PNAS RESEARCH ARTICLE | MEDICAL SCIENCES OPEN ACCESS

Global adherence to a healthy and sustainable diet and potential reduction in premature death

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Edited by Matin Qaim, Rheinische Friedrich-Wilhelms-Universitat Bonn, Germany; received November 30, 2023; accepted May 14, 2024 by Editorial Board Member Pamela C. Ronald

The Planetary Health Diet (PHD), also known as the EAT-Lancet reference diet, was developed to optimize global dietary quality while keeping the environmental impacts of food production within sustainable planetary boundaries. We calculated current national and global adherence to the PHD using the Planetary Health Dietary Index (PHDI). In addition, we used data on diet and mortality from three large US cohorts (n = 206,404 men and women, 54,536 deaths) to estimate the total and cause-specific mortality among adults 20 y of age and older that could be prevented by shifting from current diets to the reference PHD. The PHDI varied substantially across countries, although adherence was universally far from optimal (mean PHDI = 85 out of 140). By improving the global PHDI to 120, approximately 15 million deaths (27% of total deaths) could be prevented annually. Estimates of preventable deaths due to this shift ranged from 2.5 million for cardiovascular diseases to 0.7 million for neurodegenerative diseases. Our analysis suggests that adopting healthy and sustainable diets would have major direct health benefits by reducing mortality due to multiple diseases and could contribute substantially to achieving the United Nations Sustainable Development Goals. These numbers of preventable deaths are based on evidence that human biology is similar across racial and ethnic groups, but the exact numerical estimates should be interpreted with caution because some assumptions used for the calculations build on limited data. Refinement of these estimates will be possible when additional regional data on diet and mortality become available.

planetary | healthy | diet | sustainable | mortality

Significance

Global adoption of healthy and sustainable diets is urgently needed to reduce the burden of premature mortality and contain the environmental effects of food systems within safe planetary boundaries. Different from analyses of disease burden that typically rely on meta-analyzed associations between individual dietary factors and disease endpoints, our study utilized repeated assessments of diet in three large cohorts to estimate the association between long-term adherence to the Planetary Health Diet (PHD) and mortality. This approach accounts for the interactions among multiple dietary components using actual diets consumed over time. By assessing global adherence to the PHD and estimating its potential to reduce deaths, our study highlights areas for improvement and can inform policymaking to prioritize public health initiatives.

Unhealthy diets contribute to the burden of noncommunicable diseases and premature mortality globally (1). While a substantial volume of research on healthy diets has been conducted, food production poses additional challenges in the pursuit of the United Nations Sustainable Development Goals (SDGs) and the Paris Climate Agreement (2). To address these challenges, the EAT-Lancet Commission, consisting of researchers from fields of health, agriculture, social sciences, and environmental sustainability, described a flexible healthy reference diet. This dietary pattern emphasizes consumption of vegetables, fruits, whole grains, legumes, nuts, and unsaturated oils; includes modest optional consumption of seafood and poultry; limits consumption of red meat, processed meat, added sugar, salt, refined grains, and starchy vegetables; and generally suggests foods that are minimally processed or unprocessed (2). This dietary pattern also emphasizes that, without altering total energy intake, replacing foods with healthier alternatives will bring health benefits while ensuring adequate nutrient intake. For example, substituting whole grains for starchy vegetables would be beneficial, as would substituting nuts and legumes for red meats.

Since the publication of the EAT-Lancet Commission Report, the Planetary Health Diet (PHD), also known as the EAT-Lancet reference diet, has undergone extensive evaluation for its association with noncommunicable disease risks and mortality (3–11). For example, consistent evidence supports that individuals adhering to the PHD have a lower risk of type 2 diabetes and cardiovascular diseases (4, 5, 7, 9–11). To quantify adherence to the PHD and evaluate its relation to mortality more precisely, a Planetary Health Diet Index (PHDI) was recently developed and applied to three large cohorts with many repeated dietary assessments (12). Individuals with higher scores had significantly lower risks of total mortality, as well as mortality from cardiovascular diseases, cancer, respiratory diseases, and neurodegenerative diseases (12).

An understanding of the potential reduction in deaths among adults 20 y of age and older achievable by the adoption of the PHD has important public health implications. In an analysis based on dietary data from 190 countries/territories, we previously

This paper is part of a Special Feature on the Sustainability of Animal-Sourced Foods and Plant-Based Alternatives. The collection of all PNAS Special Features in the Sustainability Science portal is available here: https://www.pnas.org/sustainability-science.

The authors declare no competing interest.

This article is a PNAS Direct Submission. M.Q. is a guest editor invited by the Editorial Board.

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This article contains supporting information online at https://www.pnas.org/lookup/suppl/doi:10.1073/pnas.2319008121/-/DCSupplemental.

Published December 2, 2024.

Table 1. The PHDI and its component scores and intakes averaged across 171 countries/territories in 2018*

	Maximum Scores	Global Mean Scores†	Global Mean Intakes
PHDI‡	140.0	84.8	/
Whole grains (g/d)	10.0	5.2	55.0
Starchy vegetables (tubers) (g/d)	10.0	6.3	152.0
Non-starchy vegetables (g/d)	10.0	6.3	272.5
Whole fruits (g/d)	10.0	7.3	156.3
Dairy foods (g/d)	10.0	9.4	173.1
Red/processed meat (g/d)	10.0	5.8	49.4
Poultry (g/d)	10.0	8.3	31.0
Eggs (g/d)	10.0	8.6	25.5
Fish and shellfish (g/d)	10.0	6.7	30.6
Nuts and seeds (g/d)	10.0	2.6	13.1
Non-soy legumes (g/d)	5.0	1.1	21.3
Soybeans/soy foods (g/d)	5.0	0.4	3.8
Added unsaturated fat (% of TEI/d)	10.0	3.2	9.1
Added saturated fat (% of TEI/d)	10.0	4.8	5.5
Added sugar (% of TEI/d)	10.0	8.8	6.5

Abbreviations: PHDI, Planetary Health Diet Index; FBS, food balance sheets; GDD, Global Dietary Database; TEI, total energy intake.
*PHDI, PHDI components, and component intakes for each country/territory were calculated using dietary intakes estimated based on data from the FBS and GDD.
†The global mean PHDI were calculated based on dietary data in 171 countries/territories in 2018, weighted by the population statistics in the same year from the World Health Organization.
‡The PHDI ranges from 0 to 140, where 0 indicates nonadherence to the Planetary Health Diet and 140 indicates perfect adherence.

estimated that over 11 million premature deaths could be prevented globally each year by shifting the current national diets, quantified by the Alternative Healthy Eating Index (AHEI), to a healthy reference diet (13). Analyses based on meta-analyzed associations between individual dietary factors and disease endpoints showed similar estimates of premature deaths that could be prevented by adhering to a healthy reference diet (14, 15). Although these estimates of the reduced burden of mortality are already substantial, they might still be underestimations because the AHEI was not specifically developed to evaluate adherence to the PHD. Also, the meta-analyzed associations could be inaccurate due to measurement errors and inadequate control of confounding in individual studies. The present analysis aims to evaluate the potential reduction in the global burden of total and cause-specific mortality achievable with adoption of the PHD by estimating the population attributable fraction (PAFs). To identify areas in greatest need of dietary improvement, guide potential policymaking, and prioritize related actions, we also calculated the current country/territory-level adherence to the PHD for 171 countries and territories that represent 98% of the world population.

