Published in final edited form as:
Br J Nutr. 2020 November 14; 124(9): 960–970. doi:10.1017/S0007114520002032.

Changes in plant-based diet quality and health-related quality of life in women

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Abstract

Few studies have evaluated the association between a healthful plant-based diet and health-related quality of life (HRQoL). We followed 50,290 women in Nurses' Health Study (NHS, 1992 to 2000) and 51,784 women in NHSII (1993 to 2001) for eight years to investigate changes in plant-based diet quality in relation to changes in physical and mental HRQoL. Plant-based diet quality was assessed by three plant-based diet indices: overall plant-based diet index (PDI), healthful PDI (hPDI), and unhealthful PDI (uPDI). Physical and mental HRQoL were measured by physical component score (PCS) and mental component score (MCS) of the 36-Item Short Form survey. Diet was assessed two years before the HRQoL measurements and both were updated every 4 years. The associations between 4-year changes in PDIs and HRQoL were evaluated by multivariable generalized linear regression. Each 10-point increase in PDI was associated with an improvement of 0.07 (95% CI, 0.01, 0.13) in PCS and 0.11 (0.05, 0.16) in MCS. A 10-point

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Authorship: MYB, SK, and IK designed the study; MYB performed the statistical analyses; SK, XL, YL, and AP contributed to the statistical analyses; YK, LDK, AP, OIO, WCW, FBH, and IK contributed the acquisition or interpretation of data; MYB and SK drafted the manuscript; MYB, SK, and IK had responsibility for final content; and all authors read, critically revised, and approved the final manuscript.
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Conflict of Interest: None of the authors reported a conflict of interest related to the study.

increase in hPDI was associated with an increment of 0.13 (0.08, 0.19) in PCS and 0.09 (0.03, 0.15) in MCS. Conversely, a 10-point increase in uPDI was associated with decreases in both PCS and MCS (−0.07 [−0.12, −0.02] and −0.10 [−0.16, −0.05], respectively). Compared to a stable diet, an increase in hPDI was significantly associated with improvements in physical HRQoL in older women and with mental HRQoL in younger women. In conclusion, adherence to a healthful plant-based diet was modestly associated with improvements in both physical and mental dimensions of HRQoL.

Keywords

Plant-based diet index; Healthful plant-based diet; Diet quality; Health-related quality of life

INTRODUCTION

A plant-based diet has been associated with lower risk of chronic diseases including type 2 diabetes, cardiovascular disease (CVD), and cancer [1; 2; 3; 4; 5]. Recent studies also suggest that plant-based diets are related to mental well-being. A longitudinal study in the UK reported positive relationship between fruit and vegetable consumption and well-being [6], while a randomized controlled trial study in New Zealand showed that a plant-based diet improved mental health [7]. The interventional study with 500 patients with depression and anxiety reported that the 12 weeks anti-inflammatory plant-based diet and lifestyle modification improved their symptoms [8].

However, most previous studies have restricted the definition of plant-based diets to either vegetarian or non-vegetarian, and they failed to differentiate between plant foods based on their nutrient quality. While a higher intake of healthy plant foods, such as whole grains, vegetables, and fruits has been associated with lower risk of chronic diseases, a higher intake of less healthy plant foods, such as potatoes and added sugars has been associated with a higher cardiometabolic disease risk [9; 10; 11; 12]. To overcome these limitations, three plant-based diet indices—an overall plant-based diet index (PDI), a healthful PDI (hPDI), and an unhealthful PDI (uPDI)—that can assess the quality of plant-based diets have been developed. We have previously reported that a higher hPDI was associated with lower risk of diabetes, coronary heart disease, total and CVD mortality, as well as more favorable biomarker profiles and less weight gain, whereas a higher uPDI was associated with higher risk of these outcomes [13; 14; 15; 16; 17]).

A further limitation of previous studies is that most of them focused on the specific health outcomes such as disease incidence or mental health problems. Health-related quality of life (HRQoL) refers to a multidimensional concept that encompasses the physical, mental, emotional and social functioning of individuals, enables us to summarize a broad array of individual's functioning [18; 19]. To our knowledge, there has been no previous study that examined the relationship between the improvements specifically in the quality of an individual's plant-based diet and HRQoL change. In the current study, we followed participants in the Nurses' Health Study (NHS) and the Nurses' Health Study II (NHSII) with repeated measurements of diet and HRQoL in every 4 years during 8 years period. We took advantage of our unique data to evaluate the associations between 4-year changes in plant-based diet indices and HRQoL, adjusting for various social and lifestyle factors.

METHODS

Study Population and Design

The NHS was established in 1976 among 121,700 US female registered nurses, aged 30 to 55 years. The NHSII was established in 1989 among 116,429 younger US female registered nurses, aged 25 to 42 years. All participants completed a baseline questionnaire, and information on their health behaviors and medical histories has been updated by biennial follow-up questionnaires ever since. In both cohorts, the cumulative follow-up rates exceeded 90 % [20].

In the current study, the baseline was set at 1992 for the NHS and at 1993 for the NHSII, when we first assessed HRQoL using the Medical Outcomes Study's 36-Item Short Form Health Survey (SF-36), version 1 [21]. The SF-36 was administered again in 1996 and 2000 in the NHS, and in 1997 and 2001 in the NHSII (online Supplementary Figure S1). We excluded participants who either died before baseline or missing age information, had missing dietary information, had missing HRQoL information, had implausible baseline energy intakes (<500 kcal or >3500 kcal per day) at the FFQ just before the baseline (1992 in the NHS and 1991 in the NHSII), or were pregnant at the time of returning questionnaires (only in the NHSII). In both cohorts, the SF-36 was only included on the initially mailed long-form questionnaire and was dropped from the shortened version that was mailed to participants who did not respond to the long version. As reported previously, there was no substantial difference between excluded participants because of missing HRQoL information (mostly who completed the shortened survey) and those who completed the longer survey [21]. After exclusion, the analytical samples were 50,290 women in the NHS and 51,784 women in the NHSII. The online Supplementary Figure S2 presents the flowchart of participants.

The study protocol was approved by the institutional review boards of the Brigham and Women's Hospital and Harvard T.H. Chan School of Public Health. The completion of self-administered questionnaires was considered to imply informed consent.

