Nutrición Hospitalaria

SENPE

La ingesta de proteínas vegetales en la dieta alivia el efecto adverso del comportamiento sedentario sobre la incidencia de la enfermedad renal crónica

Dietary plant protein intake alleviates the adverse effect of sedentary behavior on chronic kidney disease incidence

10.20960/nh.05879

06/23/2025

OR 5879

Dietary plant protein intake alleviates the adverse effect of sedentary behavior on chronic kidney disease incidence

La ingesta de proteínas vegetales en la dieta alivia el efecto adverso del comportamiento sedentario sobre la incidencia de la enfermedad renal crónica

Zuoxun Xia[1], Ye Xiong[2]

[1]Yongjia People's Hospital. Wenzhou, Zhejiang. People's Republic of China. [2]Department of Infectious Diseases. State Key Laboratory for Diagnosis and Treatment of Infectious Diseases. National Clinical Research Center for Infectious Diseases. Collaborative Innovation Center for Diagnosis and Treatment of Infectious Diseases. The First Affiliated Hospital. Zhejiang University School of Medicine. Hangzhou, Zhejiang. People's Republic of China

Received: 05/04/2025

Accepted: 14/05/2025

Correspondence: Ye Xiong. Department of Infectious Diseases. State Key Laboratory for Diagnosis and Treatment of Infectious Diseases. National Clinical Research Center for Infectious Diseases. Collaborative Innovation Center for Diagnosis and Treatment of Infectious Diseases. The First Affiliated Hospital. Zhejiang University School of Medicine. 79, Qingchun Road. Hangzhou, Zhejiang. People's Republic of China

e-mail: 21918255@zju.edu.cn

Authors' contribution: Conceptualization: Z. X., and Y. X.; methodology: Z. X., and Y. X.; data curation: Z. X., and Y. X.; investigation: Z. X., and Y. X.; formal analysis: Z. X., and Y. X.; writing-

original draft and writing-review and editing Z. X., and Y. X. All authors provided their final approval and are responsible for all aspects of the work, ensuring integrity and accuracy.

Ethical approval: The NHANES study protocol was approved by the Research Ethics Review Board of the National Center for Health Statistics. Written informed consent was obtained from all participants.

Data availability statement: The National Health and Nutrition Examination Survey dataset is publicly available at https://wwwn.cdc.gov/nchs/nhanes/.

Acknowledgments: We thank all researchers at the Centers for Disease Control and Prevention (CDC) for collecting, managing, and generating the NHANES datasets. We also thank all of the participants.

Conflict of interest: The authors declare no conflict of interest.

Artificial intelligence: The authors declare not to have used artificial intelligence (AI) or any AI-assisted technologies in the elaboration of the article.

ABSTRACT

Objective: dietary plant protein exerts a preventative effect on the incidence of chronic kidney disease (CKD). However, no epidemiological study has explored whether dietary plant protein can mitigate the impact of sedentary behavior on the kidneys. This study investigates the relationship between sedentary behavior and the risk of CKD in the US population and the effect of dietary plant protein intake on CKD incidence in sedentary individuals.

Methods: data was collected from the 2007-2018 Continuous

National Health and Nutrition Examination Survey (NHANES). Weighted binary logistic regression was adopted to investigate the association between sedentary behavior and CKD risk. Weighted binary logistic regression and restricted cubic spline were performed to evaluate the correlation between dietary plant protein and CKD risk in sedentary individuals.

Results: participants with higher sedentary behavior (≥ 6 h/day) had a 1.13 times higher risk of developing CKD than those with lower sedentary behavior (< 6 h/day). In participants with higher sedentary behavior, intake of a higher plant protein ratio was associated with reduced CKD risk. In a continuous model, after adjusting for all covariates, each 10 % increase in plant protein ratio decreased CKD risk by 35.4 % (odds ratio (OR), 0.646; 95 % confidence interval (CI), 0.465-0.899). Compared with the lowest quartile, the OR for the highest quartiles was 0.740 in a categorical model (95 % CI, 0.614-0.893).

Conclusion: moderate dietary plant protein can alleviate the detrimental effects of sedentary behavior on the kidneys, reducing the incidence of CKD.

Keywords: Chronic kidney disease. Sedentary behavior. Plant protein. NHANES. Incidence.

RESUMEN

Objetivo: la proteína vegetal en la dieta ejerce un efecto preventivo sobre la incidencia de la enfermedad renal crónica (ERC). Sin embargo, ningún estudio epidemiológico ha explorado si la proteína vegetal en la dieta puede mitigar el impacto del comportamiento sedentario en los riñones. Este estudio investiga la relación entre el comportamiento sedentario y el riesgo de ERC en la población de EE. UU., así como el efecto de la ingesta de proteínas vegetales sobre la incidencia de ERC en personas sedentarias.

