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Original Article

Plant-based diet index and erectile dysfunction in the Health Professionals Follow-Up Study

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Objective

To evaluate the longitudinal association between plant-based diet index (PDI) score and incident erectile dysfunction (ED).

Materials and Methods

We conducted a prospective analysis of 21 942 men aged 40 to 75 years who were enrolled in the Health Professionals Follow-Up Study. ED was assessed with questionnaires every 4 years starting in 2000. Dietary data were collected via validated food frequency questionnaires completed every 4 years and were used to calculate total PDI scores, as well as healthy (hPDI) and unhealthy (uPDI) subscores. Multivariable Cox proportional hazards models were used to compute hazard ratios (HRs) for incident ED. All models were stratified by age (<60, 60 to <70, ≥70 years).

Results

Among men aged 60 to <70 years, hPDI was inversely associated with incident ED. Those in the highest quintile of hPDI in that age group had an 18% lower risk of ED (HR 0.82, 95% confidence interval (CI) 0.73–0.91; P-trend <0.001) compared to those in the lowest quintile. Conversely, uPDI was positively associated with ED in men aged <60 years (HR 1.27, 95% CI 1.01–1.60; P-trend = 0.02).

Conclusions

Encouraging a healthy plant-based diet may be an environmentally sustainable intervention for men interested in maintaining erectile function.

Keywords

plant-based diet, erectile dysfunction, health professionals follow-up study, men's health, andrology

Introduction

Estimated to affect at least 18 million men in the USA alone, erectile dysfunction (ED) negatively impacts the quality of life of affected men and their sexual partners [1–3]. Current ED prevention strategies consist of lifestyle modifications such as smoking cessation, exercise, weight loss, and the mitigation of other risk factors shared with cardiovascular disease (CVD), diabetes and metabolic syndrome [4].

Diet modification is a promising target for ED prevention, but the link between food intake and sexual health has not been well delineated. Emerging evidence suggests that healthy dietary patterns, such as the Mediterranean diet and the Alternative Healthy Eating Index (AHEI) 2010 diet, are associated with a reduced risk of incident ED. [5] Because these diets encourage the preferential intake of fruit and vegetables over red meat, we hypothesized that plant-based dietary patterns play a key role in these associations. While several cross-sectional studies support this idea [6–8], a longitudinal analysis of prospectively collected data has not been performed to our knowledge.

Investigating the health effects of plant-based food intake may also have broader social and cultural implications. There is a commonly perceived link between red meat consumption and traditional definitions of masculinity in many cultures [9–11]. Since these perceptions are not supported by evidence, public health messaging may benefit from additional high-quality studies assessing the relationship between plant-based diet and sexual function. Furthermore, as awareness grows of the negative environmental impact of animal product consumption, investigating the health benefits of plant-based foods has great potential to influence change from a conservation and sustainability standpoint [9,12].

To continue bridging this gap in knowledge, we explored the associations of the plant-based diet index (PDI), as well as the healthy and unhealthy plant-based diet indices (hPDI and uPDI), with incident ED in the Health Professionals Follow-Up Study.

Methods

Participants

Data were collected prospectively from US male health professionals enrolled in the Health Professionals Follow-Up Study since 1986. Food frequency questionnaires (FFQs) were collected every 4 years and surveys regarding lifestyle factors, health outcomes, and medications are collected every 2 years with a 96% response rate. Additional details regarding the methods have been described previously [13]. This study was approved by the Human Subjects Committee at the Harvard T.H. Chan School of Public Health. As approved by the Human Subjects Committee, the return of a questionnaire was considered to imply consent.

There were 51 529 men enrolled in 1986, of whom 5510 died before 1998 (Fig. S1). We excluded an additional 11 735 men who did not complete the FFQ in 1998, five men with multiple records or missing date of birth, 1986 men with a history of prostate, bladder, testicular or penile cancer to avoid confounding from cancer-related side effects, 2767 men with history of myocardial infarction, 541 men with history of stroke, and 1762 men with diabetes prior to 1998. Finally, we excluded 370 men who did not answer the baseline ED questionnaire at enrolment and 4911 men with ED at baseline based on self-reported 'poor' or 'very poor' erectile function prior to 1998. This resulted in 21 942 men who were in the final cohort for analysis.

