Dietary Patterns Derived by Reduced Rank Regression Are Inversely Associated with Type 2 Diabetes Risk across 5 Ethnic Groups in the Multiethnic Cohort1,2

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Abstract

Background: Reduced rank regression (RRR) is an approach to identify dietary patterns associated with biochemical markers and risk of type 2 diabetes (T2D).

Objective: We aimed to derive dietary patterns associated with adiponectin, leptin, C-reactive protein (CRP), and triglycerides (TGs) and to examine the prospective associations of these patterns with T2D risk in 5 ethnic/racial groups with differences in T2D rates.

Methods: The Multiethnic Cohort (MEC) included 215,831 African-American, Japanese-American, Latino, Native Hawaiian, and white adults living in Hawaii and California who completed a validated quantitative food-frequency questionnaire in 1993–1996. T2D status was based on self-report with confirmation by administrative data. Serum CRP and TGs and plasma adiponectin and leptin were measured —10 y after baseline in a subset (n = 10,008) of participants. RRR was applied to dietary data and biomarker information of 10,008 MEC participants in the combined population and in each ethnic/racial group. RRR-derived dietary patterns, simplified by removal of foods that were not found to be important, were subsequently evaluated for association with T2D risk in 155,316 cohort members (8687 incident T2D cases diagnosed by 2010) by using Cox proportional hazards regression.

Results: Combining ethnic/racial groups, we identified a dietary pattern low in processed and red meat, sugar-sweetened beverages, diet soft drinks, and white rice and high in whole grains, fruit, yellow-orange vegetables, green vegetables, and low-fat dairy that was inversely associated with CRP, TGs, and leptin and positively related to adiponectin. Comparing extreme tertiles, the dietary pattern predicted a 16–28% significantly lower T2D risk in the combined study population and also separately in African Americans, Japanese Americans, Latinos, Native Hawaiians, and whites. Ethnicity-specific derived patterns varied only modestly from the overall pattern and resulted in comparable associations with T2D.

Conclusion: This identified dietary pattern may lower T2D risk through its impact on adipokines, by lowering chronic inflammation and dyslipidemia across 5 ethnic/racial groups. Curr Dev Nutr 2017;1:e000620.

Introduction

More than 415 million people worldwide have type 2 diabetes (T2D)10; by 2040, the number of people with T2D is predicted to reach 642 million (1). In the United States, higher T2D prevalence rates are reported in Asian Americans, Pacific Islanders (2, 3), African Americans,
and Hispanics (4) than in whites. Excess body weight, genetic predisposition, and metabolic factors, as reflected in different T2D biomarker profiles across ethnic groups (5), along with modifiable lifestyle factors such as diet and exercise, may contribute to ethnic/racial differences in T2D.

Dietary patterns may capture the synergistic effects of multiple influential aspects of diet. Two approaches to characterizing overall diet are commonly distinguished: a priori indexes and a posteriori patterns. A priori indexes evaluate dietary quality and are constructed from adherence to dietary recommendations made on the basis of existing scientific evidence relating diet to chronic diseases. A posteriori–derived dietary patterns are identified through exploratory data-driven approaches, such as factor analysis, which is used to identify common underlying patterns of food consumption (6). Dietary patterns have been associated with T2D; in the Hawaii component of the Multiethnic Cohort (MEC), the associations between the a priori indexes Healthy Eating Index (HEI) and Mediterranean diet (aMED) and T2D risk were strongest in whites compared with Native Hawaiians and Japanese Americans (7), whereas factor analysis–derived dietary patterns were not significantly associated with T2D in Native Hawaiians and showed inconsistent associations in whites and Japanese Americans (8). These inconsistent findings may be due to the a priori methods not taking into account ethnicity-specific consumption patterns—for example, the concentration on one starch, such as rice—and a posteriori methods not being optimally suited to identify dietary patterns predictive of disease risk. A method that combines a priori and a posteriori approaches is reduced rank regression (RRR) (9). In contrast to a priori and a posteriori methods, RRR-derived dietary patterns use a data-driven approach, identify factors that explain covariation in food consumption, are associated with intermediate disease markers, and incorporate ethnicity-specific differences in diet and biomarkers, and thus are likely to include foods that are related to disease risk. Previous studies identified dietary patterns predictive of T2D by using different intermediate markers as response variables, including inflammatory markers (10–13), HOMA-IR (14, 15), glycated hemoglobin (HbA1c) (10, 15), fasting glucose (15), adiponectin (10, 16), HDL cholesterol (10, 16), and TGs (16).

Because previous studies (10–16) did not investigate RRR-derived dietary patterns and T2D risk in different ethnic groups in the United States, the first aim was to compare dietary patterns associated with T2D-related biomarkers (17, 18) [adiponectin, leptin, TGs, and C-reactive protein (CRP)] derived in the combined study population and each ethnic/racial group. The second aim was to evaluate the associations of these dietary patterns with T2D risk in African-American, Japanese-American, Latino, Native Hawaiian, and white MEC participants.

