The Link Between Plant-based Diet Indices With Biochemical Markers of Bone Turn Over, Inflammation and Insulin in Iranian Older Adults

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Research

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Abstract

Background: The association of plant base diets and biomarkers of bone, insulin, and inflammation is still unclear.

Objectives: We investigated the associations between biomarkers of bone, insulin, and inflammation and three plant-based diet indices: an overall plant-based diet index (PDI); a healthy plant-based diet index (hPDI); and an unhealthy plant-based diet index (uPDI).

Methods: We included 178 elderly subjects who referred to health centers in Tehran. Blood and urine samples were collected to measure osteocalcin, The Human C-telopeptide of type I collagen (u-CTX-I), highly sensitive C-reactive protein (hs-CRP) Parathyroid hormone (PTH), 25(OH) D and insulin resistance and sensitivity. We created an overall PDI, hPDI and uPDI from semi quantitative food-frequency questionnaire (FFQ) data.

Results: Dietary groups of Vegetables ($r=0.15$, $P=0.03$), nuts ($r=0.16$, $P=0.03$), dairy ($r=0.25$, $P=0.001$), eggs ($r=0.27$, $P<0.001$), red meat and animal products ($r=0.25$, $P=0.001$) were directly correlated with osteocalcin. Refined grains were also had positive association with serum insulin concentration ($r=0.14$, $P=0.04$). PTH levels are inversely associated with PDI score ($\beta=-0.18$, $P=0.01$). Also serum insulin concentration was negatively associated with PDI score ($\beta=-0.10$, $P=0.04$). Urine CTX-1 levels was significantly associated with hPDI score ($\beta=-0.06$, $P=0.04$). u-CTX-1 levels are inversely associated with uPDI score. This significance did not change with the adjustment of the confounders ($\beta=-0.28$, $P<0.001$).

Conclusions: more adherence to PDI and hPDI and less in uPDI may have beneficial effect on biomarkers of bone, inflammation, and insulin thus preserving chronic diseases.

Introduction

Osteoporosis is a progressive skeletal disease that is characterized by low bone mass and loss of bone mineral density (BMD) which may lead to a greater risk of bone fractures, mainly in the wrist, spin and hip. Osteoporosis and other bone diseases affect more than 10 million people and causing nearly 1.5 million fractures related to osteoporosis per year in the United States [1, 2]. Women are at a higher risk of osteoporosis than men because of their smaller bone structure, hormonal changes, and pattern of bone loss [3–5]. Along with early diagnosis and treatment, prevention and lifestyle changes that include physical activity and nutrition can help decrease a large portion of the harmful effects of bone disease[6]. The bone formation process needs a sufficient and constant amount of mineral and nutrients, including calcium, protein, magnesium, phosphorus, vitamin D, and potassium[7].

Plant-based diets, such as vegan and vegetarian diets are sort of eating patterns that lay emphasis on legumes, unrefined grains, vegetables, fruits, nuts, and seeds and reduction or elimination most or all animal products—are especially potent in inhibiting type 2 diabetes(T2D), which is a predominate consequence of insulin resistance[8, 9]. In addition, there are a number of clinically useful replacement measures such as Homeostasis Model Assessment for Insulin Resistance (HOMA-IR), Quantitative Insulin-sensitivity Check Index (QUICKI) for assessment of insulin resistance[10]. result of a systematic review and meta-analyses advise that those with diabetes mellitus must be encouraged to have sufficient intake of vegetables, nuts, fruits, and whole grains that are subset of plant-based diets and excellent sources of dietary fiber. in fact, dietary fiber has a beneficial effect on insulin resistance[11]. Also, plant-based diets have been associated with much lower rates of obesity, hypertension, hyperlipidemia, cardiovascular mortality, and cancer[12]. some clinical trials using vegetarian and vegan diets have showed significant improvements in body weight[13] glycemic control[14] and cardiovascular risk factors as compared with conventional therapeutic approaches[15].

Several studies have demonstrated that a diet rich in fruit and vegetables is related to increased bone mineral density (BMD) and improvement of bone microarchitecture [1, 16]. Despite the positive influences of a diet rich in fruit and vegetables on bone health, it is unclear if a plant-based diet alone is enough for preventing adverse bone metabolic changes that may have effect on the development of osteoporosis[17]. A clinical trial showed that plant-based diet decrease calcium and vitamin D intake and cause an increase in N telopeptide biomarker that consistent with increased bone resorption[18] .

Previous study on the association between plant-based diet and risk of osteoporosis, inflammation and insulin resistance has been done in western nations and limited data are available in Middle-East countries. People in the Middle-East have different dietary patterns than those in the western countries.

Given the lack of information about the association between plant-based diet with osteoporosis, inflammation and insulin resistance between Iranian older adults. we aimed to investigate the association between plant-based diet and risk of osteoporosis, inflammation and insulin resistance in this study.

Materials And Methods

Participants

This cross-sectional study was conducted on 178 elderly subjects (51 men and 127 women) with a mean age of 67.04 (60-83), referred to health centers in Tehran. Participants were selected using two-stage cluster sampling of 25 Health centers in Tehran. Health centers in Tehran were divided into five regions: North, South, East, West and Central and then prepared a list of health centers in each area and 25 health centers were selected

randomly (in attention to constraints budget and time) based on the number of health centers in each region proration. Then the total number of samples (178) divided by the number of health centers (25) and obtained the number of samples in each home centers.

This study was conducted according to the guidelines laid down in the Declaration of Helsinki and all procedures involving research study participants were approved by the ethics committee of Tehran University of Medical Sciences (Ethics Number: IR.TUMS.VCR.REC.1396.2307). Written informed consent was obtained from all subjects/patients.

Anthropometric measurements

Patient's height was measured without shoes by a wall stadiometer with sensitivity of 0.1 cm (Seca, Germany) and weight by digital scale (Seca 808, Germany) with an accuracy of 0.1 kg with light clothes (without a coat and rain coat). BMI was calculated by dividing weight in kilograms by the square of height in meters. Waist circumference was measured with a tape measure between the iliac crest and the lowest rib on the exhale. Body fat (%) was measured using body composition analyzer (InBody 720, Biospace, Tokyo, Japan).

Assessment of other variables

We obtained information on age, sex, physical activity, smoking, marital status, diabetes, hypertension and dyslipidemia through questionnaires. Physical activity categorized into very low, low and moderate/high. Smoking classified as non-smoker and former/current smoker. Diabetes, hypertension and dyslipidemia quantified as yes or no.

