Original Article

Relationship between dietary patterns and brachial-ankle pulse wave velocity among middle-aged adults in Japan

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Background and Objectives: Arterial stiffness is a leading cause of cardiovascular disease (CVD), and it is considered to be affected by dietary intake. However, few studies have examined the relationship between major dietary patterns and brachial-ankle pulse wave velocity (baPWV) among Japanese middle-aged subjects. We studied whether major dietary patterns were associated with baPWV in this population. **Methods and Study Design:** Between 2009 and 2012, 70 Japanese middle-aged subjects (39 men and 31 women) with no history of stroke, coronary heart disease, or cancer were studied. Dietary intake was documented using a validated food-frequency questionnaire, and dietary patterns were generated using factor analysis. Correlational analyses were performed between baPWV and identified dietary patterns and between baPWV and individual risk factors (total cholesterol, triglyceride, low-density lipoprotein cholesterol [LDL-C], high-density lipoprotein cholesterol [HDL-C], non-HDL-C, LDL/HDL ratio, and augmentation index). **Results:** Two dietary patterns were identified: a rice-rich pattern (high in rice, breads, oils and fats, meats, and confectionery) and a vegetable-rich pattern (high in vegetables, fruit, fish, and seaweed). The rice-rich pattern was not associated with baPWVor other risk factors. A significant inverse correlation was found between baPWV and the vegetable-rich dietary pattern ($p<0.05$). **Conclusions:** Our findings suggest that a dietary pattern characterized by high consumption of vegetables, seafood, seaweed, fruit, and pulse is inversely associated with arterial stiffness measured by baPWV. This diet offers an additional nutritional approach to the prevention and treatment of arterial stiffness.

Key Words: diet, pattern, baPWV, Japan, risk

INTRODUCTION

Cardiovascular disease (CVD) is a major contributor to the burden of disease in most countries, and arteriosclerosis is one of many dominant risk factors for morbidity and mortality. These background factors facilitate arterial stiffness, and consequently, impaired viscoelasticity of the arterial wall is the leading cause of CVD.[1]

Pulse wave velocity (PWV) is a known indicator of arterial stiffness,[2,3] and brachial-ankle PWV (baPWV) is a simple and non-invasive method of measurement with considerably high validity and reproducibility.[4-6] A previous study in a Japanese population showed that baPWV can predict all-cause mortality;[7] therefore, baPWV can be used to assess vascular damage in this population.

Food intake is one of the most important modifiable risk factors for CVD.[8] In Western countries, the Dietary Approaches to Stop Hypertension (DASH) dietary pattern, which emphasized the consumption of fruit, vegetables, and low-fat dairy and discouraged the consumption of meat, sugar-sweetened beverages, and saturated and total fat, has been shown to lower blood pressure, affect natriuresis and the renin-angiotensin-aldosterone system, reduce adrenergic tone, and increase vascular relaxation.[9-11] Additionally, the Mediterranean dietary pattern, which emphasizes the consumption of grains, vegetables, legumes and nuts, fruit, olive oil, dairy products, and fish, has been shown to reduce the risk of CVD and mortality, likely due to the anti-inflammatory properties of its foods (e.g., n-3 polyunsaturated fatty acids [PUFAs]).[12,13] These studies commonly used a "dietary pattern" approach. Dietary intake is a complex exposure variable with a large number of components, each of which differently influ-

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ence the risk of disease (some protective, others harmful). Therefore, dietary pattern analysis is an effective method for examining the association between the overall diet and arterial stiffness.[14] However, few studies have examined the association between dietary patterns and arterial stiffness, especially in Japan.

To test whether specific dietary patterns are associated with arterial stiffness, we investigated the risk factors related to arterial stiffness as well as dietary patterns among Japanese middle-aged adults. In addition, we examined how the individual food groups characterizing each dietary pattern relate to arterial stiffness.

MATERIALS AND METHODS

Study population

We studied 70 native Japanese subjects (39 men and 31 women) with no history of previously reported CVD or other serious diseases (including cancer, diabetes, drug abuse, or major psychiatric illness) that may have influenced arterial stiffness.[15] Subjects using hypolipidemic drugs or estrogen-replacement therapy were excluded from the study, because these drugs are known to reduce PWV.[15] Informed consent was obtained from all subjects. The study protocol was approved by the ethics committee of the University of Shiga Prefecture and Hikone Municipal Hospital and carried out in accordance with the principles of the Declaration of Helsinki.

