Relative influence of diet and physical activity on body composition in urban Chinese adults[1–4]

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ABSTRACT

Background: The relative influence of diet and physical activity on body fatness remains uncertain.

Objective: The objective of the study was to investigate associations of dietary variables and physical activity with body fatness in urban Chinese adults.

Design: We conducted a cross-sectional study in 130 weight-stable men and women aged 35–49 y. Subjects were selected from upper and lower tertiles of dietary fat and physical activity on the basis of screening questionnaires. Dietary intake was assessed by weighed food intake, physical activity level (PAL) was calculated as the ratio of predicted total energy expenditure (TEE) to predicted resting energy expenditure, and body composition was measured with the use of ^2H_2O. Reported energy intake and predicted TEE were validated against TEE determined with the use of $^2H_2{}^{18}O$ ($n = 73$).

Results: Body fatness was positively associated with dietary variety (ie, variety of ingredients) (partial $r = 0.186$, $P = 0.039$) and frequency of consuming restaurant foods (partial $r = 0.237$, $P = 0.001$) and negatively associated with PAL (partial $r = -0.307$, $P = 0.001$) in a multiple regression analysis that controlled for sex and confounders. The combined variance accounted for by dietary variety and restaurant food consumption (9.1%) was equivalent to that for PAL (9.4%). Neither dietary fat nor energy density predicted body fatness, but dietary energy density predicted within-subject day-to-day variation in reported energy intake ($P < 0.001$).

Conclusions: Dietary variety, frequency of restaurant food consumption, and PAL significantly predicted body fatness in urban Chinese adults, but dietary fat did not. These findings support previous studies in US adults and suggest that dietary variables other than fat have an important influence on adult body composition. *Am J Clin Nutr* 2003;77:1409–16.

KEY WORDS Physical activity level, dietary fat, energy density, dietary variety, restaurant food, body composition, doubly labeled water, China, adults

INTRODUCTION

The prevalence of overweight and obesity continues to increase nationally and worldwide (1–4). Consumption of a Western-style diet and low levels of physical activity have been widely implicated as underlying causes of the worldwide trend for weight gain (5, 6). However, there remains controversy over which specific dietary factors are the most important determinants of body fatness. Furthermore, relatively little work has examined the relative contributions of diet and physical activity to body fatness.

Of the many dietary factors that have been suggested to cause obesity, dietary fat has received particular attention (7–10). However, there remains no agreement on its overall importance in determining body fatness (7, 8, 11, 12) or on whether the effects of dietary fat are primarily mediated by energy density (13–15). Recently, we and others suggested that other dietary factors may be quantitatively more important than is dietary fat. In particular, there is evidence suggesting that great dietary variety increases energy intake in the short term (16–18) and that it is associated with greater body fatness (19). In addition, a high frequency of consumption of restaurant foods has been associated with greater energy intake (20–22) and higher body fatness (22, 23). This may be due to an associated increase in dietary variety and to high dietary fat content (20–22) and large portion size (24). Thus, further studies are needed to investigate the relative influence of different dietary variables on energy intake and body fatness.

Low levels of physical activity have been consistently associated cross-sectionally with increased body fatness (25–29). However, relatively few studies have attempted to statistically contrast the associations of dietary variables and physical activity with body fatness (3, 6, 30). Moreover, those studies used relatively inaccurate methods, such as body mass index (BMI; in kg/m^2) to indicate body fatness and occupation to estimate physical activity. Thus, the associations were potentially attenuated, and further investigations in this area are needed.

The primary purpose of this study was to investigate the cross-sectional associations of dietary variables and physical activity with body fatness by using validated methods for measuring all primary variables. We conducted the study in China, and we anticipated that the data could be contrasted with related data emerging from Western countries to further elucidate the roles of diet and physical activity in energy regulation.

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TABLE 1
Characteristics of the subjects at baseline

	Men (n = 63)	Women (n = 67)
Age (y)	42.8 ± 0.5[1]	42.3 ± 0.5
Body weight (kg)	74.6 ± 1.5	63.9 ± 1.4[2]
Height (cm)	171.1 ± 0.7	160.1 ± 0.7[2]
BMI (kg/m^2)	25.4 ± 0.4	24.9 ± 0.5
Weight change (g/d averaged over 9 d)[3]	10 ± 20	−14 ± 15
Percentage of body fat (% of wt)	27.1 ± 0.7	36.9 ± 0.6[2]
Occupation category (% [n])		
Light	44 [28]	61 [41]
Moderate	37 [23]	31 [21]
Heavy	19 [12]	8 [5]

[1] $\bar{x}$ ± SEM.
[2] Significantly different from men, $P < 0.001$.
[3] Not significantly different from 0 for either men or women.