The PHDI ranges from 0 to 140, with a minimum score indicating nonadherence to the PHD and a maximum score indicating perfect adherence. It comprises 15 component scores, each ranging from 0 to 10, with two of these components having half the weight of the others. To calculate the PHDI for each country/territory, we used national dietary data from the Food and Agriculture Organization's (FAO) Food Balance Sheets (FBS), taking into account food loss and waste, and adjusting for energy expenditure. The PAF was calculated using the current PHDI of each country/territory, a theoretical high PHDI score, and the association between PHDI scores and mortality rates. The number of preventable premature deaths was calculated by multiplying the PAFs by national mortality rates for adults.

Different from previous analyses of disease burden that used meta-analyzed associations between individual dietary factors and disease endpoints, our estimation was based on the associations between actual diets of participants in three prospective cohort studies (n = 206,404 men and women): the Nurses' Health Study (NHS), NHS II, and Health Professionals Follow-up Study (HPFS) (1, 12). In these cohorts, the calculation of PHDI accounted for the effects of the various dietary components simultaneously and potential interactions among them. Dietary intakes were measured through repeated dietary assessments over 30 y of follow-up, whereas most of the data included in earlier meta-analyses were from studies with only a single dietary assessment. Further, potential confounding was minimized because the participants had similar education and occupations; covariates were assessed repeatedly; and we have shown that further adjustments for numerous geocoded socioeconomic variables had minimal effect on diet and health associations (16). Our previous publication on this topic used the AHEI, as an intermediate diet quality score, to quantify the adherence to the PHD (13). In the current analysis, we instead used the PHDI, which provides a more comprehensive and accurate assessment of the adherence to the PHD. Also, with longer follow-up, we could include additional dietary assessments and approximately 20,000 additional deaths. These methodological improvements provided us with a more precise estimation of the premature deaths potentially preventable by shifting current global diets worldwide toward the PHD.

Results

Global Adherence to the PHD. In 2018, the global mean PHDI score was 85 out of a perfect score of 140 (Table 1). Among the PHDI components, dairy foods (PHDI = 9.4 out of 10.0), added sugar (PHDI = 8.8 out of 10.0), eggs (PHDI = 8.6 out of 10.0), and poultry (PHDI = 8.3 out of 10.0) received higher scores, while added unsaturated fats (PHDI = 3.2 out of 10.0), nuts and seeds (PHDI = 2.6 out of 10.0), non-soy legumes (PHDI = 1.1 out of 5.0), and soybeans/soy foods (PHDI = 0.4 out of 5.0) were among the food groups with the lowest scores.

The mean PHDI in lower-middle-income countries was the highest (PHDI = 92), while that in low-income countries was lower than the others (PHDI = 79) (*SI Appendix*, Table S1). The relatively high PHDI in lower-middle-income countries was attributed to high component scores for whole grains (PHDI = 10.0 out of 10.0), dairy foods (PHDI = 10.0 out of 10.0), red/processed meat (PHDI = 9.6 out of 10.0), poultry (PHDI = 10.0 out of 10.0), eggs (PHDI = 10.0 out of 10.0), and added sugar (PHDI = 9.3 out of 10.0). These component scores reflected diets with high intakes of whole grains, relatively low intakes of all animal protein sources except fish and shellfish, and low intake of added sugar in lower-middle-income countries. In contrast, while component PHDI scores for low-income countries reflected low intakes of most animal protein sources, the scores also indicated limited consumption of added unsaturated fat and healthy plant-based foods, such as non-starchy vegetables, whole fruits, nuts and seeds, and non-soy legumes. Simultaneously, the intakes of unhealthy foods, such as starchy vegetables (tubers) and added saturated fat, tended to be high, contributing to an overall low PHDI in low-income countries. Upper-middle-income countries (PHDI = 89) showed a higher mean PHDI than high-income countries (PHDI = 81), with the latter having a PHDI only slightly higher than that of low-income countries. The component scores for whole grains, nuts and seeds, and non-soy legumes were low in both high-income countries and upper-middle-income countries, indicating lower intakes. However, the low PHDI for high-income countries was also due to their higher consumption of red/processed meat, poultry, added saturated fat, and added sugar, along with low consumption of non-starchy vegetables and whole fruits.

Across different geographic regions, the Middle East and North Africa had the highest PHDI of 98, followed by South Asia (PHDI = 93) (*SI Appendix*, Table S1). Both regions exhibited high scores for starchy vegetables and animal protein sources, including dairy foods, red/processed meat, poultry, and eggs, reflecting low consumption of these foods. In comparison to the Middle Eastern and North African countries, South Asian countries had relatively lower scores due to their low consumption of non-starchy vegetables, whole fruits, fish and shellfish, and added unsaturated fat. Latin America and the Caribbean (PHDI = 70) and North America (PHDI = 78) showed the lowest PHDI among all the geographic regions. In North America, the PHDI component scores reflected diets with low intakes of whole grains, nuts and seeds, and non-soy legumes, and high intakes of dairy foods, red/processed meat, poultry, and added sugar. In Latin America and the Caribbean, the poor dietary quality was attributed to low intakes of whole grains, non-starchy vegetables, fish and shellfish, nuts and seeds, and added unsaturated fat, coupled with high intakes of red/processed meat, poultry, added saturated fat, and added sugar. The component score for soybeans/soy foods was consistently low globally, though countries in East Asia and the Pacific had higher intakes compared to other regions.