Métodos: se recopilaron datos de la Encuesta Continua Nacional de Examen de Salud y Nutrición (NHANES) 2007-2018. Se utilizó regresión logística binaria ponderada para investigar la asociación entre el comportamiento sedentario y el riesgo de ERC. También se aplicaron regresión logística binaria ponderada y modelos con *splines* cúbicos restringidos para evaluar la correlación entre la ingesta de proteína vegetal y el riesgo de ERC en personas sedentarias.
Resultados: los participantes con mayor comportamiento sedentario (≥ 6 horas/día) tuvieron un riesgo 1,13 veces mayor de desarrollar ERC en comparación con aquellos con menor comportamiento sedentario (< 6 horas/día). En los participantes con comportamiento sedentario elevado, una mayor proporción de proteína vegetal en la dieta se asoció con una reducción del riesgo de ERC. En un modelo continuo, después de ajustar por todas las covariables, cada aumento del 10 % en la proporción de proteína vegetal redujo el riesgo de ERC en un 35,4 % (razón de probabilidades (OR), 0,646; intervalo de confianza (IC) del 95 %, 0,465-0,899). En un modelo categórico, en comparación con el cuartil más bajo, la OR para el cuartil más alto fue de 0,740 (IC del 95 %, 0,614-0,893).
Conclusión: una ingesta moderada de proteína vegetal en la dieta puede aliviar los efectos perjudiciales del comportamiento sedentario sobre los riñones, reduciendo la incidencia de la enfermedad renal crónica.

Palabras clave: Enfermedad renal crónica. Comportamiento sedentario. Proteína vegetal. NHANES. Incidencia.

INTRODUCTION

Chronic kidney disease (CKD) affects approximately 8-16 % of the population (1). In 2017, over 1 million people died from CKD, with global mortality increasing by 41.5 % since 1990 (2,3). As diabetes, hypertension, and obesity become more prevalent, along with an aging global population, CKD has reached epidemic proportions (4), posing a significant public health concern.

As workplaces evolve and transportation and the internet become more widespread, sedentary lifestyles are becoming increasingly common globally. Defined as any waking activity with energy expenditure ≤ 1.5 metabolic equivalents (METs) while sitting or reclining (5), prolonged sedentary behavior poses a growing health risk. The effects of sedentary behavior on health are cumulative and long-lasting, increasing the risk of chronic non-communicable diseases, such as cardiovascular disease (CVD), metabolic disorders, musculoskeletal disorders (6-8), and CKD (9-11). However, these studies have focused primarily on middle-aged or older adults. Moreover, Lynch et al. found no significant relationship between the highest television viewing time and reduced estimated glomerular filtration rate (eGFR) levels after adjusting for covariates (12). Therefore, understanding the impact of sedentary behavior on CKD risk is crucial as it is a lifestyle that can be modified.

Plant-based diets comprise primarily plant-based foods with or without small amounts of meat. Hence, the protein source is plant-based. Increasing evidence suggests that these diets are beneficial for myriad conditions, including CVD, diabetes, metabolic syndrome, and various cancers (13-15). Moreover, many studies have shown that plant-based diets can slow CKD progression and delay dialysis (16), with higher plant-based protein intake associated with lower mortality in patients with CKD (17). Despite the growing attention to these individual factors, research on the combined impact of sedentary behavior and plant protein intake on CKD risk is limited.

This study investigates the relationship between sedentary behavior and CKD risk in the US population. Additionally, it explores the effect of plant protein intake on CKD incidence in individuals with a sedentary lifestyle.

METHODS

Study population

This study utilized data from the National Health and Nutrition Examination Survey (NHANES) database, which assesses health and nutritional data for adults and children throughout the US. Survey data covering six cycles between 2007 and 2018 were extracted from the Continuous NHANES.

A total of 59,842 individuals were enrolled in the NHANES cohort between 2007 and 2018. After excluding individuals who did not meet the eligibility criteria, as outlined in figure 1, 28,268 participants were included in the final analysis.

Daily sitting time, physical activity, dietary assessment

The NHANES study assessed daily sitting time using physical activity questionnaires. Daily sitting time was determined by asking participants about time spent at work, home, school, with friends, commuting, or engaging in recreational activities (e.g., playing cards, watching TV, and using computers) throughout a typical day. This total daily sitting time is recorded as PAD680, a variable in the NHANES dataset that quantifies self-reported sedentary behavior.

Dietary intake data were evaluated using the first 24-h dietary recall interviews conducted by NHANES's highly trained staff at mobile examination center. The United States Department of Agriculture's (USDA) automated multiple-pass method was used to estimate food intake. The Food Patterns Equivalent Database (FPED), associated with NHANES for dietary research purposes, converts American food and beverage intake from NHANES participants into 37 USDA Food pattern components. The intake levels of total protein, animal protein, and plant protein were obtained from the FPED.

Definitions

In the Continuous NHANES, serum and urinary creatinine levels were assessed using the Jaffe rate method, while urinary albumin was measured using a solid-phase fluorescent immunoassay. The eGFR was calculated using the CKD Epidemiology Collaboration (EPI) equation based on serum creatinine levels (18). ACR is the ratio of urinary albumin to urinary creatinine (19). Patients with CKD were defined by an eGFR < 60 mL/min/1.73 m^2 or ACR ≥ 30 mg/g (19). A sedentary time over 6 h/day is more likely to cause adverse health conditions than less than 6 h/day (20). Therefore, sedentary behavior was defined as high (≥ 6 h/day) or low (< 6 h/day). Total protein intake was the sum of the plant and animal proteins, while the plant–protein ratio was defined as the ratio of plant protein intake to total protein intake.

Covariates

Covariates were collected with a structured questionnaire, including age, sex, ethnicity, education level, family income (poverty index ratio (PIR)), marital status, and total calories. Smoking status was classified as a former smoker, non-smoker, or current smoker. Alcohol consumption was defined as former, heavy, moderate, mild, or never (21). Physical activity levels were defined as active (≥ 500 MET min/week), somewhat active (> 0 to < 500 MET min/week), or inactive (no reported physical activity data) (22). The body mass index (BMI) was determined using the height and weight of participants. Diabetes was defined as a self-reported diagnosis of diabetes and/or the use of antidiabetic medication. Hypertension was defined as mean systolic blood pressure ≥ 140 mmHg and/or diastolic blood pressure ≥ 90 mmHg, a self-reported diagnosis of hypertension, and/or the use of antihypertensive medication. Stroke and CVD were defined based on self-reported medical history.