SUBJECTS AND METHODS

Subjects

The subjects were 130 adults (63 men and 67 women) living in urban areas of Beijing. Study participants were recruited from 15 neighborhoods that were widely distributed in 3 of the 4 urban districts of Beijing. Basic information on 100–150 randomly selected household residents in each neighborhood was first obtained from archive records of the neighborhood committees. Those persons who were aged 35–49 y, living in the same neighborhood for ≥ 2 y, and willing to participate (45% of invited) were given a screening test. This included a screening questionnaire by interview, physical examination, and the drawing of blood to test for hemoglobin concentration. The questionnaire solicited information on medical history, physical activity level (PAL) (14 scaled questions related to activity during work, transportation, household work, and leisure time) (31), and eating habits (including consumption frequency and portion size of 10 food items that are major contributors to dietary fat content) (32, 33).

Subjects from the upper and lower tertiles of the scores for dietary fat (% energy intake) and habitual physical activity index based on the screening questionnaire were considered potentially eligible to participate. We chose to use tertiles rather than a median split to broaden the range of reported values. The purpose of this stratification was to ensure wide ranges of dietary composition and PAL within the study population, with equal numbers of subjects having each of the 4 combinations of high or low dietary fat and high or low PAL. All subjects were required to be free of any known illnesses or medical conditions that might affect energy intake or energy metabolism or prevent them from being physically active, not to be taking any medications known to influence energy regulation, and to be healthy as judged by a normal physical examination and a normal blood hemoglobin concentration [120–150 g/L for men and 105–135 g/L for women (34)]. Additional exclusion criteria included postmenopausal status in women, smoking > 20 cigarettes/d, consuming > 2 alcoholic drinks/d, weight change of > 3 kg during the past year (to exclude those whose body weight changes were due to intentional lifestyle changes, medical conditions, or other confounding factors), following a weight-control or vegetarian diet, or self-reported changes in eating habits or habitual PAL during the past year.

On the basis of the screening examination, 142 subjects qualified for the study, of whom 130 were willing to participate. The physical characteristics of the subjects are given in **Table 1**. The studies were conducted at the Institute of Nutrition and Food Hygiene, Beijing, and the human investigations review committees at the Chinese Academy of Preventive Medicine and New England Medical Center/Tufts University provided ethical approval. Written informed consent was obtained from all subjects before the start of the study.

General protocol

The study was conducted over a 9-d period. The subjects were studied in groups of 8–10 and were equally selected from 4 different lifestyle combinations (high or low dietary fat and high or low PAL) during different study months to control for potential confounding by seasonal effects. Throughout the study, the subjects were able and encouraged to pursue their usual lifestyle, and all continued their regular occupations, transportation, and leisure activities. All measurements except home food assessment were conducted at the research unit of the Institute of Nutrition and Food Hygiene, and subjects usually traveled there by leisurely walking or bicycling (< 8 km).

Subjects arrived at the research unit on study day 1 after an overnight fast. A measurement of total energy expenditure (TEE) by doubly labeled water was begun (in the first 73 subjects only, because of the worldwide $H_2{}^{18}O$ shortage), and anthropometric measurements were obtained. In addition, subjects were instructed in wearing the activity monitor, and a motion detector was installed on each subject's bicycle. They were then discharged from the research unit and during study days 2–8 lived their usual life at home, completing activity documentation as described below. In addition, food intake was measured, and daily timed urine specimens for the doubly labeled water analyses were collected by fieldworkers who visited the subjects at home. Subjects returned to the research unit on the morning of day 9 after an overnight fast for measurement of body composition and repeat anthropometric measurements. In addition, information on educational level, smoking status, and household income was obtained by questionnaire at that time.

Dietary intake

Throughout the study, all subjects were requested to continue their usual eating patterns, and a 3-d dietary survey (2 weekdays and 1 weekend day) was conducted by trained fieldworkers. During this period, all consumed foods were weighed whenever possible, or the estimated weights were obtained by recall. Ingredients of foods prepared at home were weighed, and samples of foods obtained outside the home were collected for analysis, as described below.

