World Journal of Urology
https://doi.org/10.1007/s00345-020-03276-y

ORIGINAL ARTICLE

The association between plant-based content in diet and testosterone levels in US adults

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Received: 27 March 2020 / Accepted: 25 May 2020

Abstract

Purpose To evaluate the association between the plant-based content of diet and serum testosterone levels in men from the national health and nutrition examination survey (NHANES) database.

Materials and methods Data on demographics, diet, and testosterone levels was acquired from the NHANES database. Using the food frequency questionnaire, an overall plant-based diet index (PDI) and a healthful plant-based diet index (hPDI) was developed. A higher score on PDI and hPDI indicates higher consumption of plant foods.

Results A total of 191 participants were included, average age was 45 (30–60) years and average total testosterone level was 546.7 ± 254.7 ng/dL. The mean PDI and hPDI were 50.4 ± 6 and 50.8 ± 7.2, respectively. On multiple linear regression analysis, BMI and age significantly contribute to testosterone levels ($p < 0.05$); however, neither of the diet indexes significantly predicted serum testosterone levels (PDI: $p = 0.446$; and hPDI: $p = 0.056$).

Conclusions In a well characterized national database, the plant-based diet index is unable to predict testosterone levels. Plant-based food content in diet is not associated with serum testosterone levels.

Keywords Testosterone · Diet · Plant-based diet · Vegetarian · Vegan · Index · NHANES

Introduction

Participation in diet modification, specifically to plant-based diets has grown recently. The number of USA consumers claiming to utilize a plant-based diet rose 500% between 2014 and 2017 and sales of plant-based foods rose 20% in 2018 compared to the year prior [1]. Plant-based diets promote a high intake of foods originating from plants and discourage consumption of animal products such as red meats, poultry, fish, and dairy [1]. It has previously been demonstrated that plant-based diets improve health by reducing the incidence of conditions such as obesity, hypertension, ischemic heart disease, cancer, and mortality [2–4]. Additionally, studies have demonstrated that a shift in diet to a more sustainable pattern with a reduction of animal-based foods can result in more than a 70% reduction in greenhouse gas emissions [5].

While robust studies have evaluated the impact of increased plant-based content in the diet on cardiovascular and metabolic risks, evidence on the impact of plant-based diets on the levels of testosterone in males has been inconsistent. At present, some studies have shown evidence that a vegetarian diet can lead to reduced availability of testosterone [6, 7], while other studies have shown that a vegetarian-based diet makes no significant difference in bioavailability of testosterone [7–10]. At the same time, it has been postulated that the unclear evidence could be attributed to a loose definition of plant-based diet [11]. It should be noted that most studies of vegetarian diets do not differentiate highly processed plant foods, such as refined grains and sugar-sweetened beverages, from unprocessed plant foods which have been associated with lower cardio metabolic risk profile [12–14]. Given the inconsistent literature on the association of plant-based diets and testosterone levels, we sought to examine the relationship between serum testosterone levels and plant-based content of diet using a graded approach [4]

Electronic supplementary material The online version of this article (https://doi.org/10.1007/s00345-020-03276-y) contains supplementary material, which is available to authorized users.

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Published online: 28 May 2020

of patients documented in the continuous national health and nutrition examination survey (NHANES) database.

Materials and methods

NHANES database

We obtained data on demographics, diet, and testosterone levels from the Continuous NHANES 2003–2004 [15]. This dataset was the only available collection to include both serum testosterone levels and detailed information on each participants diet and its breakdown. The NHANES is a center for disease control (CDC) program designed to assess the health of the United States population. Dietary data was obtained through the NHANES food frequency questionnaire (FFQ), which was developed and validated by the National Institute of Health, National Cancer Institute [16]. Participants were asked their frequency of food intake over the prior 12 months through a 154-question survey. Sex hormone levels were determined by immunoassay of serum samples obtained from NHANES participants [17]. Total testosterone was evaluated, because the American urological association defines testosterone deficiency as serum levels of total testosterone <300 ng/dL [18]. Patients with complete data available and men between age 18 and 75 were included.

Plant-based diet index

We applied previously published methodology to convert FFQ data from the NHANES 2003–2004 into an overall plant-based diet index (PDI) and a healthful plant-based diet index (hPDI) [4]. These indices have previously been validated and provide a robust method to stratify participants based on their food consumption patterns. PDI differentiates patients based on their frequency of consumption of plant-based foods. On the other hand, hPDI differentiates even further by distinguishing healthy plant foods from unhealthy plant foods and animal foods. We converted food frequency responses into daily serving sizes and grouped individual foods into 17 food categories (Suppl. Table 1). To calculate the PDI, participants received a score from 1 to 5 based on their quintile of consumption of foods within each category. They received a score of 5 when they fell within the highest quintile of consumption of foods categorized as plant foods, and a 1 when they fell within the highest quintile of consumption of foods categorized as animal foods. For the hPDI, participants received a score of 5 when they fell within the highest quintile of consumption of foods categorized as healthful plant foods, and a score of 1 when they fell within the highest quintile of consumption of foods categorized as unhealthful plant foods or animal foods.