Assessment of Dietary Patterns

Participants completed a validated FFQ to estimate usual dietary intake (portion size and frequency) of approximately 130 food items. PDI, hPDI and uPDI scores were then calculated using a point-based system as previously described [14]. Briefly, all food items from the FFQ were categorized

into 12 plant food groups (whole grains, fruits, vegetables, nuts, legumes, vegetable oils, tea/coffee, fruit juices, sugar-sweetened beverages, refined grains, potatoes, and sweets/desserts) and six animal food groups (animal fats, dairy, eggs, fish/seafood, meat, and miscellaneous animal-based foods). Plant food groups were further categorized as healthy (whole grains, fruits, vegetables, nuts, legumes, vegetable oils, and tea/coffee) or unhealthy (fruit juices, sugar-sweetened beverages, refined grains, potatoes, and sweets/desserts) based on established associations with diseases such as diabetes and CVD [14,15].

Quintiles were calculated for consumption of each food group measured in servings per day, and each quintile was given a score based on a positive (1–5) or reverse (5-1) designation based on the index. To generate the PDI, all plant food groups were scored positively. For hPDI, only healthy plant food groups were scored positively while unhealthy plant food groups were scored negatively; for uPDI, unhealthy plant food groups were scored positively while healthy plant food groups were scored negatively. Animal food groups were given reverse scores in all three indices.

Outcome Assessment

Starting in 2000, participants reported their ability to maintain an erection sufficient for intercourse without treatment. Response options included very poor, poor, fair, good, or very good. Consistent with previous studies, incident ED was defined as a response of poor or very poor at any point after 2000 [16,17]. Participants were also asked to report their erectile function and historically if/when erectile function changed (before 1986, 1986–1989, 1990–1994, 1995 or later). Subsequent questionnaires after 2004 asked participants to report their erectile function in the past 3 months without treatment. Date of incident ED was defined as date of the questionnaire where ED was first reported for a participant.

Data Analysis

Person-time for each participant was calculated from 1998 until incident ED, genitourinary cancer diagnosis, death, loss to follow-up, or end of the study period (1 January 2016), whichever occurred first. To account for within-person variation, dietary indices were calculated as the cumulative average of all dietary index scores for each participant until first report of ED, CVD, death, loss to follow-up, or the last FFQ in 2010. Similarly to prior studies, dietary index scores were not updated after diagnosis of CVD to minimize confounding since a CVD diagnosis is more likely to lead to both incident ED and dietary modification [5,18].

Hazard ratios (HRs) and 95% CIs for associations between quintiles of dietary index scores and risk of incident ED were

Table 1 Baseline characteristics of 21 942 men from the Health Professionals Follow-Up Study by extreme quintiles of healthy and unhealthy plant-based dietary index score.

Characteristic	hPDI score		uPDI score	
	Lowest quintile (*n* = 4922)	Highest quintile (*n* = 4036)	Lowest quintile (*n* = 4093)	Highest quintile (*n* = 4473)
Age, years, mean (SD)	59.8 (8)	64.2 (9)	63.6 (8)	60.5 (8)
BMI, kg/m^2, mean (SD)	26.1 (4)	25.6 (3)	26.4 (4)	25.6 (3)
Physical activity, MET-h/week, mean (SD)	27.5 (27)	36.0 (33)	35.9 (32)	25.9 (28)
Race, %				
White	92.8	90.8	93.1	89.5
Black	0.5	0.6	0.5	1.1
Asian	1.0	1.8	0.7	2.8
Other	5.6	6.8	5.8	6.7
Currently married, %	88.6	89.6	89.8	88.7
Smoking status, %				
Never	54.5	51.5	47.8	59.9
Past	39.2	45.7	47.6	35.5
Current	6.3	2.9	4.6	4.6
Self-reported comorbidities, %				
Hypertension	31.0	30.6	30.0	32.1
Hyperlipidaemia	43.0	46.2	42.3	47.8
Depression	12.6	13.2	12.9	12.2
Medication use, %				
Antihypertensives	22.0	22.9	20.3	24.8
Cholesterol-lowering	10.0	14.7	10.2	14.6
Antidepressant or antipsychotic drugs	5.0	4.7	4.8	5.2
Benzodiazepine	2.7	2.3	2.6	2.6
α-blockers or 5-α-reductase inhibitors	5.9	5.4	4.7	5.8
Alcohol, g/day, mean (SD)	10.6 (14)	11.1 (13)	13.8 (15)	8.3 (13)
AHEI 2010 score, mean (SD)	45.1 (10)	58.8 (11)	57.0 (10)	45.3 (10)
Mediterranean diet score, mean (SD)	3.4 (2)	4.9 (2)	5.1 (2)	3.2 (2)