**Methods**

**Study population**

The MEC is a prospective cohort study primarily established to study lifestyle and genetic factors and cancer among different ethnic/racial groups in Hawaii and California (19). The cohort includes 215,831 men and women, aged 45–75 y at recruitment (1993–1996), living in Hawaii and in Los Angeles, California, with the following ethnic/racial distribution: African American (16.3%), Japanese American (26.4%), Latino (22.0%), Native Hawaiian (6.5%), white (22.9%), and other ancestry (5.8%) (19). From 1993 to 1996, participants enrolled in the cohort by completing a self-administered mail questionnaire on diet, demographic characteristics, medical conditions, lifestyle factors, and anthropometric measures (19). Biological specimens (mainly blood and urine samples) were collected from a subset of the cohort (n = 68,740) primarily during 2001–2006. Of these 68,740 participants, a panel of biochemical markers was assessed in a biomarker subcohort of 12,578 predominantly fasting individuals, who were selected from controls in case-control studies within the MEC.

**Dietary assessment**

Dietary data were collected at baseline by a validated and calibrated self-administered quantitative FFQ (QFFQ) with >180 food items (20) specifically designed for use in this multiethnic population (19). Food mixtures were disaggregated into their components, and each ingredient was assigned to the relevant food item. Individual food items and foods from mixed dishes were classified into 41 food groups on the basis of nutrient profiles and culinary uses.

**Ascertainment of T2D**

On the basis of the information from 3 questionnaires [1993–1996 (baseline), 1999–2002, and 2003–2007] and 3 sources of administrative data [i.e., Medicare claims (21), California hospital discharge diagnoses (22), and a Hawaii health plan linkage (2)], we developed a strict definition of T2D. Only participants with ≥1 self-reported T2D diagnosis on one of the questionnaires and confirmation by ≥1 administrative data source were considered incident cases. The first report of a T2D diagnosis was considered as the year of discovery because exact dates of diagnosis were unavailable.

**Laboratory procedures**

Adiponectin and leptin from plasma were measured by using ELISA kits (catalog no. DRP300; R&D Systems). Insulin from serum was measured by using an ELISA kit (catalog no. EZHI-14K; EMD Millipore). All ELISA protocols were followed in accordance with the manufacturers’ instructions. A Cobas Mira Plus chemistry autoanalyzer (Roche Diagnostics) was used to measure serum glucose (kit from Randox), CRP, and TGs (kits from Pointe Scientific, Inc.) per the manufacturers’ instructions. HOMA-IR was calculated as follows: [fasted insulin (microunits/liter) × fasting glucose (milligrams/deciliter)]/405 (23).

For the current analysis, the 4 biomarkers—TGs, leptin, CRP, and adiponectin—were chosen as the intermediate markers of T2D serving as response variables for RRR for the following reasons: they are affected by diet (24–27), they showed a cross-sectional association with HOMA-IR as a marker of a prediabetic stage in nondiabetics from all ethnic groups in the current analysis (r across ethnic groups: −0.28 to −0.47 for adiponectin, 0.34–0.47 for leptin, 0.14–0.25 for CRP, and 0.25–0.40 for TGs), and previous studies indicate that the 4 biomarkers are related to the pathophysiology...
**TABLE 1** Food group intake medians by tertile of the original (nonsimplified) RRRDS<sub>comb</sub> and correlations of the food groups with the RRRDS<sub>comb</sub> in the biomarker subcohort<sup>1</sup>