Statistical analysis

Statistical analysis was performed with SPSS version 24 software. Continuous variables were presented as medians and interquartile ranges (25–75) or mean ± standard deviation in accordance with the data distribution. Then we analyzed the 17 food groups that were used to create the PDI and hPDI index, then using the Spearman test we determinate the correlation between the food groups and serum testosterone levels. To the primary outcome of serum testosterone, a multiple regression analysis considering as independent variables age, BMI (body mass index), diabetes mellitus (DM) (No DM = 0, DM or Pre-DM = 11), PDI, and hPDI. To avoid multicollinearity, before running the multiple regression analysis, we confirmed that none of the variables had a high degree of correlation ($r > \pm 0.7$) and the tolerance of each independent variable was calculated. In addition, we calculated the influence of data points through the Cook's distance of each case and the Durbin–Watson test was performed to assess autocorrelation of the residuals in each model. A p value <0.05 was considered statistically significant.

Results

Of the 191 analyzed participants were analyzed, average age was 45 (30–60) years, BMI 28 ± 5.5 kg/m^2, and testosterone 546.7 ± 254.7 ng/dL. Overall, plant-based diet index were 50.4 ± 6 and 50.8 ± 7.2 for PDI and hPDI, respectively (Table 1). When analyzing the overall correlation between testosterone and food consumption of each food category, there was a negative correlation between testosterone and tea and coffee consumption (−0.215; $p = 0.003$) (Table 2).

In both plant-based diet indices, multiple linear regression analysis model showed there is independence of residuals as assessed by the Durbin-Watson statistic (PDI = 1.976; hPDI = 2.001). There was no evidence of multicollinearity, as evaluated in the independent variables with no results of tolerance <0.1, and no residuals with a Cook's distance above 1. Both multiple regression models significantly predicted testosterone (PDI = [$F(4,186) = 16.964$, $p < 0.001$] and hPDI = [$F(4,186) = 17.746$, $p < 0.001$]) and account for a variation in serum testosterone for the PDI model of 24.8% ($R^2 = 0.264$, adj. $R^2 = 0.248$) and for the hPDI of 26.1%

Table 1 Clinical and demographic characteristics of the overall participants

	Overall $n = 191$ (100%)
Age in years	45 (30–60)
BMI (kg/m^2)	28 ± 5.5
Race/ethnicity	
Mexican American	102 (53.4%)
Other hispanic	35 (18.3%)
Non-hispanic white	46 (24.1%)
Non-hispanic black	5 (2.6%)
Other race including multiracial	3 (1.6%)
DM	
No DM	164 (85.9%)
DM or Pre-DM	27 (14.1%)
Testosterone (ng/dL)	546.7 ± 254.7
Testosterone levels categorized	
Testosterone > 300 ng/dL	163 (85.3%)
Testosterone ≪300 ng/dL	28 (14.7%)
PDI	50.4 ± 6
hPDI	50.8 ± 7.2

Median (interquartile range 25–75); median ± standard deviation

Table 2 Overall food consumption of the 17 food group categories, and a correlation between the food groups and testosterone

	Overall $n = 191$	r	p value
Whole grains	3 (2–4)	−0.101	0.165
Fruits	3 (2–4)	−0.098	0.176
Vegetables	3 (2–4)	−0.114	0.117
Nuts	3 (2–4)	−0.135	0.063
Legumes	3 (1–4)	0.025	0.734
Tea and coffee	4 (2–5)	−0.215	0.003
Fruit juices	3 (2–4)	0.104	0.151
Refined grain	3 (2–4)	0.061	0.404
Potatoes	3 (2–5)	0.039	0.591
Sugar-sweetened beverages	3 (2–4)	0.048	0.508
Sweets	3 (2–4)	−0.092	0.207
Animal fat	3 (2–4)	0.024	0.739
Dairy	3 (2–4)	−0.016	0.823
Egg	3 (2–4)	0.010	0.890
Fish or seafood	3 (2–4)	−0.052	0.474
Meat	3 (2–4)	−0.092	0.208
Miscellaneous	3 (2–4)	−0.036	0.618

Median (interquartile range 25–75)

($R^2 = 0.276$, adj. $R^2 = 0.261$). In both models, BMI and age significantly contribute to testosterone levels ($p < 0.05$); however, neither PID or hPDI predicted testosterone levels (PDI: $p = 0.446$; and hPDI: $p = 0.056$) (Table 3).

Discussion

Our findings suggest that there is no association between plant-based content in diet and serum testosterone levels. Our results show that even when stratifying healthy plant foods from unhealthy plant foods and meat in using the PDI and hPDI, no association was elucidated. We also correlate the overall food consumption patterns based on the 17 food categories with testosterone levels. While no impact on testosterone levels was revealed in the food categories except for tea and coffee, we found after adjusting that both of the plant-based diet index did not significantly contribute to serum testosterone levels in the selected population. We also found that BMI and age significantly contribute to serum testosterone levels in our statistic models.