Laboratory investigation

10 ml of blood and 3 ml urine samples were obtained between the hours of 7-10 am from all of fasted participants. Then blood sample were collected in acid-washed test tubes without anticoagulant. After storing at room temperature for 30 minutes and clot formation, blood samples were centrifuged at 1500 g for 20 minutes. Serums were stored in - 80° C until future testing. Serum Human N-MID Osteocalcin was measured by ELISA kit (Bioassay Technology Laboratory, Shanghai Crystal Day Biotech Co., Ltd., Shanghai, China), with CV<10% and sensitivity of 0.22 ng/ml. The Human C-telopeptide of type I collagen (u-CTX-I) ELISA kit (Bioassay Technology Laboratory, Shanghai Crystal Day Biotech Co., Ltd., Shanghai, China), with intra-Assay: CV<10% and sensitivity of 0.24 ng/ml was used for the quantitative measurement of CTX-I in urine. The measurement of highly sensitive C-reactive protein (hs-CRP) was performed by immunoturbidimetric assay based on the kit instructions (Pars Azmoon, Iran, and Tehran). The 25(OH) D and PTH were assessed by means of an enzymatic method, using commercial kits (with Pars Azmoon, Iran, Tehran and DRG, Marburg, Germany,) respectively. Insulin resistance and insulin sensitivity were assessed using the HOMA-IR [19] and the QUICKI [20], respectively.

Dietary assessment

Dietary intakes of subjects was evaluated by means of a valid and reliable semi-quantitative food frequency questionnaire (FFQ), with 168 food items [21]. Trained researchers via face-to-face interviews, asked subjects to report their frequency of intake of each food item, during the past year on a daily, weekly, or monthly basis. These reports were converted to daily intakes, then we used this dietary data to generate three versions of a plant-based diet: an overall PDI, hPDI, and uPDI [22]. Supplementary table 1 details examples of food group constituents. We created 18 food groups based on nutrient and culinary similarities within the larger categories of healthy plant foods (whole grains, fruits, vegetables, nuts, legumes, vegetable oils, tea/coffee), less healthy plant foods (fruit juices, refined grains, potatoes, sugar-sweetened beverages, sweets/desserts), and animal foods (animal fat, dairy, eggs, fish/seafood, meat, miscellaneous animal-based foods). The classification of mixed composition foods was according to predominate ingredient. Participants were ranked into quintiles according to their food intakes, which were subsequently given positive or inverse scores. With positive scores, participants above the highest quintile of a food group received a score of 5 and those below the lowest quintile received a score of 1. With inverse scores, this pattern of scoring was inversed. For PDI, plant food groups were given positive scores, while animal food groups were given inverse scores. For hPDI, positive scores were allocated to healthy plant food groups, and inverse scores to less healthy plant food groups and animal food groups. Finally, for uPDI, positive scores were allocated to less healthy plant food groups, and inverse scores to healthy plant food groups and animal food groups. The 18 food group scores were summed to establish the indices.

Statistical analysis

All statistical analysis was performed with the SPSS (Statistical Package for Social Sciences) for Windows 25.0 software package (SPSS, Chicago, IL). The level of statistical significance was pre-set at $p < 0.05$. The normality of data was evaluated by the Kolmogorov and Smirnov test. People were grouped based on the tertiles of PDI, hPDI and uPDI. To compare general characteristics among tertiles, we used one-way ANOVA for quantitative variables also qualitative variables were evaluate by Chi-square tests. Pearson correlation was conducted to assess the relation of food groups intake with test variables including serum osteocalcin, urine CTX-I, hs-CRP, 25(OH) D, PTH, serum insulin, HOMA-IR, and QUICKI. Multivariate adjusted means were performed to evaluate the relationship between tertiles of PDI, uPDI and hPDI with other variables including osteocalcin, urine CTX-I, hs-CRP, 25(OH) D, PTH, serum insulin, HOMA-IR, and QUICKI (adjusted for age, sex, BMI, smoking, physical activity, marital status, disease and energy intake). Multiple linear regression analysis was used to evaluate the association between serum osteocalcin, urine CTX-I, hs-CRP, 25(OH) D, PTH, serum insulin, HOMA-IR, and QUICKI with PDI, uPDI and hPDI score after adjustment for covariates, including age, sex, BMI, smoking, physical activity, marital status, disease and energy intake. In all the above-mentioned analyses, first tertile was regarded as the reference category.

Results

General characteristics of study participants across categories of PDI, hPDI and uPDI are presented in Table 1. There were no significant differences across tertiles plant-based diet indexes in terms of mean of age, weight, BMI, WHR, WC, percent of body fat, and distribution of sex, physical activity, smoking status, marital status, Diabetes, Hypertension and dyslipidemia.

Table 1
Characteristics of study participants by tertiles of plant based diet indexes

	Plant base Diet Indexes			
	PDI			
	T1	T2	T3	P
Mean score	43.55 ± 3.138	51.17 ± 2.14	58.83 ± 3.567	
Age (year)	67.22 ± 5.18	66.97 ± 6.82	66.94 ± 6.63	0.96
Weight (kg)	70.68 ± 10.75	72.81 ± 13.53	74.06 ± 13.61	0.38
BMI (kg/m2)	29.59 ± 4.08	29.49 ± 4.80	30.44 ± 5.55	0.51
WHR	0.94 ± 0.07	0.96 ± 0.07	0.93 ± 0.10	0.37
WC(cm)	98.27 ± 9.32	100.02 ± 11.02	100.17 ± 11.01	0.56
Body fat (%)	43.27 ± 7.11	41.19 ± 7.46	44.38 ± 9.01	0.07
Sex				0.24
Male	13(25.5%)	25(49%)	13(25.5%)	
Female	42(33.1%)	45(35.4%)	40(31.5%)	
Physical activity				0.53
Very low	28(34.1%)	31(37.8%)	23(28%)	
Low	15(24.6%)	29(47.5%)	17(27.9%)	
Moderate and upper	11(34.4%)	10(31.3%)	11(34.4%)	
Smoking				0.29
Not smoking	47(31.5%)	55(36.9%)	47(31.5%)	
Former and current smoking	8(27.6%)	15(51.7%)	6(20.7%)	
Marital status, married, n (%)	35(20.0%)	49(28.0%)	38(21.7%)	0.77
Diabetes, yes, n (%)	23(12.9%)	29(16.3%)	18(39.3%)	0.63
Hypertension, yes, n (%)	27(15.2%)	43(24.2%)	29(55.6%)	0.38
Dyslipidemia ,yes, n (%)	34(19.1%)	39(21.9%)	20(11.2%)	0.03
hPDI				
Mean score	44 ± 3.394	51.07 ± 1.472	57.38 ± 3.383	
Age (year)	66.60 ± 5.61	66.78 ± 5.99	67.66 ± 6.58	0.59
Weight (kg)	73.20 ± 13.08	73.01 ± 13.43	71.49 ± 11.96	0.72
BMI (kg/m2)	29.51 ± 5.38	30.09 ± 4.42	29.79 ± 4.73	0.81
WHR	0.95 ± 0.08	0.95 ± 0.08	0.94 ± 0.09	0.71
WC(cm)	100.10 ± 10.74	100.38 ± 10.64	98.25 ± 10.19	0.47
Body fat (%)	42.97 ± 8.39	42.76 ± 7.17	42.64 ± 8.29	0.97
Sex				0.78
Male	14(27.5%)	17(33.3%)	20(39.2%)	
Female	41(32.3%)	42(33.1%)	44(34.6%)	
Physical activity				0.87
Very low	25(32.9%)	27(30.5%)	30(36.6%)	
Low	18(29.5%)	21(34.4%)	22(36.1%)	
Moderate and upper	8(25%)	13(40.6%)	11(34.4%)	
Smoking				0.98