| Food groups, g/d | All ethnic groups combined | African American | Japanese American | Latino | Native Hawaiian | White |
|------------------|---------------------------|-----------------|------------------|-------|----------------|-------|
|                  | n                         | Median T1 (645) | Median T3 (676) |       | Median T1 (800) | Median T3 (1003) |       | Median T1 (705) | Median T3 (181) |       | Median T1 (210) | Median T3 (109) |       |
|                  | RRDS<sub>comb</sub> score  | T1 (-0.2 to 0.35) | T3 (-0.3 to 0.45) |       | T1 (-3.7 to 0.35) | T3 (-0.3 to 0.45) |       | T1 (-10.2 to 0.36) | T3 (-0.3 to 0.65) |       | T1 (-3.4 to 0.65) | T3 (-0.3 to 0.65) |       |
| range            |                           |                 |                  |       |                 |                  |       |                 |                  |       |                 |                  |       |
| Food groups, g/d |                           |                 |                  |       |                 |                  |       |                 |                  |       |                 |                  |       |
| Processed meat   | 22.1                      | 20.0            | 21.4             |       | 20.4            | 20.0             |       | 20.2            | 27.6             |       | 17.6            | 22.3             |       |
| Red meat         | 25.7                      | 41.1            | 44.7             |       | 69.2            | 66.0             |       | 60.5            | 45.6             |       | 45.6            | 74.4             |       |
| SSBs             | 63.9                      | 50.9            | 59.2             |       | 59.2            | 59.2             |       | 59.2            | 59.2             |       | 59.2            | 59.2             |       |
| Diet drinks      | 0.0                       | 11.8            | 11.8             |       | 0.0             | 11.8             |       | 11.8            | 11.8             |       | 11.8            | 11.8             |       |
| White rice       | 71.1                      | 16.4            | 13.2             |       | 17.8            | 17.8             |       | 286             | 286             |       | 56.6            | 56.6             |       |
| Whole grains     | 20.1                      | 16.4            | 13.2             |       | 17.8            | 17.8             |       | 286             | 286             |       | 56.6            | 56.6             |       |
| Fruit            | 129                       | 120             | 112              |       | 176             | 176              |       | 126             | 126              |       | 106             | 106              |       |
| Yellow-orange    | 15.7                      | 13.6            | 11.6             |       | 15.5            | 15.5             |       | 17.9            | 17.9             |       | 14.4            | 14.4             |       |
| vegetables       |                           | 34.4            | 32.7             |       | 33.4            | 33.4             |       | 31.1            | 31.1             |       | 40.2            | 40.2             |       |
| Green vegetables | 87.3                      | 77.3            | 95.5             |       | 76.3            | 76.3             |       | 101             | 101             |       | 85.5            | 85.5             |       |
| Low-fat dairy    | 97.9                      | 15.7            | 17.0             |       | 12.8            | 12.8             |       | 82.7            | 82.7             |       | 46.2            | 46.2             |       |

<sup>1</sup>Values are medians of food group intakes and Pearson correlation coefficients (r) between the food group intakes and RRDS<sub>comb</sub>; n = 10,008. Only food groups with factor loadings ≥ 0.2 in the combined analysis are shown. *P < 0.05. RRDS<sub>comb</sub> dietary pattern score obtained by combining ethnic groups; SSB, sugar-sweetened beverage; T, tertile.
American, Latino, or Native Hawaiian; only in combined analysis),
physical activity (<30 or ≥30 min/d), and smoking status (never
smoker, past smoker, or current smoker). For missing values of
smoking status and physical activity, a missing category was created
for each variable (−1% missing data). The significance of linear
trends across dietary pattern tertiles was tested by assigning each
participant the median value for his or her tertile and modeling
this value as a continuous variable.

Association of dietary patterns with T2D. For the application
of the RRR-derived dietary patterns in the entire MEC (n = 215,831),
we first excluded the biomarker subcohort participants (n = 12,578)
to obtain independent samples for the identification of dietary
pattern and to assess the association of the pattern with T2D
risk. Second, we excluded (with some overlap) prevalent dia-
etes cases at cohort entry (n = 28,153), ethnic groups other than
the major ethnic groups (n = 13,994), and those with missing
information on essential covariates (n = 11,940), resulting in a final
number of 155,316 participants representing an independent
sample without biomarker measurements.

To make the results more generalizable and easier to interpret,
and to reduce the possibility of overfitting, we simplified
the dietary pattern score by calculating the unweighted sum of
the z-standardized intakes of food groups with factor loadings
>0.2 of the absolute value (9). We subsequently applied the simpli-
ﬁed scores in the full cohort and estimated HRs for risk of T2D by
using Cox proportional hazards regression for the continuous di-
etary pattern scores and across dietary pattern tertiles. Observa-
tion started at the time of cohort entry and ended at the T2D time
of discovery, death, or closure date for follow-up (31 December
2010). The model was adjusted for age as a strata variable and
for the same confounders as used in the biomarker analysis in
the log-linear component of the model.

In sensitivity analyses, we first excluded all participants who
provided blood (n = 68,740). We then investigated the impact of
excluding participants with lipid-lowering and anti-inflammation
medications on the results of the RRR analysis. We also excluded non-
fasting participants in the RRR analysis, as well as participants with
acute in
flammation (indicated by CRP concentrations >10 mg/L),
and participants with extreme energy intakes that fell outside the rec-
commended cutoffs (<500 and >3500 kcal/d) (30). Finally, because
body fat may confound associations between food intake and bio-
markers, we additionally adjusted all biomarker values for BMI before
their use as response variables in the RRR in a separate analysis.