Assessment of dietary intake

Food consumption was assessed using a 97-item food-frequency questionnaire (FFQ).[16,17] The reproducibility and validity of nutrient and food group intake measurements from the FFQ used in this study have been described in detail elsewhere,[16,17] and the FFQ was structured to reflect the food habits of the Japanese population. Each food/beverage item provided three to six possible responses related to frequency of consumption, ranging from “never or less than once a month” to “five or more times per day.” Participants indicated how often, on average, they had consumed a given amount of the specified food/beverage during the past month. The 97 individual food items captured by the FFQ were grouped together in 14 non-overlapping food groups (Table 1). The grouping scheme was based on the similarity of nutrient profiles or culinary usage among the foods and was somewhat similar to that used in other studies.[9,18-22] Both dieticians and study subjects completed the FFQ, and the dieticians either administered the FFQ, or they reviewed the subjects’ responses. The amount of intake of each nutrient and food group was estimated using the FFQ analysis system (System Supply Co., Ltd).

Assessment of baPWV and other relevant variables

baPWV and blood pressure measurements were performed in the supine position after 5 minutes of bed rest using a validated automatic device (BP-203RPE 2 form PWV/ABI; OMRON Healthcare, Tokyo, Japan) in all subjects. Four oscillometric cuffs, each connected to a plethysmographic sensor that determined volume pulse form and an oscillometric pressure sensor that measured blood pressure, were wrapped on both the brachia and ankle, and two electrocardiogram electrodes were placed on each wrist. They were simultaneously pressurized to the approximate value of the patient’s diastolic pressure so that the pulse volume waveforms could be recorded using semiconductor pressure sensors. The distance between baPWV sampling points was calculated automatically according to the subject’s height. The path length from the suprasternal notch to the ankle (La) was calculated as La = 0.8129*height (in cm) + 12.328. The path length from the suprasternal notch to the brachium (Lb) was calculated as Lb=0.2195*height - 2.0734. baPWV was calculated according to the following formula: baPWV = (La - Lb) / Tba, where Tba is the time interval between the wave front of the brachial and ankle waveforms.[23] Two simultaneous measurements of baPWV were recorded (on the right and left side), and the average of these readings was used as the representative value for each individual.

Previous studies have found that baPWV is influenced by age, systolic blood pressure (SBP), and gender.[6,15] Yamashina et al devised nomograms of the relation between baPWV and blood pressure level and suggested that a comparison of measured baPWV with values calcu-

Table 1. Components of the 14 food groups used in the factor analysis†

Food group	Components
Rice	Pilaf, curry and rice, rice bowl dishes, sushi, rice balls
Breads	Prepared bread, sweet buns
Noodles	Wheat noodles, buckwheat noodles, somen, cold noodles, ramen, pan-fried noodles, spaghetti
Other carbohydrate	Okonomiyaki, gratin, cereal, pizza
Potatoes	Potato salad, french fries, croquette, other potato dishes
Dairy foods	Corn soup, cream stew, yogurt, cheese
Meats	Beef, chicken, pork, liver, ground meat dishes, processed meat
Pulses	Miso soup, tofu, natto, beans
Seafood	Saury, tuna, salmon, horse mackerel, bonito, mackerel, eel, capelin, sardine, salted cod roe, herring egg, squid, shrimp, oyster, fish sausage
Vegetables	Tomato, carrot, pumpkin, spinach, greens, bell pepper, broccoli, radish, burdock, lotus, cabbage, Chinese cabbage, egg apple, green bean, pickles
Seaweed	Mushroom, barilla, brown seaweed
Fruits	Citrus, apple, strawberry, persimmon, kiwi, banana, other fruits
Confectionery	Rice crackers, peanuts, cakes, steamed bean-jam bun, snack, pudding, ice cream
Oils and fats	Fritters, batter, margarine, dressing, mayonnaise

†Each row represents a single food-frequency questionnaire item.

lated from the nomograms may help to avoid underestimating the real risk of atherosclerotic CVD, including the severity of atherosclerotic vascular damage, reflected by measured baPWV in subjects with different ages and blood pressure levels.[15] The ratio with the values calculated from the nomograms and measured baPWV values is defined as %ΔbaPWV {[(measured value – calculated value) / calculated value] * 100}. It has been reported that %ΔbaPWV was not significantly associated with age and SBP.[24]

Total and high-density lipoprotein cholesterol (HDL-C) and triglyceride (TG) concentrations were measured in blood samples. Participants were asked to fast for 12 hours, avoid smoking on the morning of the examination, and avoid heavy exercise 12 hours before the examination. Low-density lipoprotein cholesterol (LDL-C) was calculated using the Friedewald equation.[25] Non-HDL-C and the LDL/HDL ratios were calculated using the formula (LDL/HDL ratio = LDL-C/HDL-C, non-HDL-C = total-cholesterol – HDL-C).