Plant base Diet Indexes				
PDI				
Not smoking	46(30.9%)	49(32.9%)	54(36.2%)	
Former and current smoking	9(31%)	10(34.5%)	10(34.5%)	
Marital status, married, n (%)	38(21.7%)	43(24.6%)	41(23.4%)	0.67
Diabetes, yes, n (%)	19(10.7%)	24(13.5%)	27(15.2%)	0.67
Hypertension, yes, n (%)	30(16.9%)	32(18.0%)	37(20.8%)	0.90
Dyslipidemia ,yes, n (%)	29(16.3%)	32(18.0%)	32(18.0%)	0.89
uPDI				
Mean score	45.78 ± 3.36	54.32 ± 2.17	62.14 ± 3.96	
Age (year)	66.60 ± 5.15	67.77 ± 7.06	66.64 ± 5.74	0.48
Weight (kg)	71.27 ± 12.68	71.58 ± 13.35	74.90 ± 12.03	0.24
BMI (kg/m2)	29.51 ± 4.54	29.66 ± 4.85	30.27 ± 5.11	0.67
WHR	0.95 ± 0.07	0.94 ± 0.09	0.94 ± 0.08	0.61
WC(cm)	98.94 ± 10.59	99.13 ± 10.89	100.58 ± 10.04	0.66
Body fat (%)	115.93 ± 42.66	105.75 ± 34.92	110.32 ± 48.96	0.42
Sex				0.73
Male	18(35.3%)	19(37.3%)	14(27.5%)	
Female	39(30.7%)	46(36.2%)	42(33.1%)	
Physical activity				0.65
Very low	29(35.4%)	26(31.7%)	27(32.9%)	
Low	19(31.1%)	23(37.7%)	19(31.1%)	
Moderate and upper	8(25%)	15(46.9%)	19(28.1%)	
Smoking				0.97
Not smoking	48(32.4%)	53(35.8%)	47(31.8%)	
Former and current smoking	9(31%)	11(37.9%)	9(31%)	
Marital status, married, n (%)	41(23.4%)	41(23.4%)	40(22.9%)	0.39
Diabetes, yes, n (%)	23(12.9%)	24(13.5%)	23(12.9%)	0.88
Hypertension, yes, n (%)	34(19.1%)	33(18.5%)	32(18.0%)	0.52
Dyslipidemia ,yes, n (%)	34(19.1%)	26(14.6%)	33(18.5%)	0.04
P value less than 0.05 was considered significant.				
Values are based on mean ± standard deviation or frequency (reported percentage).				
One-way anova for quantitative data and Chi-2 test for qualitative data have been used.				
BMI: body mass index; WHR: waist to hip ratio; WC: waist circumference				

Dietary intakes of study participants across categories of PDI, hPDI and uPDI are presented in Table 2. Participants with the highest PDI score had significantly higher whole grains (P = 0.02), fruits (P < 0.001), legumes (P < 0.01), vegetable oils (P < 0.001), tea & coffee (P < 0.01), fruit juices (P < 0.001), refined grains (P < 0.001), potatoes (P < 0.001) and sugar sweetened beverages (P < 0.01). After adjustment for confounders the association remained unchanged. Participants with the highest hPDI score had significantly lower vegetable oils (P < 0.01), refined grains (P < 0.001), potatoes (P < 0.01), sugar sweetened beverages (P < 0.001), meat (P < 0.001) and misc. animal-based foods (P < 0.01). After adjustment for confounders the association remained unchanged. Participants with the highest uPDI score had significantly lower whole grains (P = 0.01), fruits (P < 0.001), vegetables (P < 0.001), nuts (P < 0.001) animal fat (P = 0.001), dairy (P < 0.001), egg (P < 0.001), fish or seafood (P < 0.001), meat (P < 0.01) and misc.

animal-based foods ($P = 0.01$). After adjustment for confounders the association remained unchanged. Participants with the highest uPDI score had significantly higher sugar sweetened ($P < 0.01$) and also After adjustment for confounders the association remained unchanged.