### Table 2

|                     | African American | Japanese American | Latino | Native Hawaiian | White |
|---------------------|------------------|-------------------|--------|-----------------|-------|
|                     | T1 Factor        | T3 Factor         | T1 Factor| T3 Factor      | T1 Factor| T3 Factor | T1 Factor| T3 Factor | T1 Factor| T3 Factor |
| Food groups, g/d    |                  |                   |        |                 |       |
| Processed meat      | 17.1             | 23.8              | 21.0   | 24.1            |       |
| Red meat            | 39.7             | 49.2              | 66.7   | 57.6            |       |
| Poultry             | 63.9             | 37.4              | 49.7   | 41.7            |       |
| Shellfish           | 3.8              | 4.3               | 2.5    | 4.4             |       |
| Eggs                | 11.4             | 14.8              | 12.8   | 12.6            |       |
| Other tubers &      | 22.1             | 24.0              | 22.7   | 49.8            |       |
| potatoes            |                  |                   | <0.01  | 0.37            |       |
| French fries        | 3.3              | 5.8               | 5.8    | 4.6             | 5.8   |
| SSBs                | 29.6             | 50.9              | 128    | 50.9            | 11.8  |
| Diet soft drinks    | 0.0              | 0.0               | 0.0    | 25.5            |       |
| White rice          | 16.4             | 80.0              | 8.2    | 286              | 46.1  |
| Fish                | 11.1             | 20.8              | 6.1    | 3.2             | 13.6  |
| Nuts                | 3.1              | 3.1               | 1.7    | 3.4             |       |
| Whole grains        | 37.5             | 17.8              | 17.8   | 32.9            | 34.8  |
| Fruit               | 160              | 120               | 188    | 152             |       |
| Yellow-orange       | 15.6             | 17.7              | 16.9   | 23.4            |       |
| vegetables          |                  |                   | <0.05  | <0.03           |       |
| Green vegetables    | 83.7             | 104               | 78.6   | 119             |       |
| Cruciferous         | 33.6             | 39.6              | 21.8   | 47.2            |       |
| vegetables          |                  |                   | <0.16  | <0.14           |       |
| Tomatoes            | 5.8              | 5.8               | 10.3   | 9.9             |       |
| Other vegetables    | 0.0              | 2.5               | 0.0    | 2.5             |       |
| Low-fat dairy       | 19.7             | 19.7              | 14.5   | 38.0            | 97.2  |
| Legumes             | 19.4             | 11.2              | 69.8   | 13.9            |       |
| Cottage cheese      | 0.0              | 0.0               | 0.0    | 0.0             |       |
| Coffee              | 171              | 248               | 338    | 154             |       |
| Alcohol, drinks/d   | 0.1              | 0.0               | 0.1    | 0.0             |       |

1Values are medians of the food group intakes and factor loadings; n = 10,008. Only food groups with factor loadings ≥0.2 in ≥1 of the ethnic groups are shown. For African Americans, Native Hawaiians, Japanese Americans, and Latinos, the factor loadings signs were reversed to enable better comparison across ethnic groups.

RRRDSethni, dietary pattern scores derived ethnicity-specifically; SSB, sugar-sweetened beverage; T, tertile.
### TABLE 3
Baseline characteristics of the biomarker subcohort by tertile of original (nonsimplified) RRRDScomb

|                        | All ethnic groups combined | African American | Japanese American | Latino | Native Hawaiian | White |
|------------------------|----------------------------|------------------|-------------------|--------|-----------------|-------|
| **RRRDScomb score**    |                            |                  |                   |        |                 |       |
| range                  | -10.2 to 0.0               | -10.2 to 0.0     | -10.2 to 0.0      | -10.2  | -10.2 to 0.0    | -10.2 |
| n                      | 3334                      | 3334             | 3334              | 3334   | 3334            | 3334  |
| **Sex, % male**        |                            |                  |                   |        |                 |       |
| 58.0                   |                            | 58.0             | 58.0              | 58.0   | 58.0            | 58.0  |
| **Age, y**             |                            |                  |                   |        |                 |       |
| 7.77                   | 8.17                      | 8.17             | 8.17              | 8.17   | 8.17            | 8.17  |
| **BMI, kg/m²**         |                            |                  |                   |        |                 |       |
| 27.5                   | 26.3                      | 26.3             | 26.3              | 26.3   | 26.3            | 26.3  |
| **Education, %**       |                            |                  |                   |        |                 |       |
| ≤12 y                  | 41.1                      | 41.1             | 41.1              | 41.1   | 41.1            | 41.1  |
| 13–15 y                | 33.1                      | 33.1             | 33.1              | 33.1   | 33.1            | 33.1  |
| ≥16 y                  | 25.9                      | 25.9             | 25.9              | 25.9   | 25.9            | 25.9  |
| **Smoking status, %**  |                            |                  |                   |        |                 |       |
| Never                  | 40.6                      | 40.6             | 40.6              | 40.6   | 40.6            | 40.6  |
| Ever                   | 59.4                      | 59.4             | 59.4              | 59.4   | 59.4            | 59.4  |
| **Physical activity, %** |            |                  |                   |        |                 |       |
| <30 min                | 35.1                      | 35.1             | 35.1              | 35.1   | 35.1            | 35.1  |
| ≥30 min                | 64.9                      | 64.9             | 64.9              | 64.9   | 64.9            | 64.9  |
| **Energy intake, kcal** | 10122                    | 9073             | 8073              | 8073   | 8073            | 8073  |

