

Diet Quality and Lower Refined Grain Consumption are Associated With Less Weight Gain in a Multi-Ethnic Asian Adult Population

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ABSTRACT

Background: The prevalence of obesity is increasing in many Asian countries. However, longitudinal data on the impacts of dietary factors on weight gain in Asian populations are sparse.

Objectives: We evaluated the relationship between changes in intakes of nutrients, foods, and beverages and diet quality and long-term changes in body weight.

Methods: We used data ($n = 3064$) from the Singapore Multi-Ethnic Cohort, a prospective cohort including Chinese, Indian, and Malay residents aged 21–65 years. Dietary intakes were assessed using an FFQ, and body weight and waist circumference were measured during health examinations. Diet quality was evaluated using the Dietary Approaches to Stop Hypertension (DASH) and Alternative Healthy Eating Index (AHEI-2010) scores. Data were collected at baseline (2004–2010) and follow-up (2011–2016), with a mean follow-up of 6.0 years. Linear regression was used to assess the associations between dietary changes and weight change, adjusted for socio-demographic and lifestyle variables.

Results: Improvements in dietary quality scores (DASH, -0.34 kg per 5 points; AHEI-2010, -0.35 kg per 10 points) and replacement of carbohydrates with protein (-0.44 kg per 5% of energy) were significantly associated with less weight gain. Increased intakes of white rice ($+0.25$ kg per serving/d), soft drinks ($+0.69$ kg), red meat ($+0.58$ kg), and poultry with skin ($+0.74$ kg) were directly associated with weight gain. The replacement of 1 serving per day of white rice with whole grains (-0.68 kg), vegetables (-0.33 kg), poultry without skin (-0.79 kg), and eggs (-0.87 kg) was associated with less weight gain. Similar associations were observed between changes in dietary factors and changes in waist circumference.

Conclusions: Among Asian adults, increasing dietary quality, reducing soft drink consumption, and replacing white rice with whole grains, vegetables, and selected high-protein foods was associated with less weight gain. *J Nutr* 2021;151:2372–2382.

Keywords: weight change, nutrients, dietary patterns, foods and beverages, Asia

Introduction

The high prevalence of obesity worldwide (1) presents a grave public health threat, as obesity is a major risk factor for many chronic diseases, such as cardiovascular diseases, type 2 diabetes, obesity-related cancers, and osteoarthritis (2, 3). While the factors leading to obesity are multifactorial, diet plays a crucial role in the prevention and management of obesity (4).

The optimal diet for weight management has been widely debated in the literature (5). Some have suggested that high-fat diets are responsible for the obesity epidemic (6), while others have suggested that excess carbohydrates are to blame (7). Increasingly, more attention has been given to food groups rather than macronutrients (8–10), as foods with similar

macronutrient profiles (e.g., candy and fruit) can have different effects on body weight and health. While it is generally well accepted that certain foods, such as highly processed foods that are high in sugar and fat, are not conducive for weight management (11), critical knowledge gaps regarding the impacts of diet on body weight remain.

The majority of the longitudinal studies regarding diet and weight change have been conducted in Western populations (12). This limits the ability to make evidence-based recommendations that are contextually relevant for Asian populations, as dietary patterns can differ markedly between Asian and Western populations (13). For instance, refined grain consumption in the form of white rice and noodles is high in Asian populations (14, 15), but most studies on grain consumption have focused on bread and cereals in Western populations (16). Differences in

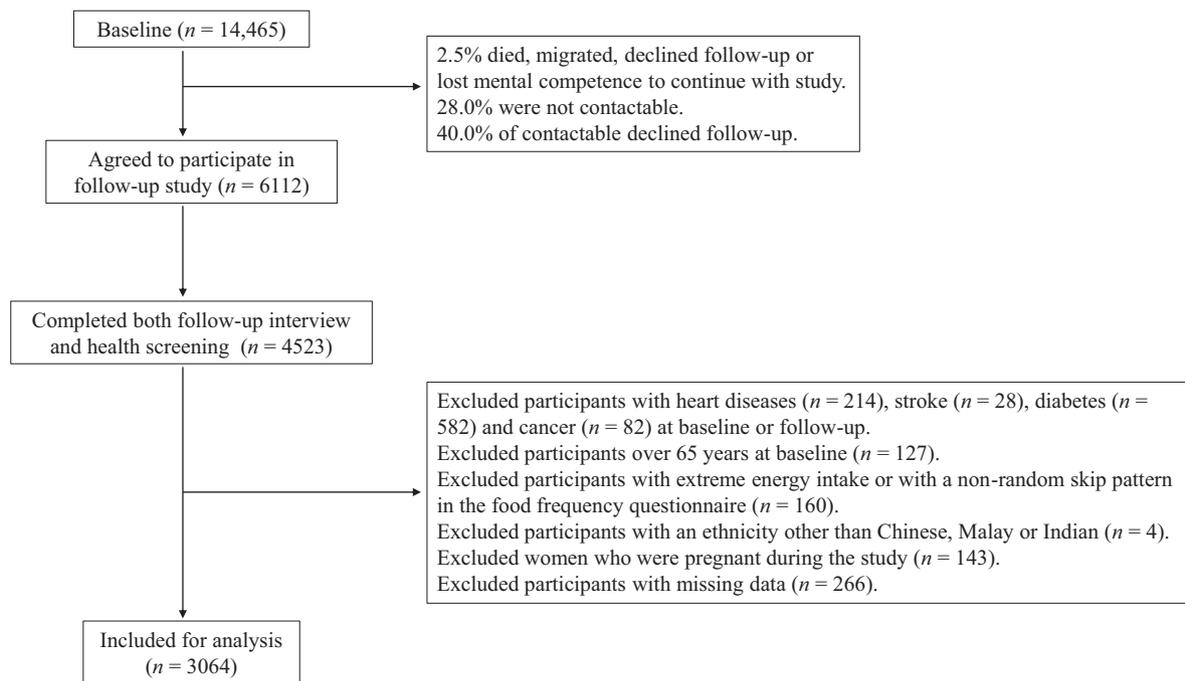


FIGURE 1 Participant flow chart.

food preparation methods across cultures can also contribute to differences in the energy content of foods (17). Even amongst studies conducted in Asia, conflicting results have been reported. Higher white rice consumption was associated with weight gain in a Japanese cohort (18) but was associated with weight loss in a Chinese cohort (19). High fruit consumption was associated with weight gain in a Japanese cohort (20), whereas fruit and vegetable consumption was associated with weight loss among Chinese men (21). These differences could be due to differences in the particular study populations, model specifications, or dietary patterns, and a comprehensive approach that evaluates dietary patterns, nutrients, and foods in relation to weight change is warranted. Furthermore, data on dietary factors and weight gain from longitudinal studies in South Asian and Southeast Asian populations are sparse.