Table 2

Dietary intakes according to tertile of plant-based diet indices

	Mean± SD	PDI			P1	P2
		Tertile 1	Tertile 2	Tertile 3		
Whole grains (g/d)	183.40±157.47	144.41±108.81	179.17±153.33	229.46±192.67	0.02	<0.01
Fruits (g/d)	499.02±274.00	377.32±224.99	537.19±263.44	574.92±295.63	<0.001	<0.001
Vegetables (g/d)	460.16±215.65	412.40±475.83	475.83±214.05	489.04±219.52	0.13	0.65
Nuts (g/d)	16.70±27.58	15.45±36.44	13.04±13.70	22.83±30.04	0.14	0.16
Legumes (g/d)	32.05±24.64	23.83±27.29	33.91±22.93	38.11±21.97	<0.01	<0.01
Vegetable oils (g/d)	18.52±13.20	14.56±10.34	17.12±11.61	24.46±15.57	<0.001	<0.001
Tea & Coffee (g/d)	646.44±351.86	547.88±301.72	622.78±352.29	799.97±364.67	<0.01	<0.01
Fruit juices (g/d)	27.28±39.58	14.52±28.94	23.52±32.64	45.48±50.22	<0.001	<0.001
Refined grains (g/d)	259.60±152.94	201.54±126.21	257.10±161.05	323.16±144.81	<0.001	<0.001
Potatoes (g/d)	22.04±21.76	12.51±10.36	22.01±22.30	31.95±25.38	<0.001	<0.001
Sugar sweetened beverages (g/d)	29.29±58.15	16.30±55.60	21.35±30.50	53.27±78.85	<0.01	<0.01
Sweets and Desserts (g/d)	44.56±136.31	18.73±20.01	62.45±213.88	47.75±31.37	0.20	0.26
Animal fat (g/d)	4.37±7.80	3.10±5.62	5.14±8.69	4.67±8.47	0.33	0.29
Dairy (g/d)	384.40±225.34	327.38±198.80	412.70±237.55	406.19±227.85	0.07	0.06
Egg (g/d)	13.78±13.92	15.19±12.20	13.80±11.85	12.27±17.72	0.55	0.27
Fish or Seafood (g/d)	9.65±10.49	11.18±10.25	10.39±12.13	7.09±7.75	0.09	0.04
Meat (g/d)	50.70±37.20	48.38±24.23	56.54±45.14	45.41±36.27	0.22	0.67
Misc. Animal-based foods (g/d)	7.32±9.58	6.08±4.81	6.33±5.76	9.91±15.32	0.06	0.04
	Mean± SD	hPDI			P1	P2
		Tertile 1	Tertile 2	Tertile 3		
Whole grains (g/d)	183.40±157.47	148.24±162.65	187.50±148.05	209.84±158.14	0.10	0.03
Fruits (g/d)	499.02±274.00	430.08±226.83	529.06±325.69	530.59±251.33	0.08	0.04
Vegetables (g/d)	460.16±215.65	415.27±180.79	464.95±220.89	494.32±234.00	0.13	0.04
Nuts (g/d)	16.70±27.58	12.28±17.29	23.75±40.76	14.00±16.72	0.052	0.73
Legumes (g/d)	32.05±24.64	32.82±23.47	29.00±20.08	34.20±29.14	0.48	0.76
Vegetable oils (g/d)	18.52±13.20	22.41±13.50	17.78±11.83	15.85±13.55	0.02	<0.01
Tea & Coffee (g/d)	646.44±351.86	639.53±371.38	629.07±325.04	668.39±362.67	0.81	0.65
Fruit juices (g/d)	27.28±39.58	33.44±42.09	27.36±44.18	21.92±32.01	0.28	0.11
Refined grains (g/d)	259.60±152.94	324.37±134.91	252.87±113.26	210.14±179.20	<0.001	<0.001
Potatoes (g/d)	22.04±21.76	27.79±25.05	22.27±16.99	16.88±21.69	0.02	<0.01
Sugar sweetened beverages (g/d)	29.29±58.15	47.41±64.13	35.72±72.71	7.79±17.73	<0.001	<0.001
Sweets and Desserts (g/d)	44.56±136.31	49.44±30.66	65.73±233.13	20.87±18.75	0.18	0.25
Animal fat (g/d)	4.37±7.80	5.48±8.32	3.75±6.1	3.99±8.65	0.44	0.30
Dairy (g/d)	384.40±225.34	398.56±232.01	374.29±223.65	381.55±224.03	0.84	0.68
Egg (g/d)	13.78±13.92	14.96±11.06	15.07±18.23	11.56±11.22	0.28	0.18
Fish or Seafood (g/d)	9.65±10.49	11.88±10.83	9.29±10.12	8.07±10.35	0.13	0.04
Meat (g/d)	50.70±37.20	64.06±48.39	50.25±32.99	39.64±24.47	0.001	<0.001
Misc. Animal-based foods (g/d)	7.32±9.58	9.20±8.77	8.62±13.60	4.51±2.98	0.01	<0.01

	Mean± SD	uPDI			P1	P2
		Tertile 1	Tertile 2	Tertile 3		
Whole grains (g/d)	183.40±157.47	220.26±180.81	207.66±163.52	117.94.39	0.01	<0.001
Fruits (g/d)	499.02±274.00	614.13±232.82	500.90±274.75	379.69±265.23	<0.001	<0.001
Vegetables (g/d)	460.16±215.65	579.55±213.64	448.97±211.70	351.64±155.35	<0.001	<0.001
Nuts (g/d)	16.70±27.58	21.97±24.87	14.68±20.68	13.68±35.73	<0.001	<0.001
Legumes (g/d)	32.05±24.64	38.84±27.19	32.41±24.45	24.71±20.08	0.021	0.11
Vegetable oils (g/d)	18.52±13.20	19.46±11.30	20.72±15.04	14.99±12.17	0.04	0.07
Tea & Coffee (g/d)	646.44±351.86	674.83±364.46	670.89±328.76	589.16±364.04	0.34	0.19
Fruit juices (g/d)	27.28±39.58	29.13±47.32	22.74±29.74	30.67±41.15	0.50	0.83
Refined grains (g/d)	259.60±152.94	239.03±125.23	266.42±173.70	272.62±153.40	0.45	0.24
Potatoes (g/d)	22.04±21.76	17.56±15.85	21.43±14.47	27.30±31.22	0.056	0.01
Sugar sweetened beverages (g/d)	29.29±58.15	11.76±32.03	29.03±34.17	47.44±88.47	<0.01	0.001
Sweets and Desserts (g/d)	44.56±136.31	32.92±30.57	34.11±25.16	68.55±239.27	0.28	0.16
Animal fat (g/d)	4.37±7.80	7.55±10.16	3.35±7.14	2.32±3.93	0.001	<0.001
Dairy (g/d)	384.40±225.34	477.77±270.18	386.03±207.17	287.47±143.32	<0.001	<0.001
Egg (g/d)	13.78±13.92	19.86±17.99	12.11±9.44	9.52±11.42	<0.001	<0.001
Fish or Seafood (g/d)	9.65±10.49	13.68±11.95	10.22±10.83	4.89±5.64	<0.001	<0.001
Meat (g/d)	50.70±37.20	63.67±44.29	49.06±31.46	39.41±31.57	<0.01	<0.001
Misc. Animal-based foods (g/d)	7.32±9.58	9.99±13.91	7.13±7.98	4.82±3.26	0.01	<0.01
P value less than 0.05 was considered significant.						
Values are based on mean ± standard deviation						
P1: Calculated by analysis of variance (ANOVA); P2: P obtained from multivariate analysis of covariance (ANCOVA) adjusted for energy intake						
PDI=plant base diet index; hPDI:healthy plant base diet index; uPDI:unhealthy plant base diet index						

