tapestry of lifestyle demography and local neighborhood geography across North America. This analysis focused on the relation between dietary patterns and GHGEs and the same dietary patterns and mortality. Hence, the direct relation between GHGEs and mortality, independent of lifestyle characteristics, was not explicitly assessed and thus needs to be further explored. Other limitations of this study include potential errors associated with the use of a food-frequency questionnaire in assessing dietary intake, which may lead to misclassification of the exposure. Residual confounding as well as unmeasured and unknown factors may influence the association between the exposure and outcome.

Because of the inconsistent use of LCA boundaries across food groups, this analysis underrepresented plant foods and overrepresented meat in relative terms. However, in absolute terms, meat products consistently have a higher impact regardless of what stage of the LCA is considered. For example, across a range of commonly consumed cooked foods, meats consistently resulted in higher GHGEs compared with plant foods, with the exception of tropical fruit exported overseas by airfreight (8). At the checkout (retail), meats were consistently higher in terms of GHGEs compared with plant foods, with the exception of exotic vegetables (10). Also, an LCA that included land found that meat products were consistently higher compared with plant foods in terms of CO_2e (46). Given that the overall impacts of food LCAs are dominated by production, typically accounting for approximately $\geq$40%, this analysis captured the majority of the impact. For example, for the average American, 54% of carbon consumed through food occurs before the point of consumption (47). Other examples also show this, where production accounted for 75% of CO_2e in eggs, 68% in tuna, 50% in chicken, 90% in beef, 50% in tofu, 80% in nuts, 80% in rice, and 45% in tomatoes (48). Hence, including a full LCA is unlikely to change the general direction of the diet-climate change mitigation potential trend observed in this analysis.

With the use of a novel approach, this analysis adds to current knowledge by confirming the potential of plant-based diets in the reduction of GHGEs. Reduced consumption of meat also benefits health, as shown through the mortality analyses. Our results suggest that even relatively minor reductions in the consumption of animal products, regardless of dietary classification, could yield benefits for human health and the environment independently. Without excluding other important strategies, the modification of diets can be a feasible and effective tool for climate change mitigation and public health improvements because the consumption of particular foods is under the immediate control of consumers and can be influenced by appropriate actions from policy makers.

We are grateful to Michael Orlich for his assistance with access to the AHS data set.

The authors' responsibilities were as follows—SS and JS: designed the research and wrote the article; AM, MB, and KJ-S: conducted the research and data analyses; HH: cowrote and coedited the final draft and customized the tables and figure; and SS: had primary responsibility for the final content of the manuscript. None of the authors had a conflict of interest to declare.

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