Dietary Assessment

From 1990 in the NHS and 1991 in the NHSII, dietary data were collected every four years using a semi-quantitative food frequency questionnaire (FFQ, online Supplementary Figure S1). The reliability and validity of the FFQ have been described elsewhere [22; 23]. Participants reported how often, on average, they had consumed defined portions of the 130 food items during the past year using 9 response categories, ranging from "never or less than once/month" to "≥ six times/day". The development of three plant-based diet indices (PDI, hPDI, and uPDI) have been also described previously ([13; 14; 15; 16; 17]). Briefly, we first created 18 food groups based on nutrients and culinary similarities, and divided these 18 food groups into the larger three categories of healthy plant foods (n=7; whole grains, fruits, vegetables, nuts, legumes, vegetable oils, tea/coffee), less healthy plant foods (n=5; fruit juices, refined grains, potatoes, sugar-sweetened beverages, sweets/desserts), and animal foods (n=6; animal fat, dairy, eggs, fish/seafood, meat, miscellaneous animal-based foods). Each intake of 18 food groups was ranked into quintiles and assigned a score of 1 to 5 positively or negatively. For creating the PDI, foods in both plant food groups were scored positively while foods in the animal food group were given reverse scores. For hPDI, foods in the healthy plant food group were given positive scores while foods in the less healthy plant and animal food groups received reverse scores. For uPDI, foods in the less healthy plant food group were assigned positive scores, and foods in the healthy plant and animal food groups were given reverse scores. Because alcohol has different associations with specific health outcomes, we did not include this as a food group but rather adjusted for it in the analyses. Likewise, because the fatty acid composition of margarine has changed over time from high-trans to high-unsaturated fats, we included this variable as a covariate in the analyses. Finally, we summed scores of 18 food groups to derive PDI, hPDI, and uPDI, ranging from 18 to 90 with higher score indicates adherence to each version of plant-based diets.

HRQoL Assessment

The SF-36 instrument was used to assess the following 8 domains of HRQoL: 1) physical functioning, 2) role limitations due to physical health problems (physical role limitations), 3) bodily pain, 4) general health perceptions (general health), 5) vitality, 6) social functioning, 7) role limitations due to emotional problems (mental role limitations), and 8) mental health [(24)]. Each domain was scored from 0 to 100, with higher scores reflecting better HRQoL [(21)]. The former four components were considered to reflect physical dimensions and the latter four components were considered to reflect mental dimensions. As the primary outcome, two summary scores capturing overall physical and mental HRQoL (physical component score [PCS] and mental component score [MCS]) were calculated from the 8 subscale scores and transformed so that a mean score of 50 (standard deviation [SD], 10) reflects the mean in the general US population [(25)]. The SF-36 questionnaire has been extensively validated elsewhere [(24; 26; 27)].

Covariate Assessment

The biennial questionnaires updated participants' information including their age, race, body weight, smoking status, physical activity, NSAIDs use, multivitamin use, menopausal status, postmenopausal hormone use, marital status, working status, spouse's education, and physician diagnosed chronic diseases. We additionally obtained information on participants' educational attainment in the NHS, as well as information on household income in the NHSII (2001). Body mass index (BMI) was calculated as kg/m^2 based on self-reported weight and height, and physical activity was assessed by metabolic equivalent task hours per week (MET-h/week). Detailed descriptions of the validity and reproducibility for body weight and physical activity have been published previously [(28; 29)].

Statistical Analyses

We examined the associations between 4-year changes in PDI, hPDI, and uPDI (1990–1994 and 1994–1998 in the NHS and 1991–1995 and 1995–1999 in the NHSII) and 4-year changes in HRQoL (1992–1996 and 1996–2000 in the NHS and 1993–1997 and 1997–2001 in the NHSII). Participants were divided into 5 groups according to diet score changes (decrease ≥ 10-point, decrease 3–9 point, relatively stable [−2 to 2 point], increase 3–9 point, and increase ≥ 10-point). We used multivariate linear regression using generalized estimating equation (the GENMOD procedure in SAS) starting from an unstructured correlation matrix to account for the correlated nature of within-person repeated measurements updated in every 4 years. Beta estimates were calculated with adjustment for age, race, baseline BMI (<21.0, 21–24.9, 25.0–29.9, 30–34.9, ≤35), baseline corresponding plant-based diet index score, baseline corresponding HRQoL score, menopausal status and postmenopausal hormone use (premenopausal, postmenopausal without hormone use, postmenopausal with past hormone use, postmenopausal with current hormone use), smoking status (never-never, current-past, past-current, never-current, past-past, current-current), NSAIDs use (never use, start use, past use, continue to use), multivitamin use (never use, start use, past use, continue to use), marital status (never, past, started, continued), working status (never, past, started, continued), husband education (more than college or not), participant's education (more than college or not, only in the NHS), household income (<50,000, 50,000–74,999, 75,000–99,999, ≤100,000, only in the NHSII), and baseline and changes in each of total energy intake (in quintiles), alcohol intake (0, 0.1–4.9, 5.0–14.9, 15.0–29.9, ≤30 g/day), margarine intake (in quintiles), and physical activity (in quintiles). To account for the potential effect of weight change and development of comorbidities on the associations between plant-based diets and HRQoL, we adjusted for weight change (in quintiles) and the onset of comorbidities (CVD, cancer, diabetes, hypertension, hypercholesterolemia, and respiratory disease) in a separate model. We also estimated the changes in PCS, MCS, and subscales of SF-36 per 10-point increase in PDI, hPDI, and uPDI by treating the diet scores as continuous variables.

In addition, to assess the clinical significance, we compared the HRQoL changes associated with a 10-point hPDI increase to the HRQoL changes associated with a 5 lbs weight increase and a 5 MET-h/week physical activity increase, the two major factors that are associated with HRQoL [21; 30]. Lastly, in order to assess the directionality of the associations between change in hPDI and change in HRQoL, we examined the association of a 10-point increase in PCS and MCS (1992–1996 and 1996–2000 in the NHS and 1993–1997 and 1997–2001 in the NHSII) to the subsequent change in hPDI (1994–1998 and 1998–2002 in the NHS and 1995–1999 and 1999–2003 in the NHSII).