To address these knowledge gaps, we conducted a longitudinal study in a multi-ethnic Asian population to evaluate changes in overall diet quality, intakes of nutrients, and intakes of foods and beverages in relation to changes in body weight.

Methods

Study population

We used data from the Singapore Multi-Ethnic Cohort (MEC), a prospective cohort assembled to study the impacts of genetic and

lifestyle factors on the development of chronic diseases (22). MEC is a population-based cohort with oversampling of ethnic minority groups to obtain a good representation of 3 major Asian ethnic groups: Chinese, Indians, and Malays. At baseline, 14,465 adult Singapore residents aged 21 to 65 years were recruited between 2004 to 2010 and were revisited between 2011 and 2016 (Figure 1). Out of the baseline participants, 2.5% were lost to follow-up because they died, migrated, declined follow-up, or lost mental competence to give consent to continue with the study, and 28% could not be contacted. Out of the contactable participants, 60% ($n = 6112$) agreed to participate in the follow-up study, and 4523 participants completed both the follow-up interview and health screening. We excluded participants with heart diseases, stroke, diabetes, and cancer at baseline or at follow-up; participants over 65 years at baseline, to avoid potential confounding from age-related weight loss; participants with extreme energy intakes (<500 kcal/d or >5157 kcal/d for males and >4404 kcal/d for females); those with a nonrandom skip pattern in the FFQ; participants with an ethnicity other than Chinese, Malay, or Indian; women who were pregnant during the study; and participants who did not complete the interview or health screening at baseline. We further excluded participants with missing anthropometric measurements at baseline or follow-up and participants with missing covariate information. After these exclusions, data on 3064 participants remained for the current analysis.

This study was approved by the National University of Singapore Institutional Review Board (06–127, 04–127, 10–424, 12–140) and SingHealth Centralised Institutional Review Board (CIRB 2001–001-C). All participants provided written consent to participate in this study.

Assessment of diet, weight, and covariates

Participants were visited at home to complete an interviewer-administered questionnaire. Dietary intakes were assessed using a semi-quantitative 169-item FFQ, which was developed locally and validated against three 24-hour dietary recalls with Pearson's correlation coefficients for derived nutrient intakes ranging from 0.39 to 0.58 (23). The FFQ included questions about consumption of rice dishes, including plain and flavored rice and rice porridge; noodle dishes, including noodles in soup, dry noodles, fried noodles, and noodles in gravy; bread, including Indian flatbreads and bread with a filling or topping; snacks and desserts, including local snacks and desserts, biscuits, pastries, and cakes; vegetables; fruits; poultry; meat; fish and seafood dishes; and other foods and beverages commonly consumed in

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Supplemental Tables 1–4 are available from the "Supplementary Data" link in the online posting of the article and from the same link in the online table of contents at <https://academic.oup.com/jn>.

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Abbreviations used: AHEI-2010, Alternative Healthy Eating Index; DASH, Dietary Approaches to Stop Hypertension; MEC, Multi-Ethnic Cohort; MET, metabolic equivalent task; SSB, sugar-sweetened beverage; WC, waist circumference.

Singapore. Participants were asked how many times they had consumed 1 standard serving of each item over the past month. Each item was matched to a food composition database developed by the Singapore Health Promotion Board that allowed us to derive information about each participant's intake of specific foods and nutrients. An updated food composition database was used for the baseline and follow-up FFQs, which aligned with the food supply at the time of data collection. As the FFQs included a number of mixed dishes, disaggregated food group databases were developed for both FFQs so that items such as meat and vegetables from mixed dishes could be accounted for. Serving sizes were defined as 90 g for red meat, poultry, and fish and seafood; 200 g of a whole milk equivalent (matched for protein) for dairy; 53 g for egg; 45 g of a tofu equivalent (matched for protein) for soy; 100 g for refined grains; 1 regular serving for whole grains from bread and cereal (e.g., 1 slice of whole-meal bread or 1 bowl of whole-grain cereal); 130 g for fruit; 100 g for vegetables; 1 regular serving for snacks and desserts (e.g., 1 slice of cake); and 330 mL for soft drinks. We included only whole grains from bread and cereals, as whole-grain rice and noodles were not included in the baseline questionnaire. The soft drink variable included sugared fruit drinks; sugared drinks made from syrup, cordial, or sweetened canned or packet drinks; carbonated drinks with sugar; and sports/energy drinks.

We evaluated the healthfulness of the overall diet using the Dietary Approaches to Stop Hypertension (DASH) score (24) and the Alternative Healthy Eating Index (AHEI-2010) score (25). The DASH score was calculated based on quintiles of intake in the population, with a score from 1 to 5 for each component (26). A higher DASH score was assigned to individuals in higher quintiles of whole grains, fruit, vegetables, nuts and legumes, and dairy intake and in lower quintiles of sugar-sweetened beverages (SSB; estimated using the soft drink variable) and red meat intake. Subsequently, the scores for all components were added, resulting in possible DASH scores ranging from 7 to 35. The AHEI-2010 score was calculated by assigning a score between 0 (lowest) to 10 (optimal) proportionally for each component, based on intakes of vegetables, fruit, whole grains, SSB, nuts and legumes, red and processed meat, long-chain (n-3) fats, PUFAs, and alcohol (25). Possible AHEI-2010 scores ranged from 0 to 90. We excluded sodium from the calculation of the DASH and AHEI-2010 scores, as sodium intakes could not be reliably estimated by the FFQ, and trans fat was not included in the AHEI-2010 score, as trans fat intake is low in Singapore and trans fat was not available in food composition tables. Supplement intakes were not assessed.