Statistical analysis

The sample weight recommended by NHANES was adopted, specifically the sample weight on a dietary day, with the selected weight record (WTDRD1). Since NHANES employs a complex probability sample design, individual sample weights were calculated as 1/6 × WTDRD1, covering six cycles from 2007 to 2018. Continuous variables were expressed as mean ± standard deviation (SD) when analyzing the baseline characteristics; those conforming to a normal distribution were compared using an independent sample *t*-test. Categorical variables were expressed as frequencies (percentages) and analyzed using the Chi-square test.

Weighted binary logistic regression was used to investigate the associations between sedentary behavior and CKD risk. Additionally, the relationship between plant protein intake and CKD risk was assessed in participants with high sedentary behavior. Plant protein ratio was included as a continuous variable in the continuous models, providing odds ratios (ORs) and 95 % confidence intervals (CIs). The plant protein ratio was transformed into a categorical variable by quartiles, and the *p*-value for the trend was calculated. Four models were applied: the crude model was not adjusted for confounding variables; Model 1 was adjusted for age, ethnicity, sex, educational level, PIR, and marital status; Model 2 was further adjusted for BMI, physical activity, smoking status, and alcohol consumption; Model 3 was adjusted for diabetes, hypertension, stroke, and CVD based on Model 2. A restricted cubic spline explored the non-linear association between the plant protein ratio and CKD in high sedentary behavior.

Sensitivity analysis was conducted by modifying the outcome indicators. Weighted ordinal logistic regression was performed using CKD progression risk as the outcome. CKD progression was assessed based on eGFR and albuminuria categories, divided into low risk, moderately increased risk, high risk, and very high risk. The graphical method recommended by Harrell was used to assess the parallel slope assumption in constructing the ordinal logistic regression. All analyses were performed using R version 4.2.1, and statistical significance was determined using a two-sided *p*-value < 0.05.

RESULTS

Baseline characteristics of the study population

In total, 28,268 participants (male: female, 13,812: 14,456) were included in the study, with a mean age of 47.449 ± 0.253 years; 5003 (17.698 %) had CKD. Additionally, 13,448 participants (51.263 %) reported a sedentary time of ≥ 6 h/day (Table I).

Sedentary behavior and CKD incidence

Three binary logistic regression models (weighted) were constructed. The fully adjusted model identified a positive relationship between sedentary behavior and CKD (OR = 1.130, 95 % CI = 1.009-1.265). Participants with high sedentary behavior were more prone to develop CKD, with a likelihood 1.13 times that of participants with low sedentary behavior (Table II).

Sedentary behavior, plant protein intake, and CKD incidence

In participants with high sedentary behavior, increased plant protein ratio was associated with a reduced risk of CKD. In a continuous model, each 10 % increase in plant protein ratio reduced the risk of CKD by 35.4 % (OR, 0.646; 95 % CI, 0.465-0.899) after adjusting for all considered covariates (Table III). Binary logistic regression analysis was conducted on the quartile of the plant protein ratio. Compared with the lowest quartile, the OR (95 % CIs) for the highest quartiles was 0.740 (95 % CI, 0.614-0.893; Table III). The inverse trend of the plant protein ratio with CKD risk was statistically significant in the fully adjusted model for all covariates (p-trend < 0.05).

The restricted cubic spline model indicated a non-linear association between plant protein ratio and CKD risk (Fig. 2). The optimal intake ranges for plant protein ratios were 0.000-59.296 %, which could reduce the risk of CKD.

Sensitivity analysis

In sensitivity analysis, the robustness of the results was confirmed when CKD prognosis was used in place of CKD risk (Table IV).

DISCUSSION

To our knowledge, this is the first study to examine how sedentary behavior and plant protein intake affect CKD risk in a nationally representative adult population (> 20 years old). A relationship was identified between sedentary behavior and CKD risk, as well as between plant protein intake and CKD risk in participants with high sedentary behavior.

The global rise of chronic non-communicable diseases and the aging population has made CKD the twelfth leading cause of mortality worldwide (23). Given that CKD is a progressive and irreversible disease, an urgent need exists to identify at-risk individuals early and implement interventions. A sedentary lifestyle, recognized as a risk factor for various diseases (24), is associated with increased CKD risk (9). This aligns with the current study results. CKD is defined by decreased renal function (eGFR < 60 mL/min/1.73 m^2) and kidney damage (albuminuria ≥ 30 mg/24 h. Sedentary behavior may cause extensive endothelial dysfunction and capillary rarefaction (25). It is also associated with adverse health outcomes, including higher blood pressure, larger waist circumference, higher BMI, higher levels of triglyceride and glucose levels, and metabolic syndrome, which individually or collectively strain the kidneys and increase CKD risk.

The daily diet of patients with CKD has been extensively researched to identify patterns conducive to optimal kidney health. High salt intake exacerbates a decrease in kidney function by negatively affecting blood pressure and blood vessels (26). However, due to prolonged observation periods and strict dietary interventions during trials, no randomized controlled studies have specifically sought to prevent CKD among healthy individuals.