Analyses were conducted separately for each cohort. As the NHS and the NHSII have similar study design, characteristics, and follow-up strategies, results were pooled with the use of an inverse, variance-weighted meta-analysis with a fixed effects model, and heterogeneity was examined using the Cochran's Q statistic [31]. All analyses were performed in SAS 9.4 (SAS Institute Inc., Cary, NC), and P value < 0.05 were considered statistically significant.

RESULTS

Baseline age-standardized characteristics of participants according to first 4-year PDI changes were shown in Table 1. The mean ages were 58 years (SD, 7 years) in the NHS and 39 years (SD, 5 years) in the NHSII. In both cohorts, participants with the PDI increase ≥

10-point had a lower baseline PDI score and a lower baseline energy intake. Participants with the hPDI increase ≥ 10-point had a lower baseline hPDI score and a higher baseline energy intake, and participants with the uPDI increase ≥ 10-point had a lower baseline uPDI score and a higher baseline energy intake (online Supplementary Table S1). Compared to the participants in the NHSII, participants in the NHS had higher baseline prevalence of comorbidities, lower (worse) scores of baseline PCS, physical functioning, physical role limitations, bodily pain, and higher (better) MCS, vitality, social functioning, mental role limitations, and mental health. During 4-year periods, PCS scores tended to decrease over time (mean change ± SD, −1.80 ± 7.85 in the NHS and −0.99 ± 7.51 in the NHSII) while MCS scores tended to improve over time (1.28 ± 7.66 in the NHS and 1.25 ± 9.29 in the NHSII), consistent with previous reports [21; 32]. The mean changes in PCS in participants with relatively stable PDI hPDI, and uPDI were −1.76 ± 7.78, −1.77 ± 7.79, and −1.71 ± 7.73, respectively in the NHS; and −0.96 ± 7.40, −0.95 ± −7.36, and −0.95 ± −7.46, respectively in the NHSII. Similarly, the mean MCS change in those with stable PDI, hPDI, and uPDI were 1.22 ± 7.62, 1.23 ± 7.63, and 1.23 ± 7.52, respectively in the NHS; and 1.22 ± 9.17, 1.17 ± 9.16, and 1.16 ± 9.22, respectively in the NHSII.

The associations of changes in PDI, hPDI, and uPDI with changes in PCS and MCS were summarized in Table 2, Table 3, Figure 1, and online Supplementary Tables S2 and S3. In the pooled results with multivariable-adjustment, compared with participants whose plant-based diet indices remained relatively stable, the PCS changes among those with ≥ 10-point increase in diet indices were 0.04 (95% confidence interval [CI]: −0.09, 0.17) for PDI, 0.06 (−0.07, 0.19) for hPDI, and −0.18 (−0.31, −0.06) for uPDI (Table 2). In contrast, the PCS changes among participants with ≥ 10-point decrease in plant-based diet indices were −0.05 (−0.18, 0.08) for PDI, −0.25 (−0.38, −0.13) for hPDI, and 0.02 (−0.11, 0.14) for uPDI (Table 2). Similar trends were observed in the participants who had mild increase and decrease in PDIs (3 to 9 points). For each 10-point increase in plant-based diet indices, the pooled PCS changes were 0.07 (0.01, 0.13) for PDI, 0.13 (0.08, 0.19) for hPDI, and −0.07 (−0.12, −0.02) for uPDI (Table 2, Figure 1).

Likewise, compared with participants whose plant-based diet indices remained relatively stable, the MCS changes among those with ≥ 10-point increase in diet indices were 0.07 (−0.07, 0.21) for PDI, 0.15 (0.01, 0.29) for hPDI, and −0.10 (−0.22, 0.03) for uPDI (Table 3). To the contrary, the MCS changes among participants with ≥ 10-point decrease in plant-based diet indices were −0.17 (−0.30, −0.03) for PDI, −0.14 (−0.27, 0.00) for hPDI, and 0.20 (0.07, 0.33) for uPDI (Table 3). Similar trends were also observed in the participants who had mild increase and decrease in PDIs. Per 10-point increase in plant-based diet indices, the pooled MCS changes were 0.11 (0.05, 0.16) for PDI, 0.09 (0.03, 0.15) for hPDI, and −0.10 (−0.16, −0.05) for uPDI (Table 3, Figure 1). The associations of changes in PDIs with changes in PCS and MCS were larger in the basic models (adjusted for age, baseline corresponding plant-based diet indices, and baseline corresponding HRQoL scores, online Supplementary Tables S2 and S3).

When we turned to the specific sub-scales of SF-36, a 10-point increase in hPDI was significantly associated with improvements in all dimensions of HRQoL (Figure 1). In addition, when we examined the joint associations of scores at baseline and 4 years later, compared to participants with consistently low hPDI scores over time, participants with the largest increase in hPDI (low to high) showed marginally increased PCS scores (0.11 [−0.08, 0.29]) and significantly increased MCS scores (0.21 [0.02, 0.40]), and those with consistently high hPDI had increased PCS scores (0.24 [0.14, 0.33]) and increased MCS scores (0.23 [0.13, 0.33]) (online Supplementary Figure S3).

There were some notable differences in the pattern of results by the cohorts. The association of hPDI increase (improved plant-based diet quality) with improvement in physical HRQoL was significant in the NHS (older women) but not in the NHSII (younger women) (Table 2). By contrast, the positive associations between hPDI increase and improvement in mental HRQoL were significant in the NHSII but not in the NHS (Table3). We illustrated the cohort specific changes in PCS and MCS per 10-point increase in plant-based diet indices in the online Supplementary Figure S4.

In the online Supplementary Table S4, we examined changes in PCS and MCS associated with changes in body weight and physical activity that were well-established predictors of HRQoL change. The coefficients from the analyses implied that in the NHS, a 10-point increase in hPDI had a comparable impact on PCS to achieving a 5-lbs weight loss or a 5-MET-h/week increase in physical activity. In the NHSII, a 10-point hPDI increase was comparable on MCS as a 5-lbs weight loss or 5-MET-h/week physical activity increase.

