

Dietary pattern, the metabolic syndrome, and left ventricular mass and systolic function: the Multi-Ethnic Study of Atherosclerosis^{1–3}

Longjian Liu, Jennifer A Nettleton, Alain G Bertoni, David A Bluemke, João A Lima, and Moyses Szklo

ABSTRACT

Background: Little is known about the relations between dietary patterns, metabolic dysfunction, and left ventricular (LV) function.

Objective: The objective was to examine associations of dietary patterns with LV mass and function and to explore the potential role of metabolic dysfunction in the association between diet and LV function.

Design: Dietary patterns that maximally explained the variation in metabolic syndrome (MetSyn) components were derived by using reduced rank regression (RRR). LV mass, stroke volume, and LV ejection fraction (LVEF) were measured by magnetic resonance imaging. Associations between dietary pattern and LV indexes were analyzed cross-sectionally.

Results: A total of 4601 participants aged 45–84 y and free of clinical CVD were studied. The primary RRR dietary pattern score was positively correlated with intake of foods with a high glycemic index, high-fat meats, cheeses, and processed foods and negatively correlated with low intakes of vegetables, soy, fruit, green and black tea, low-fat dairy desserts, seeds and nuts, and fish. Multivariate analyses showed that each 1-unit increase in the RRR dietary pattern score was associated with a 0.32-g/m² increase in LV mass/body surface area, a 0.43-mL/m² decrease in stroke volume/body surface area, and a 0.21% decrease in LVEF. The associations of the RRR dietary pattern score with LV mass and stroke indexes were attenuated and became nonsignificant after adjustment for all MetSyn components ($P > 0.05$).

Conclusions: The results suggest that the RRR dietary pattern is significantly associated with unfavorable LV function, and this association might be mediated by metabolic dysfunction. Given the cross-sectional nature of our study, these results must be confirmed with the use of longitudinal data. *Am J Clin Nutr* 2009;90:1–7.

INTRODUCTION

More than 5 million Americans live with heart failure, and 550,000 new cases are diagnosed yearly, resulting in $\approx 300,000$ deaths each year (1, 2). The incidence and prevalence of heart failure have been increasing in the past 20 y, partly because of the improvement in survival rates of patients with coronary heart disease and an increase in the elderly population. Heart failure is the leading cause of hospitalization among US seniors (1–4). Identification of modifiable risk factors such as diet is important given the effect of heart failure on health-related costs in the United States (1). Although some studies suggest that dietary factors may influence heart failure development and progression, these relations have not been well characterized (5).

Asymptomatic left ventricular systolic dysfunction (LVSD) is used to identify those at high risk of developing heart failure. Prior studies have shown significant associations of individual foods or nutrients deficiencies with heart failure and LVSD, such as hypovitaminosis D and deficiencies in vitamin B-6 and vitamin B-12 (6, 7). However, foods are not usually consumed individually; thus, their combined effects may differ from their isolated effects.

Recent studies are increasingly adding dietary pattern approaches to the more traditional focus on individual foods, nutrients, or dietary constituents. In epidemiologic studies, principal component analysis (PCA) and factor analysis, similar in their mathematical foundation, have been dominantly applied (8, 9). Taking into account the correlation matrix of multiple foods consumed in the diet, these 2 methods construct a linear function of food intake that maximally explains the variation in foods entered into the PCA models. Dietary patterns derived by PCA and factor analysis reflect food usage patterns in the study population. Hoffmann et al recently proposed the use of the reduced rank regression (RRR) technique to characterize dietary patterns (10). In contrast with the commonly used PCA and factor analysis, RRR produces a linear combination of food groups (eg, dietary pattern) that maximally explains the variation in investigator-specified intermediate response variables (ie, intermediate risk factors for disease). Thus, this technique allows specific hypotheses to be tested regarding pathways (represented by the response variables) between diet and disease (10, 11). In the present study, we applied the RRR method to examine interrelations between dietary patterns, the metabolic syndrome (MetSyn), and LVSD.

¹ From the Department of Epidemiology & Biostatistics, Drexel University School of Public Health, Philadelphia, PA (LL); the Department of Epidemiology, University of Texas Health Sciences Center, Houston, TX (JAN); the Department of Public Health Sciences, Wake Forest University Health Sciences, Winston-Salem, NC (AGB); the National Institutes of Health/Clinical Center, Bethesda, MD (DAB); and the Departments of Cardiology (JAL) and Epidemiology (MS), Johns Hopkins University, Baltimore, MD.

² Supported by contracts N01-HC-95159 through N01-HC-95166, N01-HC-95168, and N01-HC-95169 from the National Heart, Lung, and Blood Institute.

³ Address correspondence to L Liu, Drexel University School of Public Health, Department of Epidemiology & Biostatistics, 1505 Race Street, Philadelphia, PA 19102. E-mail: longjian.liu@drexel.edu.

Received January 28, 2009. Accepted for publication May 4, 2009.

doi: 10.3945/ajcn.2009.27538.