1 Values are means ± SDs unless otherwise indicated; n = 10,008. Missing data: Smoking status, n = 123; Physical activity, n = 130. RRRDScomb, dietary pattern score obtained by combining ethnic groups; T, tertile.
The simplified RRR-derived pattern showed moderate correlations with the previously published a priori index scores (7) \((r = 0.65, 0.51, 0.42, \text{ and } 0.67 \text{ for HEI-2010, AHEI-2010, aMED, and DASH, respectively})\) and factor analysis–derived patterns (8) \((r = -0.43, 0.44, \text{ and } 0.49 \text{ for the ”fat and meat,” ”vegetables,” and ”fruit and milk” factors, respectively})\) in the full cohort.

**Dietary pattern and incident T2D in the full cohort**

We identified 8687 incident T2D cases between cohort entry and 2010 among 155,316 participants of the full MEC (mean follow-up time = 14.8 y). Comparing extreme tertiles, the RRRDS\(_{\text{comb}}\) was significantly related to a 16–28% T2D risk reduction in the combined analysis and across ethnic groups (Table 5). RRR scores 1, 3 and 4 were not related to T2D risk (data not shown). When comparing extreme tertiles of the RRRDS\(_{\text{ethni}}\), there was a significant 16–31% reduction in T2D risk across ethnic groups in the multivariable–adjusted model (Table 6), with apparently stronger associations in Native Hawaiians.

**Sensitivity analyses**

After additional adjustment of all biomarker values for BMI before their use as response variables in the RRR, diet soft drinks were no longer an important component of the second RRR pattern, whereas the other foods identified as important in the main analysis still showed factor loadings >0.15; and a similar association of the pattern with biomarkers and slightly weaker associations with T2D as in the main analysis was observed. The exclusion of participants with lipid-lowering and anti-inflammatory medication use, nonfasting participants, participants with acute inflammation, and participants with extreme energy intake yielded similar results in the RRR analysis; and all participants who provided blood yielded similar results compared with the main analysis in the Cox regression (data not shown).

**Discussion**

With the use of the RRR method, we derived a dietary pattern low in processed and red meat, SSBs, diet soft drinks, and white rice and high in whole grains, fruit, yellow-orange and green vegetables, and low-fat dairy. This dietary pattern was longitudinally associated with T2D-related biomarkers of inflammation, dyslipidemia, and adipokines. Comparing extreme tertiles, the pattern was associated with a 16–28% lower T2D incidence in 5 ethnic groups. Ethnicity–specific derived dietary patterns showed similar characteristics with small ethnic differences and yielded a similar magnitude of a 16–31% risk reduction for T2D across ethnic groups comparing extreme tertiles, with an apparently stronger risk reduction in Native Hawaiians.

The simplified RRR-derived pattern showed moderate correlations with the previously published a priori index scores (7) \((r = 0.65, 0.51, 0.42, \text{ and } 0.67 \text{ for HEI-2010, AHEI-2010, aMED, and DASH, respectively})\) and factor analysis–derived patterns (8) \((r = -0.43, 0.44, \text{ and } 0.49 \text{ for the ”fat and meat,” ”vegetables,” and ”fruit and milk” factors, respectively})\) in the full cohort.

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data-driven methods by incorporating previous knowledge of the relation between diet and biomarkers as intermediate measures of disease risk and, therefore, is more likely to identify a disease-related dietary pattern (9). A priori dietary indexes were originally created and tested in individuals of European and African-American (for DASH) heritage and therefore food consumption patterns of other ethnic groups are not as well represented in the a priori indexes. In contrast, the RRR method identifies dietary patterns that typically exist in the study population, including foods consumed by different ethnic groups.

Whereas some of the important food components of the current RRR-derived pattern were also components of some of the previously (7) investigated a priori indexes (e.g., processed and red meat, whole grains, SSBs, fruit), the food components “white
TABLE 5 Ethnicity-specific HRs (95% CIs) of T2D by tertile of the simplified RRRDScomb score in the full MEC1