Lastly, when we examined the directionality of the association between changes in hPDI and HRQoL, we found that many of significant associations were bi-directional. A 10-point increase in PCS score was associated with hPDI increase in the NHS (0.14 [0.09, 0.18]), while a 10-point increase in MCS score was associated with hPDI increase in the NHSII (0.07 [0.03, 0.12]).

DISCUSSION

The current study examined the associations of 4-year changes in plant-based diet quality with 4-year changes in HRQoL during an 8-year follow-up period. Based on the data of two large US cohorts of women, we found that adherence to a healthful plant-based diet was associated to the improvements in both physical and mental HRQoL.

Our results on hPDI and physical HRQoL are in line with previous studies that implicate hPDI in the prevention of chronic diseases [13; 14; 17]. The beneficial effects of hPDI has been explained by several biological mechanisms. An increase in hPDI implies increased consumption of whole grains, fruits, vegetables, and tea and coffee. Higher consumption of these foods has been associated with lower risk of CVD and cancer [9; 10], partially explained through anti-inflammatory and antioxidant effects of dietary fibers and polyphenols ([33; 34; 35; 36; 37; 38]). More recently, studies have begun to focus on the impact of plant-based diets on psychological well-being ([6; 7; 8; 39; 40; 41]), which is also consistent with the association of hPDI and mental HRQoL in our study. Although the mechanisms are still incompletely understood, one potential explanation is the anti-inflammatory and antioxidant effects of vitamins in fruits and vegetables linking with lower depression risk [6; 42; 43]. Another possible mechanism is via the gut-brain microbiota axis. Diets high in fruit and fibers have been associated with greater microbial diversity and favorable differences in fecal microbiota [44], and the bidirectional communication between gut microbiota and the central nervous system has been affecting stress reactivity [45; 46]. Future work should consider the role of healthy plant-based diet in altering the gut microbiome and, thereby, improving physical and mental HRQoL.

A strength of this study is the repeated assessments of diet, HRQoL, and numerous validated covariates that enables us to examine the changes in plant-based diet quality and HRQoL. Our within-individual fixed effects design differences out all observed and unobserved time-invariant confounding factors. It is noteworthy that the relationship between hPDI increase and improvement in physical HRQoL was more prominent in the older cohort (NHS), whereas the impacts on mental HRQoL were more pronounced in the younger cohort (NHSII). This might be partly explained by ceiling effects in the HRQoL measurement, i.e., at younger ages, most participants score highly on their physical functioning. Stated differently, the physical function items on the SF-36 instrument are more sensitive to moderate or greater deficits in physical functioning (e.g., inability to walk up a flight of stairs); subtle deficits may not be picked up. To test whether switching to a healthful plant-based diet in midlife leads to long-term cumulative improvements in physical functioning with age will necessitate longer follow-up than what we have reported here. Another strength of this study is that our plant-based diet indices are different from a vegetarian diet and can assess the plant-based diet quality without complete exclusion of animal foods. Such an approach is desirable and easily translatable to public health recommendations to general population because it is flexible and allows individuals to make gradual changes in their diets. For example, a 10-point hPDI increase could be achieved by increasing healthy plant foods (such as whole grains, fruits, and vegetables) by 3 servings/day and decreasing less healthy plant foods (such as refined grains and sugar sweetened beverages) and some animal foods (such as processed meat) by about 2 servings/day [17]. A healthy plant-based diet closely aligns with the principles of other healthy dietary patterns, such as the Alternate Healthy Eating Index and the Alternate Mediterranean Diet. The correlations between our healthful plant-based diet index and the Alternate Healthy Eating Index were 0.67 in the NHS and 0.68 in the NHSII. The correlations between our index and the Alternate Mediterranean Diet score were 0.37 in the NHS and 0.35 in the NHSII [47]. However, our plant-based diet indices are different from these other dietary indices in several aspects. First, the plant-based diet indices focus solely on the quality of plant foods included in an individual’s diet. Second, the plant-based diet indices score all animal foods negatively, including fish, poultry, and dairy that are known to be associated with better health outcomes. A significant finding from our study is that a worsening in quality of plant-based diet was associated with lower physical and mental HRQoL. This has important public health implications for nutritional recommendations that are distinct from advocating other diets, such as the Mediterranean diet, by accounting for the quality of plant foods. In the analyses, we adjusted for baseline diet scores as participants with lower baseline scores tended to increase their diet scores. The observed significant associations after adjustment for baseline diet scores suggest that even who’s diet quality is poor at baseline, improving diet quality can be related to improved HRQoL.

To our knowledge, this is the first study to elucidate the associations of changes in plant-based diet quality with HRQoL change. However, several limitations should be mentioned. First, although we controlled for several factors that have been associated with health-related quality of life and applied a within-individual fixed effects design to difference out all time-invariant confounding factors, we cannot infer causality due to the observational nature of our study, nor exclude the possibility of time-varying residual confounding, i.e. simultaneous changes in diet and quality of life over time. Second, our study design was unable to establish the directionality of the associations between plant-based diet quality and HRQoL (i.e. whether a healthy plant-based diet improves the HRQoL, or women with a higher HRQoL have better access to or motivation to consume healthy foods). Indeed, we do find some suggestion of bidirectional associations, viz., increased hPDI leads to improved HRQoL, but at the same time, improved HRQoL is correlated with changes in dietary indices although the associations were small. The English Longitudinal Study of Ageing reported that higher versus lower psychological well-being was associated with greater likelihood of meeting recommended levels of fruits and vegetable consumption over 6 years of follow-up [(48)]. Ultimately, the associations we observed need to be confirmed in experimental designs. Third, because the participants in this study were female registered nurses and predominantly white, the generalizability may be limited. In addition, although we observed consistently positive associations between hPDI and HRQoL and negative associations between uPDI and HRQoL, the changes in HRQoL scores were modest. However, our analyses showed that increasing hPDI score by 10-point had a comparable impact on HRQoL compared to changes in other known factors such as weight and physical activity. Lastly, because the PDIs were scored based on the quintiles of food intakes, other scoring approach (e.g. using absolute intake values) might be required when we compare the different populations with different dietary patterns.