Mediterranean countries had a higher-than-average PHDI score (Fig. 1 and *SI Appendix*, Table S2). Lebanon (PHDI = 102), Tunisia (PHDI = 102), Greece (PHDI = 101), Egypt (PHDI = 100), Libya (PHDI = 100), and Cyprus (PHDI = 99) were among the countries with the highest PHDI (*SI Appendix*, Table S2). The component scores indicated that they generally had high intakes of non-starchy vegetables, whole fruits, added unsaturated fat, along with low intakes of eggs, added saturated fat, and added sugar. The other countries with the highest scores include Iran (PHDI = 104), Maldives (PHDI = 99), Cameroon (PHDI = 99), and Mali (PHDI = 99). Five of the ten countries with the lowest PHDI are in the Latin America & Caribbean: Chile (PHDI = 66), Honduras (PHDI = 65), Argentina (PHDI = 62), Bolivia (PHDI = 62), and Colombia (PHDI = 57). Low intakes of whole grains, non-starchy vegetables, fish and shellfish, non-soy legumes, added unsaturated fat, and high intakes of red/processed meat, added saturated fat, and added sugar were the major contributors to their low scores.

Preventable Premature Deaths Attributable to Improved Adherence to the PHD. Globally, we estimated that improving dietary quality from the current state to a reference healthy diet with a PHDI of 120 could prevent about 15 million premature deaths among adults per year (Table 2). This accounted for 27% (95% CI: 24%, 30%) of deaths due to all causes in 2019. After excluding deaths due to traumatic events, more than 13 million

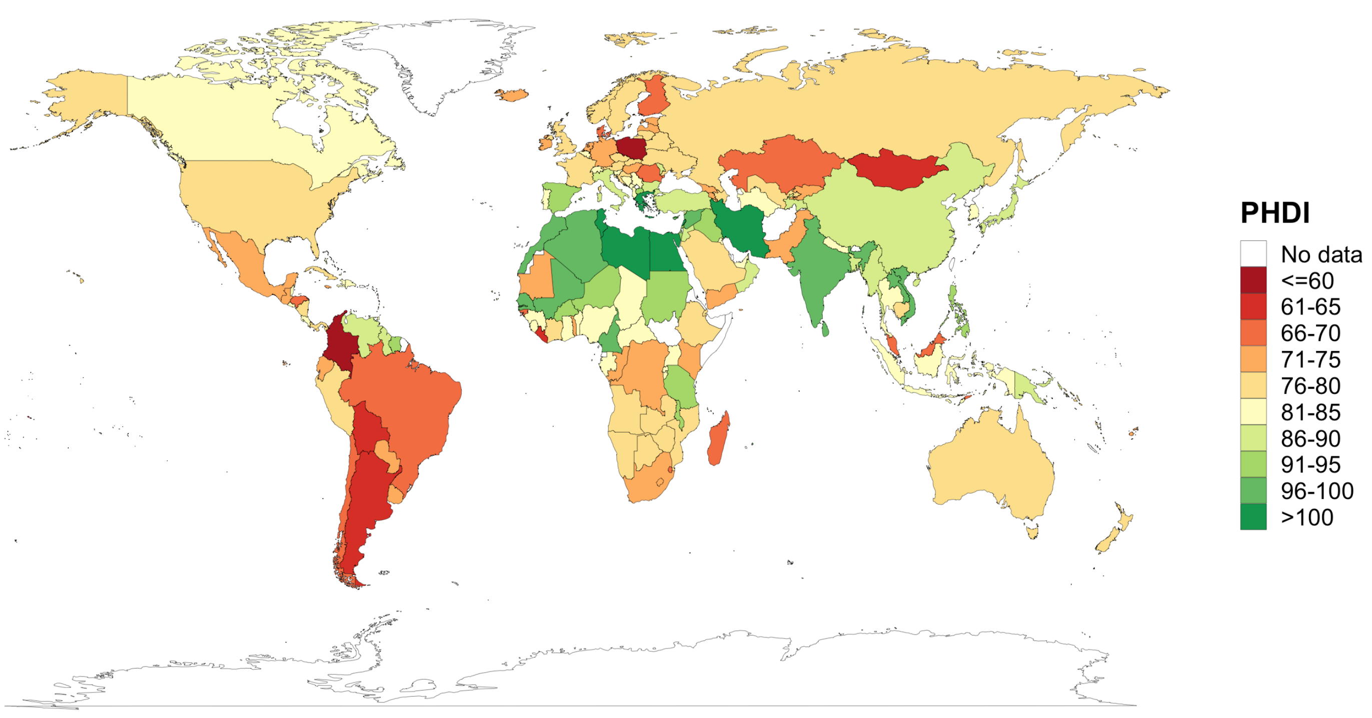

Fig. 1. Geographic distribution of the PHDI for people aged over 20 in 171 countries/territories in 2018. The PHDI ranges from 0 to 140, where 0 indicates nonadherence to the Planetary Health Diet and 140 indicates perfect adherence. PHDI, Planetary Health Diet Index.

preventable premature deaths remained. For our primary analyses, we used a PHDI of 120 as the reference, rather than a perfect score of 140 because this represents a more realistic goal, and it corresponds to the 99th percentile of the most recent PHDI scores in the NHS, NHS II, and HPFS cohorts. However, assuming that the global population could perfectly align with the PHD and achieve a PHDI of 140, an additional estimated 6 million deaths could be prevented in a year, equivalent to 39% (95% CI: 36%, 42%) of deaths due to all causes in 2019. Indeed, targeting a lower PHDI of 100, which is only 15 points higher than the global average in 2018, the improvement in dietary quality could also prevent 7 million deaths in a year. In a sensitivity analysis, calculating PAFs based on the associations between PHDI and mortality endpoints from statistical models not adjusting for potential mediators, such as body mass index (BMI), hypertension, and hypercholesterolemia, had a minimal effect on our results. (*SI Appendix*, Table S3).

We estimated that about 2.5 million premature deaths due to cardiovascular diseases could be prevented per year by improving dietary quality to a PHDI of 120, followed by 2.0 million deaths due to respiratory diseases, 1.6 million deaths due to infectious diseases, 1.4 million deaths due to cancer, and 0.7 million deaths due to neurodegenerative diseases (Table 2). These estimates corresponded to PAF estimates of 49% of deaths due to respiratory diseases, 32% of deaths due to neurodegenerative diseases, 22% of deaths due to infectious diseases, 15% of deaths due to cancer, and 14% of deaths due to cardiovascular diseases in 2019 could be prevented by consuming a healthy and sustainable diet.

