Original Article

Gender-specific association of body fat mass with muscle meat-vegetable intake ratio in Shaanxi, China

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Background and Objectives: The effects of muscle meat and vegetable intake on body fat mass remain unclear in the general population. This study aimed to investigate the association of body fat mass and fat distribution with a muscle meat-vegetable intake (MMV) ratio. **Methods and Study Design:** In total, 29,271 participants aged 18–80 years were recruited from the Shaanxi cohort of the Regional Ethnic Cohort Study in Northwest China. The associations of muscle meat, vegetable and MMV ratio, as the independent variable, with body mass index (BMI), waist circumference, total body fat percentage (TBF) and visceral fat (VF), as dependent variables were evaluated by gender-specific linear regression models. **Results:** There was 47.9% of men whose MMV ratio was greater than or equal to 1 and this figure was about 35.7% for women. For men, higher muscle meat intake was associated with higher TBF (standardized coefficient [ß], 0.508; 95% CI, 0.187–0.829), higher vegetable intake was associated with lower VF (ß, -0.109; 95% CI, -0.206 – -0.011), and higher MMV ratio was associated with higher BMI (ß, 0.195; 95% CI, 0.039–0.350) and VF (ß, 0.523; 95% CI, 0.209–0.838). For women, both higher muscle meat consumption and MMV ratio were associated with all fat mass markers, but vegetable intake was not correlated with body fat mass markers. The positive association of MMV on body fat mass was more pronounced in higher MMV ratio group, with both men and women. The intake of pork, mutton and beef was associated positively with fat mass markers but no such association was observed for poultry or seafood. **Conclusions:** An increased intake of muscle meat or a higher MMV ratio was associated with increased body fat, especially among women, and such impact may mainly be attributed to increasing intake of pork, beef and mutton. The dietary MMV ratio could be thus a useful parameter for nutritional intervention.

Key Words: muscle meat-vegetable intake ratio, body mass index, waist circumference, total body fat, visceral fat

INTRODUCTION

The prevalence of obesity is approximately 13% among adults (≥18 years old) according to a 2016 World Health Organization report.[1] In China, the prevalence of overweight and obesity have consistently increased over recent decades to 32.3% and 6.2% in the adult population in 2016, respectively;[2,3] these numbers have been increasing together with the level of economic development. Obesity is strongly related to various comorbidities, such as type 2 diabetes (T2D), inflammation, excess fat within the liver and pancreas, hypertension, and certain types of cancer.[4,5] Thus, practical and effective strategies for preventing obesity must be implemented. Although the body mass index (BMI) has been the standard measure to define overweight and obesity in public health and clinical guidelines,[6,7] it can neither distinguish muscle from fat nor account for body shape or fat distribution.[8,9] An individual's health and risk of disease are also determined by where their fat is deposited. For example, the accumulation of fat in the abdominal area, a common phenomenon among men, is closely linked to insulin resistance and cardiometabolic disease.[10] By contrast, the accumulation of fat in the gluteal–femoral region, a common phenomenon among women, is associated with protection against metabolic diseases.[11] Compared with BMI or waist circumference (WC), total and visceral fat (VF) percentages are more accurate indicators of obesity type and related health consequences, particularly with regard to fat distribution.[12-15]

Diet plays a key role in body fat mass abnormality and its related health outcomes throughout an individual's life-course.[16] Foods derived from animals rather than plants are likely to contribute to fat mass characteristics, which in turn affects the individual's health. In Chinese diets, muscle meat products typically consist of pork,

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mutton (sheep and goat), beef, and poultry. Vegetables from a wide variety of plants, notably leafy greens, root vegetables (e.g., taro), beans (e.g., soy, mung, and broad beans), and sprouts, are commonly consumed. Muscle meats rich in essential amino acids, micronutrients, and a wide range of minerals (e.g., heme iron, and zinc) and vitamins (e.g., Vitamins A and B) are also a key part of many diets.[17-19] The daily consumption of vegetables is advised because they are a rich source of essential vitamins, minerals and other nutrients, notably phytonutrients.[20,21] Findings for the relationship between obesity and vegetable consumption remain inconsistent.[22] Numerous clinical trials have investigated vegetable-based diets that promote weight loss,[23] and a meta-analysis of experimental studies conclude that the effect of increased fruit and vegetable intake on obesity is small and nonsignificant when there is no instruction to restrict the intake of other foods.[24] The relationship between obesity and vegetable consumption also differs by gender.[25] A large European study has reported that greater vegetable intake may have a protective effect on weight loss in men, but not women.[26] However , Chinese and Western diets differ: people in the west generally have more muscle meat and fewer vegetables while Chinese consume more staple foods, such as rice or noodles, vegetables and fewer muscle meats.[27] Over the past 30 years in the United States, the proportion of muscle meat in a typical diet has decreased, but obesity rates have increased considerably.[28] With dietary transition, investigation of the associations of muscle meat and vegetable intake may provide insight into body fatness trends, especially among Chinese people. Although studies have generally utilized dietary and surrogate indicators of body fatness (e.g., BMI), direct measures of body composition have become more readily available; however, studies often been of small sample size or focused on subpopulations (e.g., older adults). The association of the muscle meat-vegetable (MMV) ratio and body fatness remains unclear, especially with respect to ethnicity and gender. The present study investigates the MMV ratio as a putative determinant of body fat mass and distribution among Chinese men and women.