The results of this study concur with several prior studies. In a study by Key et al., androgen levels were evaluated in men consuming a variety of diets with different vegetarian-based content. The results suggested that no significant difference in serum free testosterone was present when comparing these different diet compositions [8]. Similarly, Raben et al. showed that a lacto-ovo vegetarian diet (consisting of vegetables, eggs, and dairy products but not meat) produces a minor decrease in total testosterone; however, it does not result in any significant difference in free serum testosterone levels [9]. It has also previously been shown that a fried-processed dietary pattern is negatively associated with testosterone levels and positively associated with the severity of chronic kidney disease. In the same study, results showed that a vege-seafood dietary pattern is negatively associated with severity of impaired kidney function and has no association with testosterone levels [19]. Therefore, it is apparent that there is substantial evidence that has not distinguished an association with the plant-based content of diet and testosterone levels.

With diet being an important factor in the health of patients, it's important to understand the far-reaching implications of various diets and lifestyle decisions. In this case, it will be reassuring to patients to know that committing to a plant-based will not negatively impact their testosterone levels and physicians can confidently counsel them on this effect. This is especially important for those who desire to undertake primarily to reduce their risks of cardio-metabolic morbidity, obesity, type 2 diabetes, malignancy, and coronary heart disease, but have concerns about potential risks to their sexual health [20–22]. Furthermore, a growing body of evidence has demonstrated that high-income countries have moved towards adopting

Table 3 Multiple linear regression analysis used to predict serum testosterone levels

Variable	PDI				hPDI			
	B	95% CI		*p* value	*B*	95% CI		*p* value
		Lower	Upper			Lower	Upper	
Age in years	−3.16	−5.26	−1.05	0.004	−2.88	−4.99	−0.78	0.008
BMI (kg/m^2)	−17.05	−23.05	−11.06	< 0.001	−17.39	−23.35	−11.44	< 0.001
Pre-DM or DM	−69.64	−169.58	30.30	0.171	−57.78	−157.76	42.2	0.256
Plant-based diet Index	−2.09	−7.51	3.32	0.446	−4.46	−9.03	0.12	0.056

B Unstandardized regression coefficient, *CI* confidence interval

sustainable diets to lower their environmental footprint from food production [23]. It has been shown that a reduction in environmental footprint (i.e., greenhouse gas emissions, and water consumption) is generally proportional to the magnitude of animal-based food restriction [5]. Thus, it's evident that an increase in the plant-based content of foods can have a substantial impact on a person's overall health status as well as make a positive impact on the environment without impacting their testosterone levels.

Our study has strengths and limitations. To our knowledge, our study is the first to evaluate the effects of a plant-based diet on male testosterone level using a graded plant-based diet index. Unlike prior studies, we differentiated patients based on the quantity and quality of plant-based foods to allow for better transparency into the actual impact of their diet content. Our study also presents a moderate population size with 191 participants. The limitations of this study include: (1) the NHANES database is a cross-sectional data which does not account for longitudinal changes in diet, serum T, medications, genetic conditions, unreported comorbidities, and other undiagnosed comorbidities. (2) The diet questionnaire was self-reported and is subject to recall bias and self-serving bias. (3) The serum testosterone levels from this database were measured at only one time point but AUA guidelines recommend two levels to take intra-individual diurnal serum testosterone variations into consideration. (4) Although venipuncture for participants occurred at regularly scheduled times, the specific timing was not recorded in the database.

Although our results are substantial, future prospective studies would help elucidate the questions of this study more conclusively. It would be necessary to regulate compliance and diet content to elucidate a definitive association. Moreover, it might be difficult to generalize to the population due to intrinsic variations in metabolism and the array of factors that can affect testosterone levels which may be impossible to wholly account for. Future studies might also benefit from evaluating the effect of plant-based diets on long-term health outcomes or metrics of clinical significance, such as fertility.

Conclusion

In a well characterized national database with self-reported the content of their diet to NHANES database, plant-based food content in diets was not associated with serum testosterone levels and the plant-based diet index does not predict testosterone levels. Further studies need to be performed to confirm our findings.

Author contributions M Kuchakulla: protocol/project development, manuscript writing/editing. S Nackeeran: protocol/project development, data collection or management, data analysis, manuscript writing/editing. R Blachman-Braun, M.D.: data collection or management, data analysis, manuscript writing/editing. Ramasamy, M.D.: protocol/project development, manuscript writing/editing

Funding Not applicable.

Compliance with ethical standards

Conflict of interest Not applicable.

Animal or human participants Research involving human participants: de-identified data obtained from NHANES, no IRB approval was required.

Informed consent Not applicable.

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