In low-income countries, adopting the PHD could prevent about 1.2 million deaths, or 30% (95% CI: 27%, 33%) of deaths from all causes (*SI Appendix*, Tables S4 and S5). In Latin American and Caribbean countries, the same dietary improvement could prevent 36% (95% CI: 32%, 39%) of all-cause mortality, equivalent to over 1.4 million deaths. Among the 171 countries assessed, Colombia, which had the lowest PHDI, is anticipated to benefit the most from the improvement in dietary quality, with an expected 43% (95% CI: 39%, 46%) reduction in total deaths (*SI Appendix*, Table S6). For Iran, which already had the highest PHDI, further improvement in dietary quality could still reduce all-cause mortality by 13% (95% CI: 11%, 15%).

Discussion

In this global study of 171 countries and territories, we found that adherence to the PHD varied substantially across the world, and the suboptimal PHDI scores indicated a large potential for improving dietary quality. Notably, countries with the lowest and highest incomes had poorer dietary quality compared to middle-income countries. Countries in Latin America, the Caribbean, and North America ranked among those with the lowest PHDI scores. Improving dietary quality from its current state to a realistic reference level could prevent 27% of total deaths worldwide, amounting to approximately 15 million in absolute numbers annually. The countries with lower PHDI would benefit more from dietary improvements.

Table 2. Population attributable fraction (PAF, %) and number of potentially preventable deaths due to PHDI improvement from the current state to low-risk levels in 171 countries/territories in 2018[*,†]

	Reference PHDI = 120[¶]		Reference PHDI = 100		Reference PHDI = 140	
Causes of death	PAF % (95% CI)[§]	Preventable deaths (95% CI)[‡]	PAF % (95% CI)	Preventable deaths (95% CI)	PAF % (95% CI)	Preventable deaths (95% CI)
All causes	26.9 (24.2, 29.6)	14,663,232 (13,185,138, 16,141,326)	12.8 (10.6, 14.9)	6,972,099 (5,804,513, 8,139,686)	38.7 (35.5, 41.9)	21,125,986 (19,366,794, 22,885,177)
Nontraumatic causes[#]	26.5 (23.7, 29.4)	13,336,973 (11,903,790, 14,770,156)	12.6 (10.4, 14.8)	6,334,295 (5,238,324, 7,430,265)	38.3 (34.8, 41.7)	19,235,773 (17,506,346, 20,965,199)
Cardiovascular diseases	14.2 (8.7, 19.6)	2,502,154 (1,544,357, 3,459,950)	6.5 (3.7, 9.2)	1,144,569 (656,957, 1,632,182)	21.2 (13.5, 29.0)	3,747,538 (2,380,238, 5,114,838)
Cancer	14.8 (9.5, 20.1)	1,362,996 (876,370, 1,849,622)	7.0 (4.2, 9.7)	640,844 (386,438, 895,251)	22.0 (14.5, 29.4)	2,023,787 (1,336,756, 2,710,819)
Respiratory diseases	49.4 (43.6, 55.2)	2,020,685 (1,781,955, 2,259,414)	23.4 (18.5, 28.3)	956,245 (755,415, 1,157,074)	66.6 (60.6, 72.5)	2,723,230 (2,480,356, 2,966,104)
Neurodegenerative diseases	31.6 (25.2, 37.9)	721,616 (576,699, 866,534)	16.0 (12.0, 20.0)	366,074 (274,207, 457,941)	44.2 (36.4, 52.1)	1,011,197 (831,800, 1,190,594)
Infectious diseases	21.5 (3.3, 39.6)	1,608,928 (247,720, 2,970,136)	10.0 (0.9, 19.1)	750,903 (69,953, 1,431,853)	31.1 (6.1, 56.1)	2,335,658 (459,763, 4,211,552)

Abbreviations: PAF, population attributable fraction; PHDI, Planetary Health Diet Index; CI, confidence interval.
*For each country, the population attributable fractions (PAFs) for total and cause-specific death were calculated based on the comparison of PHDI in 2018 and the reference PHDI levels, and the associations between PHDI and total and cause-specific death estimated from the NHS, NHS II, and HPFS.
†For each country, the preventable deaths in year were calculated by multiplying total and cause-specific deaths estimated by the World Health Organization with the estimated PAFs.
‡Total preventable total/cause-specific deaths were calculated as the sum of country/territory-specific preventable total/cause-specific deaths.
§PAFs averaged across 171 countries were calculated by dividing the sum of preventable total/cause-specific deaths due to PHDI improvements by the sum of total/cause-specific deaths in a year.
¶The PHDI ranges from 0 to 140, where 0 indicates nonadherence to the Planetary Health Diet and 140 indicates perfect adherence. A PHDI of 120 corresponds to the 99th percentile of the score measured with the most recent dietary assessment in the NHS, NHS II, and HPFS.
#Nontraumatic causes include causes of deaths unrelated to physical injury, homicide, and suicides.

The PHD is characterized by a high intake of healthy plant-based foods, including non-starchy vegetables, fruits, nuts, legumes, and whole grains, and a limited intake of added sugar and animal protein sources such as red and processed meats. The observation that Mediterranean countries had relatively high PHDI scores is consistent with the similarity between the PHD and the traditional Mediterranean Diet, even though the targets for each dietary component were developed individually (17, 18) and the diets in these countries have shifted toward the industrial diets of northern Europe in recent years (13, 19). A strong inverse association between the Mediterranean Diet and cardiovascular disease mortality was found in meta-analyses of randomized controlled trials (17). Also in randomized trials, the Mediterranean diet has reduced the incidence of cardiovascular disease (20, 21). Moreover, the Mediterranean Diet has a low environmental impact and is sustainable, evidenced by its thousands-year-old production systems (17, 22). This comprehensive evidence supporting the benefits and sustainability of the Mediterranean Diet reinforces the robustness of our findings and suggests that the PHD, with its similar principles, is a practical and achievable dietary model (23).