AHEI, Alternative Healthy Eating Index; BMI, body mass index; hPDI, healthy plant-based diet index; MET, metabolic equivalent of task; PDI, plant-based diet index; uPDI, unhealthy plant-based diet index.

calculated using multivariable adjusted Cox proportional hazard models. Based on prior literature and our own previous studies, dividing food groups into quintiles allows for visualization of the shape of an association without assuming a linear relationship [5,19,20]. We stratified baseline hazard by calendar year, using age in months as the time scale. Final models were adjusted for smoking status (never, past, or current 1–14, 15–24, or ≥ 25 cigarettes/day), body mass index (BMI; kg/m^2), physical activity (total metabolic equivalent task-hours/week), and time-updated incident CVD during follow-up, self-reported history of diabetes, hypertension, depression, antidepressant or antipsychotic medication use, benzodiazepine medication use, α-blocker or 5-α-reductase inhibitor use [21], marital status (married, divorced, separated, widowed, or never married), self-reported race, and total caloric intake (kilocalories/day).

To test for linear trends, the median value for each PDI score within each quintile was treated as a continuous variable, and the significance of the association was reported as a *P*-trend. To remain consistent with the previous literature and because age is a strong risk factor for ED [13,22,23] and an effect modifier for both dietary and lifestyle factors [24–26], we stratified all models by age < 60, 60 to <70, and ≥ 70 years. Consistent with previous analyses of this dataset, smoking

status, history of hypertension or hyperlipidaemia, BMI, and physical activity did not modify our observed associations.

All analyses were completed using SAS statistical software version 9.4 (SAS Institute). This study is reported in accordance with the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) reporting guideline.

Results

Among the 21 942 men included in the analytical sample, the mean age was 61.7 ± 8 years, and 11 292 (51.4%) men developed incident ED over a mean of 12.0 years of follow-up. After stratifying by age, we observed 994 cases per 58 102 person-years in men aged <60 years, 4160 cases per 114 457 person-years in men aged 60 to <70 years, and 6138 cases per 91 661 person-years in men aged ≥70 years. Compared to the lowest quintile, men in the highest quintile of hPDI were older, more physically active, and had higher AHEI and Mediterranean dietary index scores (Table 1). Conversely, men in the highest quintile of uPDI were younger, less physically active, and had lower AHEI and Mediterranean dietary index scores compared to the lowest quintile. PDI and hPDI scores were weakly positively correlated (0.29, *P* < 0.001), PDI and uPDI scores were weakly inversely

correlated (−0.13, *P* < 0.001), and hPDI and uPDI scores were moderately inversely correlated (−0.32, *P* < 0.001).

The associations of PDI, hPDI and uPDI with incident ED are shown in Fig. 1 and Table 2. Higher PDI was associated with a lower risk of incident ED in men aged 60 to <70 years, with those in the highest quintile of PDI having a 9% lower risk of ED compared to those in the lowest quintile (HR 0.91, 95% CI 0.82–1.01; *P*-trend = 0.007). We did not observe any associations between PDI and incident ED in men aged <60 or ≥ 70 years (*P*-trend >0.05 for both). Similarly, hPDI was associated with a lower risk of ED in men aged 60 to <70 years (HR 0.82, 95% CI 0.73–0.91; *P*-trend <0.001) but not in younger men. For men aged ≥70 years, the highest quintile of hPDI was associated with a lower risk of ED (HR 0.92, 95% CI 0.84–0.99), although overall the trend did not reach statistical significance (*P*-trend = 0.06). Conversely, uPDI was associated with increased risk of ED in men aged <60 years; men in the highest quintile of uPDI had a 27% higher risk of ED compared to men in the lowest quintile (HR 1.27, 95% CI

1.01–1.60; *P*-trend = 0.04), whereas no association was observed between uPDI and ED among men aged ≥60 years. When age groups were pooled and analysed together, multivariable-adjusted models showed an inverse association of higher quintiles of hPDI with incident ED (*P*-trend <0.001), while a statistically significant association of PDI and uPDI with incident ED was not detected (*P*-trend 0.09 and 0.4, respectively; Fig. S2).