Statistical analysis

Statistical Analysis Software (Ekuseru-Toukei 2012, Social Survey Research Information Co., Ltd. Japan) was used to conduct data analyses. To identify dietary patterns in our study population, factor analysis (principal component method) was conducted. The factors were orthogonally transformed using varimax rotation to achieve a structure with independent (non overlapping) factors and greater interpretability. Components with an eigenvalue >1, Scree test results, and the interpretability of the factors were considered when determining the number of factors to retain.[18-22] Food groups with absolute factor loadings ≥0.30 were considered as significant contributors to the pattern (Table 2). The factor loadings of the food groups by dietary patterns are provided in Table 2. Food groups with positive loadings contribute to the dietary pattern, whereas food groups with negative loadings are inversely associated with the dietary pattern.

We used a simple linear regression model to assess the relation between dietary patterns and arterial stiffness and relevant variables. Data are expressed as the mean±standard deviation (SD). Differences among the four groups were evaluated using a one-way analysis of variance, and a p value <0.05 was considered statistically significant.

Table 2. Factor-loading matrix for dietary patterns†

Foods	Dietary pattern	
	Rice-rich	Vegetable-rich
Rice	0.70	–
Breads	0.64	–
Fats and oils	0.59	–
Potatoes	0.58	–
Dairy products	0.47	–
Meats	0.51	–
Other carbohydrates	0.46	–
Confectionery	0.64	–
Noodles	0.62	–
Pulse	–	0.49
Fruits	–	0.49
Seaweed	–	0.62
Seafood	–	0.66
Vegetables	–	0.72

†Absolute values of factor loadings <0.30 were omitted for simplicity. The food groups are presented in descending order of loading values on the rice-rich dietary pattern.

RESULTS

We identified two major dietary patterns using factor analysis. The first pattern was characterized by a high positive loading for rice, breads, oils and fats, potatoes, meat, other carbohydrates, confectionery, and noodles; because the largest contributor to this diet was rice, we named this dietary pattern the "rice-rich" pattern. In the second pattern, vegetables, seafood, seaweed, fruit, and pulse were positively correlated with pattern scores; because the largest contributor was vegetables, we named this dietary pattern the "vegetable-rich" pattern. Table 3 shows the characteristics of study subjects according to the quartiles for the rice-rich and vegetable-rich patterns.

Table 3. Characteristics of study subjects across quartile (Q) of dietary pattern score†‡

	Group				
	Q1 (n=18)	Q2 (n=18)	Q3 (n=17)	Q4 (n=17)	p for trend§
Rice-rich pattern					
Age (y)	61.9±9.7	58.2±10.1	53.3±11.2	55.2±9.7	<0.05
Height (cm)	165±8.4	162±7.4	161±9.2	164±7.8	0.786
Body weight (kg)	59.8±12.2	62.1±11.3	61.0±10.0	60.9±10.6	0.996
BMI (kg/m^2)	21.7±2.9	23.6±2.9	23.3±3.0	22.6±3.7	0.988
Systolic blood pressure (mmHg)	129±16.2	128±9.0	121±13.7	122±14.9	<0.05
Diastolic blood pressure (mmHg)	79.8±12.5	78.4±5.7	74.1±11.1	75.7±8.9	0.072
Vegetable-rich pattern					
Age (y)	54.8±13.0	56.6±9.8	55.5±10.6	61.9±6.9	0.059
Height (cm)	165±8.2	165±9.7	160±7.6	163±6.9	0.368
Body weight (kg)	64.5±13.3	62.0±10.2	56.6±10.7	60.5±7.8	0.188
BMI (kg/m^2)	23.7±4.3	22.7±2.6	21.9±2.9	22.9±2.4	0.329
Systolic blood pressure (mmHg)	127±18.7	124±10.3	120±12.3	128±12.0	0.871
Diastolic blood pressure (mmHg)	81.4±9.2	76.5±12.9	73.4±8.7	76.7±7.3	0.131

†Values are shown as mean±SD except for number of study subjects.
‡Q; quartile of factor score.
§p-value from linear regression analysis for quantitative variables and chi-square test for qualitative variables.