Diabetes mellitus has been established as one of the premier risk factors for heart failure. Some studies have shown that even a 1% increase in hemoglobin A_{1c} increases the risk of heart failure by 15% (12, 13). It has been suggested that the association between diabetes and heart failure is partly due to LVSD (14, 15). Given this hypothesized relation between diabetes and LVSD, we used the RRR method to derive a dietary pattern (called RRR dietary pattern) that maximally explains variation in the MetSyn components (high waist circumference, systolic and diastolic blood pressure, serum triglyceride and glucose, and low serum HDL cholesterol). We then examined the association between RRR dietary patterns and LVSD and hypothesized that a dietary pattern that would explain the variation in MetSyn components would be significantly associated with LVSD.

SUBJECTS AND METHODS

Participants

We used data from the Multi-Ethnic Study of Atherosclerosis (MESA). The MESA was described in detail elsewhere (16). In brief, MESA aims to investigate the prevalence, correlates, and progression of subclinical CVD. Between July 2000 and August 2002, 6814 men and women aged 45–84 y who identified themselves as white, black, Hispanic, or Chinese were recruited from 6 US communities: Baltimore City and Baltimore County, MD; Chicago, IL; Forsyth County, NC; Los Angeles County, CA; northern Manhattan and Bronx, NY; and St Paul, MN. Participants without self-reported physician-diagnosed cardiovascular diseases (heart attack, angina, heart failure, stroke, and current atrial fibrillation) were recruited. Subjects with serious medical conditions that would prevent them from long-term participation, including those currently being treated for cancer, pregnant women, and those living in a nursing home, were also excluded (16). MESA protocols were approved by each field center's institutional review board, and the present analyses were also approved by the Drexel University institutional review board.

Of 6814 MESA participants at baseline, 5004 (73%) completed cardiac magnetic resonance imaging (MRI) scans and had technically adequate measures of LV function. Of these 5004 participants, 4601 (92%) completed a diet assessment using the food-frequency questionnaire (FFQ) and had complete laboratory data. The present cross-sectional analysis includes data from these 4601 participants ($n = 2185$ men and 2416 women).

Left ventricular structure and function assessments

In the MESA, participants underwent a cardiac MRI scan a median of 16 d after the baseline evaluation; 95% of the MRIs were completed by 11 wk after the baseline examination. The MRI exams were performed by using scanners with 1.5-T magnets as previously described (17). All imaging was performed with a 4-element phased-array surface coil positioned anteriorly and posteriorly, electrocardiographic gating, and brachial artery blood pressure monitoring. Imaging consisted of fast-gradient echo cine images of the left ventricle with time resolution <50 ms. Functional parameters and mass were determined by volumetric imaging. Imaging data were read by using MASS software (version 4.2; Medis, Leiden, Netherlands) at a single reading center by readers trained in the MESA pro-

tolocol and without knowledge of risk factor information. LV mass and end-diastolic and end-systolic volumes were measured. Stroke volume was calculated as end-diastolic volume minus end-systolic volume. The LV ejection fraction was calculated as (stroke volume/end-diastolic volume) \times 100. The reliability of the MRI readings was determined by calculating intraclass correlation (ICC) as the ratio of the variance of the variable if precisely measured (without measurement error) over the observed variance of the variable (with measurement error) for a set of 155 duplicate readings. An ICC reliability estimate of 0.95 means that 5% of the total variability is attributed to reader measurement error. The ICC was 0.97 (95% CI: 0.96, 0.98) for LV mass, 0.98 (95% CI: 0.97, 0.99) for end-diastolic volume, and 0.95 (95% CI: 0.93, 0.96) for end-systolic volume. In the present study, LV mass and stroke volume were indexed according to body surface area (BSA; in m²). BSA (m²) was calculated as $0.20247 \times \text{height (m)}^{0.725} \times \text{weight (kg)}^{0.425}$ (17).

Dietary assessment

At the baseline examination, each participant completed a self-administered 120-item FFQ. The FFQ was developed in the Block format (18) and was based on the FFQ used in the Insulin Resistance Atherosclerosis Study (IRAS), which was validated in nonHispanic, white, African American, and Hispanic persons (19). Participants recorded serving size (small, medium, or large) and frequency of consumption of specific beverages and food items. Nine frequency options were given, ranging from "rare or never" to a maximum of "2+ times per day" for foods and a maximum of "6+ times per day" for beverages. Servings per day for each item were calculated as the product of the reported frequency and serving size ("small" weighted by 0.5, "medium" by 1.0, and "large" by 1.5) and further categorized into 47 food groups (11, 20).

Assessment of nondietary exposures

Information on participants' characteristics, including age, sex, race-ethnicity, and education level, and lifestyle traits, including cigarette smoking, alcohol consumption, and physical activity, were collected at baseline with a combination of self-administered and interviewer-administered questionnaires. Resting seated blood pressure was measured 3 times with a Dinamap model Pro 100 automated oscillometer (Critikon Tampa, FL). The average of the last 2 measures was used in the analysis. BMI (weight in kilograms divided by the square of height in meters) was calculated from weight measured to the nearest 0.5 kg and height measured to the nearest 0.1 cm. Waist circumference was measured at the umbilicus to the nearest centimeter. Three measurements were taken, and the average of the last 2 measurements was used in the analysis (16).