The servings per day of individual dietary score components by lowest and highest quintile of hPDI and uPDI are reported in Table S1 and their individual associations with incident ED are reported in Table S2. In the 'healthy' plant-based foods category, fruits and legumes were inversely associated with incident ED, while in the animal-based food groups, meat was positively associated with risk of ED. Contrary to the observed relationships with overall dietary patterns, tea and coffee, which are categorized as a 'healthy' plant-based food group, were positively associated with incident ED, whereas fruit juice, categorized as an 'unhealthy' plant-based food group, was inversely associated with ED.

Fig. 1 Multivariable-adjusted association of plant-based diet indices with erectile dysfunction stratified by age.
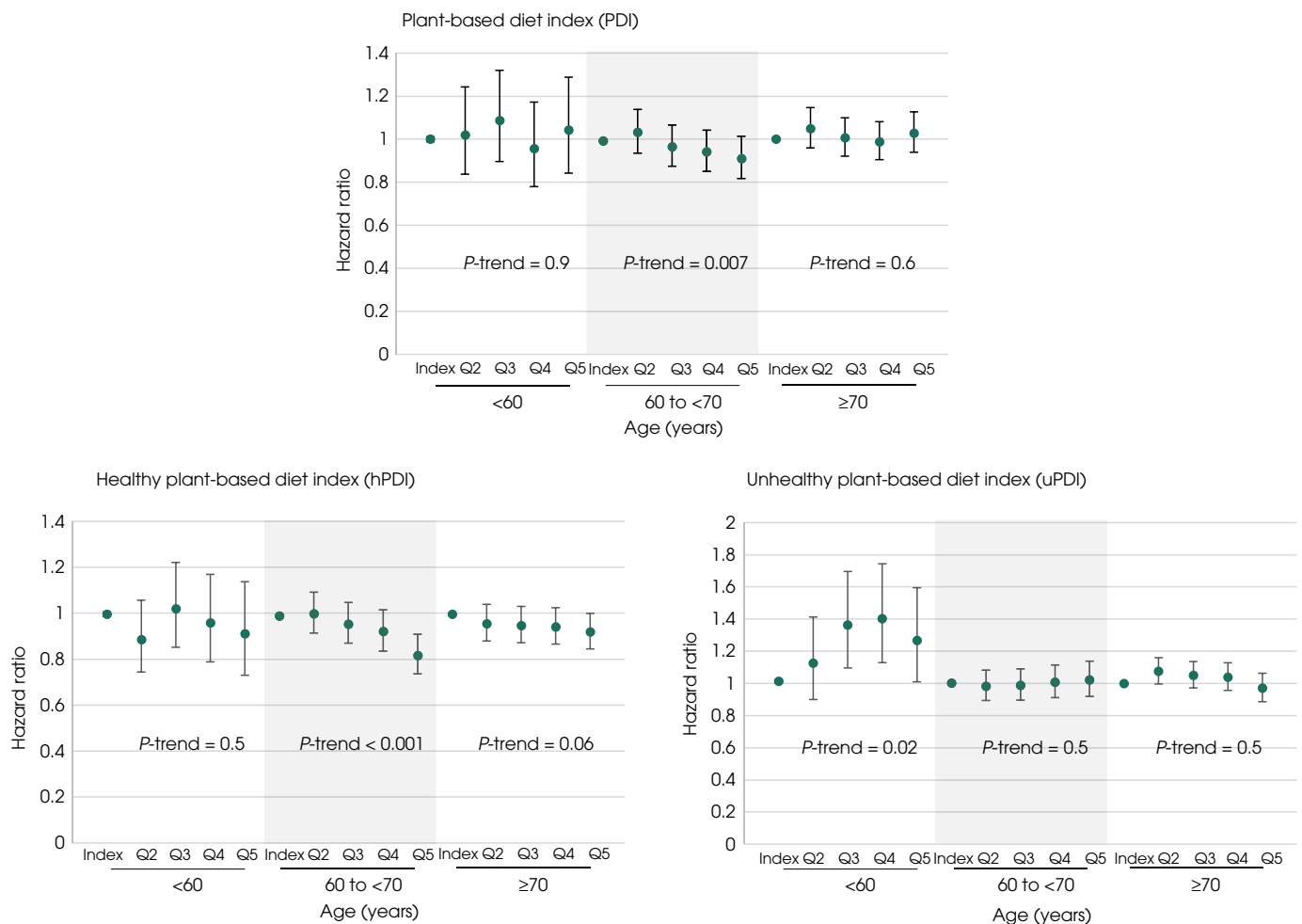
Table 2 Multivariable-adjusted association of plant-based diet index, healthy plant-based diet index, and unhealthy plant-based diet index with incident erectile dysfunction among men from the Health Professionals Follow-Up study, stratified by age.