In conclusion, adherence to a healthful plant-based diet was associated with both physical and mental HRQoL improvements. Although the associations were moderate, our results suggest a potential clinical significance of improving plant-based diet quality on physical and mental HRQoL.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

ACKNOWLEDGEMENTS

Financial Support: This study has been supported by grants (UM1 CA186107, U01 CA176726, and P30 DK46200) from the National Institutes of Health. Dr. Baden is supported by a fellowship from the Manpei Suzuki Diabetes Foundation. Dr. Kino is supported by the Japan Society for the Promotion of Science Postdoctoral Fellowship for Research Abroad. The funders of the study had no role in the design, analysis or writing of this article.

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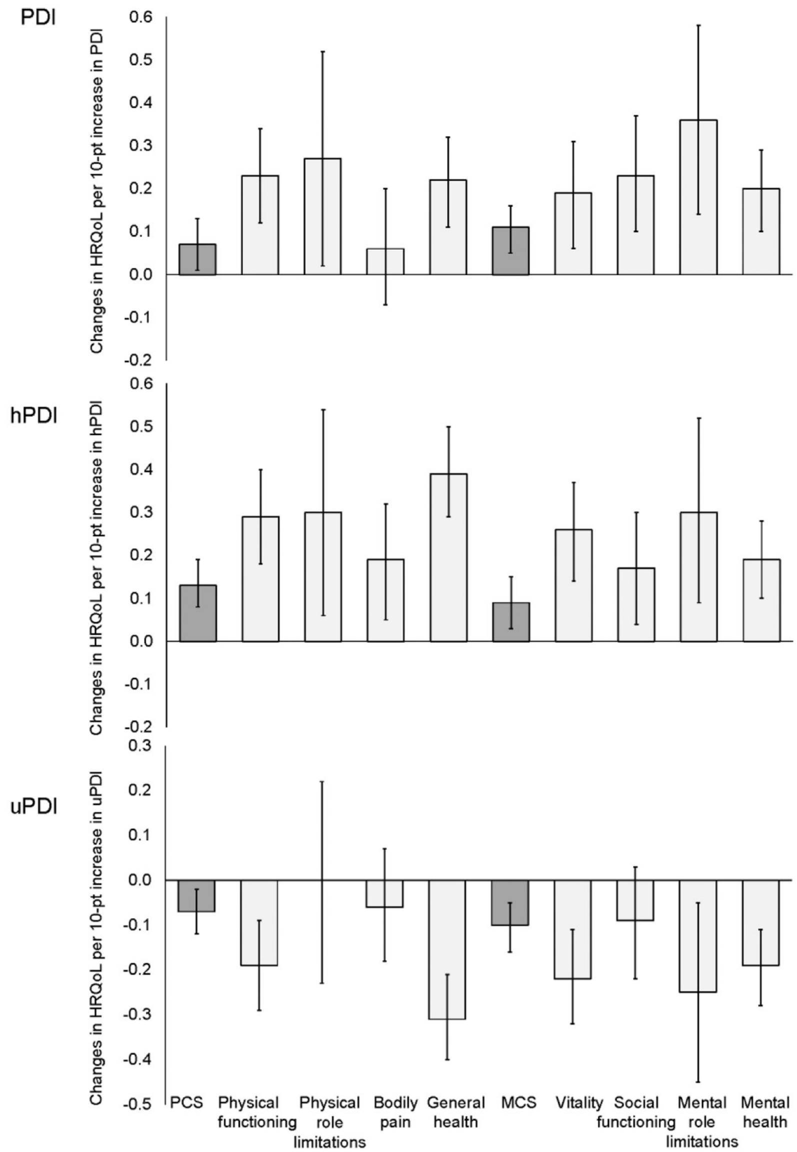

Figure 1. Differences and 95 % confidence intervals of changes in HRQoL scores per 10-point increase in plant-based diet indices.

The bar graphs show the pooled multivariable-adjusted differences of each HRQoL dimension. The dark bars are summary scores of physical and mental HRQoL (physical component score and mental component score). Error bars indicate 95% confidence intervals. hPDI, healthful plant-based diet index; HRQoL, health-related quality of life; PDI, overall plant-based diet index; uPDI, unhealthful plant-based index.

Table 1.

Baseline (1992 in the NHS and 1993 in the NHSII) characteristics of participants according to the first 4-year changes in overall plant-based diet index (PDI)*

	Decrease ≥ 10 pt	Decrease 3 to 9 pt	Relatively stable (± 2 pt)	Increase 3 to 9 pt	Increase ≥ 10 pt
Nurses' Health Study (NHS)					
n	3,440	14,884	16,267	12,940	2,759
PDI score					
Baseline	60.9 (5.7)	57.3 (5.9)	54.6 (6.1)	51.8 (6.0)	48.4 (5.7)
Change	−12.3 (2.2)	−5.4 (1.9)	0.0 (1.4)	5.4 (1.9)	12.2 (2.1)
Age (year)†	59 (7)	59 (7)	58 (7)	58 (7)	57 (7)
Body-mass index	26.1 (4.9)	25.9 (4.9)	25.9 (4.9)	25.9 (4.9)	26.1 (4.9)
Physical activity (Met-hours/week)	19.0 (21.7)	19.5 (22.3)	20.0 (23.2)	20.0 (23.8)	20.4 (23.0)
Alcohol intake (g/day)	5.2 (9.6)	5.2 (9.5)	5.3 (9.6)	5.0 (9.3)	5.2 (10.0)
Margarine Intake (servings/day)	1.0 (1.0)	0.9 (1.0)	0.9 (1.0)	0.8 (1.0)	0.7 (0.9)
Energy Intake (kcal/day)	1899 (505)	1810 (511)	1749 (506)	1686 (493)	1609 (464)
White race (%)	98	98	98	98	98
Current Smoker (%)	13	12	13	12	13
Premenopausal (%)	21	21	22	22	21
Postmenopausal hormone use (%)	31	32	32	32	32
Comorbidities (%)					
Cardiovascular disease	8	9	8	8	9
Cancer	9	9	9	9	10
Diabetes	5	5	4	4	4
Hypertension	33	33	31	33	33
Hypercholesterolemia	51	47	45	46	45
Respiratory diseases	12	11	11	11	11
NSAIDs use (%)	48	49	49	50	48
Multivitamin use (%)	42	43	43	42	46
Social status (%)					
Currently married	82	84	83	83	81
Currently working	91	90	90	90	90