Consumption of red and processed meat is associated with an increased risk of developing CKD among Iranian and US participants (27,28). Conversely, legume and nut consumption is linked to a lower risk of CKD development (27). In individuals with normal renal function, diets rich in plant-based sources are associated with decreased production of uremic toxins, such as *p*-cresyl sulfate and indoxyl sulfate (29). Uremic toxins are linked to the progression of kidney disease, inflammation, and CVD (30). Furthermore, dietary patterns that tend to be plant-based, such as the Mediterranean diet and the Dietary Approaches to Stop Hypertension (DASH), have garnered widespread attention. Adherence to these diets is associated with a lower risk of developing CKD and can decelerate its progression (31-34). This emphasizes the benefits of plant-derived protein over animal-derived protein for kidney health. Moreover, a recent longitudinal study of participants with no history of CKD reported that greater dietary plant protein intake is inversely related to incident CKD (35). However, no study has examined the protective effect of plant protein on kidney health in sedentary individuals.

In the current study, a high plant protein ratio was associated with a lower risk of CKD in individuals with high sedentary behavior (≥ 6 h/d). Furthermore, the restricted cubic spline model was used to explore the optimal range of plant protein intake, revealing that, in sedentary individuals, a dietary plant protein ratio between 0.000 and 59.296 % was associated with a reduced risk of incident CKD. Various mechanisms have been proposed to explain the benefits of plant protein intake on kidney health. Hypertension, type 2 diabetes *mellitus*, and obesity all contribute to kidney disease. Meanwhile, compared to animal proteins, plant-based food intake is linked to lower blood pressure, weight loss, and a lower risk of type 2 diabetes *mellitus* (36,37). A study of ten healthy individuals who consumed an equivalent amount of animal or plant protein for 3 weeks showed that plant protein intake decreased renal plasma flow, fractional clearance of albumin, and IgG while increasing renal vascular resistance (38). The variation in amino acid consumption from plant versus animal proteins could explain their differing effects on kidney health (39,40).

This study has certain limitations. First, NHANES is a cross-sectional survey, preventing causal relationships from being determined. Second, the dietary data were based on self-reported first 24-h dietary recall, which may not reflect normal or long-term dietary behavior and may be influenced by memory bias. Finally, although the models adjusted for numerous potential confounding factors, residual confounding factors cannot be fully excluded.

CONCLUSION

This study suggests that high sedentary behavior increases the risk of CKD; however, a higher dietary plant protein ratio lowers this risk. These results provide dietary guidance for preventing CKD in sedentary individuals.

REFERENCES

1. Chen TK, Knicely DH, Grams ME. Chronic Kidney Disease Diagnosis and Management: A Review. JAMA 2019;322(13):1294-304. DOI: 10.1001/jama.2019.14745
2. GBD Chronic Kidney Disease Collaboration. Global, regional, and national burden of chronic kidney disease, 1990-2017: a systematic analysis for the Global Burden of Disease Study 2017. Lancet 2020;395(10225):709-33. DOI: 10.1016/S0140-6736(20)30045-3
3. Cockwell P, Fisher LA. The global burden of chronic kidney disease. Lancet 2020;395(10225):662-4. DOI: 10.1016/S0140-6736(19)32977-0
4. Ruiz-Ortega M, Rayego-Mateos S, Lamas S, Ortiz A, Rodrigues-Diez RR. Targeting the progression of chronic kidney disease. Nat Rev Nephrol 2020;16(5):269-88. DOI: 10.1038/s41581-019-0248-y
5. Tremblay MS, Aubert S, Barnes JD, Saunders TJ, Carson V, Latimer-Cheung AE, et al. Sedentary Behavior Research Network (SBRN) - Terminology Consensus Project process and outcome. Int J Behav Nutr Phys Act 2017;14(1):75. DOI: 10.1186/s12966-

017-0525-8

6. Borodulin K, Kärki A, Laatikainen T, Peltonen M, Luoto R. Daily Sedentary Time and Risk of Cardiovascular Disease: The National FINRISK 2002 Study. J Phys Act Health 2015;12(7):904-8. DOI: 10.1123/jpah.2013-0364
7. Wu J, Zhang H, Yang L, Shao J, Chen D, Cui N, et al. Sedentary time and the risk of metabolic syndrome: A systematic review and dose-response meta-analysis. Obes Rev 2022;23(12):e13510. DOI: 10.1111/obr.13510
8. Tholl C, Bickmann P, Wechsler K, Froböse I, Grieben C. Musculoskeletal disorders in video gamers - a systematic review. BMC Musculoskelet Disord 2022;23(1):678. DOI: 10.1186/s12891-022-05614-0
9. Volaklis K, Mamadjanov T, Meisinger C. Sedentary behavior and kidney function in adults: a narrative review. Wien Klin Wochenschr 2021;133(3-4):144-52. DOI: 10.1007/s00508-020-01673-2
10. Hawkins M, Newman AB, Madero M, Patel KV, Shlipak MG, Cooper J, et al. TV Watching, but Not Physical Activity, Is Associated With Change in Kidney Function in Older Adults. J Phys Act Health 2015;12(4):561-8. DOI: 10.1123/jpah.2013-0289
11. Kosaki K, Tanahashi K, Matsui M, Akazawa N, Osuka Y, Tanaka K, et al. Sedentary behaviour, physical activity, and renal function in older adults: isotemporal substitution modelling. BMC Nephrol 2020;21(1):211. DOI: 10.1186/s12882-020-01869-8
12. Lynch BM, White SL, Owen N, Healy GN, Chadban SJ, Atkins RC, et al. Television viewing time and risk of chronic kidney disease in adults: the AusDiab Study. Ann Behav Med 2010;40(3):265-74. DOI: 10.1007/s12160-010-9209-1
13. Satija A, Hu FB. Plant-based diets and cardiovascular health. Trends Cardiovasc Med 2018;28(7):437-41. DOI: 10.1016/j.tcm.2018.02.004