| Ethnic groups combined | Tertile of simplified dietary pattern score | Continuous simplified dietary pattern score2 |
|------------------------|--------------------------------------------|---------------------------------------------|
|                        | 1                          | 2                          | 3                          |                               |
| RRDScomb score range   | −7.94 to −0.37            | −0.37 to 0.30              | 0.30 to 13.3               |                               |
| Diabetes cases/population at risk, n/n | 3654/52,526               | 2695/51,566                | 2338/51,224                | 8687/155,316                 |
| Multivariable-adjusted HR (95% CI) | 1.00 (ref)                  | 0.87 (0.83, 0.92)          | 0.79 (0.75, 0.84)          | 0.91 (0.89, 0.93)            |
| African American       |                            |                            |                            |                               |
| RRDScomb score range   | −7.28 to −0.37            | −0.37 to 0.30              | 0.30 to 10.7               |                               |
| Diabetes cases/population at risk, n/n | 496/7712                   | 503/9086                   | 370/7588                   | 1369/24,386                  |
| Multivariable-adjusted HR (95% CI) | 1.00 (ref)                  | 0.92 (0.81, 1.05)          | 0.81 (0.70, 0.94)          | 0.93 (0.87, 0.99)            |
| Latino                 |                            |                            |                            |                               |
| RRDScomb score range   | −6.85 to −0.37            | −0.37 to 0.30              | 0.30 to 6.78               |                               |
| Diabetes cases/population at risk, n/n | 1268/16,591                | 796/14,372                 | 748/14,778                 | 2812/45,741                  |
| Multivariable-adjusted HR (95% CI) | 1.00 (ref)                  | 0.88 (0.80, 0.96)          | 0.84 (0.76, 0.93)          | 0.89 (0.83, 0.97)            |
| Native Hawaiian       |                            |                            |                            |                               |
| RRDScomb score range   | −7.94 to −0.37            | −0.37 to 0.30              | 0.30 to 10.9               |                               |
| Diabetes cases/population at risk, n/n | 706/10,495                 | 639/10,950                 | 529/10,674                 | 1874/32,119                  |
| Multivariable-adjusted HR (95% CI) | 1.00 (ref)                  | 0.94 (0.84, 1.05)          | 0.81 (0.72, 0.92)          | 0.89 (0.85, 0.93)            |
| White                 |                            |                            |                            |                               |
| RRDScomb score range   | −6.41 to −0.37            | −0.37 to 0.30              | 0.30 to 8.62               |                               |
| Diabetes cases/population at risk, n/n | 762/13,967                 | 541/14,613                 | 434/15,039                 | 1737/43,619                  |
| Multivariable-adjusted HR (95% CI) | 1.00 (ref)                  | 0.83 (0.74, 0.93)          | 0.72 (0.63, 0.81)          | 0.87 (0.83, 0.92)            |

1 n = 155,316. Participants from the biomarker subcohort were excluded in the full cohort for independent samples. The simplified dietary pattern score was calculated as the sum of unweighted standardized intakes of food items, based on the RRR results derived by combining ethnic groups (fruit + low-fat dairy + green vegetables + yellow-orange vegetables + whole grains – processed meat – red meats – white rice – sugar-sweetened beverages – diet soft drinks). Stratified by age (continuous), sex, education (=12 y, 13–15 y, or ≥16 y), race/ethnicity (white, African American, Native Hawaiian, Japanese American, or Latino; only in combined analysis), physical activity (<30 or ≥30 min/d), and smoking status (never smoker, past smoker, or current smoker). MEC, Multiethnic Cohort; ref, reference; RRR, reduced rank regression; RRRDScomb, dietary pattern score obtained by combining ethnic groups, T2D, type 2 diabetes.

2 z-standardized (mean = 0, SD = 1).

rice,” “green vegetables,” “yellow-orange vegetables,” and “low-fat dairy” are newly identified foods that had not been part of the a priori indexes, with the exception of “low-fat dairy” in the DASH index. A meta-analysis reported that white rice consumption was consistently directly associated with T2D risk, particularly in Asian populations (31), which may be due to its contribution to dietary glycemic load (e.g., white rice explains 58.5% of the dietary glycemic load in Japanese women) (32). Moreover, in comparison with minimally processed whole grains, white rice is poor in nutrients, including insoluble fiber and magnesium, that have been associated with lower T2D risk in the MEC (33).

Recent meta-analyses of cohort studies also described inverse associations of low-fat dairy (34) and green leafy and yellow vegetables (35) with T2D risk. A high consumption of low-fat dairy products may reduce T2D risk via weight reduction and lower inflammation (36), consistent with the weak inverse correlation between low-fat dairy products and CRP seen in the current analysis. Green vegetables are rich sources of fiber, polyphenols, vitamin C, and other bioactive compounds that contain anti-inflammatory properties (37), consistent with a weak inverse correlation of green vegetable intake with CRP in the current analysis. Processed meat (38), red meat (38, 39), and SSBs (40) were also directly related to T2D risk; and fruit intake (35) was inversely related to T2D risk in meta-analyses. Independent of BMI, red meat correlated inversely with adiponectin and directly with CRP, leptin, and TGs in the current study, whereas previous studies described no association of red meat with adiponectin (41, 42) and TGs (42) and a direct association of red meat with CRP, which was not independent of BMI (41, 42). With the use of the BMI-adjusted biomarker concentrations as responses in RRR, only diet soft drinks were no longer an important component of the pattern. Confounding or reverse causation might therefore explain the identification of diet soft drinks as a pattern component.