A previous study that used the AHEI to quantify global adherence to the PHD similarly concluded that the coastal countries/territories around the Mediterranean Sea had better dietary quality attributed to higher scores for vegetables, nuts/legumes, red/processed meat, and sugar-sweetened beverages (13). Although our estimated mean PHDI score surpassed its halfway mark, exceeding Wang et al.'s AHEI-based estimation that was at the midpoint of its full scale, both studies concluded that global dietary quality remains far from optimal. Iran, having the highest PHDI score in our study, was also ranked among the countries with the highest AHEI scores. Contrary to the study by Wang et al., our study indicates that dietary quality measured by the PHDI is also high in India and generally low in Latin American and Caribbean countries. Such differences could mainly be attributed to the dietary components included in the PHDI and AHEI and their scoring criteria. Both dietary indexes penalize the intake of added sugar or sugar-sweetened beverages. As a result, India received a high PHDI component score for added sugar due to its low consumption of sugar-sweetened beverages (24). In contrast, countries in Latin America and the Caribbean, like Mexico, have a high consumption of sugar-sweetened beverages and therefore scored lower in this respect (24). However, compared with the AHEI, the PHDI places greater emphasis on limited intakes of animal protein sources, and distinguishes starchy and non-starchy vegetables, but may not adequately penalize for trans-fatty acids because of the limited data on current national intakes. India has one of the largest vegetarian populations in the world, with the rest of its population consuming a diet low in red meat (25). This is likely a combined result of cultural and religious factors, the limited purchasing power of the economically underprivileged, and historical bans on the slaughtering of certain animals, particularly cattle (25). While an increasing number of countries have banned trans-fatty acids due to their associations with increased risks of major chronic disease, India continues to struggle with high consumption of these fats and faces challenges in implementing effective regulations (26). Similarly, the PHDI scores in Latin American and Caribbean countries are substantially lowered due to high consumption of red meat and starchy vegetables, while these unhealthy components have a lesser impact on dietary quality as measured by the AHEI.

Under the current global economic development assumptions, the future dietary quality in low-income countries is predicted to shift toward the current diets of high-income countries. However, in our analysis, the PHDI for high-income countries is only slightly higher than that for low-income countries and is substantially lower than that of upper-middle-income and lower-middle-income countries. In low-income countries, limited purchasing power constrains purchases of nutrient-dense foods and encourages low-cost less-healthy dietary energy sources, such as refined grains, starchy vegetables, and saturated or partially hydrogenated added fats (27). In high-income countries, poor dietary quality is a consequence of both economic factors and agricultural policies that support commodity crops that are mainly fed to animals, resulting in low costs of red meat and high costs of fruits and vegetables (28, 29). Despite a positive association between socioeconomic status and dietary quality within countries (30), our findings suggest that economic development alone may not sufficiently address the issue of poor dietary quality. Efforts should also be made to transform the entire food production system in a healthy and sustainable direction.

Our findings suggest that improving dietary quality shifting toward the PHD is an effective and realistic approach to achieve the third United Nations Sustainable Development Goal (SDG), which targets a one-third reduction of premature mortality from noncommunicable diseases. Our estimates of PAFs for cause-specific mortality have substantial implications for public health, particularly in guiding country-specific policymaking to achieve the third SDGs. Cardiovascular diseases remain the leading cause of mortality worldwide (31). Our study found that the number of deaths potentially preventable by dietary shifts was the greatest for cardiovascular diseases among all examined causes, despite having a moderate PAF of 14%. In middle-income countries, where nearly 80% of global cardiovascular deaths is occurring, alongside a rise in risk factors (32), even an 11% to 12% reduction in cardiovascular disease mortality would be a major public health benefit. The GBD study estimated that in 2019, chronic respiratory diseases, including chronic obstructive pulmonary disease (COPD), asthma, pneumoconiosis, interstitial lung disease (ILD), and pulmonary sarcoidosis, ranked as the third leading cause of death worldwide (33). In recent studies, strong inverse associations have been seen between healthy eating patterns and lower risk of COPD (34). This includes higher intake of fruits, vegetables, and other plant foods that are major sources of antioxidants and phenolic compounds that can modulate oxidative stress and systemic inflammation, both of which are likely pathways in the pathogenesis of COPD (35). Consumption of processed meats, some of which contain added nitrites, can exacerbate inflammation in the airways and lung parenchyma, and thereby increase the risk of COPD (36). Based on our results, in East Asian and Pacific, South Asian, and Sub-Saharan African countries, where the rate of deaths and disability-adjusted life-years (DALYs) from chronic respiratory diseases are high, we estimated that 43% to 54% of these deaths could be prevented by improving dietary quality. This could substantially alleviate both health and economic burdens considering that COPD will be among the top three most costly diseases in East Asia and the Pacific, and South Asia by 2050 (37). The burden of disability and mortality from neurodegenerative diseases is predominantly found in high-income countries, whereas it is expected to become more prominent in the rest of the world. Specifically for Parkinson's disease, 40.2% of the deaths occur in high-income countries, yet the most significant increase in incidence is observed in middle-income countries (38).

With a more direct estimation of the PAF and preventable deaths than in previous analyses, our study confirmed that adopting a healthy and sustainable diet could substantially reduce the burden of mortality globally (13). While the AHEI is a well-established index for quantifying the overall healthfulness of diet, it may not be optimal for measuring adherence specifically to the PHD. In contrast, the PHDI was specifically based on the reference PHD, enabling us to examine directly adherence to the PHD and mortality. The estimated effect of adherence to the PHD on mortality draws on unique strengths of the three rigorously conducted prospective cohort studies with long follow-up and validated dietary assessments (NHS, NHS II, and HPFS). In these studies, the PHDI was calculated using dietary data from up to seven repeated assessments conducted over three decades. By modeling the indexes as cumulative averages, the estimated effects accounted for dietary changes over time and minimized measurement errors. The extended follow-up time in these studies provided the opportunity to assess the impact of diet on chronic diseases that develop over decades and the large number of deaths, over 54,000, provided sufficient statistical precision for extensive sensitivity analyses. Moreover, with a comprehensive and frequent collection of health-related data and lifestyle factors, these studies could carefully adjust for many potential confounding factors as time-varying covariables and minimize potential residual confounding. In addition, our values for national food intakes were derived from a globally comparable database standardized to total energy intakes based on doubly labeled water.

Questions have been raised about nutrient adequacies of the PHD, and differing analyses have been published (39, 40). An analysis published with the EAT-Lancet Commission Report suggests that the PHD provides adequacy for most nutrients in a general adult population (2). Vitamin D intakes from food alone are inadequate in this and almost all diets because the primary source is from solar exposure. Vitamin B-12 would likely be low if intakes of animal-sourced food are below the PHD targets of about two servings of animal-sourced foods per day; if so, supplements or fortified foods should be used. An analysis based on newly proposed harmonized nutrient reference values and adjustments for bioavailability found inadequacy of calcium and iron in addition to vitamin B-12 and zinc in the PHD for adults aged over 25 y and women of reproductive age (39). However, the criteria for adequacy in that analysis used recommended daily intake (RDAs) rather than estimated average requirements (EARs) as suggested when using the harmonized reference values to evaluate population adequacy (41). The methodological differences between these nutrient adequacy analyses, including the assumed bioavailability of iron and zinc, have been discussed (40, 42). Adding to uncertainty about nutrient adequacy is that the criteria for adequacy are often based on short-term studies that may not reflect long-term adequacy, e.g., for calcium (43); that intakes below the recommendations for zinc do not have clear implications for health in adults; that the nutrient content of a specific food can vary substantially by cultivar and local environmental conditions so that calculated intakes may not reflect the actual intake (44); and that many factors such as infectious diseases, inflammation, and nutrient losses can affect biochemical status and nutritional requirements. Thus, whether nutrient intake is adequate in a specific population requires careful evaluation based on multiple types of information; if intakes are determined to be inadequate for some parts of the population, various strategies should be considered, including promotion of available foods high in that nutrient, fortification, biofortification, and/or supplementation. A recent analysis in the US found that aligning diets with the PHD targets would enhance nutrient adequacy (45), and improvements are likely to be greater in low-income countries with poorer-quality diets.