14. Thomas MS, Calle M, Fernandez ML. Healthy plant-based diets improve dyslipidemias, insulin resistance, and inflammation in metabolic syndrome. A narrative review. Adv Nutr 2023;14(1):44-54. DOI: 10.1016/j.advnut.2022.10.002
15. Hardt L, Mahamat-Saleh Y, Aune D, Schlesinger S. Plant-Based Diets and Cancer Prognosis: a Review of Recent Research. Curr Nutr Rep 2022;11(4):695-716. DOI: 10.1007/s13668-022-00440-1
16. Adair KE, Bowden RG. Ameliorating Chronic Kidney Disease Using a Whole Food Plant-Based Diet. Nutrients 2020;12(4):1007. DOI: 10.3390/nu12041007
17. Chen X, Wei G, Jalili T, Metos J, Giri A, Cho ME, et al. The Associations of Plant Protein Intake With All-Cause Mortality in CKD. Am J Kidney Dis 2016;67(3):423-30. DOI: 10.1053/j.ajkd.2015.10.018
18. Levey AS, Stevens LA, Schmid CH, Zhang YL, Castro AF 3rd, Feldman HI, et al. A new equation to estimate glomerular filtration rate. Ann Intern Med 2009;150(9):604-12. DOI: 10.7326/0003-4819-150-9-200905050-00006
19. Kidney Disease: Improving Global Outcomes (KDIGO) Glomerular Diseases Work Group. KDIGO 2021 Clinical Practice Guideline for the Management of Glomerular Diseases. Kidney Int 2021;100(4S):S1-S276. DOI: 10.1016/j.kint.2021.05.021
20. Cao Z, Xu C, Zhang P, Wang Y. Associations of sedentary time and physical activity with adverse health conditions: Outcome-wide analyses using isotemporal substitution model. EClinicalMedicine 2022;48:101424. DOI: 10.1016/j.eclinm.2022.101424
21. Gui J, Ding R, Huang D, Wang L, Han Z, Yang X, et al. Associations between urinary heavy metals and anxiety among adults in the National Health and Nutrition Examination Survey (NHANES), 2007-2012. Chemosphere 2023;341:140085. DOI: 10.1016/j.chemosphere.2023.140085

22. Kanagasabai T, Thakkar NA, Kuk JL, Churilla JR, Ardern CI. Differences in physical activity domains, guideline adherence, and weight history between metabolically healthy and metabolically abnormal obese adults: a cross-sectional study. Int J Behav Nutr Phys Act 2015;12:64. DOI: 10.1186/s12966-015-0227-z
23. Lo R, Narasaki Y, Lei S, Rhee CM. Management of traditional risk factors for the development and progression of chronic kidney disease. Clin Kidney J 2023;16(11):1737-50. DOI: 10.1093/ckj/sfad101
24. Wu J, Fu Y, Chen D, Zhang H, Xue E, Shao J, et al. Sedentary behavior patterns and the risk of non-communicable diseases and all-cause mortality: A systematic review and meta-analysis. Int J Nurs Stud 2023;146:104563. DOI: 10.1016/j.ijnurstu.2023.104563
25. Coresh J, Selvin E, Stevens LA, Manzi J, Kusek JW, Eggers P, et al. Prevalence of chronic kidney disease in the United States. JAMA 2007;298(17):2038-47. DOI: 10.1001/jama.298.17.2038
26. Sugiura T, Takase H, Ohte N, Dohi Y. Dietary Salt Intake is a Significant Determinant of Impaired Kidney Function in the General Population. Kidney Blood Press Res 2018;43(4):1245-54. DOI: 10.1159/000492406
27. Haring B, Selvin E, Liang M, Coresh J, Grams ME, Petruski-Ivleva N, et al. Dietary Protein Sources and Risk for Incident Chronic Kidney Disease: Results From the Atherosclerosis Risk in Communities (ARIC) Study. J Ren Nutr 2017;27(4):233-42. DOI: 10.1053/j.jrn.2016.11.004
28. Mirmiran P, Yuzbashian E, Aghayan M, Mahdavi M, Asghari G, Azizi F. A Prospective Study of Dietary Meat Intake and Risk of Incident Chronic Kidney Disease. J Ren Nutr 2020;30(2):111-8. DOI: 10.1053/j.jrn.2019.06.008
29. Patel KP, Luo FJ, Plummer NS, Hostetter TH, Meyer TW. The production of *p*-cresol sulfate and indoxyl sulfate in vegetarians