An increasing number of studies have used the RRR approach to identify dietary patterns predictive of T2D by using different intermediate markers as response variables, including inflammatory markers (10–13), HOMA-IR (14, 15), Hba1c (10, 15), fasting glucose (15), adiponectin (10, 16), HDL cholesterol (10, 16), and TGs (16). The explained variation in biomarkers in these studies ranged from 3.9% to 8% (10–16), which is slightly higher than in our findings (1.2–3.6% across ethnic groups). This may be due to the assessment of biomarkers in the follow-up examination after ~10 y in the current analysis, whereas previous studies mainly used cross-sectional assessments of diet and biomarkers.

Because previous analyses (10, 16, 43) suggested that a single RRR dietary pattern is unlikely to explain several different and independent pathways, the dietary pattern in the present analysis...
white rice was an important contributor in whites, Native ful foods across ethnic groups. Ethnic di

Americans and Latinos, respectively, in the MEC. Only 1
values of 56, 242, and 275 g/d in whites, Native Hawaiians, and
population who reported a higher intake of white rice, with mean
score component in whites, Native Hawaiians, and Japanese
to the present pattern,

processed and red meat, SSBs, diet soft drinks, and fruit). Unique
pared with the patterns identi
similarities in important food groups in the present analysis com-

TABLE 6 Ethnicity-specific HRs (95% CIs) for T2D by tertile of the simplified RRRDS\textsubscript{ethnic} in the full MEC cohort\textsuperscript{1}

| Ethnicity       | Diabetes cases/population at risk, n/n | Tertile of simplified dietary pattern score | Continuous simplified dietary pattern score\textsuperscript{2} |
|-----------------|----------------------------------------|---------------------------------------------|-----------------------------------------------------|
| African American|                                         | 1                                          | 2                                              |
|                  |                                         | 1.00 (ref)                                 | 0.99 (0.87, 1.13)                                  | 0.84 (0.73, 0.96) | 0.93 (0.88, 0.99) |
|                  |                                         | 2                                          | 0.69 (0.57, 0.82)                                  | 0.89 (0.78, 0.97) |
|                  |                                         | 3                                          | 0.89 (0.85, 0.93)                                  |                      |
| Japanese American|                                         | 1.00 (ref)                                 | 0.88 (0.80, 0.96)                                  | 0.82 (0.74, 0.91) | 0.92 (0.88, 0.96) |
|                  |                                         | 2                                          | 0.76 (0.67, 0.86)                                  | 0.89 (0.85, 0.93) |
|                  |                                         | 3                                          | 0.89 (0.85, 0.93)                                  |                      |
| Latino           |                                         | 1.00 (ref)                                 | 0.89 (0.80, 1.00)                                  | 0.83 (0.74, 0.94) | 0.92 (0.88, 0.97) |
|                  |                                         | 2                                          | 0.76 (0.67, 0.86)                                  | 0.89 (0.85, 0.93) |
|                  |                                         | 3                                          | 0.89 (0.85, 0.93)                                  |                      |
| Native Hawaiian  |                                         | 1.00 (ref)                                 | 0.89 (0.80, 1.00)                                  | 0.83 (0.74, 0.94) | 0.92 (0.88, 0.97) |
|                  |                                         | 2                                          | 0.76 (0.67, 0.86)                                  | 0.89 (0.85, 0.93) |
|                  |                                         | 3                                          | 0.89 (0.85, 0.93)                                  |                      |
| White            |                                         | 1.00 (ref)                                 | 0.81 (0.72, 0.91)                                  | 0.76 (0.67, 0.86) | 0.89 (0.85, 0.93) |
|                  |                                         | 2                                          | 0.76 (0.67, 0.86)                                  | 0.89 (0.85, 0.93) |
|                  |                                         | 3                                          | 0.89 (0.85, 0.93)                                  |                      |

\textsuperscript{1}n = 155,316. Participants from the biomarker subcohort were excluded in the full cohort for independent samples. The simplified dietary pattern score was calculated as the sum of unweighted standardized intakes of food groups, based on RRR pattern analysis derived separately for African Americans (yellow-orange vegetables + cruciferous vegetables + green vegetables + tomatoes + low-fat dairy + whole grains – processed meat – red meat – poultry – shellfish – other potatoes and tubers), Japanese Americans (green vegetables + yellow-orange vegetables + legumes + fruit + low-fat dairy + whole grains – processed meat – red meat – eggs – white rice), Latinos (fish + green vegetables + yellow-orange vegetables + fruit + nuts + low-fat dairy + whole grains – processed meat – red meat – sugar-sweetened beverages), Native Hawaiians (coffee + alcohol + nuts + cottage cheese – red meat – poultry – diet soft drinks – other potatoes and tubers – French-fried potatoes – white rice), and whites (legumes + cruciferous vegetables + green vegetables + other vegetables + fruit – red meat – white rice – sugar-sweetened beverages). For African Americans, Native Hawaiians, Japanese Americans, and Latinos, the factor loadings signs were reversed to enable better comparison across ethnic groups. Stratifed by age (continuous), adjusted for BMI (continuous), total energy intake (continuous, kilojoules per day), sex, education (≤12 y, 13–15 y, or ≥16 y), physical activity (<30 or ≥30 min/d), and smoking status (never smoker, past smoker, or current smoker). MEC, Multiethnic Cohort; ref, reference; RRR, reduced rank regression; RRRDS\textsubscript{ethnic}, dietary pattern scores derived ethnicity-specifically, T2D, type 2 diabetes.