Fasting blood samples were drawn, processed, and stored by using standardized procedures. Total cholesterol, HDL cholesterol, triglycerides, glucose, and insulin were measured at the Collaborative Studies Clinical Laboratory at Fairview–University Medical Center (Minneapolis, MN). Measurements of lipids were performed on the Roche COBAS FARA centrifugal analyzer. LDL cholesterol was calculated in plasma specimens with a triglyceride value <400 mg/dL by using Friedewald et al's formula (21). Serum glucose was measured by rate reflectance

spectrophotometry by using thin film adaptation of the glucose oxidase method on the Vitros analyzer (Johnson & Johnson Clinical Diagnostics Inc, Rochester, NY). Serum triglycerides and fasting glucose values were log-transformed in statistical analyses because of their skewed distributions. Insulin resistance (IR) was also studied as a covariate in multivariate analyses. IR was estimated by using the homeostasis model assessment of insulin resistance method [fasting insulin concentration ($\mu\text{U}/\text{mL}$) \times fasting glucose concentration (mmol/L)/22.5] (22).

Assessment of metabolic syndrome

Criteria for defining MetSyn have been suggested by several organizations (23). In our study, we used the American Heart Association/National Heart, Lung, and Blood Institute criteria in which MetSyn is defined as the presence of ≥ 3 of the following components: 1) elevated waist circumference (≥ 102 cm for men and ≥ 88 cm for women), 2) elevated triglycerides (≥ 150 mg/dL), 3) reduced HDL cholesterol (< 40 mg/dL for men and < 50 mg/dL for women), 4) elevated systolic or diastolic blood pressure ($\geq 130/85$ mm Hg), and 5) elevated fasting glucose (≥ 100 mg/dL).

Statistical analyses

We used reduced rank regression (RRR) to derive dietary patterns (10). In the RRR model, 5 components of MetSyn (as continuous variables) were the dependent variables (Y_i) and were used simultaneously in the model, and 47 food groups (X_i) were the independent variables. The mathematical model can be expressed as $Y_i = a + \beta \times X_i + \xi$, where ξ is the random error. The RRR model identified a linear function of predictors (ie, food groups) that explained the variations in responses (ie, MetSyn components) as much as possible. To present data concisely, we used the primary dietary pattern (RRR) for subsequent analyses because it explained the largest amount of variation in MetSyn components. A score for each participant for the primary RRR dietary pattern was calculated as the weighted sum of the 47 food groups, with each food group weighted according to its respective factor load value (11). We then calculated Pearson correlation coefficients for the associations between the RRR score and the food groups to characterize the dietary pattern.

We examined participant characteristics across the quintiles of RRR dietary pattern score. We used a chi-square test to examine differences in categorical variables and analysis of variance to test differences in means of continuous variables. We examined linear trends across the quintiles using linear regression analysis.

Finally, we performed multiple linear regression analyses to evaluate associations between RRR dietary patterns and LV function with adjustment for age, sex, and race-ethnicity (model 1) and for education ($<$ high school, high school, and college+), smoking status (none, former, and current), alcohol consumption (none, former, and current), total leisure time activity (metabolic equivalent tasks per min/wk), and study sites (model 2). To explore whether the associations between the dietary pattern and LV mass and function might be mediated by MetSyn components, we included adjustment for each and all MetSyn components. We also examined the sensitivity of results by excluding persons who took insulin or hypoglycemic medication

for diabetes treatment ($n = 416$) from the analysis, because they had poorer LV function than did those not taking these medications; however, because results in those without diabetes were not different from those in the total sample, we present only the results for the total sample. All data analyses were conducted by using SAS version 9.1 (SAS Institute Inc, Cary, NC). Statistical significance was defined as a P value < 0.05 in 2-sided tests.

RESULTS

Of the 4601 participants included in the study, 40% were white, 24% were black, 14% were Chinese, and 22% were Hispanic. The mean (\pm SD) ages were 62.6 ± 10.2 y in whites, 62.5 ± 9.9 y in blacks, 62.3 ± 10.3 y in Chinese, and 61.0 ± 10.2 y in Hispanic groups; 53% of the whites, 56% of the blacks, 52% of the Chinese, and 49% of the Hispanics were women. The primary RRR pattern score explained 5.3% of the variation in food group intake and 2.8% of the variation in response variables of waist circumference, serum triglycerides, glucose, HDL cholesterol, and blood pressure (systolic and diastolic blood pressure).

Participant characteristics by quintiles of dietary pattern

Although there were significant differences between participants by sex, race-ethnicity, education, and smoking status across quintiles of dietary pattern score, a graded relation was seen overall between the dietary pattern score and MetSyn (P for trend < 0.001), as shown in **Table 1**. Participants with higher RRR scores had worse serum profiles (lower HDL concentrations, higher triglyceride and glucose concentrations, and greater IR) ($P < 0.001$) and poorer LV function measures (greater LV mass, lower stroke volume, and lower EF) ($P < 0.001$). There were statistically significant linear trends in mean LV mass/BSA, stroke volume, and LVEF across the dietary pattern score quintiles (P for trend < 0.01).