For foods prepared at home, a fieldworker was present and weighed all raw ingredients used in each dish with the use of a portable electronic scale (Model LS2000; Ohaus Corp, Florham Park, NJ). The cooked weight of each dish was also determined, so that water losses could be estimated. A portion of each dish somewhat in excess of the amount anticipated to be consumed by the subject was then weighed and served in a container separate from the communal serving bowl of the other family members. Subjects were requested to eat the amount of food they would usually eat, and the leftover food was weighed. The intake of each ingredient in the dish was then calculated from the net weight of food consumed and the recipe used. The intakes of macronutrients from the ingredients were determined by using the 1991 Chinese food composition table (35). To evaluate the accuracy of using the Chinese food composition table for analysis of the nutrient contents of prepared dishes, 201 representative samples of dishes prepared at home were collected from the first 12 subjects, stored at −20 °C, and subsequently transported on dry ice to Tufts University for analysis of gross energy content. The samples were freeze-dried to constant weight and ground to fine powder in a stainless steel blender. Known amounts of powder were then combusted to determine total heat content with the use of an isoperibol bomb calorimeter (model 1271; Parr Instrument Co, Moline, IL). The CV for repeated analyses was 0.1%. The measured and calculated gross energy contents of the 201 dishes were highly correlated ($r = 0.89$, $P < 0.001$), with a mean (±SEM) difference in energy content per dish of 26 ± 31 kJ and a 95% CI of −38, 90 kJ. Furthermore, the mean CV between measured and calculated energy content per dish was 19%. Thus, the food composition table was generally accurate, with relatively large individual variations.

For foods obtained outside the home (ie, workplace cafeteria or restaurant), subjects were requested to take the portable scale with them and to weigh the amount of the dish they were going to consume or to estimate the weight if they could not weigh it. Representative samples of these dishes ($n = 468$) were also collected for analyses of gross energy and total fat contents. The total fat content of the dishes was determined in the dried samples by acid hydrolysis (36) (Covance Laboratories Inc, Madison, WI).

The daily reported energy intake (rEI) and fat intake of each subject were determined by summing the energy and fat contents of all consumed foods. The percentage of energy intake supplied by fat (assuming energy contents of 37.7 kJ/g for fat), and the average dietary energy density (ie, rEI per unit weight of food) were calculated. In addition, dietary variety was defined as the total number of recipe ingredients consumed over 3 d in home-prepared dishes. Because we were not able to identify the individual ingredients of prepared-food items (ie, those from a store, workplace cafeteria, or takeout), each of those items was counted as one ingredient. Note that we did not include restaurant dishes in the estimate of dietary variety. The frequency of consumption of restaurant food was defined as the number of meals consumed at restaurants during the 3 d.

Measurement of TEE and estimation of physical activity

An 8-d doubly labeled water study was conducted to measure TEE in 73 subjects and used to validate determinations of rEI and predicted TEE. A detailed description of the measurement procedure was given elsewhere (37). Briefly, a mixed $^2H_2{}^{18}O$ dose containing 0.10 g $H_2{}^{18}O$/kg body wt and 0.08 g ^2H_2O/kg body wt was given orally early in the morning of study day 1 after subjects had fasted overnight and after the collection of baseline urine specimens. Urine samples were collected at 3, 4, and 5 h after dose administration and on study days 2, 7, and 8 (samples were the second void of the day, collected when the fieldworker was present in the home). Isotope analyses were performed with the use of isotope-ratio mass spectrometry (PDZ Europa Ltd, Crewe, United Kingdom) as described elsewhere (37). TEE was calculated with the use of standard equations (37) with a food quotient value of 0.88 determined by 24-h recall in the 1992 China National Nutrition Survey (38, 39) as discussed elsewhere (37).

Resting energy expenditure (REE) was predicted with the use of a cross-validated equation for healthy Chinese adults (40): predicted REE (MJ/d) = 0.0581 × body wt (kg) + 1.7405 × height (m) − 0.0144 × age (y) − 0.4703 × sex (men = 0; women = 1) + 0.2274. We used an Asian-specific equation because Western equations (41) have been suggested to overestimate REE in Asians by as much as 10% on average (40, 42, 43).

Because we were able to measure TEE by doubly labeled water only in the first 73 subjects, predicted TEE was also obtained for all subjects from activity monitors, estimations of activity when the monitor was not worn, and supplemental information on bicycling (because the monitor chosen did not detect this kind of activity).

The chosen activity monitor was a uniaxial accelerometer (MTI ActiGraph, Fort Walton Beach, FL) designed to measure accelerations in the vertical direction and to be worn at the waist along the right anterior axillary line. Subjects were instructed to wear the monitor during all waking hours except when conducting activities involving water (eg, bathing or swimming) and when getting up at night for a short time.