Weight was measured on SECA digital scales (SECA 700 series), and height was measured without shoes on a portable stadiometer (SECA 200 series). Waist circumference (WC) was measured by technicians using a stretch-resistant tape at the midpoint between the last rib and iliac crest.

Physical activity was assessed using a validated questionnaire, which covers physical activity domains such as leisure, transport, occupational, and household activities, expressed in metabolic equivalent task (MET) hours per week (27). Information about socio-demographic variables; lifestyle behaviors, including cigarette smoking history; and personal medical history were obtained from the standardized interviewer-administered questionnaire at baseline and follow-up.

Statistical analysis

Changes in dietary intakes and lifestyle variables were calculated as the differences between baseline and follow-up values. For categorical variables, categories were included to reflect both the baseline status and the changes from baseline. The correlations between changes in dietary variables were evaluated using partial correlations adjusted for total energy intakes.

Linear regression with a robust variance estimator (28) was used to estimate the mean change in weight and 95% CIs associated with changes in intakes of nutrients, foods, and beverages; the DASH score; and the AHEI-2010 score. Dietary variables were analyzed as continuous variables in increments of 5% of energy for macronutrients, 10 g/day for fiber, 5 points for the DASH score, 10 points for the AHEI-2010 score, and 1 serving/d for foods and beverages. We used 3 models for changes in intakes of nutrients and foods and beverages. Model 1

was a minimally adjusted model that adjusted for age (continuous, years), sex (male, female), ethnicity (Chinese, Malay, Indian), baseline weight (continuous, kg), and baseline height (continuous, cm). Model 2 was adjusted for the variables in Model 1 and further adjusted for baseline intakes (continuous), baseline education status (primary and below, secondary, above secondary), baseline and change in smoking status (never smoked/no change, smoker/no change, started smoking, stopped smoking), alcohol intake (continuous, serving/d), physical activity (continuous, MET-h/wk), and marital status (never married/no change, married/no change, separated/no change, got married, got separated). For carbohydrates, Model 3 was adjusted for the variables in Model 2 and further adjusted for baseline values and changes in fiber intakes. For protein, fat, and fiber, Model 3 was adjusted for the variables in Model 2 and mutually adjusted for baseline values and changes in intakes of protein, fat, and fiber. The coefficients for protein and fat intakes represent the estimated effects of substituting 5% of energy from carbohydrates with protein or fat, respectively (29). For foods and beverages, Model 3 was mutually adjusted for baseline values and changes in intakes of all other foods and beverages. For the models involving subcategories of foods (e.g., poultry with skin), the main category (e.g., poultry) was left out of the model. As white rice intake was high in our population, we modeled the substitution of white rice with other foods using the difference between the regression coefficients, variance, and covariance (30). To evaluate the associations between changes in the DASH score, AHEI-2010 score, and weight, we adjusted for the same set of variables described in Model 1 and Model 2. A change in total energy intake was not included in any of the models, as it was expected to be part of the causal pathway between dietary intakes and weight gain.

To evaluate potential deviations from linearity, analyses using categories were also performed, where the changes in all dietary variables except soft drinks were analyzed in quartiles, with the lowest quartile as the reference. Changes in soft drink intakes were grouped into 4 categories [moderate decrease (>0.50 serving/d); small decrease (0.01–0.50 serving/d); no change to small increase (0–0.5 serving/d); and moderate increase (>0.50 serving/d)] instead of quartiles, as there were substantial overlaps between the second and third quartiles.

Effect modifications by sex, ethnicity, and overweight status at baseline (BMI ≥ 25.0 kg/m²) were evaluated by including multiplicative interaction terms in the multivariable model separately for each dietary variable and testing whether the interaction terms were simultaneously equal to 0 using the Wald test. To supplement our findings on weight change, we also performed similar analyses using the change in WC as the dependent variable. Stata 13 (StataCorp LP) was used for all statistical analyses, and the level of significance was 0.05.

Results

Participants' characteristics

Participants' characteristics and dietary intakes at baseline according to ethnicity are shown in Table 1. The main source of energy was carbohydrates, followed by fat and protein. Intake of refined grains ranged from 3.9–4.3 servings per day, mostly from white rice, white bread, and noodles. The correlations between changes in intakes of nutrients, foods, and beverages; the DASH score; and the AHEI-2010 score are shown in Supplementary Table 1. Changes in the DASH score were strongly positively correlated with changes in the AHEI-2010 score ($r = 0.70$; $P < 0.001$). Both the DASH and AHEI-2010 scores were positively correlated with changes in fruit, vegetable, whole-grain, and soy intakes (r values ranging from 0.19 to 0.38; $P < 0.001$) and negatively correlated with refined grains, soft drink, and red meat intakes (r values ranging from -0.17 to -0.32 ; $P < 0.001$). Changes in intakes of refined grains were inversely correlated with changes in intakes of other major food groups, particularly of whole grains ($r = -0.21$; $P < 0.001$) and vegetables ($r = -0.21$; $P < 0.001$).

TABLE 1 Participants' characteristics and dietary intakes at baseline according to ethnicity in the Singapore Multi-Ethnic Cohort¹