versus omnivores. Clin J Am Soc Nephrol 2012;7(6):982-8. DOI: 10.2215/CJN.12491211
30. Joshi S, McMacken M, Kalantar-Zadeh K. Plant-Based Diets for Kidney Disease: A Guide for Clinicians. Am J Kidney Dis 2021;77(2):287-96. DOI: 10.1053/j.ajkd.2020.10.003
31. Asghari G, Yuzbashian E, Mirmiran P, Azizi F. The association between Dietary Approaches to Stop Hypertension and incidence of chronic kidney disease in adults: the Tehran Lipid and Glucose Study. Nephrol Dial Transplant 2017;32(suppl_2):ii224-30. DOI: 10.1093/ndt/gfw273
32. Banerjee T, Crews DC, Tuot DS, Pavkov ME, Burrows NR, Stack AG, et al. Poor accordance to a DASH dietary pattern is associated with higher risk of ESRD among adults with moderate chronic kidney disease and hypertension. Kidney Int 2019;95(6):1433-42. DOI: 10.1016/j.kint.2018.12.027
33. Lee HS, Lee KB, Hyun YY, Chang Y, Ryu S, Choi Y. DASH dietary pattern and chronic kidney disease in elderly Korean adults. Eur J Clin Nutr 2017;71(6):755-61. DOI: 10.1038/ejcn.2016.240
34. Khatri M, Moon YP, Scarmeas N, Gu Y, Gardener H, Cheung K, et al. The association between a Mediterranean-style diet and kidney function in the Northern Manhattan Study cohort. Clin J Am Soc Nephrol 2014;9(11):1868-75. DOI: 10.2215/CJN.01080114
35. Heo GY, Koh HB, Kim HJ, Kim KW, Jung CY, Kim HW, et al. Association of Plant Protein Intake With Risk of Incident CKD: A UK Biobank Study. Am J Kidney Dis 2023;82(6):687-97.e1. DOI: 10.1053/j.ajkd.2023.05.007
36. Joshi S, Ettinger L, Liebman SE. Plant-Based Diets and Hypertension. Am J Lifestyle Med 2019;14(4):397-405. DOI: 10.1177/1559827619875411
37. Li J, Glenn AJ, Yang Q, Ding D, Zheng L, Bao W, et al. Dietary Protein Sources, Mediating Biomarkers, and Incidence of Type 2 Diabetes: Findings From the Women's Health Initiative and the

UK Biobank. Diabetes Care 2022;45(8):1742-53. DOI: 10.2337/dc22-0368

38. Kontessis P, Jones S, Dodds R, Trevisan R, Nosadini R, Fioretto P, et al. Renal, metabolic and hormonal responses to ingestion of animal and vegetable proteins. Kidney Int 1990;38(1):136-44. DOI: 10.1038/ki.1990.178

39. Elliott P, Stamler J, Dyer AR, Appel L, Dennis B, Kesteloot H, et al. Association between protein intake and blood pressure: the INTERMAP Study. Arch Intern Med 2006;166(1):79-87. DOI: 10.1001/archinte.166.1.79

40. Kontessis PA, Bossinakou I, Sarika L, Iliopoulou E, Papantoniou A, Trevisan R, et al. Renal, metabolic, and hormonal responses to proteins of different origin in normotensive, nonproteinuric type I diabetic patients. Diabetes Care 1995;18(9):1233. DOI: 10.2337/diacare.18.9.1233

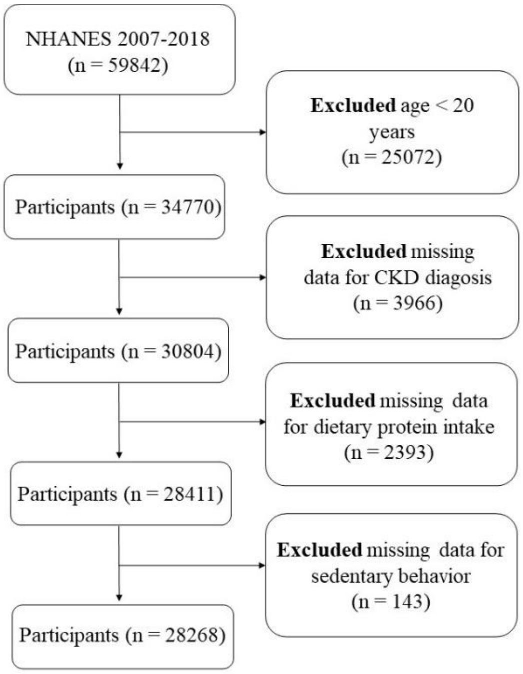

Figure 1. Participant screening flow chart.

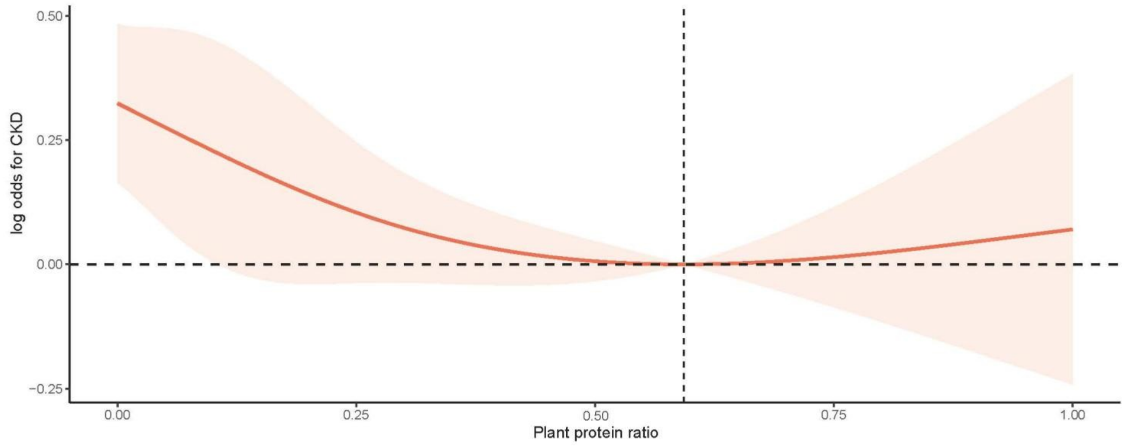

Figure 2. Restricted cubic spline of the association between dietary plant protein and CKD risk in sedentary participants.