In addition, subjects kept a diary of the types and duration of activities performed when the MTI monitor was not worn, and the energy expenditure of these activities was predicted with the use of literature values for metabolic equivalents [the predicted ratio of TEE to REE during the activity (44)] (45). Energy expenditure during sleep without hindrance was assumed to equal 90% of predicted REE (46, 47).

Because the MTI monitor is insensitive to bicycling, which requires little vertical movement, and because bicycling is a common form of transport in China, the average daily distance and speed of bicycling were also determined by connecting a motion detector (Bike Computer Model 800; Sigma Sport, Olney, IL) to the bicycle of each subject. The duration, distance, and speed of bicycling were recorded daily. Energy expenditure was then predicted with the use of published metabolic equivalent values for bicycling at different speeds (45).

The predicted TEE of each subject was determined by summing the above described activity components (MTI monitoring, bicycling, and other time periods without the monitor), and a ratio of predicted TEE to predicted REE was also calculated to give PAL. There was a significant association between measured TEE and predicted TEE ($r = 0.81$, SEE = 1.233, $P < 0.001$), with a mean (±SEM) difference of 0.02 ± 145.42 kJ and a 95% CI of −289.9, 290.0 kJ, which suggests that the prediction approach was accurate. Cross-validation of this method in an independent population group in future studies is needed.

Measurement of body composition

On the morning of day 9, subjects consumed 0.05 g ^2H_2O/kg body wt after an overnight fast and collection of a baseline urine specimen. Urine specimens were collected at 3, 4, and 5 h, and abundances of ^2H_2O were measured as described elsewhere (48). Total body water was calculated as the ^2H_2O dilution space 5 h after the dose, divided by 1.04 (49). Fat-free mass was then calculated assuming a fat-free mass hydration of 0.732 (50, 51). The appropriateness of applying the standard hydration factor to this Chinese study population was confirmed by our recent analysis with the use of total body water from ^2H_2O dilution and fat-free mass from a 3-compartment model based on densitometry and body water, as described elsewhere (48). Percentage body fat (%BF) was then computed from body weight and fat-free mass.

Anthropometric measurements of weight and height were obtained in triplicate in the fasting state on day 1 and day 9 by a single trained fieldworker (MY) who used standard methods (52) as described elsewhere (48).

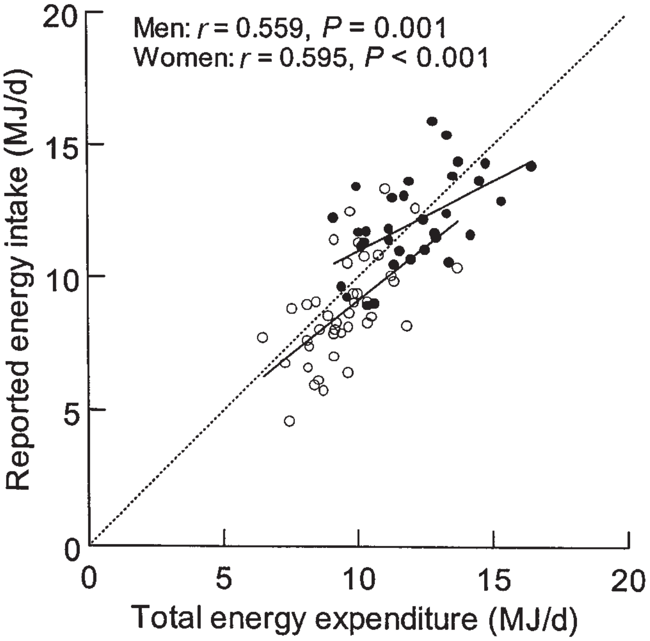

FIGURE 1. Relation between reported energy intake estimated from 3-d weighed food intake and total energy expenditure determined with the use of the doubly labeled water method in 73 urban Chinese men and women. The dotted line is $y = x$.