	Decrease ≥ 10 pt	Decrease 3 to 9 pt	Relatively stable (± 2 pt)	Increase 3 to 9 pt	Increase ≥ 10 pt
Education (more than Bachelor)	30	30	31	31	32
Husband Education (more than college)	46	46	48	46	45
Baseline SF-36 scores					
Physical component score	50.0 (8.9)	50.2 (8.8)	50.3 (8.7)	50.2 (8.8)	50.2 (9.0)
Mental component score	52.0 (8.6)	52.2 (8.4)	52.2 (8.4)	52.2 (8.4)	51.7 (8.7)
Physical functioning	85.5 (17.6)	86.2 (17.3)	86.6 (16.9)	86.4 (17.1)	86.1 (17.8)
Physical role limitations	75.9 (35.1)	76.2 (35.2)	76.8 (34.7)	76.4 (35.2)	75.9 (35.5)
Bodily pain	74.2 (20.3)	74.5 (20.0)	74.5 (19.9)	74.5 (20.2)	74.1 (20.5)
General health	79.8 (17.8)	80.1 (17.4)	80.3 (17.4)	80.4 (17.5)	79.9 (18.2)
Vitality	64.2 (18.2)	64.4 (18.0)	64.6 (18.0)	64.5 (18.1)	64.4 (18.7)
Social functioning	89.1 (18.6)	89.7 (17.9)	90.1 (17.6)	89.8 (18.1)	88.6 (19.2)
Mental role limitations	84.2 (28.9)	84.4 (28.8)	84.9 (28.1)	84.6 (28.6)	83.1 (30.0)
Mental health	76.9 (14.3)	77.3 (14.0)	77.3 (14.2)	77.4 (14.0)	76.7 (14.3)
Nurses' Health Study II (NHS II)					
n	3,903	15,294	16,174	13,320	3,093
PDI score					
Baseline	60.7 (5.6)	57.2 (5.9)	54.5 (5.9)	52.1 (5.9)	48.8 (5.7)
Change	−12.4 (2.2)	−5.4 (1.9)	0.0 (1.4)	5.3 (1.9)	12.4 (2.3)
Age (year)†	39 (4)	39 (5)	39 (5)	39 (5)	38 (5)
Body-mass index	25.3 (5.7)	25.1 (5.6)	25.0 (5.5)	25.1 (5.6)	25.2 (5.7)
Physical activity (Met-hours/week)	21.6 (26.4)	20.3 (27.0)	20.0 (25.4)	20.5 (26.5)	20.8 (23.9)
Alcohol intake (g/day)	3.2 (6.1)	3.2 (6.2)	3.2 (6.2)	3.1 (6.0)	3.2 (6.5)
Margarine Intake (servings/day)	0.7 (0.8)	0.7 (0.8)	0.7 (0.8)	0.6 (0.8)	0.6 (0.8)
Energy Intake (kcal/day)	1966 (546)	1856 (537)	1779 (537)	1717 (522)	1628 (504)
White race (%)	97	97	97	98	97
Current Smoker (%)	11	10	10	10	9
Premenopausal (%)	93	94	94	94	93
Postmenopausal hormone use (%)	5	4	4	4	5
Comorbidities (%)					
Cardiovascular disease	4	3	3	3	4
Cancer	2	2	2	2	2

	Decrease ≥ 10 pt	Decrease 3 to 9 pt	Relatively stable (± 2 pt)	Increase 3 to 9 pt	Increase ≥ 10 pt
Diabetes	1	1	1	1	1
Hypertension	9	7	8	8	8
Hypercholesterolemia	20	19	18	18	19
Respiratory diseases	10	10	9	10	10
NSAIDs use (%)	10	10	10	10	10
Multivitamin use (%)	43	42	43	44	45
Social status (%)					
Currently married	84	85	85	84	80
Currently working (%)	96	96	95	95	95
Husband Education (more than college)	69	71	71	71	70
Income status (%)					
less than $50,000	14	13	13	14	14
$50,000 to less than $75,000	25	23	24	23	24
$75,000 to less than $100,000	18	19	18	18	16
$100,000 or more	28	29	30	31	32
Baseline SF-36 scores					
Physical component score	53.1 (7.8)	53.1 (7.7)	53.2 (7.6)	53.3 (7.6)	53.1 (8.0)
Mental component score	47.7 (9.7)	48.0 (9.2)	48.1 (9.2)	48.1 (9.3)	47.8 (9.7)
Physical functioning	91.7 (13.8)	91.9 (13.7)	92.0 (13.6)	92.2 (13.4)	91.6 (14.0)
Physical role limitations	82.8 (30.6)	83.7 (29.9)	83.7 (29.9)	83.6 (30.0)	83.0 (30.8)
Bodily pain	77.0 (19.0)	77.4 (18.6)	77.6 (18.5)	77.8 (18.6)	77.1 (19.3)
General health	80.0 (17.4)	80.3 (17.1)	80.6 (16.9)	80.8 (17.0)	80.7 (17.5)
Vitality	55.1 (19.2)	55.6 (19.1)	55.8 (19.1)	56.0 (19.2)	55.8 (19.9)
Social functioning	85.8 (20.2)	86.6 (19.2)	86.8 (19.0)	86.9 (18.9)	85.7 (20.3)
Mental role limitations	81.3 (30.7)	82.1 (30.0)	82.1 (30.0)	81.5 (30.7)	80.5 (31.7)
Mental health	71.1 (15.6)	71.8 (14.9)	72.0 (14.9)	72.0 (14.9)	71.6 (15.5)

NHS, Nurses' Health Study; NHS II, Nurses' Health Study II; PDI, overall plant-based diet index; SF-36, 36-Item Short Form Health Survey.

* Values were means (SDs) or percentages and were standardized to the age distribution of the study population.

† Value was not age-adjusted.

Table 2.