	PDI quintile					
	1	**2**	**3**	**4**	**5**	*P* for trend
Age < 60 years						
Events/person-years	199/11272	197/11514	213/12162	194/11948	191/11206	
Event rate, per 1000 person-years	17.7	17.1	17.5	16.2	17.0	
Index score, mean (SD)	46.0 (2.6)	51.1 (1.0)	54.5 (0.9)	57.9 (1.0)	63.2 (2.9)	
Multivariable model, HR (95% CI)	1 (index)	1.02 (0.84–1.24)	1.09 (0.90–1.32)	0.96 (0.78–1.17)	1.00 (0.99–1.01)	>0.9
Age 60 to < 70 years						
Events/person-years, No.	731/19423	866/22233	907/24648	865/24345	791/23809	
Event rate, per 1000 person-years	37.6	39.0	36.8	35.5	33.2	
Index score, mean (SD)	45.9 (2.8)	51.1 (1.1)	54.5 (1.0)	57.9 (1.0)	63.3 (2.8)	
Multivariable model, HR (95% CI)	1 (index)	1.03 (0.94–1.14)	0.97 (0.87–1.07)	0.94 (0.85–1.04)	0.91 (0.82–1.01)	0.007
Age ≥ 70 years						
Events/person-years	890/13481	1172/17353	1302/19303	1352/20400	1422/21124	
Event rate, per 1000 person-years	66.0	67.5	67.5	66.3	67.3	
Index score, mean (SD)	45.7 (2.9)	51.0 (1.1)	54.5 (1.0)	58.0 (1.1)	63.3 (3.0)	
Multivariable model, HR (95% CI)	1 (index)	1.05 (0.96–1.15)	1.01 (0.92–1.10)	0.99 (0.90–1.08)	1.03 (0.94–1.13)	0.6

	hPDI quintile					
	1	**2**	**3**	**4**	**5**	*P* for trend
Age < 60 years						
Events/person-years	304/16720	208/13540	204/11331	160/9189	118/7323	
Event rate, per 1000 person-years	18.2	15.4	18.0	17.4	16.1	
Index score, mean (SD)	44.5 (3.2)	50.7 (1.2)	54.7 (1.1)	58.6 (1.2)	64.6 (3.2)	
Multivariable model, HR (95% CI)	1 (index)	0.89 (0.74–1.06)	1.02 (0.85–1.22)	0.96 (0.79–1.17)	0.91 (0.73–1.14)	>0.9
Age 60 to < 70 years						
Events/person-years	1032/26949	939/24695	833/22864	753/20578	603/19371	
Event rate, per 1000 person-years	38.3	38.0	36.4	36.6	31.1	
Index score, mean (SD)	44.8 (2.9)	50.8 (1.2)	54.7 (1.1)	58.7 (1.2)	64.8 (3.1)	
Multivariable model, HR (95% CI)	1 (index)	1.00 (0.91–1.09)	0.95 (0.87–1.05)	0.92 (0.84–1.02)	0.82 (0.73–0.91)	<0.001
Age ≥ 70 years						
Events/person-years	1103/16054	1188/17794	1231/18389	1257/19073	1359/20351	
Event rate, per 1000 person-years	68.7	66.8	66.9	65.9	66.8	
Index score, mean (SD)	45.2 (2.7)	50.9 (1.2)	54.7 (1.1)	58.7 (1.2)	64.8 (3.3)	
Multivariable model, HR (95% CI)	1 (index)	0.96 (0.88–1.04)	0.95 (0.87–1.03)	0.94 (0.87–1.02)	0.92 (0.84–0.99)	0.06