Statistical analysis

Values are expressed as means ± SEMs. Statistical analyses were performed with the use of SPSS 10.0 for WINDOWS, SYSTAT 9.0 for WINDOWS (both: SPSS Inc, Chicago), and SAS 8e for WINDOWS (SAS Institute Inc, Cary, NC). Normality was examined by using normal probability plots and the Kolmogorov-Smirnov test, and homogeneity of variance was assessed by using Levene's test. Differences between the men and the women were examined with the use of independent-sample *t* tests. Differences between TEE and rEI and between TEE and predicted TEE were examined with the use of paired *t* tests. A one-sample *t* test was used to determine whether the reporting accuracy (100 × rEI:TEE) of the dietary method differed from 100%. A mixed linear model procedure with Tukey's honestly significant difference multiple-comparison procedure was used to assess the least-square means and to determine whether within-subject meal composition (eg, energy content, energy density, and dietary fat percentage) differed by meal type (ie, home-prepared, home-prepared plus takeout, restaurant, or workplace cafeteria) or mealtime (ie, breakfast, lunch, or dinner). A mixed linear model procedure was also used to determine the predictors of within-subject day-to-day variability in rEI. Stepwise multiple regression with general linear model analysis of variance was performed to examine the associations of physical activity and dietary variables (including dietary fat percentage, energy density, dietary variety, and frequency of consumption of restaurant food) with body fatness, adjusted for sex, educational level, smoking status, alcohol intake, and household income. The final model with the fewest covariates but the same predictive power was selected as the best-fitting model for predicting body fatness. The residuals plotted against the predicted values were scattered without apparent pattern around zero. Statistical significance was set at $P < 0.05$.

TABLE 2
Dietary variables from 3-d weighed food intake in subjects

	Men (n = 63)	Women (n = 67)
Energy intake (MJ/d)	11.6 ± 0.3 (7.3–17.4)[1]	8.9 ± 0.2 (4.6–13.3)[2]
Dietary fat (% of energy)	33.3 ± 0.9 (12.4–46.5)	35.3 ± 0.6 (24.1–51.0)
Energy density (kJ/g)	5.3 ± 0.1 (2.8–8.0)	5.0 ± 0.1 (2.5–6.6)
Dietary variety		
(no. of ingredients/3 d)	32 ± 1 (10–49)	34 ± 1 (14–51)
Restaurant food-consumption frequency (% [*n*])		
0–2 meals/3 d	62 [39]	75 [50]
2.01–4 meals/3 d	29 [18]	21 [14]
4.01–9 meals/3 d	10 [6]	5 [3]

[1] $\bar{x}$ ± SEM; range in parentheses.
[2] Significantly different from men, $P < 0.001$.

RESULTS

Both men and women had small mean changes in body weight during the study period that did not differ significantly from 0. The mean BMIs in the men and in the women in the current study were slightly higher than those in 2328 urban adult residents of Beijing (23.8 for the men and 23.9 for the women) from the 2000 National Disease Control and Monitoring Survey (GH Yang, KY Ge, FY Zai, unpublished observations, 2000).

The comparison of TEE determined with the use of the doubly labeled water method and of rEI calculated from the 3-d weighed food intake is shown in **Figure 1**. There was a significant association between TEE and rEI (men: $r = 0.56$, $P = 0.001$; women: $r = 0.60$, $P < 0.001$). The women significantly ($P = 0.003$) underreported energy intake on average (100 × rEI:TEE = 92%), but the extent of underreporting was small. Men did not significantly underreport energy intake (100 × rEI:TEE = 101%). There was no correlation between the percentage of energy derived from fat and rEI:TEE (data not shown). On the basis of these analyses, we used data from all subjects in the primary analyses.

As shown in **Table 2**, dietary intakes of the subjects estimated from 3-d weighed food intake varied widely. Energy intake was significantly ($P < 0.001$) higher in the men than in the women. However, the mean values for dietary fat percentage, energy density, and dietary variety did not differ significantly between the men and the women. The table also shows the percentages of the men and the women who consumed restaurant meals, categorized into 3 frequency levels.

A summary of within-subject meal composition variables by mealtime (breakfast, lunch, and dinner) and meal type (home-prepared, home-prepared plus takeout, restaurant, and workplace cafeteria) is given in **Table 3**. As shown, meal type and mealtime had significant effects on the energy intake, energy density, and dietary fat percentage of meals. In general, restaurant meals had the highest values for energy intake and energy density, and home-prepared food or workplace cafeteria meals had the lowest values. In addition, energy intake at breakfast was significantly ($P < 0.001$) lower than that at lunch or dinner.

Multiple regression models predicting within-subject day-to-day variability in energy intake are summarized in **Table 4**. As shown in model 1, in addition to the frequency of consumption of restaurant food, energy density was a significant predictor of within-subject day-to-day variation in energy intake independent of sex.