Dietary groups of Vegetables ($r = 0.15$, $P = 0.03$), nuts ($r = 0.16$, $P = 0.03$), dairy ($r = 0.25$, $P = 0.001$), eggs ($r = 0.27$, $P < 0.001$), red meat and animal products ($r = 0.25$, $P = 0.001$) were directly correlated with osteocalcin. Consumption of vegetables was also inversely associated with hs-CRP serum levels ($r = -0.30$, $P < 0.001$). Consumption of refined grains were negatively associated with PTH serum levels ($r = -0.16$, $P = 0.03$). Refined grains were also had positive association with serum insulin concentration ($r = 0.14$, $P = 0.04$). Potatoes consumption had positive association with serum insulin concentration ($r = 0.15$, $P = 0.04$) (Table 3.) Participants with the highest PDI score had significantly lower PTH ($P = 0.04$) just after adjusting for confounders, including age, sex, smoking, physical activity, marital status, income levels, BMI, total energy, diabetes, hypertension and dyslipidemia, they also had significantly higher insulin serum levels ($P < 0.05$), which was also seen after the confounders were adjusted. There were only a significant association between the insulin sensitivity index with people who were in the highest hPDI score, after adjusting the confounders. Participants with the highest uPDI score had a significant lower osteocalcin ($p < 0.001$), PTH ($P = 0.01$) and they had a significant higher insulin serum levels ($P = 0.02$). After adjustment for confounders the association remained unchanged for both osteocalcin ($P = 0.01$), PTH ($P = 0.05$) and insulin ($P = 0.02$). Participants with the highest uPDI score had significantly higher insulin resistance ($P = 0.05$) but after adjusting for confounders, the association was not ($P = 0.09$). However, no significant association was found between uPDI and urine CTX-1 ($p = 0.26$), hs-CRP ($p = 0.60$) and 25(OH)D ($p = 0.32$) Table 4. according to Multiple regression analysis models Table 5, PTH levels are inversely associated with PDI score. This significance did not change with the adjustment of the confounders ($\beta = -0.18$, $P = 0.01$). Also serum insulin concentration was negatively associated with PDI score ($\beta = -0.10$, $P = 0.04$). Urine CTX-1 levels was significantly associated with hPDI score ($\beta = -0.06$, $P = 0.04$). u-CTX-1 levels are inversely associated with uPDI score. This significance did not change with the adjustment of the confounders ($\beta = -0.28$, $P < 0.001$). Adherence to an uPDI significantly increases insulin serum levels even after adjusting for confounders ($\beta = 0.16$, $P = 0.04$). But there was no significant linear association between insulin sensitivity markers such as HOMA_{IR} and Quicki with PDI, hPDI and uPDI.

Table 3

Correlation of food groups intake with biochemical markers of bone, inflammation and insulin

Subgroup analysis	Osteocalcin		Urine CTX-I		25(OH)D		PTH		hs-CRP		Insulin		HOMA_IR		Quicki	
	r	p	r	p	r	p	r	p	r	p	r	p	r	p	r	p
Whole grains (g/d)	0.08	0.24	0.11	0.12	-0.09	0.20	0.08	0.26	-0.04	0.55	-0.13	0.07	-0.11	0.13	0.03	0.65
Fruits (g/d)	0.01	0.79	-0.02	0.78	-0.04	0.55	-0.50	0.50	-0.05	0.45	-0.01	0.94	0.04	0.52	0.01	0.81
Vegetables (g/d)	0.15	0.03	-0.03	0.69	0.01	0.87	-0.01	0.85	-0.30	<0.001	-0.4	0.58	-0.01	0.94	0.04	0.57
Nuts (g/d)	0.16	0.03	0.06	0.37	0.04	0.55	-0.08	0.24	0.01	0.86	0.02	0.78	-0.02	0.79	-0.01	0.87
Legumes (g/d)	0.03	0.62	-0.06	0.42	-0.06	0.39	-0.06	0.45	0.01	0.92	0.01	0.81	0.12	0.11	-0.05	0.44
Vegetable oils (g/d)	0.07	0.33	-0.01	0.84	-0.05	0.45	0.02	0.77	0.03	0.62	0.01	0.89	-0.02	0.77	-0.08	0.29
Tea & Coffee (g/d)	0.07	0.34	-0.03	0.63	-0.04	0.59	-0.03	0.64	-0.07	0.33	0.02	0.79	-0.04	0.56	0.01	0.88
Fruit juices (g/d)	0.25	0.001	0.04	0.51	-0.04	0.58	-0.08	0.24	-0.06	0.35	-0.02	0.77	-0.02	0.75	0.06	0.40
Refined grains (g/d)	0.05	0.45	-0.01	0.85	-0.05	0.49	-0.16	0.03	0.02	0.79	0.14	0.04	0.03	0.74	-0.04	0.59
Potatoes (g/d)	-0.12	0.08	-0.06	0.41	-0.08	0.26	0.03	0.62	0.12	0.09	0.15	0.04	0.08	0.28	-0.11	0.15
Sugar sweetened beverages (g/d)	-0.07	0.29	-0.03	0.67	-0.06	0.38	-0.01	0.98	-0.02	0.76	0.07	0.34	0.02	0.73	-0.10	0.17
Sweets and Desserts (g/d)	-0.02	0.73	-0.05	0.46	-0.07	0.32	0.03	0.61	0.01	0.91	-0.05	0.46	-0.04	0.60	0.03	0.66
Animal fat (g/d)	0.08	0.26	0.02	0.72	-0.07	0.36	0.13	0.07	0.02	0.76	-0.09	0.23	-0.07	0.31	0.05	0.49
Dairy (g/d)	0.25	0.001	-0.02	0.98	0.06	0.39	0.02	0.72	-0.01	0.80	0.01	0.89	0.01	0.89	-0.02	0.71
Egg (g/d)	0.27	<0.001	-0.04	0.57	0.05	0.50	-0.10	0.18	-0.06	0.43	0.01	0.83	-0.03	0.64	-0.03	0.67
Fish or Seafood (g/d)	-0.03	0.61	-0.04	0.58	0.06	0.36	-0.01	0.93	-0.03	0.67	-0.13	0.07	-0.12	0.09	0.10	0.16
Meat (g/d)	0.15	0.04	0.03	0.61	-0.04	0.51	0.04	0.56	-0.03	0.62	-0.01	0.89	-0.02	0.75	0.01	0.88
Misc. Animal-based foods (g/d)	0.25	0.001	0.12	0.10	0.03	0.67	0.04	0.59	0.07	0.32	-0.01	0.86	-0.02	0.78	-0.05	0.51
Data are Pearson correlation coefficients.																
High sensitivity c-reactive protein (hs-CRP); 25-hydroxyvitamin D (25(OH)D); parathormone (PTH); urine terminal telopeptide of type I collagen (u-CTX); HOMA-IR: Homeostasis Model Assessment for Insulin Resistance; QUICKI: Quantitative Insulin-sensitivity Check Index																