Dietary pattern and food groups

The results of correlation analysis with adjustment for age, sex, and race-ethnicity are shown in **Table 2**. The data suggest that the RRR dietary pattern score was significantly and positively correlated with intake of food with a high glycemic index (refined-grain bread/pasta, white potatoes, and sweet breads), high-fat meats, cheeses, and processed foods (fried potatoes, salty snacks, pizza, and ice cream) and negatively correlated with intake of vegetables, soy, fruit, green and black tea, low-fat dairy desserts, seeds and nuts, and fish. Overall, there were positive correlations between foods with a high glycemic index, high-fat foods, and RRR dietary pattern score and between low-fat foods and the dietary pattern score. The RRR dietary pattern score was also significantly correlated with major components of MetSyn (ie, waist circumference, triglycerides, glucose, HDL, and systolic blood pressure), although the correlation was somewhat weaker between RRR score and systolic blood pressure and diastolic blood pressure.

Dietary pattern, LV mass, and systolic function

Adjusted associations of LV mass and function indexes with the RRR dietary pattern score (as a continuous variable) are

TABLE 1Participant characteristics and left ventricular (LV) indexes by dietary pattern score quintile (Q) in the Multi-Ethnic Study of Atherosclerosis: 2000–2002 ($n = 4601$)¹

	Dietary pattern (toward high-fat intake)					<i>P</i> value ²
	Q1	Q2	Q3	Q4	Q5	
Dietary pattern score	-1.508 ± 0.66^3	-0.582 ± 0.15	-0.107 ± 0.13	0.442 ± 0.19	1.755 ± 0.95	<0.001
Categorical variables (%)						
Female	67.4	60.2	53.8	45.4	35.8	<0.001
White	47.4	43.8	39.3	39.2	30.5 ⁴	
Chinese	21.5	22.0	16.4	7.8	2.0 ⁴	<0.001
Black	24.1	22.8	25.0	24.8	23.9 ⁴	
Hispanic	7.0	11.4	19.3	28.2	43.6 ⁴	
Bachelor's degree or higher	51.7	44.8	37.8	32.2	25.0	<0.001
Current smokers	7.9	10.1	11.1	13.6	18.2	<0.001
AHA-MetSyn	31.1	37.2	42.5	46.3	51.3	<0.001
Continuous variables						
Age (y)	63.4 ± 10.1	63.7 ± 10.1	62.0 ± 10.3	61.7 ± 10.0	59.9 ± 9.8	<0.001
Waist circumference (cm)	92.6 ± 13.1	93.7 ± 13.0	95.6 ± 12.6	98.9 ± 13.1	101.2 ± 12.5	<0.001
SBP (mm Hg)	123.6 ± 21.1	124.5 ± 21.2	126.1 ± 21.8	126.4 ± 21.0	125.8 ± 20.5	<0.001
DBP (mm Hg)	70.4 ± 10.3	70.5 ± 10.2	72.2 ± 10.4	72.6 ± 10.1	73.1 ± 10.1	<0.001
Total cholesterol (mmol/L)	5.03 ± 0.9	5.06 ± 0.9	4.97 ± 0.9	5.02 ± 1.0	5.04 ± 0.9	0.23
HDL cholesterol (mmol/L)	1.46 ± 0.4	1.38 ± 0.4	1.32 ± 0.4	1.27 ± 0.4	1.20 ± 0.3	<0.001
LDL cholesterol (mmol/L)	2.99 ± 0.8	3.03 ± 0.8	2.99 ± 0.8	3.03 ± 0.8	3.09 ± 0.8	0.079
Triglycerides (mmol/L)	1.28 ± 0.7	1.41 ± 0.8	1.47 ± 0.9	1.57 ± 1.0	1.68 ± 1.0	<0.001
Glucose (mmol/L)	5.44 ± 1.1	5.59 ± 1.2	5.70 ± 1.7	5.84 ± 1.8	6.05 ± 2.2	<0.001
log-HOMA-IR (mmol/L)	0.78 ± 0.4	0.86 ± 0.4	0.89 ± 0.4	0.95 ± 0.4	1.03 ± 0.5	<0.001
LV mass/BSA (g/m^2)	75.1 ± 4.9	75.2 ± 15.4	77.3 ± 16.2	79.3 ± 16.2	82.3 ± 16.9	<0.001
Stroke volume/BSA (mL/m^2)	47.2 ± 8.4	46.7 ± 8.7	46.5 ± 9.6	46.5 ± 8.8	46.8 ± 9.6	<0.001
LVEF (%)	70.4 ± 6.9	70.2 ± 6.9	69.0 ± 7.5	68.1 ± 7.6	67.8 ± 7.8	<0.001

¹ SBP, systolic blood pressure; DBP, diastolic blood pressure; HOMA-IR, homeostasis model assessment of insulin resistance; LVEF, left ventricular ejection fraction; BSA, body surface area; AHA-MetSyn, American Heart Association–defined metabolic syndrome.