Nutrient inadequacies are a particular concern in populations with special nutritional needs, such as young children, women of reproductive age, and older adults. Despite relatively high PHDI scores in some West and North African countries, consistent with dietary traditions and low rates of noncommunicable disease in adults, undernutrition and stunting continue to be serious problems in children in these regions (46), attributable to multiple factors including recurrent and chronic infections, and insufficient overall food intake. Modifications to the PHD, subject to ongoing research, could be made to address the needs of young children and adolescents. Iron deficiency anemia is common among both pregnant women and nonpregnant women of reproductive age, in part due to menstrual losses, but simply increasing iron intake is often not effective due to poor absorption that appears related to infectious diseases and chronic inflammation (47). Zinc adequacy has also been a concern in this population and is often related to a very high intake of nutrient-poor carbohydrates, whereas the macronutrient composition of the PHD is more balanced. Some have suggested increasing red meat to address intake of these micronutrients, but this has been associated with higher risks of both gestational diabetes (48) and type 2 diabetes (16). Better options would usually include the consumption of other food sources of these nutrients, fortification/biofortification, and/or targeted supplementation; these would be far less costly and more environmentally sustainable (14).

Our study has several limitations. The PHDIs used for estimating the biological effects were calculated based on self-reported dietary data, which is inevitably affected by measurement error. However, the questionnaires used in these cohorts have good validity in measuring nutrients, foods, food groups, and dietary quality when compared to weighed and measured dietary records and biomarkers (49–53). In addition, random measurement error due to within-person variations in the diet has been substantially reduced by modeling the repeatedly measured PHDI as cumulative averages from the baseline FFQ up to the start of each 4-y follow-up interval. Remaining errors are likely to have led to underestimation of PAFs. Also, we assume causality when estimating PAFs based on PHDI scores in relation to mortality, these effects were estimated from three observational studies. Despite thorough statistical control of the potential confounders, including lifestyle factors and socioeconomic status, we cannot rule out the possibility of residual confounding. Causality is further supported by randomized trials with risk factors as outcomes (54), and a large trial of the Mediterranean diet with a similar composition in relation to the risk of cardiovascular disease (20). The estimated associations between diet and mortality may also have limited generalizability, considering that the study populations of the NHS, NHS II, and HPFS consist predominantly of European Americans with relatively homogeneous educational and occupational backgrounds. Although limited diversity in the population enhances internal validity by reducing the potential for residual confounding, these association estimates are still not ideal for a global extrapolation due to possible variation in susceptibility to certain diseases and cause-specific mortalities across the world. Therefore, our estimates of preventable death estimates are susceptible to additional uncertainties. In previous analyses, associations of dietary patterns with health outcomes have been similar across different racial and ethnic groups (55). Although diets and disease rates of low-and-middle-income countries have historically been quite different than those of our study population, in recent years, diets, obesity rates, and risks of noncommunicable disease of most regions have been converging toward those of wealthier countries (31, 56–60). Additionally, the range of PHDI scores in the three cohorts readily overlapped the average scores for all countries. Thus, we anticipate that the diet and mortality associations used in these analyses are likely applicable to the future experiences of most regions if present trends continue. However, acquiring additional data from other countries would be desirable and would allow for further refinement of estimated mortality reduction through diet improvements. Such datasets are currently unavailable due to the absence of large cohorts in many regions, and collecting them would require decades of follow-up. Also, our data on national diets are not optimal because they were derived primarily from national reports on food production and may not fully capture food processing such as refinement of grains and partial hydrogenation of fats. This may have led to overestimate of diet quality in some countries such as India and Iran, which would also have led to underestimation of the PAF. In some countries, such as India, a relatively high PHDI coincides with a substantial burden of noncommunicable diseases (61), despite the expectation of an inverse association between PHDI and the risks of such diseases. This discrepancy could also be attributed to high intakes of refined grains and unhealthy fats, which might not be accurately reflected in available national dietary data and are associated with type 2 diabetes. Additionally, the high susceptibility to type 2 diabetes among individuals of Asian heritage could also contribute to the elevated rates of noncommunicable diseases (55). Our analyses did not account for the benefits of limiting sodium intake due to limited data on national sodium intakes, likely leading to an underestimation of avoidable premature mortality (62, 63). Improvements in dietary surveillance would be desirable in most countries. The potential reduction in mortality for persons under age 20 y that could result from improvements in diet quality was not estimated in the current study; thus, the number of deaths potentially prevented is likely underestimated, particularly in countries with a higher burden of childhood undernutrition. Our estimation of PAF for all-cause mortality may not fully account for the heterogeneity in distributions of specific causes of death in different countries due to the limited number of causes being included in the current analysis. A previous analysis showed that calculations based on country-specific distributions of causes of death, rather than directly using HRs for dietary quality's association with all-cause mortality, made little difference in the PAF estimates (13). Finally, while the CIs of the PAF estimates are derived from SEs obtained through Monte Carlo simulations, they likely do not comprehensively capture all uncertainties, including errors in national dietary data and uncertainty in estimating the associations between PHDI and mortality due to the aforementioned errors in measuring long-term dietary intake and residual confounding.

In conclusion, global adherence to the PHD varies substantially among countries and remains far from optimal. The relatively high PHDI scores in regions consuming the traditional Mediterranean Diet suggest that the PHD is practical and sustainable. By improving global dietary quality while simultaneously maintaining food production within safe environmental boundaries, approximately 15 million premature deaths could be prevented annually. Our study provides evidence supporting the adoption of the PHD as an effective approach for reducing the mortality burden from many diseases and achieving the third United Nations Sustainable Development Goal. Refinement of these estimates will be possible when additional regional data on diet and mortality become available.