Table I. Baseline characteristics of the study participants

Characteristic	Overall (n = 28,268)	Non-CKD (n = 23,265)	CKD (n = 5003)	p-value
Demographic characteristics				
Age, n (no. weighted %)				
20-35	7094 (27.727)	6696 (30.568)	398 (10.485)	
35-50	7147 (26.826)	6507 (28.875)	640 (14.390)	
50-65	7444 (27.104)	6213 (27.421)	1231 (25.183)	
≥ 65	6583 (18.343)	3849 (13.136)	2734 (49.942)	*< 0.001†*
Sex, n (no. weighted %)				
Female	14,456 (51.665)	11,856 (50.845)	2600 (56.644)	
Male	13,812 (48.335)	11,409 (49.155)	2403 (43.356)	*< 0.001†*
Ethnicity, n (no., weighted %)				
Mexican American	4374 (8.864)	3713 (9.095)	661 (7.461)	
Non-Hispanic Black	5796 (10.736)	4693 (10.522)	1103 (12.036)	
Non-Hispanic White	11,904 (66.585)	9531 (66.220)	2373 (68.800)	
Other	6194 (13.815)	5328 (14.162)	866 (11.703)	*< 0.001†*
Education, n (no., weighted %)				< 0.001†
High school	6438 (23.061)	5223 (22.704)	1215 (25.308)	

Less than high school	6753 (15.267)	5238 (14.244)	1515 (21.527)	
More than high school	15,055 (61.622)	12,788 (63.052)	2267 (53.166)	
PIR, n (no., weighted %)				
< 1	5456 (13.730)	4434 (14.508)	1022 (16.388)	
1-3	10,903 (33.092)	8709 (34.380)	2194 (43.066)	
≥ 3	9430 (46.111)	8089 (51.112)	1341 (40.546)	< 0.001†
BMI, n (no., weighted %)				
< 25	7883 (29.056)	6742 (30.137)	1141 (23.537)	
25-30	9288 (32.809)	7744 (33.438)	1544 (30.209)	
≥ 30	10,888 (37.602)	8654 (36.426)	2234 (46.254)	< 0.001†
Lifestyle characteristics				
Plant protein intake, g/d	37.987 ± 0.800	39.117 ± 0.822	31.129 ± 1.410	< 0.001†
Total protein intake, g/d	193.751 ± 1.455	197.538 ± 1.597	170.765 ± 2.356	< 0.001†
Plant protein ratio, %	18.352 ± 0.330	18.605 ± 0.339	16.814 ± 0.626	0.004*
Calorie intake, kcal/d	2160.485 ± 8.210	2200.160 ± 9.311	1919.711 ± 16.239	< 0.001†
Marital status, n (no., weighted %)				
Married/cohabiting	16,958 (62.822)	14,201 (63.529)	2757 (58.659)	
Never married	5115 (18.799)	4589 (20.078)	526 (11.077)	
Widowed/divorced/separated	6184 (18.350)	4467 (16.393)	1717 (30.264)	< 0.001†
Smoking status, n (no., weighted %)				< 0.001†

Former smoker	6834 (24.783)	5183 (23.441)	1651 (32.990)	
Non-smoker	15,750 (55.596)	13,225 (56.357)	2525 (51.112)	
Current smoker	5671 (19.586)	4848 (20.202)	823 (15.898)	
Alcohol use, n (no., weighted %)				
Former	4045 (11.713)	2931 (11.293)	1114 (20.975)	
Heavy	5321 (20.506)	4729 (23.533)	592 (13.340)	
Mild	8829 (34.183)	7327 (36.725)	1502 (37.808)	
Moderate	4078 (16.469)	3571 (18.538)	507 (12.964)	
Never	3616 (9.829)	2828 (9.910)	788 (14.912)	< 0.001†
PA, n (no., weighted %)				
Active	17,437 (66.590)	15,116 (69.167)	2321 (50.948)	
Inactive	7332 (21.378)	5333 (19.193)	1999 (34.633)	
Somewhat active	3499 (12.032)	2816 (11.639)	683 (14.418)	< 0.001†
Sedentary behavior, n (no., weighted %)				
Low (< 6 h/day)	14,820 (48.737)	12,408 (49.448)	2412 (44.420)	
High (≥ 6 h/day)	13,448 (51.263)	10,857 (50.552)	2591 (55.580)	< 0.001†
Comorbidity				
Diabetes, n (no., weighted %)				< 0.001†
No	24,263 (89.486)	20,919 (92.351)	3344 (72.102)	

Yes	4005 (10.514)	2346 (7.649)	1659 (27.898)	
Hypertension, n (no., weighted %)				
No	19,382 (63.754)	17,641 (68.626)	1741 (34.330)	
Yes	13,211 (36.242)	9159 (31.374)	4052 (65.670)	< 0.001†
Stroke, n (no., weighted %)				
No	27,141 (96.941)	22,640 (97.908)	4501 (91.688)	
Yes	1098 (2.969)	606 (2.092)	492 (8.312)	< 0.001†
CVD, n (no., weighted %)				
No	25,202 (91.340)	21,544 (93.780)	3658 (76.551)	
Yes	3063 (8.656)	1720 (6.220)	1343 (23.449)	< 0.001†
Blood biochemistry indexes				
eGFR, mL/min/1.73 m^2	94.558 ± 0.329	98.065 ± 0.306	73.276 ± 0.582	< 0.001†
Scr (µmol/L)	77.795 ± 0.275	74.491 ± 0.215	97.842 ± 1.196	< 0.001†