² Test for trend across quintiles of reduced rank regression dietary pattern score except for race-ethnicity.

³ Mean \pm SD (all such values).

⁴ Chi-square test.

shown in **Table 3**. Model 2 indicates that a 1-unit increase in RRR dietary pattern score was associated with a 0.32-g/m² increase in LV mass/BSA and decreases of 0.43 mL/m² in stroke volume/BSA and of 0.21% in LVEF.

With adjustment for individual components of MetSyn, waist circumference had the strongest influence on the association between the dietary pattern and LV mass indexes (assessed by the changes in the regression coefficients as compared with model 2). After adjustment for all 5 components of MetSyn (model 3), the strengths of the associations of dietary pattern with LV mass and stroke volume were greatly attenuated. The regression coefficients decreased from 0.32 g/m² in model 2 to 0.13 g/m² in model 3 for LV mass/BSA and increased from $-0.43 \text{ mL}/\text{m}^2$ to $-0.22 \text{ mL}/\text{m}^2$ for stroke volume. On the other hand, the strength of the association with LVEF remained virtually unchanged after adjustment for individual or all MetSyn components. No significant interactions between RRR dietary pattern and age, sex, race, and MetSyn status on LV mass and function indicators were observed.

DISCUSSION

The progressive nature of heart failure has generated increased interest in its early preclinical stages. The current American College of Cardiology/American Heart Association practice guidelines for heart failure divide the disorder into 4 stages, 2 of

which (stages A and B) are asymptomatic (24). Stage A denotes a “high risk of heart failure but without structural heart disease” and includes individuals with hypertension, diabetes, or known atherosclerotic disease. Individuals with asymptomatic LVSD are included in stage B, ie, structural heart disease but without symptoms of heart failure. Several studies have examined the association between diabetes, MetSyn, and heart failure as well as the association between dietary patterns and diabetes (20, 25). Ours, however, is the first study to examine the associations between dietary patterns and LV mass and function measured by MRI in a large multiethnic population sample.

Principal findings

Using a novel statistical method, we derived a dietary pattern that maximally explained the variation in MetSyn components, which was characterized by intake of foods with a high glycemic index, high-fat meats, cheeses, processed foods and low intake of vegetables, soy, fruit, green and black tea, low-fat dairy desserts, seeds and nuts, and fish. This dietary pattern was significantly and unfavorably associated with LV mass and systolic function. After adjustment for all MetSyn components, the associations of the RRR dietary pattern score with LV mass and stroke volume were greatly attenuated (assessed by using regression coefficients). Notwithstanding the cross-sectional nature of the study, these findings, which should be confirmed longitudinally, suggest that

TABLE 2

Partial correlation coefficients between reduced rank regression (RRR) score and food groups, homeostasis model assessment of insulin resistance (HOMA-IR), and metabolic syndrome (MetSyn) components in the Multi-Ethnic Study of Atherosclerosis: 2000–20002 ($n = 4601$)¹