Materials and Methods

National Dietary Assessment. We combined multiple data sources to estimate globally comparable dietary intakes for adults aged over 20 y of age. To inform dietary composition, we used data from the FBS of the Food and Agriculture Organization of the United Nations (FAO) and adjusted for the amount of food wasted (64, 65). To obtain absolute intakes of food groups, we calculated the energy requirements to sustain current levels of body weight, height, and physical activity levels based on equations developed from doubly labeled water studies and adjusted the FAO values proportionally (66–69). Last, we used data from the Global Dietary Database (GDD) to inform the proportions of grains that were refined and meats that were processed, as well as the distribution of dietary intakes across age and sex cohorts (70, 71). The dietary data for our analyses have been deposited in a publicly accessible online repository (72).

Ideally, we would have used one consistent database on dietary intake. However, neither the GDD nor the FAO's food balance sheet contains estimates for all foods and the detail needed to construct the PHDI. For example, the GDD does not differentiate between soybeans/soy foods and other legumes, and it does not include estimates of poultry intake, while the FBS does not include any sociodemographic detail and only specifies the total availability of foods at the national level. Our combined proxy of dietary intake addresses those shortcomings at a globally comparable level. *SI Appendix*, Table S7 contains an overview of the estimates of dietary intake by food group and region.

National Mortality Data. All-cause and cause-specific mortality estimates for each country were obtained from the World Health Organization (WHO) Global Health Estimates (GHE 2019) (73). GHE 2019 provided estimates from year 2000 onward for 183 WHO Member States with populations over 90,000 in 2019. All-cause mortality was estimated based on the death rates from the WHO life table and resident populations from the UN Population Division (74). For countries with a high-quality vital registration system, cause-specific mortality was estimated with the cause-of-death statistics reported annually to the WHO Mortality Database. For countries that do not have high-quality death registration data, the GHE 2019 drew updated estimates from the Institute of Health Metrics and Evaluation (IHME), which is part of the Global Burden of Disease 2019 study (GBD 2019) (75). To estimate cause-specific mortality, IHME employed modeling strategies that integrated available death registration data, supplementary sources of information regarding deaths, patterns of causes of death in comparable countries, and covariate regression modeling. To ensure that the cause-specific mortality estimates could be summed to the all-cause mortality estimate, IHME further adjusted the cause-specific mortality estimates proportionally, giving greater rescaling to estimates with wider uncertainty ranges (1). Detailed information about the data sources and methods used in GHE 2019 were documented elsewhere (75).

The PHD and PHDI. The EAT-Lancet Commission described a healthy reference diet, later named the PHD, based on extensive evidence from controlled feeding studies in humans, observational studies, and randomized trials regarding the associations between foods, dietary patterns, and health outcomes (2). The commission also determined that this reference diet would allow the production and consumption of foods for the projected global population of nearly 10 billion people in 2050 to stay within the boundaries necessary to maintain the planet's stability, including those related to greenhouse gas emissions and land use (12). The criteria for the PHD primarily apply to food groups, with other dietary constituents, such as added fats and sugar, are taken into consideration (SI Appendix, Supplementary Method 1). To enable global adoption of the diet with the potential for local adaptation and scalability, the proposed criteria include intake ranges in addition to target intakes for each food group (2).

Multiple scores have been developed to quantify adherence to the PHD (3, 4, 76–78). However, some of these scores either did not comprehensively credit the healthy food groups or discount unhealthy foods that align with the PHD, and some used binary or three-level scorings that narrowed the range of possible scores and limited the discrimination of adherence (12). The PHDI ranges from 0 to 140 and includes 15 component food groups. A minimum score of 0 indicates nonadherence to the PHD while a maximum score of 140 indicates perfect adherence. Scoring criteria were derived from the dose–response relationships between each food group and the risks of major chronic diseases reported in the literature (12).

Ranges of intakes were determined by examining the distribution of consumption across countries, using data from the Food and Agriculture Organization. All components of the PHDI are scored from 0 to 10, with non-soy legumes and soybeans/soy foods weighted as half when calculating the total PHDI. For healthy component food groups (e.g., non-starchy vegetables and whole fruits), higher scores are assigned to higher daily intakes, and a minimum score usually represents low daily intakes associated with the least health benefit. For unhealthy component food groups (e.g., red/processed meat, added saturated fats), maximum scores are assigned to low to zero daily intake. Details of PHDI scoring, including component food groups and criteria, are shown in SI Appendix, Supplementary Method 1. The grouping of individual foods in the FAO food balance sheet corresponding to the PHDI components is shown in *SI Appendix*, Table S8.

Estimation of the Relation of Diet to Mortality. To estimate the effects of diet on mortality, we used associations between increments in the PHDI and risks of total mortality and mortality due to nontraumatic events (e.g., events unrelated to physical injury, homicide, and suicides), cardiovascular diseases, cancer, respiratory diseases, neurodegenerative diseases, and infectious diseases from an analysis conducted in the NHS, NHS II, and HPFS (12). The NHS recruited 121,700 female, registered nurses aged 30 to 55 y in 1976; the NHS II enrolled 116,429 female, registered nurses aged 25 to 42 y in 1989; and the HPFS is a study of 51,529 male veterinarians, dentists, pharmacists, optometrists, osteopath physicians, & podiatrists aged 40 to 75 y in 1986. Participants of these three cohorts have been followed through biennial mailed questionnaires about health-related topics. Detailed study designs of the NHS, NHS II, and HPFS are described elsewhere (79, 80).

The study on PHDI and mortality risks was conducted among participants who provided dietary data in 1986 for the NHS and HPFS and in 1991 for the NHS II. Participants who had cancer, diabetes, myocardial infarction, angina, stroke, coronary artery surgery, reported energy intake <600 kcal/day or >3,500 kcal/day for women, or <800 kcal/day or >4,200 kcal/day for men, or who died during the first two years of follow-up were excluded from the final analytical population, which comprised 159,130 women and 44,275 men. Dietary intakes were assessed every 4 y using semiquantitative food frequency questionnaires (FFQs) that asked about average intakes of more than 130 foods and beverages over the past 12 mo. Validity of these FFQs has been extensively documented by comparisons with weighed diet records and biomarkers of diet (49–52). Through 2019, deaths were reported by next of kin and postal authorities or identified through state vital statistics, death certificates, or the National Death Index. The causes of death were confirmed by physicians, who reviewed medical records or autopsy reports with the consent of the study participants or their family members. *SI Appendix*, Table S9 shows the International Classification of Diseases (ICD) codes used to group causes of death.