Table 4

Multivariate adjusted means for biochemical markers of bone, inflammation and insulin across tertiles of plant-based diet indices

	All	Tertiles of PDI			P1	P2	P3
	Mean $\pm$ SD	Tertile1	Tertile2	Tertile3			
Osteocalcin (ng/mL)	20.5 $\pm$ 14.5	21.6 $\pm$ 15.0	19.9 $\pm$ 14.3	20.0 $\pm$ 14.5	0.79	0.57	0.66
uCTX-I (ng/mL)	32.5 $\pm$ 7.30	32.7 $\pm$ 8.65	31.7 $\pm$ 7.08	32.5 $\pm$ 7.30	0.78	0.89	0.86
PTH (ng/L)	50.7 $\pm$ 27.1	56.6 $\pm$ 34.3	51.6 $\pm$ 26.9	45.1 $\pm$ 18.6	0.06	0.02	0.04
hs-CRP (mg/L)	4.88 $\pm$ 13.9	3.84 $\pm$ 3.88	7.54 $\pm$ 23.4	3.27 $\pm$ 3.24	0.20	0.82	0.31
25(OH)D (ng/mL)	11.0 $\pm$ 6.77	11.4 $\pm$ 6.40	10.5 $\pm$ 6.57	11.0 $\pm$ 7.30	0.76	0.70	0.92
HOMA_IR	3.78 $\pm$ 5.48	3.88 $\pm$ 7.26	2.67 $\pm$ 2.32	4.75 $\pm$ 5.69	0.12	0.39	0.11
Insulin(μ u/mL)	13.6 $\pm$ 14.5	12.1 $\pm$ 11.6	10.4 $\pm$ 9.81	18.0 $\pm$ 19.1	0.01	0.03	0.03
Quicki	0.34 $\pm$ 0.04	0.34 $\pm$ 0.04	0.35 $\pm$ 0.04	0.33 $\pm$ 0.04	0.05	0.16	0.14
	All	Tertiles of hPDI			P 1	P 2	P 3
	Mean $\pm$ SD	Tertile1	Tertile2	Tertile3			
Osteocalcin (ng/mL)	20.5 $\pm$ 14.5	21.7 $\pm$ 16.0	20.7 $\pm$ 16.6	19.1 $\pm$ 10.4	0.61	0.33	0.84
uCTX-I (ng/mL)	32.3 $\pm$ 7.64	31.7 $\pm$ 7.01	32.0 $\pm$ 8.65	33.1 $\pm$ 7.26	0.55	0.30	0.40
PTH (ng/L)	50.7 $\pm$ 27.1	49.6 $\pm$ 21.5	53.1 $\pm$ 27.7	49.5 $\pm$ 31.4	0.71	0.98	0.71
hs-CRP (mg/L)	4.88 $\pm$ 13.9	4.91 $\pm$ 9.74	5.34 $\pm$ 21.8	4.41 $\pm$ 4.50	0.93	0.84	0.90
25(OH)D (ng/mL)	11.0 $\pm$ 6.77	10.9 $\pm$ 6.46	11.1 $\pm$ 7.30	10.9 $\pm$ 6.64	0.98	0.94	0.98
HOMA_IR	3.78 $\pm$ 5.48	3.97 $\pm$ 3.94	3.18 $\pm$ 4.88	4.19 $\pm$ 7.21	0.59	0.83	0.62
Insulin(μ u/mL)	13.6 $\pm$ 14.5	15.2 $\pm$ 16.2	12.5 $\pm$ 15.3	13.1 $\pm$ 11.9	0.57	0.43	0.38
Quicki	0.34 $\pm$ 0.04	0.33 $\pm$ 0.04	0.35 $\pm$ 0.04	0.33 $\pm$ 0.04	0.06	0.92	0.04
	All	Tertiles of uPDI			P 1	P 2	P 3
	Mean $\pm$ SD	Tertile1	Tertile2	Tertile3			
Osteocalcin (ng/mL)	20.5 $\pm$ 14.5	27.5 $\pm$ 21.0	17.8 $\pm$ 9.50	16.5 $\pm$ 7.02	<0.001	<0.001	<0.001
uCTX-I (ng/mL)	32.3 $\pm$ 7.64	32.0 $\pm$ 8.28	33.5 $\pm$ 7.83	31.2 $\pm$ 6.64	0.26	0.58	0.24
PTH (ng/L)	50.7 $\pm$ 27.1	58.9 $\pm$ 36.4	43.9 $\pm$ 19.0	50.5 $\pm$ 22.1	0.01	0.09	0.02
hs-CRP (mg/L)	4.88 $\pm$ 13.9	6.15 $\pm$ 22.2	5.00 $\pm$ 9.54	3.50 $\pm$ 3.81	0.60	0.32	0.72
25(OH)D (ng/mL)	11.0 $\pm$ 6.77	10.4 $\pm$ 6.48	12.0 $\pm$ 7.02	10.4 $\pm$ 6.74	0.32	0.94	0.30
HOMA_IR	3.78 $\pm$ 5.48	3.14 $\pm$ 4.51	3.16 $\pm$ 2.91	5.18 $\pm$ 8.01	0.08	0.05	0.09
Insulin(μ u/mL)	13.6 $\pm$ 14.5	10.7 $\pm$ 11.3	12.5 $\pm$ 12.0	17.9 $\pm$ 18.9	0.02	0.01	0.02
Quicki	0.34 $\pm$ 0.04	0.34 $\pm$ 0.04	0.34 $\pm$ 0.04	0.33 $\pm$ 0.04	0.46	0.24	0.42
P value less than 0.05 was considered significant.							
Values are based on mean $\pm$ standard deviation.							
P1: P ANOVA test; P2: P trend; P3: P ANCOVA test adjusted for age, sex, smoking, marital status, Disease, physical activity, BMI and energy							
u-CTx: urinary C-terminal telopeptide of type I collagen; hs-CRP: high sensitivity c-reactive protein; PTH: parathormone; OH: hydroxyl; HOMA_IR: Homeostasis Model Assessment for Insulin Resistance; QUICKI: Quantitative Insulin-sensitivity Check Index							
ng/mL: nanogram per mili liter; ng/L: nanogram per liter; mg/L: milligram per liter; μ u/mL: micro international unit per mili liter							

Table 5
Multiple regression analysis models exploring the association of biochemical markers of bone, inflammation and insulin with plant-based diet indices