	Correlations between food groups and MetSyn components							
	RRR dietary pattern score ²	HOMA-IR	Waist circumference	Triglyceride	Glucose	HDL	SBP	DBP
RRR dietary pattern score	1	0.16 ³	0.20 ³	0.16 ³	0.10 ³	-0.14 ³	0.06 ³	0.01
Positive associations with diet score								
Fried potato	0.47 ³	0.10 ³	0.17 ³	0.03 ⁴	0.04 ⁵	-0.04 ⁴	0.04 ⁴	0.02
Legumes	0.43 ³	0.03 ⁴	0.05 ⁵	0.11 ³	0.03	-0.05 ⁵	0.01	-0.04 ⁴
White bread	0.42 ³	0.07 ³	0.03 ⁴	0.12 ³	0.03 ⁴	-0.09 ³	0.01	-0.03
High-fat meat	0.41 ³	0.10 ³	0.16 ³	-0.01	0.03 ⁴	0.00	0.07 ³	0.05 ⁵
Red meat	0.38 ³	0.11 ³	0.08 ³	0.10 ³	0.03 ⁴	-0.04 ⁴	0.03	0.00
Tomato	0.29 ³	0.04 ⁴	0.11 ³	0.08 ³	0.01	-0.03	0.00	-0.06 ³
Fat and oils	0.28 ³	0.07 ³	0.19 ³	-0.01	0.01	0.00	0.03 ⁴	0.03
High-fat cheese	0.27 ³	0.07 ³	-0.03	0.07 ³	0.04 ⁵	-0.03 ⁴	-0.01	-0.02
Soda	0.27 ³	0.03 ⁴	0.10 ³	0.02	-0.02	-0.05 ⁵	0.02	0.01
Sweet breads	0.24 ³	0.03	0.09 ³	-0.02	0.01	-0.03 ⁴	0.06 ³	0.03 ⁴
White potatoes	0.24 ³	0.04 ⁴	0.06 ³	0.04 ⁴	-0.01	-0.04 ⁴	0.05 ⁵	0.04 ⁴
Diet soda	0.24 ³	0.05 ⁵	0.14 ³	0.01	0.06 ³	-0.02	0.02	-0.01
Salty snacks	0.23 ³	0.04 ⁴	0.12 ³	0.02	0.01	-0.02	0.01	-0.01
Pizza	0.21 ³	0.05 ⁵	0.13 ³	0.01	-0.02	-0.04 ⁴	0.01	0.00
Potato and pasta salads	0.20 ³	0.03 ⁴	0.10 ³	0.00	0.01	0.00	0.07 ³	0.06 ³
Eggs	0.20 ³	0.06 ³	0.07 ³	-0.03	0.05 ⁵	0.02	0.02	0.00
Poultry	0.19 ³	0.04 ⁴	0.11 ³	-0.01	0.02	0.01	0.05 ⁵	0.02
Whole milk	0.19 ³	0.04 ⁴	0.02	0.02	0.04 ⁴	-0.03 ⁴	-0.03 ⁴	-0.04
Fruit juice	0.18 ³	0.01	0.03	0.02	-0.05 ⁵	-0.02	0.01	0.02
High-fat Chinese	0.16 ³	0.07 ³	0.03 ⁴	0.07 ³	0.04	-0.03 ⁴	-0.01	-0.02
Ice cream	0.15 ³	0.03	0.08 ³	-0.01	-0.02	-0.01	0.00	0.02
Other soup	0.13	0.01	0.07 ³	0.05 ⁵	0.03 ⁴	-0.06 ³	0.02	0.02
Low-fat milk	0.13 ³	0.02	0.06 ³	0.04 ⁴	0.00	-0.04 ⁴	-0.02	-0.04 ⁴
Hot chocolate	0.12 ³	0.04 ⁴	0.03 ⁴	0.02	-0.01	-0.03 ⁴	0.00	0.01
Coffee	0.11 ³	-0.01	0.11 ³	-0.01	-0.03	0.00	0.00	-0.01
Negative associations with diet score								
Fish	-0.11 ³	-0.01	-0.03	-0.06 ³	0.02	0.03 ⁴	0.01	0.03 ⁴
Seeds and nuts	-0.11 ³	-0.02	0.01	-0.06 ³	-0.03 ⁴	0.03 ⁴	0.00	-0.01
Low-fat dairy desserts	-0.15 ³	-0.04 ⁴	-0.01	-0.05 ⁵	-0.03	0.03	0.03	0.03
Green and black tea	-0.16 ³	-0.02	-0.05 ⁵	0.00	0.00	0.01	-0.01	-0.01
Fruit	-0.16 ³	-0.02	-0.04 ⁴	-0.02	-0.03	0.02	0.01	0.01
Soy	-0.19 ³	-0.04 ⁴	-0.08 ³	-0.02	-0.01	0.02	-0.01	0.02
Dark-yellow vegetables	-0.26 ³	-0.04 ⁴	-0.13 ³	0.00	-0.01	-0.01	-0.02	-0.01
Cruciferous vegetables	-0.31 ³	-0.04 ⁴	-0.14 ³	-0.02	0.01	-0.01	-0.02	-0.01
Green leafy vegetables	-0.37 ³	-0.03 ⁴	-0.01	-0.10 ³	-0.05 ⁵	0.08 ³	-0.01	0.01

¹ Partial correlation coefficients were adjusted for age, sex, and race. SBP, systolic blood pressure; DBP, diastolic blood pressure.

² RRR dietary pattern score was estimated by using RRR analysis. To simplify the presentation, only partial correlation coefficients with absolute values ≥ 0.11 are shown. Food groups are presented in descending order according to correlation coefficient values on the dietary pattern score.

³ $P < 0.001$.

⁴ $P < 0.05$.

⁵ $P < 0.01$.

the associations between diet, LV mass, and LV function may be mediated by metabolic dysfunction.

Dietary pattern and LVSD

Prior prospective studies showed MetSyn and individual components of MetSyn, including high blood pressure, obesity, and elevated serum glucose concentrations, to be significantly associated with poor LV function (15, 25, 26). Our results showed that waist circumference (one of the MetSyn components) had the strongest influence on the association between the dietary pattern and LV mass, followed by stroke volume and LVEF. IR appeared to have the strongest influence on the association between the

dietary pattern and stroke volume, although the association remained significant after adjustment for IR alone. Our study results are consistent with previous studies showing associations of MetSyn with LV mass and stroke volume elsewhere (15, 27). In a study by Burchfiel et al (27), for example, the age-adjusted mean LV mass index increased in a graded fashion with increasing number of MetSyn components (none, any 1, any 2, and all 3). Our results and previous results suggest that the association between dietary pattern and LV function may be mediated by metabolic dysfunction. In agreement with previous studies (15, 28, 29), our study also suggests that MetSyn components appear to have little, if any, influence on the association between RRR dietary pattern and LVEF.