TABLE 3
Comparison of within-subject meal composition by meal type and mealtime[1]

	Meal type			
Mealtime	Home-prepared	Home-prepared plus takeout	Restaurant	Workplace cafeteria
Breakfast				
EI (MJ)	2.1 ± 0.1	2.3 ± 0.3	2.6 ± 0.2	2.9 ± 0.5
ED (kJ/g)	6.7 ± 0.2	7.4 ± 0.6	7.5 ± 0.4	6.2 ± 1.1
Fat (% of EI)[2]	31.3 ± 0.9^{a}	38.7 ± 2.5^{a}	35.3 ± 1.7^{a}	11.9 ± 4.8^{b}
Lunch				
EI (MJ)	3.9 ± 0.1	4.5 ± 0.4	4.6 ± 0.2	3.6 ± 0.2
ED (kJ/g)	6.0 ± 0.2	6.9 ± 0.7	6.7 ± 0.4	5.9 ± 0.4
Fat (% of EI)[2]	35.0 ± 0.9	37.4 ± 3.2	34.1 ± 1.6	30.9 ± 1.8
Dinner				
EI (MJ)	3.8 ± 0.1	3.9 ± 0.3	4.4 ± 0.2	4.2 ± 0.6
ED (kJ/g)	5.7 ± 0.2	5.7 ± 0.7	6.2 ± 0.4	5.9 ± 1.2
Fat (% of EI)[2]	37.2 ± 0.8	37.1 ± 3.0	32.3 ± 2.0	—
All meals				
EI (MJ)[3]	3.3 ± 0.1^{a}	3.6 ± 0.2^{a,b}	3.9 ± 0.1^{b}	3.6 ± 0.3^{a,b}
ED (kJ/g)[4]	6.1 ± 0.1^{a}	6.7 ± 0.4^{a,b}	6.8 ± 0.2^{b}	6.0 ± 0.6^{a,b}
Fat (% of EI)	34.5 ± 0.6	37.7 ± 1.7	34.0 ± 1.1	27.2 ± 2.6

[1] $\bar{x}$ ± SEM. Total number of meals used in this analysis was 1102. EI, energy intake; ED, energy density. Values in the same row with different superscript letters are significantly different, $P < 0.05$ (Tukey's honestly significant difference multiple comparison procedure).

[2] Significant main effects of meal type ($P = 0.008$), mealtime ($P = 0.002$), sex ($P = 0.02$), and meal type × mealtime interaction ($P = 0.004$) on dietary fat percentage.

[3] Significant main effects of meal type ($P < 0.001$), mealtime ($P < 0.001$), and sex ($P < 0.001$), but no significant effect of meal type × mealtime interaction on EI.

[4] Significant main effect of meal type ($P = 0.04$) and marginally significant effect of mealtime ($P = 0.07$), but no significant effects of sex or of meal type × mealtime interaction on ED.

However, dietary fat (% energy intake) was not a significant predictor. In addition, in both models, dietary variety was not a significant predictor.

As shown in **Table 5** and **Figure 2**, multiple regression analysis of the between-subject associations of dietary variables and PAL with body fatness revealed that physical activity expressed as the PAL index was inversely associated with %BF (partial $r = -0.307$, $P = 0.001$), whereas dietary variety was positively associated with %BF (partial $r = 0.186$, $P = 0.039$). The frequency of consumption of restaurant food was also positively associated with %BF (partial $r = 0.237$, $P = 0.001$), and subjects who consumed 4.01–9 meals at restaurants during the 3-d dietary survey had a significantly ($P = 0.001$) higher %BF than did those who consumed 0–2 (mean %BF difference of 6.5%) and 2.01–4 (mean %BF difference of 5.0%) meals at restaurants. In these analyses, dietary variety and frequency of consumption of restaurant food together explained 9.1% of the variance in body fatness, and PAL accounted for 9.4% of the variance. Neither dietary fat percentage nor energy density significantly predicted %BF in any analyses. Interactions between dietary variables and PAL were also tested but were not significant.

TABLE 4
Predictors of within-subject day-to-day variability in energy intake[1]

Model and variables	Regression coefficient	SE	P
Model 1			
Constant	4.60	0.54	
Energy density (kJ/g)	0.81	0.09	<0.001
Meals at restaurants (times/d)	0.47	0.18	0.011
Male sex[2]	2.36	0.37	<0.001
Model 2			
Constant	8.47	0.65	
Fat intake (% of energy)	0.00	0.02	0.770
Meals at restaurants (times/d)	0.54	0.20	0.007
Male sex[2]	2.61	0.36	<0.001

[1] Dietary variety was not a significant predictor of within-subject day-to-day variability in energy intake in either model.

[2] Coefficient = 0 for women.