4-year changes in physical component scores (1992–2000 in NHS and 1993–2001 in NHSII) according to 4-year changes in plant-based diet indices (1990–1998 in NHS and 1991–1999 in NHSII)*

	Decrease ≥ 10 pt	Decrease 3 to 9 pt	Relatively stable (± 2 pt)	Increase 3 to 9 pt	Increase ≥ 10 pt	Changes/10-point increase in indices (95% CIs)	*P*
Overall Plant-Based Diet Index (PDI)							
Nurses' Health study							
Model 1	−0.21 (−0.40, −0.01)	−0.14 (−0.25, −0.02)	0.00	0.05 (−0.06, 0.17)	0.15 (−0.05, 0.36)	0.17 (0.09, 0.26)	<0.001
Model 2	−0.14 (−0.34, 0.06)	−0.10 (−0.21, 0.02)	0.00	0.06 (−0.06, 0.17)	0.19 (−0.02, 0.40)	0.14 (0.05, 0.23)	0.002
Nurses' Health study II							
Model 1	−0.10 (−0.28, 0.07)	−0.09 (−0.19, 0.02)	0.00	0.02 (−0.09, 0.12)	−0.03 (−0.21, 0.14)	0.07 (−0.01, 0.14)	0.09
Model 2	−0.02 (−0.19, 0.15)	−0.05 (−0.16, 0.05)	0.00	0.01 (−0.09, 0.11)	−0.07 (−0.24, 0.11)	0.02 (−0.06, 0.09)	0.63
Pooled Results							
Model 1	−0.15 (−0.28, −0.02)	−0.11 (−0.19, −0.03)	0.00	0.03 (−0.04, 0.11)	0.05 (−0.09, 0.18)	0.11 (0.06, 0.17)	<0.001
Model 2	−0.05 (−0.18, 0.08)	−0.07 (−0.15, 0.00)	0.00	0.03 (−0.05, 0.11)	0.04 (−0.09, 0.17)	0.07 (0.01, 0.13)(14; 17; 48) †	0.02
Healthful Plant-Based Diet Index (hPDI)							
Nurses' Health study							
Model 1	−0.39 (−0.57, −0.20)	−0.12 (−0.24, −0.01)	0.00	0.03 (−0.09, 0.15)	0.16 (−0.05, 0.37)	0.20 (0.11, 0.28)	<0.001
Model 2	−0.29 (−0.48, −0.10)	−0.12 (−0.24, −0.01)	0.00	0.07 (−0.05, 0.19)	0.31 (0.10, 0.52)	0.22 (0.14, 0.30)	<0.001
Nurses' Health study II							
Model 1	−0.28 (−0.46, −0.11)	−0.06 (−0.17, 0.04)	0.00	0.00 (−0.11, 0.11)	−0.09 (−0.26, 0.08)	0.10 (0.02, 0.17)	0.01
Model 2	−0.22 (−0.39, −0.05)	−0.04 (−0.15, 0.06)	0.00	0.00 (−0.11, 0.10)	−0.11 (−0.28, 0.06)	0.07 (−0.01, 0.14)	0.08
Pooled Results							
Model 1	−0.33 (−0.46, −0.20)	−0.09 (−0.17, −0.01)	0.00	0.01 (−0.07, 0.09)	0.01 (−0.12, 0.15)	0.14 (0.09, 0.20)	<0.001
Model 2	−0.25 (−0.38, −0.13)	−0.08 (−0.16, 0.00)	0.00	0.03 (−0.05, 0.11)	0.06 (−0.07, 0.19)†	0.13 (0.08, 0.19) †	<0.001
Unhealthful Plant-Based Diet Index (uPDI)							
Nurses' Health study							
Model 1	−0.01 (−0.20, 0.18)	−0.11 (−0.23, 0.01)	0.00	−0.12 (−0.23, 0.00)	−0.25 (−0.43, −0.07)	−0.06 (−0.14, 0.02)	0.14
Model 2	0.16 (−0.04, 0.35)	−0.06 (−0.17, 0.06)	0.00	−0.10 (−0.22, 0.01)	−0.22 (−0.40, −0.04)	−0.11 (−0.18, −0.03)	0.01
Nurses' Health study II							
Model 1	−0.11 (−0.27, 0.06)	−0.04 (−0.14, 0.07)	0.00	−0.05 (−0.16, 0.05)	−0.20 (−0.36, −0.03)	−0.03 (−0.11, 0.03)	0.26

	Decrease ≥ 10 pt	Decrease 3 to 9 pt	Relatively stable (± 2 pt)	Increase 3 to 9 pt	Increase ≥ 10 pt	Changes/10-point increase in indices (95% CIs)	***P***
Model 2	−0.08 (−0.24, 0.08)	−0.03 (−0.13, 0.08)	0.00	−0.06 (−0.16, 0.05)	−0.16 (−0.32, 0.00)	−0.04 (−0.11, 0.02)	0.21
Pooled Results							
Model 1	−0.06 (−0.19, 0.06)	−0.07 (−0.15, 0.01)	0.00	−0.08 (−0.16, 0.00)	−0.22 (−0.34, −0.10)	−0.05 (−0.10, 0.00)	0.07
Model 2	0.02 (−0.11, 0.14)	−0.04 (−0.12, 0.04)	0.00	−0.08 (−0.16, 0.00)	−0.18 (−0.31, −0.06)	−0.07 (−0.12, −0.02)	0.008

NHS, Nurses' Health Study; NHS II, Nurses' Health Study II.

* Values were beta coefficients (95% CIs) in physical component scores. Pooled results were calculated with a fixed effects model.

† The *P* value for Q-statistic for heterogeneity <0.05, indicating statistically significant heterogeneity between the NHS and the NHSII.

Model 1: Adjusted for age, race, baseline corresponding plant-based diet indices, baseline corresponding HRQoL scores, baseline BMI, and baseline and changes in each of smoking status, menopausal status and postmenopausal hormone use, NSAIDs use, multi vitamin use, marital status, working status, husband education, physical activity, alcohol intake, margarine intake, and total energy intake. For the NHS, models were additionally adjusted for educational attainment. For the NHSII, models were additionally adjusted for household income.

Model 2: Further adjusted for cardiovascular disease, cancer, respiratory disease, hypertension, hypercholesterolemia, diabetes, and weight change.

Table 3.