	uPDI quintile					
	1	**2**	**3**	**4**	**5**	*P* for trend
Age < 60 years						
Events/person-years	132/8664	177/10997	215/11618	241/12843	229/13981	
Event rate, per 1000 person-years	15.2	16.1	18.5	18.8	16.4	
Index score, mean (SD)	45.4 (2.8)	50.9 (1.1)	54.7 (1.0)	58.4 (1.1)	64.2 (3.1)	
Multivariable model, HR (95% CI)	1 (index)	1.13 (0.90–1.41)	1.36 (1.10–1.70)	1.40 (1.13–1.74)	1.27 (1.01–1.60)	0.04
Age 60 to < 70 years						
Events/person-years, No.	810/21375	890/24220	846/23616	835/23224	779/22022	
Event rate, per 1000 person-years	37.9	36.8	35.8	36.0	35.4	
Index score, mean (SD)	45.1 (3.0)	50.9 (1.1)	54.6 (1.0)	58.3 (1.1)	63.9 (3.0)	
Multivariable model, HR (95% CI)	1 (index)	0.98 (0.89–1.08)	0.99 (0.90–1.09)	1.01 (0.91–1.11)	1.02 (0.92–1.14)	0.5
Age ≥ 70 years						
Events/person-years	1420/21198	1374/19719	1309/19258	1127/16823	908/14664	
Event rate, per 1000 person-years	67.0	69.7	68.0	67.0	61.9	
Index score, mean (SD)	45.2 (3.1)	50.9 (1.1)	54.6 (1.0)	58.2 (1.1)	63.9 (2.9)	
Multivariable model, HR (95% CI)	1 (index)	1.08 (1.00–1.16)	1.05 (0.97–1.14)	1.04 (0.96–1.13)	0.97 (0.89–1.06)	0.5

HR, hazard ratio; hPDI, healthy plant-based diet index; PDI, plant-based diet index; uPDI, unhealthy plant-based diet index.

Discussion

This longitudinal cohort study investigates the associations of overall, healthy and unhealthy plant-based dietary consumption with incident ED. Our data demonstrate that men aged 60 to <70 years with the greatest PDI—particularly hPDI—were less likely to develop ED compared to men in this age group with the lowest consumption. Among men aged <60 years, those with the highest consumption of unhealthy plant-based foods had the highest incidence of ED.

These findings align with previous studies suggesting a role for healthy plant-based diets in reducing CVD. The results also suggest that healthy plant-based dietary patterns may represent an environmentally sustainable intervention for men interested in maintaining erectile function. As a comparison, the HRs reported in our study are similar in magnitude to the associations seen between healthy eating and CVD [27].

To our knowledge, this is the first prospective study to evaluate the association between PDIs and incident ED. Our findings are consistent with cross-sectional evidence showing that higher hPDI reduces the risk of ED in men participating in the National Health and Nutrition Examination Survey and that fruit and vegetable intake is associated with lower prevalence of ED in diabetic men [6,7]. A case–control study also showed that men diagnosed with ED have lower PDI and hPDI scores [8]. A single longitudinal study testing the relationship between fruit and vegetable intake and ED was insufficiently powered to detect any significant associations [28]. Our study significantly contributes to the existing literature, with a large sample of men and validated dietary questionnaires repeated every 4 years over nearly two decades to better assess long-term dietary patterns.