TABLE 5
Multiple regression models predicting percentage body fat in healthy Chinese adults

Model and variables[1]	Regression coefficient	SE	P
Constant	55.37	5.84	
PAL[2]	−11.80	3.31	0.001
Dietary variety (ingredients/3 d)	0.13	0.06	0.039
Restaurant food-consumption frequency[3]			0.001
0–2 meals/3 d	−6.55	1.77	<0.001
2.01–4 meals/3 d	−4.99	1.85	0.008
Male sex[3]	−6.93	1.10	<0.001
Nonsmokers[3]	2.79	1.14	0.016

[1] Further adjustment for educational level, alcohol intake, and household income did not change the predictive power (ie, the same predictors and overall R^2). Therefore, only the final model with the fewest covariates, including sex and smoking status, is shown. Overall adjusted R^2:P, 0.56:<0.001.

[2] Physical activity level calculated from predicted TEE and predicted REE (PAL = predicted TEE:predicted REE).

[3] Coefficient = 0 for women, smoking status, and 4.01–9 meals consumed at restaurants.

DISCUSSION

The major finding of this study in urban Chinese adults was that dietary variety and the frequency of consumption of restaurant food were positively associated with body fatness, but that dietary fat percentage and energy density were not significantly associated with body fatness. In addition, dietary variety and the frequency of consumption of restaurant food together appeared to contribute to between-subject variability in body fatness equally as much as did PAL (9.1% compared with 9.4% of variability). Subjects were selected nonrandomly to ensure a wide range of dietary fat intakes and PALs, and therefore they were not necessarily representative of the overall Chinese population. Nevertheless, the results are consistent with our previous work in a US population, and they indicate that dietary variables other than fat are important predictors of body fatness. The fact that similar results have now been obtained in 2 very different populations with different dietary habits and social norms regarding eating behavior suggests generalizable associations that may help explain variability in body fatness among individuals and perhaps even explain changes over time within communities.

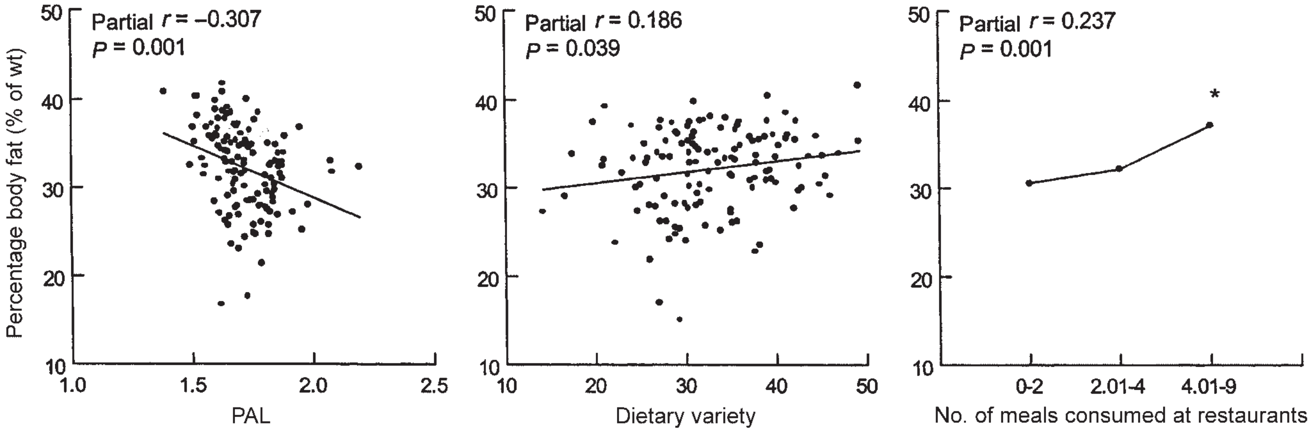

FIGURE 2. Associations of physical activity level (PAL), dietary variety (no. of ingredients in consumed foods), and frequency of consumption of restaurant food with percentage body fat. *Significantly different from those who consumed 0–2 ($P = 0.001$) or 2.01–4 ($P = 0.019$) meals at restaurants.