The PHDI was calculated with each repeated dietary assessment and was modeled as the cumulative averages from the baseline FFQ to the beginning of each 4-y follow-up interval. Hazard ratios (HRs) and corresponding 95% CIs for the associations between PHDI and mortality endpoints (*SI Appendix*, Table S10) were estimated from Cox proportional hazards models stratified jointly by age in months and calendar time in two-year groups and adjusted for race, BMI at baseline, family history of diabetes, family history of myocardial infarction or cancer, baseline history of hypertension or hypercholesterolemia, marital status, living alone, socioeconomic status, premenopausal status and hormonal use (if women), smoking, alcohol consumption, physical activity, high blood pressure, high cholesterol, multivitamin use, aspirin use, and total energy intake. To avoid overadjustment, in a sensitivity analysis, we excluded potential mediators, such as BMI, hypertension, and hypercholesterolemia, from this model and estimated the associations between PHDI and mortality endpoints (*SI Appendix*, Table S10).

Statistical Analysis. For each country/territory, national income category, and geographical region, we calculated the component and total PHDI based on the aforementioned scoring criteria and dietary intake estimates. Intakes of PHDI components, such as added unsaturated fats, saturated fats, and sugar, estimated in units of kcal per day, were converted into percentages of total daily energy intake. The remaining components estimated in grams per day did not require further conversion. PHDI components that fell outside the lower and higher ranges of possible scores were assigned scores of 0 and 10 respectively. The SD of each PHDI component intake was estimated using the mean-SD relationship from the GBD 2019. For food groups that were not estimated in GBD 2019, mean-SD relationships of the most related food groups were applied. To estimate the SD of the total PHDI for each country, we simulated dietary data for populations of 10,000 individuals with means and SDs for each food group, calculated the PHDI for each observation in the simulated population, and estimated the SD of the PHDIs within the simulated population. SDs of the total PHDI for each country are presented in *SI Appendix*, Table S2. We computed the global mean PHDI and its component scores in 2018 weighted by the national populations from WHO statistics.

We used the PAF to estimate the potential reduction in all-cause and cause-specific mortality due to improvement in the PHDI from for current diets to a theoretical low risk PHDI level. In our primary analysis, we defined the low risk level as 120 (140 being perfect adherence), which is similar to the 99th percentile of PHDI measured with the most recent dietary assessment in the NHS, NHS II, and HPFS. This represents a more realistic and achievable goal for the global population than a perfect score, as it is based on a diet currently consumed by an actual population and is not based on extrapolation beyond the distribution of PHDI scores used to estimate the relation of PHDI scores to mortality. We also considered scenarios representing a theoretically perfect planetary health diet (PHDI of 140 as the reference) and a scenario for a score of 100, which is only modestly above the country with the highest score. Our calculation of PAFs was based on the following formula (13, 19):

$$PAF = \frac{\int_{x=0}^{m} RR(x)P1(x)dx - \int_{x=0}^{m} RR(x)P2(x)dx}{\int_{x=0}^{m} RR(x)P1(x)dx},$$

where RR(x) is the estimated effect of PHDI on mortality (calculated as hazard ratios) at a PHDI level of x estimated from the NHS, NHS II, and HPFS. P1(x) is the probability density function of the PHDI at level x assuming a PHDI distribution representing the current suboptimal dietary quality status. P2(x) is the probability density function of the PHDI at level x assuming the populations consume a diet consistent with our predefined reference (e.g., having a mean PHDI of 120), and m is the maximum level of PHDI. To account for uncertainty in the PAF estimates, we employed a simulation-based approach that randomly drew RR and empirical PHDI estimates from their respective distributions before calculating the PAF. We repeated this iteration for 1,000 times and used the SD of the PAF estimates as the SE for calculating the 95% CI. Detailed steps for the PAF calculation are presented in SI Appendix, Supplementary Method 2. The estimated effect of PHDI on mortality and the corresponding SE are presented in *SI Appendix*, Table S11.

For each country/territory, income region, and geographical region, the number of deaths that could be prevented by improving the PHDI to the reference level was calculated by multiplying the estimated total and cause-specific PAFs by the corresponding mortality estimates. The 95% CIs of preventable deaths were calculated by multiplying the upper and lower limits of the estimated total and cause-specific PAFs by the corresponding mortality estimates. Finally, to account for the distributions of global population and heterogeneity in estimating country-specific PAFs, we calculated the global and regional average total and cause-specific PAFs by dividing the global or regional sum of preventable total/cause-specific deaths from our study by the global or regional sum of total/cause-specific deaths from WHO. We performed all data analyses using R version 4.2.0 (R Foundation for Statistical Computing).

Data, Materials, and Software Availability. Global dietary estimates and analysis programs have been deposited online (https://doi.org/10.6084/m9.figshare.26414347.v2).

ACKNOWLEDGMENTS. This work has been supported by the EAT-Lancet 2.0 Commission funded by the Rockefeller Foundation grant agreement no. 2022 FOD 007. The Nurses' Health Study (NHS), NHS II, and Health Professionals Follow-up Study (HPFS) are supported by the NIH grants UM1 CA186107, P01 CA87969, R01 HL034594, U01 CA176726, U01 CA167552, R01 HL035464, R01 DK120870, and R01 DK126698. The content is solely the responsibility of the authors and does not necessarily represent the official views of the Rockefeller Foundation or NIH.We would like to acknowledge the contribution to the NHS, NHS II, and HPFS from central cancer registries supported through the Centers for Disease Control and Prevention's National Program of Cancer Registries (NPCR) and/or the National Cancer Institute's Surveillance, Epidemiology, and

End Results (SEER) Program. Central registries may also be supported by state agencies, universities, and cancer centers. Participating central cancer registries include the following: Alabama, Alaska, Arizona, Arkansas, California, Delaware, Colorado, Connecticut, Florida, Georgia, Hawaii, Idaho, Indiana, Iowa, Kentucky, Louisiana, Maine, Maryland, Massachusetts, Michigan, Mississippi, Montana, Nebraska, Nevada, New Hampshire, New Jersey, New Mexico, New York, North Carolina, North Dakota, Ohio, Oklahoma, Oregon, Pennsylvania, Puerto Rico, Rhode Island, Seattle SEER Registry, South Carolina, Tennessee, Texas, Utah, Virginia, West Virginia, Wyoming.

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Author contributions: X.G. and W.C.W. designed research; M.S. contributed data and analytic tools; X.G. analyzed data; L.P.B. and F.W. reviewed programs; and X.G., L.P.B., F.W., D.D.W., M.S., and W.C.W. wrote the paper.

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