	Chinese (<i>n</i> = 1595)	Malay (<i>n</i> = 697)	Indian (<i>n</i> = 772)
Age, y	44.8 ± 10.1	43.4 ± 10.1	43.4 ± 10.1
Weight, kg	61.2 ± 12.2	68.0 ± 14.7	68.3 ± 14.2
Height, cm	163.4 ± 8.7	160.9 ± 9.1	162.5 ± 9.2
BMI, kg/m ²	22.8 ± 3.7	26.2 ± 5.0	25.8 ± 4.9
Sex			
Male	721 (45.2)	282 (40.5)	303 (39.3)
Female	874 (54.8)	415 (59.5)	469 (60.8)
Education level			
Primary and below	281 (17.6)	159 (22.8)	191 (24.7)
Secondary	604 (37.9)	335 (48.1)	281 (36.4)
Above secondary	710 (44.5)	203 (29.1)	300 (39.9)
Marital status			
Never married	320 (20.1)	94 (13.5)	97 (12.6)
Currently married	1220 (76.5)	565 (81.1)	625 (81.0)
Separated	55 (3.5)	38 (5.5)	50 (6.5)
Smoking status			
Never smoked	1330 (83.4)	512 (73.5)	651 (84.3)
Stopped smoking	100 (6.3)	46 (7.0)	34 (4.4)
Currently smoking	165 (10.3)	136 (19.5)	87 (11.3)
Alcohol consumers	265 (16.6)	23 (3.3)	127 (16.5)
Physical activity, MET-h/wk	102.2 ± 71.1	116.1 ± 63.0	115.8 ± 67.5
Systolic blood pressure, ² mmHg	123.2 ± 17.3	123.6 ± 17.4	118.9 ± 17.1
LDL cholesterol, ³ mmol/L	3.2 ± 0.8	3.5 ± 0.9	3.5 ± 0.8
HDL cholesterol, ⁴ mmol/L	1.4 ± 0.4	1.3 ± 0.3	1.1 ± 0.3
HbA1c, ⁵ %	5.5 ± 0.4	5.6 ± 0.5	5.7 ± 0.6
Baseline diet quality indices			
DASH	20.5 ± 4.4	20.2 ± 4.7	24.1 ± 4.8
AHEI-2010	50.3 ± 7.7	48.2 ± 8.8	54.5 ± 9.6
Baseline intakes of nutrients			
Carbohydrates, % energy	53.3 ± 6.7	54.7 ± 6.3	54.2 ± 6.0
Protein, % energy	15.5 ± 2.2	14.1 ± 2.0	13.2 ± 2.0
Fat, % energy	30.7 ± 5.6	31.2 ± 5.3	32.0 ± 5.5
Fiber, g/d	20.4 ± 7.9	20.6 ± 7.7	29.0 ± 14.8
Baseline intakes of foods and beverages			
Fruit, serving/d	1.9 (1.0 to 3.4)	1.4 (0.6 to 2.4)	2.0 (0.9 to 3.2)
Vegetables, serving/d	1.9 (1.3 to 2.9)	1.5 (0.9 to 2.4)	1.8 (1.2 to 2.7)
Refined grains, serving/d	3.9 (3.0 to 5.2)	4.6 (3.1 to 5.3)	4.3 (2.8 to 5.2)
Rice, serving/d	1.5 (1.1 to 2.2)	2.1 (1.2 to 2.3)	1.9 (1.1 to 2.2)
Noodles, serving/d	0.6 (0.3 to 0.9)	0.3 (0.1 to 0.5)	0.2 (0.1 to 0.5)
Bread, serving/d	0.7 (0.2 to 1.4)	1.2 (0.6 to 2.1)	1.0 (0.4 to 2.0)
Whole grains, ⁶ serving/wk	0.5 (0 to 2.3)	3.8 (0 to 1.6)	3.4 (0.8 to 9.1)
Soft drinks, serving/wk	0.2 (0 to 0.9)	0.2 (0 to 1.8)	0 (0 to 0.9)
Snacks and desserts, ⁷ serving/wk	4.7 (2.4 to 8.1)	5.5 (2.8 to 10.1)	6.9 (3.6 to 11.9)
Red meat, serving/wk	3.6 (1.8 to 6.2)	1.6 (0.9 to 2.9)	1.1 (0.5 to 1.9)
High-fat	0.6 (0.3 to 1.5)	0.4 (0.2 to 0.7)	0.3 (0.1 to 0.6)
Lean	1.8 (0.8 to 3.7)	0.8 (0.3 to 1.6)	0.4 (0.1 to 1.0)
Poultry, serving/wk	3.3 (1.9 to 5.4)	3.3 (2.0 to 5.3)	2.5 (1.3 to 4.7)
With skin	1.0 (0.3 to 2.8)	1.0 (0.4 to 2.8)	0.5 (0.2 to 1.1)
Without skin	1.4 (0.6 to 3.1)	1.1 (0.2 to 3.0)	1.5 (0.5 to 3.1)
Fish and seafood, serving/wk	7.5 (5.0 to 10.8)	6.7 (4.2 to 10.2)	4.5 (2.5 to 7.4)
Dairy, serving/wk	3.9 (1.4 to 7.9)	5.5 (2.5 to 10.3)	7.4 (4.5 to 13.2)
Egg, serving/wk	3.7 (2.3 to 5.7)	3.8 (2.3 to 5.7)	2.9 (1.7 to 4.6)
Soy, serving/wk	3.4 (1.8 to 5.8)	2.6 (1.3 to 4.8)	2.4 (0.9 to 4.5)

¹ Values are means ± SDs for continuous variables, medians (25th to 75th percentiles) for dietary intakes of foods and beverages, or frequencies (%) for categorical variables. AHEI-2010, Alternative Healthy Eating Index; DASH, Dietary Approaches to Stop Hypertension; HbA1c, glycated hemoglobin; MET, metabolic-equivalent task.

² Included *n* = 1588 Chinese, *n* = 697 Malay, and *n* = 772 Indian participants.

³ Included *n* = 1584 Chinese, *n* = 695 Malay, and *n* = 769 Indian participants.

⁴ Included *n* = 1595 Chinese, *n* = 696 Malay, and *n* = 772 Indian participants.

⁵ Included *n* = 1309 Chinese, *n* = 606 Malay, and *n* = 620 Indian participants.

⁶ Included only whole grains from bread and breakfast cereals.

⁷ Included local snacks and desserts, biscuits, pastries, and cakes.