Many studies in Western populations suggest that underreporting of total energy intake and selective underreporting of foods considered to be unhealthy are widespread, and the extent of underreporting varies among different types of subjects (53, 54). In this new study of Chinese adults, there was no significant difference between rEI and TEE in men and only an 8% difference in women, which indicated that subjects were to a large extent consuming and accurately reporting their usual energy intake. The reasons that this Chinese population gave notably accurate reports of energy intake are not known, but they may relate to the current lack of self-consciousness about eating behavior and a lack of focus on the role of food in health in China. We also developed a method for accurately predicting TEE in this population from a combination of data obtained from activity monitors, bicycling information, and activity records, and we were able to estimate PAL by using predicted REE values from the literature. It should be noted that predicted TEE values gave broadly similar results to measured TEE values in this study. For example, PAL ratios calculated from predicted TEE for the whole population gave similar partial correlations with ratios of %BF to PAL calculated with measured TEE for the doubly labeled water subset (partial correlation using predicted TEE, $n = 130$, was −0.314; partial correlation using measured TEE, $n = 73$, was −0.307; $P < 0.05$ for both).

Our finding that dietary variety and the frequency of consumption of restaurant food were significantly ($P = 0.039$ and 0.001, respectively) associated with body fatness is consistent with results from several previous studies. Studies in laboratory animals show that access to a variety of foods reproducibly leads to increases in energy intake and body fatness (16, 17, 55). Single-meal studies and a single short-term variety intervention in humans confirm the food intake observations in animals (18, 56–60), as does our observation of a significant association between dietary variety and body fatness in adult men and women living in the USA (19). In the present study, we used the total number of recipe ingredients as an index of dietary variety because the variability in the number of ingredients in a recipe is typically greater than that in the number of dishes consumed at any one meal. However, we recognize that there are currently no validated methods for quantifying the different types of dietary variety, and further work in this area is needed. It is possible that the method we used underestimated the association between dietary variety and body fatness. In particular, this results from the facts that the ingredient variety from restaurant foods was not included in the analysis and the ingredient variety of prepared-food items was necessarily undercounted (because the number of ingredients was not known). With regard to the association between the frequency of consumption of restaurant food and body fatness, we obtained a similar result in a US population (22) and speculated that the greater variety and higher energy content of restaurant meals may have been important (21, 22).

Another interesting finding in our study was that the variability in %BF statistically accounted for by variability in dietary variety and the frequency of consumption of restaurant foods appeared to be equal to that accounted for by variability in PAL. It is possible that the use of predicted TEE and predicted REE to estimate PAL resulted in a somewhat imprecise assessment of PAL that underestimated the overall effect of physical activity. However, methods for assessing dietary variety are extremely inexact, and they probably also underestimated the contribution of dietary variety to individual variability in body fatness. Several previous studies suggested that dietary composition may be a relatively unimportant determinant of body fatness compared with physical activity (26–28, 61, 62), and our results exploring dietary variables more broadly suggest that further evaluation of this view is now warranted.

In contrast to the significant effects of dietary variety and frequency of consumption of restaurant foods on body fatness, neither the percentage of energy from dietary fat nor dietary energy density was found to be associated with body fatness in this population. Dietary energy density (but not dietary fat percentage) was, however, associated with within-subject day-to-day variability in energy intake. The combination of these results and the body composition data suggest that there was long-term compensation for between-subject variability in energy density in these free-living Chinese subjects, with the result that energy density did not influence absolute between-subject levels of energy intake or %BF. In the short term, however, energy density was not compensated for, and consequently it contributed to within-subject day-to-day variability in energy intake.

There is substantial controversy about whether dietary fat content influences long-term energy regulation to a significant extent. In support of a role for dietary fat, some dietary intervention trials showed that a reduction in dietary fat results in a significant reduction in body weight, which confirms many studies in animal models (7, 63, 64). However, the effect of fat consumption within the range of 18–40% of energy on body fatness is small in the longer-term (≥1 y) intervention studies (11, 12). Dietary underreporting may also have contributed to this controversy (54). These concerns provided some of the impetus for conducting the present study in China. Using validated methods for the assessment of energy intake and energy expenditure for physical activity, we showed that, for dietary fat values in the range of 12–51%, there was no significant association of dietary fat content with body fatness. Thus, our results support the concept of a small role for dietary fat in long-term energy regulation relative to other dietary factors, including dietary variety and frequency of consumption of restaurant meals.

In conclusion, using validated methods for assessing dietary intake and physical activity in an urban Chinese population, we found that great dietary variety and high frequency of consumption of restaurant meals were predictors of body fatness equal in importance to low PAL. Dietary fat percentage and energy density were not significant predictors of body fatness, but energy density predicted within-subject variability in energy intake. These findings highlight the potential importance of dietary variety and frequency of consumption of restaurant meals in influencing dietary intake and body fatness. Additional research using longitudinal study designs is needed to examine further the role of different dietary variables in energy regulation.

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