CKD: chronic kidney disease; PIR: poverty income ratio; BMI: body mass index; PA: physical activity; CVD: cardiovascular disease; eGFR: estimated glomerular filtration rate; Scr: serum creatinine. Missing rates were 0.039 % for marital status, 0.078 % for education, 8.770 % for PIR, 0.739 % for BMI, 0.046 % for smoking status, 8.416 % for alcohol use, 0.004 % for hypertension, 0.103 % for stroke and 0.011 % for CVD. **p*-Value < 0.01; †*p*-value < 0.001.

Table II. Weighted binary logistic regression for the association between sedentary bahavior and CKD risk

Sedentary behavior	Crude model OR (95 % CI)	*p*-value	Model 1 OR (95 % CI)	*p*-value	Model 2 OR (95 % CI)	*p*-value	Model 3 OR (95 % CI)	*p*-value
Low	1.000 (ref)	-	1.000 (ref)	-	1.000 (ref)	-	1.000 (ref)	-
High	1.256 (1.137, 1.386)	< 0.001‡	1.298 (1.165, 1.447)	< 0.001‡	1.173 (1.051, 1.310)	0.005†	1.130 (1.009, 1.265)	0.035*

Crude Model: adjusted for no potential confounders; Model 1 was adjusted for age, ethnicity, sex, education, PIR and marital status; Model 2 was adjusted for age, ethnicity, sex, education, PIR, marital status, BMI, PA, smoking status and alcohol use. Model 3 was adjusted for age, ethnicity, sex, education, PIR, marital status, BMI, PA, smoking status, alcohol use, diabetes, hypertension, stroke and CVD. CKD: chronic kidney disease; PIR: poverty income ratio; BMI: body mass index; PA: physical activity; CVD: cardiovascular disease. **p*-Value < 0.05. †*p*-Value < 0.01. ‡*p*-Value < 0.001.

Table III. Weighted binary logistic regression for the association between plant protein and CKD risk in high sedentary behavior participants

	Categorical models					**Continuous models**	
Plant protein ratio							
	Q1 OR (95 % CI)	Q2 OR (95 % CI)	Q3 OR (95 % CI)	Q4 OR (95 % CI)	*p-trend*	OR (95 % CI)	*p-value*
Crude model	1.000 (Ref)	0.787 (0.534, 1.158)	0.799 (0.682, 0.934)	0.734 (0.620, 0.868)	< 0.001‡	0.618 (0.463, 0.823)	0.001†
Model 1	1.000 (Ref)	0.811 (0.516, 1.273)	0.848 (0.721, 0.997)	0.684 (0.568, 0.824)	< 0.001‡	0.562 (0.405, 0.780)	< 0.001‡
Model 2	1.000 (Ref)	0.826 (0.520, 1.314)	0.885 (0.754, 1.039)	0.728 (0.602, 0.881)	0.002†	0.616 (0.442, 0.857)	0.005†
Model 3	1.000 (Ref)	0.847 (0.528, 1.357)	0.885 (0.750, 1.045)	0.740 (0.614, 0.893)	0.002†	0.646 (0.465, 0.899)	0.010*

Associations are given in the form of odds ratio (95 % confidence inteval). Q1 (0.000, 0.000), Q2 (0.000, 1.379 %), Q3 (1.379 %, 28.634 %), Q4 (28.634 %, 100.000 %). **p*-Value < 0.05; †*p*-value < 0.01; ‡*p*-value < 0.001. Crude Model : adjusted for no potential confounders. Model 1 was adjusted for age, ethnicity, sex, education, PIR and marital status. Model 2 was adjusted for age, ethnicity, sex, education, PIR, marital status, BMI, PA, smoking status and alcohol use. Model 3: was adjusted for age, ethnicity, sex, education, PIR, marital status, BMI, PA, smoking status, alcohol use, diabetes, hypertension, stroke and CVD. CKD: chronic kidney disease; PIR: poverty income ratio; BMI: body mass index; PA: physical activity; CVD: cardiovascular disease.

Table IV. Weighted ordinal logistic regression for the association between plant protein ratio and CKD prognosis in high sedentary behavior participants

	OR (95 % CI)	***p*-value**
Crude Model	0.615 (0.465, 0.813)	< 0.001†
Model 1	0.546 (0.400, 0.745)	< 0.001†
Model2	0.594 (0.435, 0.810)	0.001*
Model 3	0.624 (0.458 ,0.850)	0.003*

Crude model: adjusted for no potential confounders; Model 1 was adjusted for age, ethnicity, sex, education, PIR and marital status; Model 2 was adjusted for age, ethnicity, sex, education, PIR, marital status, BMI, PA, smoking status and alcohol use; Model 3 was adjusted for age, ethnicity, sex, education, PIR, marital status, BMI, PA, smoking status, alcohol use, diabetes, hypertension, stroke and CVD. CKD: chronic kidney disease; PIR: poverty income ratio; BMI: body mass index; PA: physical activity; CVD: cardiovascular disease. **p*-Value < 0.01. †*p*-Value < 0.001.