TABLE 2 Associations between changes in intakes of nutrients and changes in body weight over a mean follow-up time of 6.0 ± 1.5 years in the Singapore Multi-Ethnic Cohort¹

	Mean change in weight, kg (95% CI)					
	Model 1 ²	P value	Model 2 ³	P value	Model 3 ⁴	P value
Carbohydrates	0.15 (0.04 to 0.25)	0.006	0.12 (−0.03 to 0.27)	0.11	0.11 (−0.04 to 0.26)	0.14
Protein	−0.36 (−0.67 to −0.05)	0.022	−0.45 (−0.85 to −0.06)	0.024	−0.44 (−0.86 to −0.01)	0.045
Fat	−0.15 (−0.28 to −0.02)	0.019	−0.08 (−0.27 to 0.11)	0.40	−0.00 (−0.20 to 0.20)	0.97
Fiber	−0.07 (−0.23 to 0.09)	0.39	−0.09 (−0.31 to 0.12)	0.40	−0.08 (−0.30 to 0.14)	0.47

¹Total *n* = 3064. Values are beta coefficients (95% CIs) from linear regression, representing the mean change in weight (kg) associated with an increase of 5% of energy from carbohydrates, protein, and fat and 10 g/d of fiber.

²Model 1 was adjusted for age, sex, ethnicity, and baseline weight and height.

³Model 2 was adjusted for the variables in Model 1 and further adjusted for baseline dietary intake, baseline education status, baseline and change in smoking status, alcohol intake, physical activity, and marital status.

⁴For carbohydrates, Model 3 was adjusted for the variables in Model 2 and was further adjusted for baseline and change in fiber intake. For protein, fat, and fiber, Model 3 was adjusted for the variables in Model 2 and mutually adjusted for baseline values and changes in intakes of protein, fat, and fiber. The coefficients for protein and fat represent the effects of substituting 5% energy from carbohydrates with protein and fat, respectively.

Over a mean follow-up of 6.0 years (± 1.5 years), participants gained an average of 2.0 kg (± 4.7 kg).

Associations between changes in intakes of nutrients and changes in weight

The associations between changes in intakes of nutrients and changes in body weight are shown in Table 2. Increases in the percentage of energy from carbohydrates were directly associated with weight gain in Model 1 and increases in the percentage of energy from fat were inversely associated with weight gain in Model 1, which adjusted for age, sex, ethnicity, and baseline weight and height. However, these associations were attenuated and not significant in Model 2 after further adjustment for baseline intakes and other lifestyle variables. In contrast, an increase in protein intake was significantly

associated with less weight gain across all models. Replacing 5% of energy from carbohydrates with protein was associated with less weight gain (−0.44 kg; 95% CI, −0.86 to −0.01; Figure 2). Increased intake of dietary fiber was not substantially associated with weight change.

Associations between changes in intakes of foods and beverages and changes in weight

We observed a significant, direct association between increased refined grain intake and weight gain across all models (Table 3). Each serving per day increase in refined grain intake was associated with 0.18 kg (95% CI, 0.08 to 0.29) weight gain in the fully adjusted Model 3. We further investigated the associations between different types of refined grains and weight change. While a change in consumption of white bread was not associated with

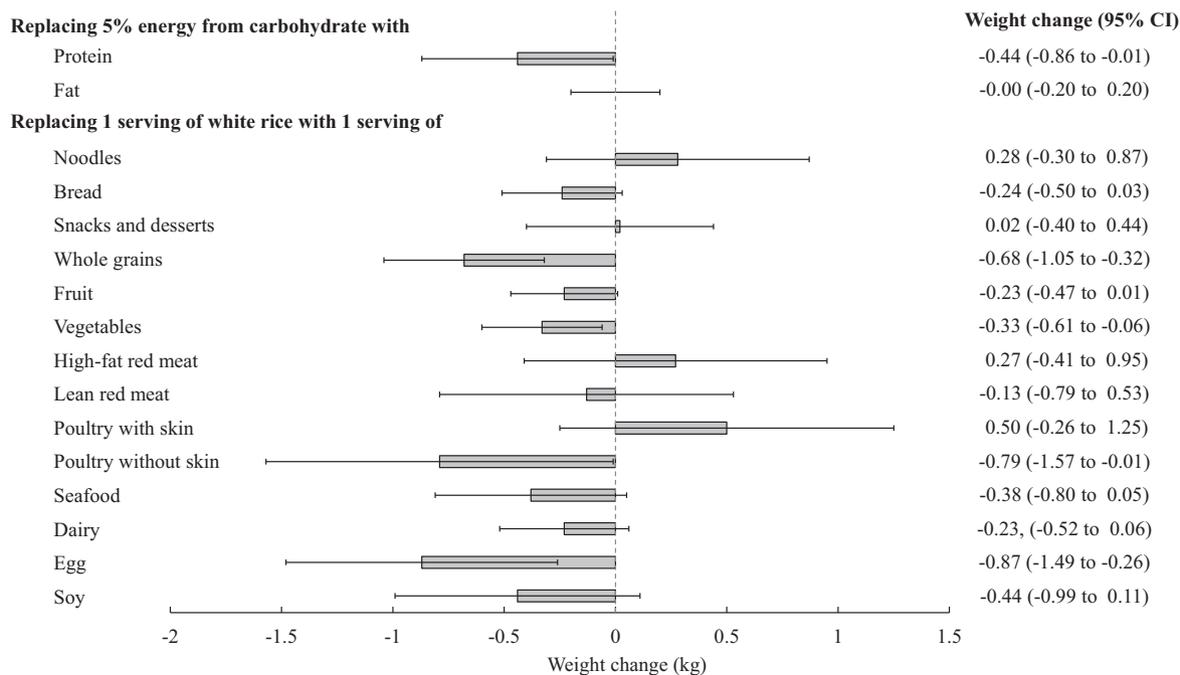


FIGURE 2 Estimated weight change (kg) from replacing 5% of energy from carbohydrates with protein or fat and replacing 1 serving/d of white rice with other foods over a mean follow-up time of 6.0 ± 1.5 years in the Singapore Multi-Ethnic Cohort (*n* = 3064). Estimates are based on multivariable models with adjustments for age, sex, ethnicity, baseline weight, height and education status, baseline and change in smoking status, alcohol intake, physical activity, and marital status. The carbohydrate substitution model was further adjusted for baseline values and changes in intakes of protein, fat, and fiber. The food substitution model was mutually adjusted for baseline and changes in intakes of other foods. Error bars denote 95% CIs.