Table 4. Energy and nutrient intake of study subjects according to the 1st and 4th quartile (Q) of dietary pattern score†‡

	Rice-rich pattern			Vegetable-rich pattern		
	Q1	Q4	*p* for trend§	Q1	Q4	*p* for trend§
Energy (kcal/d)	1738±463	2508±421	<0.001	2036±527	2239±509	0.055
Protein (g)	33.4±6.4	33.9±3.2	0.992	30.2±4.4	37.3±4.6	<0.001
Fat (g)	22.9±5.6	31.1±4.7	<0.001	25.0±7.3	27.9±4.6	0.056
Carbohydrate (g)	144±14.1	132±14.3	<0.05	232±108	283±79.0	0.203
Calcium (mg)	273±95.3	245±75.1	0.443	456±211	632±238	0.062
Magnesium (mg)	144±23.8	118±17.9	<0.01	117±21.9	150±24.5	<0.01
Potassium (mg)	1313±278	1084±189.7	<0.05	1045±288	1499±328	<0.001
Saturated fat (g)	6.6±2.3	8.9±2.0	<0.001	7.2±2.7	7.7±2.1	0.403
Monounsaturated fat (g)	7.6±2.1	10.8±1.8	<0.001	8.6±2.7	9.5±1.7	0.156
Polyunsaturated fat (g)	5.4±1.1	6.7±1.0	<0.001	5.5±1.4	6.6±1.2	<0.01
Fibre (g)	6.1±2.0	5.5±1.1	0.297	4.7±1.2	8.0±1.9	<0.001

†Values are shown as mean±SD which are adjusted for total energy intake (1,000kcal/day), except energy.
‡Q; quartile of factor score.
§*p*-value from linear regression analysis.

Table 5. Select cardiovascular disease risk factor across quartiles (Q) of dietary pattern score†‡

	Group				
	Q1	Q2	Q3	Q4	*p* for trend§
Rice-rich pattern					
TC (mg/dL)	210±37.6	212±43.4	200±30.4	214±27.6	0.701
TG (mg/dL)	103±49.5	111±52.9	94±37.2	122±46.8	0.662
LDL-C (mg/dL)	131±27.9	134±33.8	119±30.2	133±23.6	0.942
HDL-C (mg/dL)	58.6±16.4	55.9±15.0	61.8±11.0	57.5±15.0	0.466
nonHDL-C (mg/dL)	152±30.6	157±37.3	138±31.8	158±26.5	0.791
LDL/HDL ratio	2.4±0.7	2.5±0.7	2.0±0.8	2.5±0.7	0.719
%ΔbaPWV (%)	4.9±16.3	5.5±10.8	2.5±10.6	7.3±7.9	0.656
Vegetable-rich pattern					
TC (mg/dL)	207±37.2	208±31.4	196±36.1	224±33.0	0.206
TG (mg/dL)	118±49.1	101±47.3	118±54.9	94±34.8	0.353
LDL-C (mg/dL)	129±32.3	126±28.9	119±25.7	143±26.9	0.333
HDL-C (mg/dL)	54.9±14.4	62.2±15.4	53.6±14.4	62.9±11.7	0.107
nonHDL-C (mg/dL)	154±36.3	146±31.4	143±30.3	161±30.0	0.569
LDL/HDL ratio	2.6±0.9	2.1±0.8	2.3±0.6	2.3±0.6	0.263
%ΔbaPWV (%)	9.9±14.5	3.6±11.0	4.2±8.1	2.3±11.7	<0.05

TC, total cholesterol; TG, triglyceride; LDL-C, low-density lipoprotein cholesterol; HDL-C, high-density lipoprotein cholesterol; PWV, pulse wave velocity.
†All values are shown as mean±SD.
‡Q; quartile of factor score.
§*p*-value from linear regression analysis for quantitative variables.

All components presented a linear trend through the quartiles, with increasing or decreasing trend. Persons in the upper quartiles of the rice-rich pattern were more likely to be young and have low systolic blood pressure (*p* for trend <0.05 for all), whereas no correlation was found between the vegetable-rich pattern and any of the risk factors or variables analyzed.

Table 4 shows the nutrient composition (energy adjusted, in 1,000 kcal/d) of each dietary pattern. Persons with high rice-rich pattern scores consumed more total fat, saturated fat, monounsaturated fat, and PUFA (*p* for trend <0.001 for all) and less potassium and magnesium than persons with lower scores (*p* for trend <0.05 and <0.01, respectively). On the other hand, the vegetable-rich pattern generally showed trends opposite that of the rice-rich pattern in that these subjects consumed more protein, magnesium, potassium, PUFA, and fibre (*p* for trend <0.001 for all, except for magnesium and PUFA [*p*<0.01]). The CVD risk factors across quartiles of dietary pattern scores are summarized in Table 5. Although we observed no association between dietary patterns and the major CVD risk factors (TC, TG, LDL-C, HDL-C, non-HDL-C, and LDL/HDL ratio), %ΔbaPWV significantly decreased in subjects reporting a vegetable-rich dietary pattern (*p* for trend <0.05), however the trend in %ΔbaPWV was not statistically significant in subjects reporting a rice-rich dietary pattern.