\textsuperscript{2}z-standardized (mean = 0, SD = 1).

seems to mainly explain variations in adiponectin and TGs and, to
a lesser extent, in CRP and scarcely in leptin. We detected some
similarities in important food groups in the present analysis
pared with the patterns identified in largely white study popula-
tions that used biomarkers of similar pathways (10–13) (e.g.,
processed and red meat, SSBs, diet soft drinks, and fruit). Unique
to the present pattern, “white rice” was also an important pattern
score component in whites, Native Hawaiians, and Japanese
Americans. This may be due to the Hawaiian part of the MEC pop-
ulation who reported a higher intake of white rice, with mean
values of 86, 242, and 275 g/d in whites, Native Hawaiians, and
Japanese Americans compared with 37 and 37 g/d in African
Americans and Latinos, respectively, in the MEC. Only 1–2% of
participants in the Nurses’ Health Study reported consumption of
≥107 g white rice/d (44).

The pattern derived in the combined population compared
with the patterns derived in specific ethnic/racial groups showed
differences in strength of associations with the biomarkers, with
the least significant associations observed in whites and African
Americans. This may be due to the smaller sample size of whites
in the biomarker subcohort and ethnic differences in the bio-
marker profile (5). In all groups, the ethnicity-specific derived pat-
ters were characterized by a high contribution of processed
meat, red meat, SSBs, and fruit; and the relation of the patterns
with T2D risk was mainly similar to that of the combined pattern.
These findings indicate a common ground of protective and harm-
ful foods across ethnic groups. Ethnic differences were observed
with regard to the importance of specific food groups: for example,
white rice was an important contributor in whites, Native
Hawaiians, and Japanese Americans. These ethnic groups pri-
marily reside in Hawaii where food intake often combines ele-
ments of Eastern and Western diets. Further examples of ethnic
differences include a high contribution of legumes to the
pattern associated with whites, poultry with African Americans
and Native Hawaiians, eggs with Japanese Americans, and nuts and
fish with Latinos. This may be due to the consumption of
different foods within food groups across ethnic groups.

As a major advantage in the present study, information on di-
etary intake from cohort entry, assessed biomarker information
~10 y later, and long-term follow-up for T2D risk with a vali-
dated diagnosis (i.e., self-report confirmed by administrative
data) was available. The use of a QFFQ designed for the relevant
ethnic populations allowed us to study a heterogeneous popula-
tion with wide variations in dietary habits, which may contribute
to the differences of strength of association in the dietary pattern–
T2D association that the authors found. Multiple data sources for
T2D status were available, making it possible to create a robust
definition of diagnosis that provides high specificity and avoids
misclassification.

RRR shares a number of limitations with the data-driven ap-
proaches, including that the identified food intake patterns are
pecific to the population under study. This can partially be
addressed by validation efforts in differing populations, such as
were performed in 2 previous studies (45, 46) and across ethnic
groups in the present study. The consistency of the results across
5 different ethnic populations in the current analysis adds consid-
erably to the validity of the findings. In this analysis, we reduced
the data dependency of the pattern variables by constructing

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simplified dietary patterns, and we applied a split-sample approach to address this issue, although generalizability to other populations remains a concern. Although the validation of the QFFQ with 24-h recalls indicated acceptable results (20), the 1-time dietary assessment by self-reported QFFQ was a limitation.

In conclusion, the results of the current analysis in a prospective cohort with 5 ethnic groups suggest that a diet high in fruit, low-fat dairy, green and yellow-orange vegetables, and whole grains and low in processed and red meat, white rice, SSBS, and diet soft drinks may lower the risk of developing T2D, possibly by influencing adipokine concentrations, inflammation, and dyslipidemia. The findings of the current analysis highlight the importance of studying relations between nutrition, T2D-related biomarkers, and T2D risk across ethnic groups with different food-consumption habits and varying T2D rates. These findings need to be validated in other nonwhite cohorts before translating the results into specific recommendations, including ethnicity-specific food recommendations for high-risk groups.

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