4-year changes in mental component scores (1992–2000 in NHS and 1993–2001 in NHSII) according to 4-year changes in plant-based diet indices (1990–1998 in NHS and 1991–1999 in NHSII)*

	Decrease ≥ 10 pt	Decrease 3 to 9 pt	Relatively stable (± 2 pt)	Increase 3 to 9 pt	Increase ≥ 10 pt	Changes/10-point increase in indices (95% CIs)	*P*
Overall Plant-Based Diet Index (PDI)							
Nurses' Health study							
Model 1	−0.11 (−0.28, 0.07)	0.02 (−0.09, 0.12)	0.00	0.17 (0.06, 0.27)	−0.01 (−0.19, 0.18)	0.07 (−0.01, 0.14)	0.10
Model 2	−0.07 (−0.25, 0.11)	0.03 (−0.08, 0.14)	0.00	0.17 (0.06, 0.27)	0.00 (−0.19, 0.19)	0.05 (−0.03, 0.13)	0.22
Nurses' Health study II							
Model 1	−0.32 (−0.52, −0.11)	−0.08 (−0.21, 0.05)	0.00	0.07 (−0.05, 0.20)	0.15 (−0.06, 0.36)	0.18 (0.09, 0.27)	<0.001
Model 2	−0.30 (−0.50, −0.09)	−0.08 (−0.20, 0.05)	0.00	0.07 (−0.06, 0.19)	0.15 (−0.06, 0.36)	0.18 (0.09, 0.27)	<0.001
Pooled Results							
Model 1	−0.19 (−0.33, −0.06)	−0.02 (−0.10, 0.06)	0.00	0.13 (0.05, 0.21)	0.06 (−0.07, 0.20)	0.12 (0.06, 0.18)	<0.001
Model 2	−0.17 (−0.30, −0.03)	−0.01 (−0.09, 0.07)	0.00	0.12 (0.04, 0.21)	0.07 (−0.07, 0.21)	0.11 (0.05, 0.16) †	<0.001
Healthful Plant-Based Diet Index (hPDI)							
Nurses' Health study							
Model 1	−0.07 (−0.24, 0.09)	0.05 (−0.05, 0.15)	0.00	0.12 (0.02, 0.23)	0.11 (−0.08, 0.30)	0.04 (−0.04, 0.11)	0.31
Model 2	−0.02 (−0.19, 0.16)	0.06 (−0.05, 0.16)	0.00	0.14 (0.03, 0.25)	0.14 (−0.05, 0.33)	0.04 (−0.04, 0.11)	0.34
Nurses' Health study II							
Model 1	−0.32 (−0.53, −0.12)	−0.01 (−0.13, 0.12)	0.00	0.11 (−0.02, 0.24)	0.14 (−0.07, 0.34)	0.15 (0.06, 0.24)	<0.001
Model 2	−0.31 (−0.52, −0.11)	−0.01 (−0.13, 0.12)	0.00	0.12 (−0.01, 0.24)	0.16 (−0.04, 0.37)	0.16 (0.07, 0.25)	<0.001
Pooled Results							
Model 1	−0.17 (−0.30, −0.04)	0.03 (−0.05, 0.11)	0.00	0.12 (0.04, 0.20)	0.12 (−0.02, 0.26)	0.09 (0.03, 0.14)	0.003
Model 2	−0.14 (−0.27, 0.00) †	0.03 (−0.05, 0.11)	0.00	0.13 (0.05, 0.21)	0.15 (0.01, 0.29)	0.09 (0.03, 0.15)	0.003
Unhealthful Plant-Based Diet Index (uPDI)							
Nurses' Health study							
Model 1	0.11 (−0.06, 0.28)	0.09 (−0.02, 0.20)	0.00	0.07 (−0.04, 0.17)	−0.12 (−0.29, 0.04)	−0.08 (−0.15, −0.01)	0.03
Model 2	0.16 (−0.01, 0.34)	0.11 (0.01, 0.22)	0.00	0.07 (−0.04, 0.17)	−0.12 (−0.29, 0.04)	−0.10 (−0.17, −0.03)	0.01
Nurses' Health study II							
Model 1	0.22 (0.03, 0.41)	0.17 (0.04, 0.30)	0.00	0.09 (−0.04, 0.22)	−0.07 (−0.27, 0.12)	−0.10 (−0.18, −0.02)	0.01

	Decrease ≥ 10 pt	Decrease 3 to 9 pt	Relatively stable (± 2 pt)	Increase 3 to 9 pt	Increase ≥ 10 pt	Changes/10-point increase in indices (95% CIs)	*P*
Model 2	0.25 (0.05, 0.44)	0.18 (0.05, 0.31)	0.00	0.09 (−0.04, 0.22)	−0.06 (−0.26, 0.13)	−0.11 (−0.19, −0.03)	0.01
Pooled Results							
Model 1	0.16 (0.03, 0.29)	0.12 (0.04, 0.21)	0.00	0.08 (0.00, 0.16)	−0.10 (−0.23, 0.02)	−0.09 (−0.14, −0.03)	0.001
Model 2	0.20 (0.07, 0.33)	0.14 (0.06, 0.22)	0.00	0.08 (0.00, 0.16)	−0.10 (−0.22, 0.03)	−0.10 (−0.16, −0.05)	<0.001

NHS, Nurses' Health Study; NHS II, Nurses' Health Study II.

* Values were beta coefficients (95% CIs) in mental component scores. Pooled results were calculated with a fixed effects model.

† The *P* value for Q-statistic for heterogeneity <0.05, indicating statistically significant heterogeneity between the NHS and the NHSII.

Model 1: Adjusted for age, race, baseline corresponding plant-based diet indices, baseline corresponding HRQoL scores, baseline BMI, and baseline and changes in each of smoking status, menopausal status and postmenopausal hormone use, NSAIDs use, multi vitamin use, marital status, working status, husband education, physical activity, alcohol intake, margarine intake, and total energy intake. For the NHS, models were additionally adjusted for educational attainment. For the NHSII, models were additionally adjusted for household income.

Model 2: Further adjusted for cardiovascular disease, cancer, respiratory disease, hypertension, hypercholesterolemia, diabetes, and weight change.