TABLE 3

Reduced rank regression (RRR) dietary patterns in relation to left ventricular (LV) mass, stroke volume indexes, and left ventricular ejection fraction (LVEF) in the Multi-Ethnic Study of Atherosclerosis: 2000–2002 ($n = 4601$)¹

RRR dietary pattern in relation to LV indexes	LV mass (g)/BSA (m ²)			Stroke index (mL/m ²) ²			LVEF (%)		
	β	SE	<i>P</i> value	β	SE	<i>P</i> value	β	SE	<i>P</i> value
Adjusted for									
M1 ³	0.390	0.185	0.035	-0.457	0.117	<0.001	-0.270	0.091	0.003
M2 ⁴	0.322	0.188	0.087	-0.429	0.118	<0.001	-0.214	0.092	0.019
M2 + waist circumference	0.075	0.191	0.694	-0.322	0.120	0.007	-0.183	0.093	0.049
M2 + triglycerides	0.390	0.190	0.040	-0.298	0.118	0.012	-0.245	0.093	0.008
M2 + glucose	0.266	0.188	0.158	-0.367	0.118	0.002	-0.209	0.092	0.025
M2 + insulin resistance	0.233	0.190	0.220	-0.255	0.118	0.031	-0.219	0.093	0.018
M2 + HDL cholesterol	0.305	0.189	0.108	-0.359	0.119	0.003	-0.219	0.092	0.018
M2 + SBP	0.152	0.180	0.399	-0.462	0.117	<0.001	-0.223	0.092	0.007
M2 + DBP	0.347	0.185	0.059	-0.432	0.118	<0.001	-0.216	0.091	0.018
M3 ⁵	0.130	0.187	0.486	-0.222	0.119	0.063	-0.208	0.094	0.026

¹ In the multiple linear regression analyses, RRR dietary pattern score was used as a continuous variable in the models. BSA, body surface area; SBP, systolic blood pressure; DBP, diastolic blood pressure; M1, M2, and M3, models 1, 2, and 3.

² Stroke index = stroke volume/BSA.

³ Adjusted for age, sex, and race.

⁴ Adjusted for M1 plus education, physical activity, smoking, alcohol consumption, and study sites.

⁵ Fully adjusted for M2 plus all components of the metabolic syndrome (waist circumference, SBP, HDL, triglycerides, and glucose).

Strengths and limitations

The present study had several strengths. First, in contrast with previous studies that used PCA to characterize dietary patterns, our study used the RRR method, which allowed us to generate hypotheses about potential mediators between dietary patterns and LV function. Second, the accuracy and reproducibility of cardiac MRI permitted us to identify relations between dietary patterns and LV function that would have been otherwise difficult to detect with previously available noninvasive methods. Third, the large sample size allowed the detection of very small differences in mass and systolic function in relation to dietary patterns in participants free of clinical cardiovascular disease.

Several limitations should also be considered when interpreting the results. First, temporality and causality cannot be inferred from cross-sectional data such as ours; thus, inferences on mediating factors need to be confirmed by longitudinal data. Second, participants were excluded at study entry based on their self-reported cardiovascular disease status; therefore, it was possible that underreporting of these diseases occurred. Third, the MESA cohort is not necessarily representative of all populations, which may limit the generalizability of our findings.

Notwithstanding these limitations, the results of the present study suggest that a dietary pattern characterized by intake of foods with a high glycemic index, high-fat meats, cheeses, and processed foods and low intakes of vegetables, soy, fruit, green and black tea, low-fat dairy desserts, seeds and nuts, and fish is significantly associated with unfavorable LV function, and this association might be mediated by metabolic dysfunction.

We thank the other investigators, staff, and participants of the Multi-Ethnic Study of Atherosclerosis for their valuable contributions. A list of participating MESA investigators and institutes can be found at <http://www.mesa-nhlbi.org>.

The authors' responsibilities were as follows—LL: analytical design, data analyses, and manuscript preparation; JAN: analytical design, data analysis and critical review of the manuscript; AGB: critical review of the manuscript;

DAB: critical review of the manuscript; JAL: critical review of the manuscript; and MS: analytical design, data acquisition, and critical review of the manuscript. None of the authors had a conflict of interest to report.