DISCUSSION

In this cross-sectional study of Japanese middle-aged adults, we identified two major dietary patterns using factor analysis. The vegetable-rich pattern was characterized by the consumption of a wide variety of foods, such as vegetables, seafood, seaweed, fruit, and pulse. The rice-rich pattern included rice, breads, oils and fats, potatoes, meats, other carbohydrates, confectionery, and noodles. We observed an inverse association between the vegetable-rich pattern factor score and arterial stiffness derived from baPWV.

Several studies have examined the relationship between a single nutrient or a few nutrients or foods and CVD risk factors. Lopez et al examined the association between a diet rich in vegetables, fruit, and fish and inflammation markers such as C-reactive protein and E-select in and found an inverse relation after adjusting for age, body mass index, physical activity, smoking status, and average alcohol consumption.[19] Fukuoka et al reported that a fish-based diet effectively prevented an increase in baPWV in low-risk coronary artery disease patients.[26] Fish is a major source of omega-3 fatty acids, eicosapentaenoic acid (EPA),and docosahexaenoic acid (DHA), which are considered promising treatments for the prevention of major coronary events, especially non-fatal ones, in the Japanese population.[27] The Japan EPA lipid intervention study (JELIS) and the Japan public health center-based (JPHC) study showed that the consumption of fish and n-3 PUFA reduced the incidence of major coronary events.[27,28] Aatola et al reported that vegetable consumption was the only lifestyle risk factor that was an independent predictor of PWV when adjusted for lifestyle or traditional risk factors.[29] In another report, high fruit and vegetable consumption was related to a reduced CVD risk in prospective settings among middle-aged and elderly subjects.[30]

Our study provides evidence of a significant inverse association between consumption of a vegetable-rich pattern consisting of a variety of foods and arterial stiffness among Japanese middle-aged adults. In our analysis of individual food items, we confirmed the inverse association between arterial stiffness and the consumption of vegetables, seafood, seaweed, fruit, and pulse reported in earlier studies.[26-30] The individual consumption of vegetables, fish, and seafood was not associated with arterial stiffness, which were the major food items characterizing the vegetable-rich pattern, although these foods are considered elements of a healthy diet. Wahlqvist et al reported that food variety is associated with less macro vascular disease,[31] and the increased variety among plant foods eaten might be predictive of better arterial compliance. Additionally, consumption of fish rich in n-3 PUFAs, has been previously found to be protective against arterial stiffness and related risk factors,[27,28] which might explain the beneficial effects of the vegetable-rich pattern on arterial stiffness. Furthermore, we postulate benefits from other constituents of the vegetable-rich pattern including monounsaturated fatty acids, fibre, high-quality protein, low glycemic index, vitamins, minerals, and other bioactive compounds and that the rice-rich pattern included limited amounts of these constituents.

The strengths of the present study included its population-based setting, the use of standardized methods to identify outcomes, and consideration of a broad range of confounding variables. However, several limitations should be considered while interpreting our findings. First, the cross-sectional design made it difficult to examine the causal relationships between dietary patterns and arterial stiffness; therefore, further prospective or intervention studies are necessary to confirm our findings. Second, several assumptions were made when constructing food groups (e.g., when mixed dishes were aggregated into component food groups and when questions containing nutritionally diverse foods were categorized). However, our dietary patterns and loading scores were similar to those reported in other studies, and associations between dietary patterns and arterial stiffness were as expected; this suggests that our assumptions were valid.[9,18-22] Third, regardless of our findings, which are based on empirically derived dietary patterns, it is possible that other food combinations may be more strongly related to arterial stiffness and other relevant variables. However, we found no independent relationships between arterial stiffness and food groups that did not have high factor loadings for any dietary pattern.

In conclusion, this is the first study to demonstrate a relationship between dietary patterns and arterial stiffness in Japanese middle-aged adults. Our findings suggest that a dietary pattern characterized by a high consumption of vegetables, seafood, seaweed, and fruit is inversely associated with arterial stiffness. Such a diet offers an additional nutritional approach to the prevention and treatment of arterial stiffness.

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AUTHOR DISCLOSURES

None of the authors have any personal or financial conflicts of interest.

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