	PDI			hPDI			uPDI		
	$\beta \pm SE$	95% CI	P _{value}	$\beta \pm SE$	95% CI	P _{value}	$\beta \pm SE$	95% CI	P _{value}
Osteocalcin									
Model 1	-0.08 ± 0.16	-0.51,0.13	0.25	-0.05 ± 0.18	-0.49,0.22	0.45	-0.30 ± 0.14	-0.87,-0.30	< 0.001
Model 2	-0.10,0.17	-0.56,0.10	0.17	-0.03 ± 0.18	-0.43,0.30	0.73	-0.28 ± 0.15	-0.84,-0.26	< 0.001
Urine CTX-I									
Model 1	-0.05 ± 0.08	-0.24,0.10	0.43	-0.02 ± 0.09	-0.16,-0.21	0.02	0.01 ± 0.08	-0.14,0.17	0.85
Model 2	-0.04 ± 0.09	-0.22,0.12	0.58	-0.06 ± 0.09	-0.13,-0.27	0.04	0.03 ± 0.08	-0.12,0.19	0.65
25(OH)D									
Model 1	-0.08 ± 0.07	-0.23,0.06	0.28	-0.01 ± 0.08	-0.14,0.18	0.83	0.04 ± 0.07	-0.10,0.17	0.60
Model 2	-0.07 ± 0.08	-0.23,0.08	0.33	-0.04 ± 0.08	-0.22,0.11	0.54	0.05 ± 0.07	-0.09,0.19	0.48
PTH									
Model 1	-0.17 ± 0.30	-1.30,-0.10	0.02	-0.04 ± 0.33	-0.87,0.46	0.54	-0.13 ± 0.28	-1.04,0.05	0.08
Model 2	-0.18 ± 0.31	-1.40,-0.15	0.01	-0.02 ± 0.33	-0.79,0.57	0.75	-0.14 ± 0.28	-1.10,0.02	0.06
hs-CRP									
Model 1	-0.03 ± 0.16	-0.40,0.24	0.60	-0.01 ± 0.17	-0.39,0.28	0.75	-0.05 ± 0.14	-0.38,0.19	0.51
Model 2	-0.02 ± 0.16	-0.37,0.29	0.81	-0.01 ± 0.18	-0.37,0.33	0.91	-0.03 ± 0.15	-0.36,0.22	0.63
Insulin									
Model 1	-0.11 ± 0.17	-0.09,-0.60	0.02	-0.06 ± 0.18	-0.52,0.20	0.38	0.15 ± 0.16	0.001,0.61	0.04
Model 2	-0.10 ± 0.18	-0.13,-0.59	0.04	-0.08 ± 0.19	-0.58,0.16	0.27	0.16 ± 0.16	0.01,0.64	0.04
HOMA_IR									
Model 1	0.06 ± 0.06	-0.07,0.18	0.43	-0.03 ± 0.07	-0.10,-0.17	0.03	0.08 ± 0.05	-0.05,0.17	0.28
Model 2	0.07 ± 0.07	-0.07,0.19	0.38	-0.02 ± 0.07	-0.12,-0.16	0.04	0.08 ± 0.06	-0.05,0.18	0.30
Quicki									
Model 1	-0.08 ± 0.001	-0.002,0.001	0.30	0.02 ± 0.001	-0.001,0.001	0.78	-0.07 ± 0.001	-0.001,0.001	0.36
Model 2	-0.06 ± 0.001	-0.002,0.001	0.40	0.03 ± 0.001	-0.001,0.001	0.64	-0.08 ± 0.001	-0.001,0.001	0.33
P value less than 0.05 was considered significant. P _{value} obtained from Linear regression									
Model 1: Not adjusted for any variables									
Model2: The model was adjusted for age, sex, energy intake, marital status, smoking, disease, physical activity, and BMI									
β: standardized coefficients; SE: standard error; CI: confidence interval; u-CTX: urinary C-terminal telopeptide of type I collagen; hs-CRP: high sensitivity c-reactive protein; PTH: parathormone; OH: hydroxyl; HOMA_IR: Homeostasis Model Assessment for Insulin Resistance; QUICKI: Quantitative Insulin-sensitivity Check Index									

Discussion

In this cross-sectional study of Iranian older adults, we found no significant association between overall PDI and osteocalcin as bone formation marker or uCTX-1 as a resorption marker. This results as well as seen in hPDI but an inverse association observed between uPDI and osteocalcin. These findings confirm support to the findings of earlier intervention studies which also failed to show any significant effect of increased fruit and vegetable consumption on bone turnover markers[23, 24]. Results from a 2-year study in women, aged 55–65 years, showed no significant effect of increased fruit and vegetable consumption on bone turnover markers or BMD loss[25]. Similarly, the Women's Health Initiative Dietary Modification Trial, which was also conducted in postmenopausal women, failed to show any significant effect of increased fruit and vegetable consumption (five or more servings per day) on vertebral or total body BMD or fracture over an 8-year period[24]. In contrast, a clinical trial study showing increased intake of a selection of vegetables/herbs and fruit decreased bone formation (P1NP) and resorptive (CTX) markers in Post-Menopausal Women[26].

No significant association observed between overall PDI, hPDI, and uPDI and hs-CRP) serum levels and in this study. A cross-sectional study investigated that higher intake of healthy plant foods, instead of unhealthy plant foods such as sweets and desserts, reduced hs-CRP levels. Furthermore, higher adherence to uPDI (refined grains, starches sweetened with sugar, sweets, desserts, and juices) in women was not associated with higher level of hs-CRP[27]. In the Nurse's Health Study, adherence to healthy vegetarian diet significantly reduced insulin resistance, inflammatory biomarkers in women participants[28]. Several studies designed to evaluate the effect of Dietary Approaches to Stop Hypertension (DASH) diet on hs-CRP as well as other inflammatory markers (such as IL-6 and TNF- α) have shown conflicting results. Some RCTs have supported the link between DASH diet adherence and reduced CRP levels, while the others did not reveal the same results [29–32]. The DASH diet emphasizes the increasing intake of fruit, vegetables, whole grains, low-fat dairy products, fish, poultry, and nuts and a reduced intake of fats, red meat and sugar-containing beverages. Furthermore, this diet emphasizes low intake of total and saturated fat as well as cholesterol and increased consumption of magnesium, potassium, calcium, fiber, and protein[33]. The conflicting results can be attributed to differences in study design and its sample size as well as differences in dietary composition of plant based dietary pattern.