REFERENCES

- Rosamond W, Flegal K, Friday G, et al. Heart disease and stroke statistics—2007 update: a report from the American Heart Association Statistics Committee and Stroke Statistics Subcommittee. *Circulation* 2007;115:e69–171.
- Liu L. A new epidemic of heart failure in the United States: findings from the National Hospital Discharge Surveys, 1980–2006. *Circulation* 2008b;118:S1092 (abstr).
- Rich MW. Heart failure in older adults. *Med Clin North Am* 2006;90:863–85, xi.
- Liu L, Yin X, Ikeda K, Sullivan DH, Eisen HJ. Micronutrients, inflammation, and congestive heart failure among the elderly; nutritional perspectives on primary prevention and clinical treatment. *Clin Exp Pharmacol Physiol* 2007;34:S14–6.
- Ershow AG, Costello RB. Dietary guidance in heart failure: a perspective on needs for prevention and management. *Heart Fail Rev* 2006;11:7–12.
- Bhattacharya SK, Ahokas RA, Carbone LD, et al. Macro- and micro-nutrients in African-Americans with heart failure. *Heart Fail Rev* 2006;11:45–55.
- Liu L, Eisen HJ. Serum vitamin D concentration and congestive heart failure in the elderly. *J Card Fail* 2006;12:S90 (abstr 291).
- Pala V, Sieri S, Masala G, et al. Associations between dietary pattern and lifestyle, anthropometry and other health indicators in the elderly participants of the EPIC-Italy cohort. *Nutr Metab Cardiovasc Dis* 2006;16:186–201.
- Fung TT, Schulze M, Manson JE, Willett WC, Hu FB. Dietary patterns, meat intake, and the risk of type 2 diabetes in women. *Arch Intern Med* 2004;164:2235–40.
- Hoffmann K, Schulze MB, Schienkiewitz A, Nothlings U, Boeing H. Application of a new statistical method to derive dietary patterns in nutritional epidemiology. *Am J Epidemiol* 2004;159:935–44.
- Nettleton JA, Steffen LM, Schulze MB, et al. Associations between markers of subclinical atherosclerosis and dietary patterns derived by principal components analysis and reduced rank regression in the Multi-Ethnic Study of Atherosclerosis (MESA). *Am J Clin Nutr* 2007;85:1615–25.

12. Iribarren C, Karter AJ, Go AS, et al. Glycemic control and heart failure among adult patients with diabetes. *Circulation* 2001;103:2668–73.
13. Stratton IM, Adler AI, Neil HA, et al. Association of glycaemia with macrovascular and microvascular complications of type 2 diabetes (UKPDS 35): prospective observational study. *BMJ* 2000;321:405–12.
14. de las Fuentes L, Brown AL, Mathews SJ, et al. Metabolic syndrome is associated with abnormal left ventricular diastolic function independent of left ventricular mass. *Eur Heart J* 2007;28:553–9.
15. Rutter MK, Parise H, Benjamin EJ, et al. Impact of glucose intolerance and insulin resistance on cardiac structure and function: sex-related differences in the Framingham Heart Study. *Circulation* 2003;107:448–54.
16. Bild DE, Bluemke DA, Burke GL, et al. Multi-ethnic study of atherosclerosis: objectives and design. *Am J Epidemiol* 2002;156:871–81.
17. Natori S, Lai S, Finn JP, et al. Cardiovascular function in Multi-Ethnic Study of Atherosclerosis: normal values by age, sex, and ethnicity. *AJR Am J Roentgenol* 2006;186:S357–65.
18. Block G, Woods M, Potosky A, Clifford C. Validation of a self-administered diet history questionnaire using multiple diet records. *J Clin Epidemiol* 1990;43:1327–35.
19. Mayer-Davis EJ, Vitolins MZ, Carmichael SL, et al. Validity and reproducibility of a food frequency interview in a Multi-Cultural Epidemiology Study. *Ann Epidemiol* 1999;9:314–24.
20. Nettleton JA, Steffen LM, Ni H, Liu K, Jacobs DR Jr. Dietary patterns and risk of incident type 2 diabetes in the Multi-Ethnic Study of Atherosclerosis (MESA). *Diabetes Care* 2008;31:1777–82.
21. Friedewald WT, Levy RI, Fredrickson DS. Estimation of the concentration of low-density lipoprotein cholesterol in plasma, without use of the preparative ultracentrifuge. *Clin Chem* 1972;18:499–502.
22. McAuley KA, Williams SM, Mann JI, et al. Diagnosing insulin resistance in the general population. *Diabetes Care* 2001;24:460–4.
23. Grundy SM. A constellation of complications: the metabolic syndrome. *Clin Cornerstone* 2005;7:36–45.
24. Aronow WS. ACC/AHA guideline update: treatment of heart failure with reduced left ventricular ejection fraction. *Geriatrics* 2006;61:22–9.
25. McNaughton SA, Mishra GD, Brunner EJ. Dietary patterns, insulin resistance, and incidence of type 2 diabetes in the Whitehall II Study. *Diabetes Care* 2008;31:1343–8.
26. Ashrafian H, Frenneaux MP, Opie LH. Metabolic mechanisms in heart failure. *Circulation* 2007;116:434–48.
27. Burchfiel CM, Skelton TN, Andrew ME, et al. Metabolic syndrome and echocardiographic left ventricular mass in blacks: the Atherosclerosis Risk in Communities (ARIC) Study. *Circulation* 2005;112:819–27.
28. Devereux RB, Roman MJ, Liu JE, et al. Congestive heart failure despite normal left ventricular systolic function in a population-based sample: the Strong Heart Study. *Am J Cardiol* 2000;86:1090–6.
29. Bertoni AG, Tsai A, Kasper EK, Brancati FL. Diabetes and idiopathic cardiomyopathy: a nationwide case-control study. *Diabetes Care* 2003;26:2791–5.