TABLE 3 Associations between changes in intakes of foods and beverages and changes in body weight over a mean follow-up time of 6.0 ± 1.5 years in the Singapore Multi-Ethnic Cohort¹

	Mean change in weight, kg (95% CI)					
	Model 1 ²	P value	Model 2 ³	P value	Model 3 ⁴	P value
Refined grains	0.14 (0.05 to 0.22)	0.001	0.19 (0.09 to 0.28)	<0.001	0.18 (0.08 to 0.29)	<0.001
Rice ⁵	0.24 (0.06 to 0.42)	0.008	0.34 (0.14 to 0.54)	0.001	0.25 (0.04 to 0.45)	0.018
Noodles ⁵	0.08 (−0.24 to 0.40)	0.63	0.34 (−0.09 to 0.77)	0.12	0.53 (−0.03 to 1.09)	0.063
Bread ⁵	0.10 (−0.01 to 0.21)	0.086	0.06 (−0.10 to 0.22)	0.47	0.01 (−0.15 to 0.18)	0.87
Soft drink	0.59 (0.26 to 0.92)	0.001	0.84 (0.20 to 1.47)	0.010	0.69 (0.05 to 1.33)	0.036
Snacks	0.31 (−0.05 to 0.67)	0.088	0.31 (−0.06 to 0.69)	0.10	0.24 (−0.13 to 0.61)	0.21
Whole grains	−0.10 (−0.28 to 0.08)	0.30	−0.57 (−0.89 to −0.26)	<0.001	−0.51 (−0.83 to −0.19)	0.002
Fruit	−0.04 (−0.13 to 0.05)	0.39	−0.01 (−0.14 to 0.11)	0.86	0.01 (−0.12 to 0.14)	0.91
Vegetable	−0.06 (−0.15 to 0.02)	0.15	−0.07 (−0.20 to 0.06)	0.31	−0.13 (−0.31 to 0.04)	0.11
Red meat	0.10 (−0.17 to 0.37)	0.46	0.50 (0.08 to 0.92)	0.019	0.58 (0.10 to 1.06)	0.017
High-fat ⁵	0.29 (−0.13 to 0.71)	0.17	0.79 (0.22 to 1.37)	0.007	0.52 (−0.14 to 1.17)	0.12
Lean ⁵	−0.18 (−0.55 to 0.20)	0.35	−0.09 (−0.70 to 0.52)	0.77	0.12 (−0.51 to 0.75)	0.71
Poultry	0.08 (−0.30 to 0.45)	0.68	0.41 (−0.10 to 0.92)	0.12	0.15 (−0.41 to 0.72)	0.59
With skin ⁵	0.49 (−0.01 to 0.99)	0.055	1.17 (0.51 to 1.83)	0.001	0.74 (0.04 to 1.44)	0.037
Without skin ⁵	−0.34 (−0.85 to 0.17)	0.19	−0.79 (−1.51 to −0.07)	0.032	−0.54 (−1.29 to 0.21)	0.16
Fish and seafood	−0.06 (−0.28 to 0.16)	0.58	−0.01 (−0.32 to 0.30)	0.95	−0.05 (−0.40 to 0.29)	0.76
Dairy	−0.07 (−0.20 to 0.07)	0.34	−0.01 (−0.22 to 0.19)	0.89	0.01 (−0.20 to 0.22)	0.92
Egg	−0.30 (−0.63 to 0.03)	0.076	−0.33 (−0.81 to 0.15)	0.17	−0.59 (−1.11 to −0.07)	0.025
Soy	−0.27 (−0.56 to 0.01)	0.058	−0.17 (−0.60 to 0.25)	0.42	−0.18 (−0.67 to 0.31)	0.47

¹Total *n* = 3064. Values are regression coefficients (95% CIs) from a linear regression analysis, representing the mean change in weight (kg) associated with an increase of 1 serving/d of specific foods and beverages.

²Model 1 was adjusted for age, sex, ethnicity, and baseline weight and height.

³Model 2 was adjusted for the variables in Model 1 and further adjusted for baseline dietary intake, baseline education status, baseline and change in smoking status, alcohol intake, physical activity, and marital status.

⁴Model 3 was adjusted for the variables in Model 2 and mutually adjusted for baseline values and changes in intakes of all other foods and beverages.

⁵Main category was excluded when sub-categories were used.

weight change, increased intake of white rice was significantly associated with weight gain (+0.25 kg per serving/d; 95% CI, 0.04 to 0.45) and increased intake of noodles was nonsignificantly associated with weight gain (+0.53 kg; 95% CI, −0.03 to 1.09). Increased intake of soft drinks was also associated with weight gain (+0.69 kg; 95% CI, 0.05 to 1.33). In contrast, increased intake of whole grains was significantly associated with less weight gain (−0.51 kg; 95% CI, −0.83 to −0.19).

Increased red meat intake was associated with weight gain (+0.58 kg per serving/d; 95% CI, 0.10 to 1.06), with a suggestion of a stronger association for high-fat red meat as compared with lean red meat. Increased intake of poultry with skin was associated with weight gain (+0.74 kg; 95% CI, 0.04 to 1.44), but this was not observed for poultry without skin. Increased egg intake was significantly inversely associated with weight gain (−0.59 kg; 95% CI, −1.11 to −0.07).

In substitution models, the replacement of 1 serving per day of white rice with whole grains (−0.68 kg; 95% CI, −1.05 to −0.32), vegetables (−0.33 kg; 95% CI, −0.61 to −0.06), poultry without skin (−0.79 kg; 95% CI, −1.57 to −0.01), and eggs (−0.87 kg; 95% CI, −1.49 to −0.26) was significantly associated with less weight gain (Figure 2). In contrast, the replacement of white rice with noodles, high-fat red meat, and poultry with skin was nonsignificantly associated with weight gain.

Associations between changes in diet quality indices and changes in weight

Increases in the DASH (−0.34 kg for every 5-point increment; 95% CI, −0.55 to −0.13) and AHEI-2010 (−0.35 kg for every 10-point increment; 95% CI, −0.60 to −0.10) scores were

associated with less weight gain after adjustments for socio-demographic and lifestyle variables.