Compared to previously reported associations between other dietary patterns, such as the Mediterranean diet or AHEI 2010, and ED, associations with plant-based dietary patterns appear to differ across age groups [5]. For example, while both Mediterranean diet score and AHEI 2010 index were most strongly associated with ED risk in men aged <60 years, hPDI was associated with lower ED risk in men aged ≥60 years. One possible explanation is that the hPDI was unable to identify small but clinically meaningful associations in men aged <60 years due to the smaller number of incident ED cases in this age group. Moreover, this age group is more affected by non-dietary causes of ED [29,30], therefore, associations between plant-based diets and ED may vary by age group due to age-related differences in ED pathophysiology. Interestingly, in men aged <60 years, uPDI was positively associated with an increased risk of developing ED. This is a novel finding that corroborates a large body of evidence supporting a whole-foods plant-based diet for overall cardiovascular health, and it highlights the importance of counselling men about the possible benefit of avoiding not only meat but also unhealthy plant-based foods for optimal sexual health [31,32]. However, associations observed among younger men may also be more susceptible to residual confounding due to psychological stressors which can cause both poor dietary choices and ED. Additional studies are needed to confirm this finding.

The differences in component scoring within each index can provide a degree of mechanistic insight in the context of the observed associations of each PDI with ED, although these associations may not be causal and must be interpreted cautiously. A healthy plant-based diet emphasizes components that provide higher quantities of dietary fibre, antioxidants such as polyphenols, and unsaturated fatty acids and lower quantities of saturated fat [14]. Dietary fibre, polyphenols, and antioxidants in particular have been shown in randomized clinical trials and prospective studies to improve glucose metabolism, reduce inflammation, and ultimately improve endothelial function [33–35]. Conversely, the unhealthy plant-based diet positively scores components that have a high glycaemic index and higher calorie content, qualities that would promote weight gain, insulin resistance, and endothelial dysfunction [14], although some of these components, such as fruit juice, could also have beneficial effects specific to ED pathophysiology. Ultimately, many components of the hPDI are associated with a reduced risk of CVD and type 2 diabetes, while many components of the uPDI are associated with an increased risk of these conditions. Since these diseases share biological pathways with ED [36–38], we expected that the corresponding associations of PDIs with ED would be consistent. Finally, it should be noted that the meat products within each dietary index have been consistently found to be associated with an increased risk of ED.

We acknowledge several limitations to this study. Due to the observational study design and lack of randomization to specific dietary patterns, unmeasured confounding remains possible. For example, psychosocial stressors may promote the development of ED and increased consumption of unhealthy food. However, we expect confounding by psychosocial stressors to be at least partially captured by variables we included in the multivariable model, including history of depression and current antidepressant use. Additionally, we adjusted for a comprehensive set of demographic and health-related behaviours, but we also acknowledge that there are complex relationships between dietary choices, health-related behaviours and socioeconomic status that may also lead to residual confounding. Future studies would benefit from including a more diverse and international study population.

From a methodology standpoint, both differential and non-differential measurement error are possible when using self-reported diet as a predictor. FFQs were used to prospectively evaluate dietary patterns before participants developed ED, however, and non-differential measurement error would bias our results towards the null. The PDIs used were not created specifically with respect to ED risk and therefore intake of certain non-plant-based foods that are inversely associated with ED in prior studies, such as fish intake [5], may not contribute as expected to dietary indices. Conversely, a strength of this study is the use of previously developed dietary indices to estimate the consumption of healthy and unhealthy plant-based foods. Finally, ED was assessed using a

single-item question, which may also be subject to misclassification. The use of self-reported ED has been validated, however, and again this would bias our results towards the null [39].

In conclusion, encouraging a healthy plant-based diet may be an environmentally sustainable intervention for men interested in maintaining erectile function. Men should be counselled that consuming meat products and unhealthy plant-based foods is associated with an increased risk of developing ED.

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Disclosure of Interests

The authors have no other disclosures to report.

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Abbreviations: CVD, cardiovascular disease; ED, erectile dysfunction; FFQ, food frequency questionnaire; hPDI, healthy plant-based diet index; HR, hazard ratio; PDI, plant-based diet index.

Supporting Information

Additional Supporting Information may be found in the online version of this article:

Table S1. Servings per day of individual dietary components in extreme quintiles of healthy and unhealthy plant-based diet score quintile.

Table S2. Multivariable-adjusted association of individual components with incident erectile dysfunction.

Figure S1. Study flow chart.

Figure S2. Multivariable-adjusted association of plant-based diet scores with erectile dysfunction, not stratified by age.