In the present study, no significant association was found between hPDI with PTH. In contrast, a significant positive association was found between overall PDI with PTH serum levels and an inverse association was found between uPDI and PTH serum levels. PTH indirectly induces bone resorption through osteoclasts as well as its receptors excited on osteoblasts[34]. Vitamin D is a well-known beneficial nutrient for bone health. However, the beneficial effect of vitamin D on bone mass may depend on the level of intake and other factors. In our study no significant association existed between 25-hydroxy vitamin D concentrations and PDI, hPDI, and uPDI. In a cross-sectional study serum 25- hydroxyvitamin D concentrations in vegans, but not in lacto-ovo vegetarians, were slightly lower than those in omnivores[35]. In another study vegans had higher serum PTH concentration and lower 25(OH)-D serum concentrations[36].

Findings of the current study also suggested there is no significant association between PDI, hPDI, and uPDI and insulin resistance. A clinical trial study suggested that plant protein, as a part of a plant-based diet, is associated with reductions in both body weight and insulin resistance[37]. A study conducted by Esfandiari et al indicated there was no significant association between Mediterranean dietary pattern and healthy eating index with the development of insulin resistance. In contrast, individuals adhered to the DASH dietary pattern have a lower risk of insulin resistance and its associated metabolic outcomes[38]. Decreased insulin resistance was also reported in pre-hypertensive individuals that adhered to 20- week DASH diet[39]. In another cross-sectional study vegetarian diet, particularly vegan diet is inversely associated with insulin resistance, independent of body mass index[40]. In contrast, no beneficial effect was observed on insulin sensitivity following 6 months DASH dietary pattern intervention, in both individuals with and without metabolic syndrome[41].

Our results showed that there is a significant effect of overall PDI on lowering insulin serum levels but there is an inverse association between uPDI and insulin serum levels. Also, no correlation was found between plant-based dietary indicators and insulin sensitivity markers such as HOMA_IR and Quicki.

Prospective cohort studies clearly suggested that dietary fiber specially insoluble fiber significantly reduce insulin resistance and developing Type 2 diabetes[42] olfert et al in their study indicated that Vegetarian diets include vegan diets (no animal products), lacto-ovi-vegetarian diets (no animal meat, but milk and eggs), pesco-vegetarian diets (fish), and semi-vegetarian (Occasional consumption of meat) are associated with a reduced risk of diabetes[43].

Results of a Narrative Review suggested that the intake of polyphenols through plant-based foods including whole grains, vegetables, fruits, coffee, tea, and nuts may be beneficial for both insulin resistance and T2D risk[44]. In contrast, some studies believe that there is no convincing evidence that soluble dietary fibers from fruit and vegetables might reduce the risk of diabetes[42].

There are several mechanisms that justify our results. In fact, the plant-based diet containing in general less calcium, less vitamin D, less iron and less of other nutrients that have a positive influence on bone health[45, 46]. However, it should be noted the main source of vitamin D is sunlight. This is may be the reason that we were observed no association between PDI and 25-hydroxy vitamin D. Plant foods rich in zinc, such as legumes, whole grains, seeds, and nuts, are also high in phytic acid, a main inhibitor of zinc bioavailability. In other hand bioavailability of zinc is enhanced by dietary protein, but plant sources of protein are also generally high in phytic acid [47]. Furthermore, carotenoids may contribute to bone resorption via an antioxidant mechanism. In general, only a protein intake of less than 0.8 g/kg bodyweight is considered as insufficient for bone health. It can be concluded that plant-based diets often contain lower amounts of protein than those of other diets. Therefore, vegetarians might be risk candidates for osteoporosis [48]. On the other hand, the plant-based diet also has some characteristics that are positive for bone. The positive effect of fruit and vegetables can be partially explained by the calcium-sparing effect of potassium[49]. In addition, this diet contains more potassium, vitamins, phytochemicals, antioxidants and bear a much lower acid load, both being reported as positive for bone[45]. All these negative and positive influences of the plant-based diet may neutralize the effect of each other. Therefor these reasons clarify our results that no associations were observed between PDI and bone turnover biomarkers.

Our research has many points of strength. To best our knowledge, this is the first time that the association between the PDI and bone turnover is evaluated in older adults. In this paper, the food frequency questionnaire method was used to assess the dietary intake of patients that could reflect long-term intake in adults. Moreover, we considered that the potential beneficial influences of a more plant-based diet were independent of less healthy plant foods, for instance, sweets, sugary beverages, and refined grains, thereby the quality of plant-based foods ingested is so important.

Furthermore, we tried to adjust all possible potential confounders. However, this study does possess limitations, Because of cross-sectional design, the possibility of residual confounding could not be ignored. The reliance on self-reported methods to assess dietary intake was also a limitation due to measurement error and misclassification of participants. Another limitation was the small sample size that could affect the power of the study to identify a weak relationship.

Conclusion

In conclusion, data from this study in Iranian older adults demonstrated that more adherence to PDI and hPDI and less in uPDI may have beneficial effect on biomarkers of bone, inflammation, and insulin thus preserving chronic diseases. To clarify, more research in large cohort studies and well-designed clinical trials is needed.

Abbreviations

PDI: Plant based Diet Index; hPDI: Healthy Plant based Diet Index; uPDI: Unhealthy Plant based Diet Index; BMD: Bone Mineral Density; FFQ: Food Frequency Questionnaire; HOMA-IR: Homeostasis Model Assessment for Insulin Resistance; QUICKI: Quantitative Insulin-sensitivity Check Index; T2D: Type 2 Diabetes; BMI: Body Mass Index; u-CTX: urinary C-terminal telopeptide of type I collagen; hs-CRP: high sensitivity c-reactive protein; PTH: Parathormone; OH: hydroxyl; WC: Waist Circumference; WHR: waist to hip ratio;

Declarations

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Authors contributions

HSH and SS-b contributed to conception/design of the research; NP, FS and SN contributed to acquisition, analysis, or interpretation of the data; HSH and MRA drafted the manuscript; KD and SS-b critically revised the manuscript; and SS-b agrees to be fully accountable for ensuring the integrity and accuracy of the work. All authors read and approved the final manuscript.

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Availability of data and materials

The datasets generated or analyzed during the current study are not publicly available but are available from the corresponding author on reasonable request.

Ethics approval and consent to participate

This study was conducted according to the guidelines laid down in the Declaration of Helsinki and all procedures involving research study participants were approved by the ethics committee of Tehran University of Medical Sciences (Ethics Number: IR.TUMS.VCR.REC.1396.2307). Written informed consent was obtained from all subjects/patients.

Consent for publication

Participants were provided a study overview and verbal consent was attained.

Competing interests

The authors declare that they have no competing interests.

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