Additional analyses

Categorical analyses using the lowest category as the reference revealed similar findings (Supplementary Table 2). For example, there was a monotonic increase in weight gain from the first quartile (greatest reduction in intake) to the fourth quartile (greatest increase in intake) of change in refined grain intake. In contrast, an increasing amount of weight loss (decreasing net weight gain) was observed from the first to fourth quartile of change in whole-grain intake.

We evaluated the potential effect modification of associations between changes in intakes of nutrients, foods and beverages, diet quality indices, and weight gain by sex, ethnicity, and overweight status (Supplementary Table 3). Increased soft drink intake was significantly associated with weight gain among ethnic Indians (+2.18 kg per serving/d; 95% CI, 1.19 to 3.18) but not among Chinese (+0.38 kg; 95% CI, −0.45 to 1.21) or Malay (+0.02 kg; 95% CI, −0.67 to 0.71; *P*-interaction = 0.031). The inverse association between increased intake of poultry without skin and weight gain was stronger among men (−1.13 kg; 95% CI, −2.34 to 0.09) compared to women (−0.13 kg; 95% CI, −1.04 to 0.78; *P*-interaction = 0.025). The inverse association between increased egg consumption and weight gain was stronger among overweight (−0.90 kg per serving/d; 95% CI, −1.83 to 0.03) as compared with leaner participants (−0.34 kg; 95% CI, −0.94 to 0.26; *P*-interaction = 0.001).

We also performed analyses using the change in WC as the dependent variable, and the results were consistent with those

for changes in body weight (Supplementary Table 4). Increases in DASH (-0.35 cm per 5-point increase; 95% CI, -0.65 to -0.04) and AHEI-2010 (-0.40 cm per 10-point increase; 95% CI, -0.74 to -0.06) scores were associated with reductions in WC. In addition, the replacement of 5% of energy from carbohydrates with protein was associated with a decrease in WC (-0.73 cm; 95% CI, -1.37 to -0.09), while increased intakes of refined grains ($+0.21$ cm; 95% CI, 0.07 to 0.36) and white rice ($+0.35$ cm; 95% CI, 0.06 to 0.64) were associated with increases in WC.

Discussion

In this study, we evaluated the association between changes in diet and changes in body weight over an average follow-up time of 6 years in a multi-ethnic Asian population. Improvements in the quality of diet according to the DASH and AHEI-2010 scores were associated with less weight gain. On the nutrient level, increases in the percentage of energy from protein were associated with less weight gain. In contrast, we did not observe significant associations between changes in intakes of carbohydrates, fat, and fiber and changes in weight after adjustments for socio-demographic and lifestyle factors. Changes in intakes of several foods and beverages were associated with weight changes. Increased intakes of white rice, soft drinks, red meat, and poultry with skin were associated with more weight gain, whereas increased intakes of whole grains and eggs were associated with less weight gain. In substitution models, replacing 5% of energy from carbohydrates with protein and replacing 1 serving per day of white rice with whole grains, vegetables, poultry without skin, and eggs was inversely associated with weight gain.

The effects of macronutrient compositions on body weight have been widely debated. Results from some studies have suggested that high-protein diets (31–33), low-carbohydrate diets (34), or low-fat diets (35, 36) are beneficial for weight loss. However, results from other studies have suggested that low-carbohydrate, low-fat, or high-protein diets per se are not necessarily superior to their counterparts for long-term weight management under free-living conditions (8, 10, 37–40), and that more emphasis should be placed on specific types of foods and beverages (8, 9). Our findings suggest that in a population with relatively high intakes of carbohydrates from refined grains, replacing carbohydrates with protein may result in modest weight loss. This could be due to favorable effects of dietary protein on diet-induced energy expenditure (41) and the displacement of refined grains, which was directly associated with weight gain in this study.

The potential mechanisms behind the observed direct association between refined grain consumption and weight gain have been postulated to include refined grain's low cereal fiber content and high glycemic index (42–45). In addition, some popular rice dishes in Singapore are high in energy, fat, and sodium (46, 47), which may act independently or interact to promote overconsumption (48, 49). Studies on grain consumption in relation to weight change have mostly been conducted in Western populations and have mainly focused on bread and cereals (16). These results may not apply to Asian populations, where rice and noodles form the bulk of the grain intake (14, 15, 50). Our findings regarding the direct association between increased white rice consumption and weight gain are supported by results from a Japanese cohort (18) but not those from a Chinese cohort, where higher white rice

intake was associated with less weight gain (19). Differences in socioeconomic status may explain this discrepancy. White rice is an affordable staple food, and lower intake could be an indicator of greater affluence (51), which has been associated with weight gain in emerging economies (51–53). Even though the authors adjusted for occupation and education, residual confounding by socioeconomic status is likely to be present, as the participants were recruited from urban and rural regions in China with varying economic development levels (19).

We did not find a significant association between changes in dietary fiber intakes and weight changes, which appears to conflict with previous findings in randomized controlled trials (54). In European and US cohorts, cereal fiber was more strongly inversely associated with weight gain than vegetable fiber (55) or fruit and vegetable fiber (56). These findings are consistent with the inverse association between whole-grain intake and weight change in our study. However, given the much lower intake of whole grains than fruit and vegetables in our study, only a small proportion of total fiber was cereal fiber, which may explain the lack of an association between fiber intake and weight change. Although we did not find significant associations between increased fruit and vegetable intakes and weight changes, significantly less weight gain was observed when white rice was replaced with vegetables, and a similar trend was observed for fruit. Findings from previous longitudinal studies in US and European cohorts have been mixed, with studies showing direct associations (57), no association (58), and inverse associations (59) between increased fruit or vegetable intake and weight change. In a Japanese cohort, increased intake of vegetables was associated with a small decrease in weight, while the opposite was observed for fruit intake (20). In a cohort study in China, increased fruit and vegetable consumption was associated with weight loss among Chinese men (21). These mixed findings could be due to differences in food preparation methods or differences in dietary patterns and types of foods being substituted, as increased fruit and vegetable consumption was more effective at promoting weight loss when it was used to replace other energy-dense foods (60).

To date, most longitudinal studies on the effects of SSB consumption on adiposity have been focused on Western populations, and evidence from Asian settings is limited (61). While prospective studies in Korea did not show clear associations between SSB intake and weight gain (62, 63), studies conducted in Thai (64), Japanese (65), and Chinese (66) populations demonstrated direct associations between SSB consumption and weight gain. In our study, soft drink consumption was directly associated with weight gain in the overall cohort, with the strongest association among ethnic Indians. This finding may have important public health implications, as SSB consumption has been rising in India (67). We speculate that this could be due to differences in insulin sensitivity, as Indian ethnicity was associated with higher insulin resistance than Malay and Chinese ethnicity (68, 69), which may potentiate the obesogenic effects of fructose through increased lipogenesis (70, 71). However, this potential interaction between ethnicity and SSB consumption warrants further confirmation.

We found that increased consumption of red meat and poultry with skin was associated with greater weight gain. While this appears to contradict our results on the nutrient level (i.e., protein intake being inversely associated with weight change), it becomes less of a discrepancy when we consider the results of our analysis with substitution of foods. A consistent trend of less weight gain was observed when white rice (the main contributor of carbohydrates in our population) was replaced with

protein-rich foods, with the exception of high-fat meats. Previous prospective studies among Western populations showed direct associations between red meat and poultry consumption and weight gain (72–75). However, most of these studies did not differentiate between lean and high-fat meat. Increased intake of high-fat red meat but not lean red meat was associated with increased WC in a cohort of Chinese men (76). In US cohorts, higher-fat meat consumption was associated with weight gain, while consumption of lean meats, including poultry without skin, was associated with less weight gain (72, 77). Taken together, these findings suggest that the fat content of meat may be relevant for weight gain. Possible explanations include the difference in energy density between lean and fatty cuts of meat (78) and the potentially higher palatability of meats with higher fat content, which may promote overconsumption (79, 80).

Previous studies on egg consumption and obesity conducted in Asian populations have been cross-sectional (81, 82), and egg consumption was not associated with weight changes in US cohorts (72). However, egg consumption led to lower subsequent energy intake compared with isocaloric meals without eggs in randomized controlled trials (83–87). This finding could be due to effects of egg consumption on appetite-regulating hormones, such as ghrelin and glucagon-like peptide-1 (84, 87); the impact of egg consumption on greater satiety was found even when protein intake in the control group was matched (88). We noted a stronger inverse association between increased egg consumption and weight change in overweight as compared with leaner participants, which requires confirmation in independent studies.

The mean weight gain during follow-up in this population was 2 kg over 6 years. This magnitude of weight gain is comparable with observations from Western regions, such as the US (72) and European countries (58), and those from some high-income Asian populations, such as residents of Hong Kong (89) and Japan (18). Our effect estimates suggest that this amount of weight gain could be avoided by a combination of several dietary changes: for example, replacing 1 serving of white rice with whole grains, vegetables, or lean protein sources and reducing soft drink consumption by 1 serving per day. These effect sizes should be confirmed, ideally in randomized trials, but they are comparable with the effect sizes observed in US cohorts (90) and may be relevant for preventing weight gain in the general population.

This study's strengths include the use of repeated dietary and body weight assessments that allowed us to evaluate the associations between changes in diet and changes in weight. This approach has been shown to produce more robust, consistent, and biologically plausible associations between diet and weight change compared with the use of baseline diet data to predict weight changes (91). Furthermore, changes in the food supply over time were accounted for using food composition databases that were constructed at each time point. There are also several potential limitations of our study. First, 28% of participants were not contactable for follow-up, and 40% of the contactable participants declined to participate in the follow-up study. While the socio-demographic characteristics of the participants who were lost to follow-up were mostly comparable to those of the follow-up study participants, the latter tended to have higher education levels. Although we do not have reason to expect that associations between dietary changes and weight changes were different in cohort participants who did not attend the follow-up, we cannot completely exclude the possibility of selection bias. Second, the use of self-reported dietary information may have resulted in misclassification of exposure status due to

reporting errors. Although the FFQ used in this study has been validated against three 24-hour diet recalls with fairly good accuracy and agreement (23), it has not been validated for measuring changes in diet across 2 time points. Our assessment of whole-grain intake was limited to bread and cereals, because brown rice and whole-grain noodles were uncommon in the diet at baseline. Hence, the change in whole-grain intake was likely to be underestimated. These sources of measurement error are most likely nondifferential and may have weakened the observed associations. Third, temporality cannot be established, since changes in the diet were assessed simultaneously with weight changes. Fourth, residual confounding may be present due to the study's observational nature, although our results were generally robust across models, with different adjustments for potential confounders. Finally, our study only included participants of Chinese, Malay, or Indian ethnicity, and results may not be fully generalizable to other ethnic groups due to reasons such as differences in food culture and genetics.

In conclusion, in this study we evaluated the associations between changes in diet and changes in weight in a multi-ethnic Asian population. Replacing carbohydrates with protein was associated with less weight gain over a period of about 6 years. When we examined food sources of carbohydrates, increased intakes of refined grains and soft drinks were associated with more weight gain, whereas increased intake of whole grains was associated with less weight gain. Furthermore, replacement of white rice with whole grains, vegetables, eggs, and poultry without skin, but not replacement with high-fat meats, was associated with less weight gain. These results highlight the importance of interpreting data on nutrient intakes and weight gain in the context of dietary patterns and food sources, as aggregating food intakes into macronutrients may obscure the nuanced effects of dietary exposures on energy balance. In terms of public health guidance, our findings add to the evidence that following dietary patterns with higher intakes of whole grains and protein and lower intakes of refined grains, SSB, and high-fat meats can contribute to the prevention of excess weight gain in Asian adults.

Acknowledgments

The authors' contributions were as follows – CGYL, RMvD: designed research and analyzed data; CGYL: had primary responsibility for the final content; and all authors: wrote the paper and read and approved the final manuscript.

Data Availability

The data sets used during the current study can be requested from the Singapore Population Health Studies team (<https://bl.og.nus.edu.sg/sphs/>).

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