METHODS

Study design and participants

Baseline data from the Shaanxi cohort of the Regional Ethnic Cohort Study in Northwest China as detailed in a previous report have been used.[29] Participants were recruited between June 2018 and May 2019 from all five provinces of Northwest China (Shaanxi, Xinjiang, Ningxia, Gansu, and Qinghai). A face-to-face questionnaire interview was conducted to collect baseline information, specifically demographic and socioeconomic characteristics, behavioral characteristics, environmental exposures, medical history, mental health status, and reproductive history. Initially, the Shaanxi cohort had 48,025 participants. To avoid effects of extreme data points, vegetarians and individuals with no vegetable intake (n = 8275) and individuals younger than 18 or older than 80 years (n = 138) were excluded. Participants with incomplete data about dietary intake (n = 5686), body measurement (n = 2537), or the principal covariates (n = 2118) were excluded. Finally, 29,271 participants (13,653 men and 17,618 women) were included (Figure 1). This study was conducted in accord with the Declaration of Helsinki, and approved by the Human Research Ethics Committee of Xi'an Jiaotong University Health Science Center (No: XJTU2016-411). Written informed consent was obtained from all participants.

Dietary measurement and muscle meat-vegetable intake ratio

All dietary information was collected using a semiquantitative food frequency questionnaire (FFQ) with 31 food groups including staple foods, animal-based foods, plant-based foods, soft drinks, and other specific types of foods.[30] The participants were asked to report the average intake frequency and portion size for each food group consumed over the past 12 months. Intake frequency was divided into five levels: daily, 4–6 times/week, 1–3 times/week, 1–3 times/month, and none or rarely, which were quantified into 7, 5, 2, 0.5, and 0 times a week in the data analysis. In the present study, the term "vegetables" referred to all types of fresh vegetables, including beans (e.g., legumes, edamame, green beans, broad beans, cowpeas, and other beans), root vegetables (e.g., carrot, onion, potato, and taro), gourds (e.g., wax gourd, towel gourd, pumpkin, and cucumber, but not including watermelon and honeydew melon), solanaceous fruits (e.g., eggplant, green pepper, and tomato), tender stems, leaf mosses, and flower vegetables (e.g., green vegetables, spinach, cabbage, Chinese cabbage, celery, bamboo shoot, and leek). Processed vegetables (for example, pickled, dried, or precooked vegetables), vegetable juice, tofu, dried bean curd and soybean milk were not included in this category. The FFQ used in the present study just collect intake of food groups, so analysis on vegetables was based on vegetable food group but not specific type of vegetable. The term "muscle meat" referred to all kinds of fresh, frozen or specially processed (such as pickled/salted/sun-dried/salted) pork, mutton, beef, poultry, and seafood. Poultry including chickens, ducks, geese and wild birds. Seafood including freshwater fish, sea fish, shrimp, crab, and all kinds of shells and snails. Non-flesh animal including egg and dairy items were not included among the muscle meats. Muscle meat-vegetable ratio (MMV ratio) was defined as the sum of frequency of each type of muscle meat intake divided by frequency of vegetable intake (times per week). The participants were split into a high MMV ratio group (MMV ratio ≥ 1) and low MMV ratio group (MMV ratio <1). The log function was used to transform muscle meat consumption and MMV ratio for the data to have more of a normal distribution; the high MMV ratio group was defined when log MMV ratio was ≥ 0, and vice versa.

Definition of outcomes

BMI and total body fat percentage (TBF%) were used as indicators of body fat mass, and WC and visceral fat (VF) were used as the indicator of fat distribution.[31] Height was measured to the nearest 0.1 cm with a calibrated stadiometer, and weight was measured to the nearest 0.1 kg using a metric scale. When being weighed, the participants were required to fast, wear light clothing, and remove

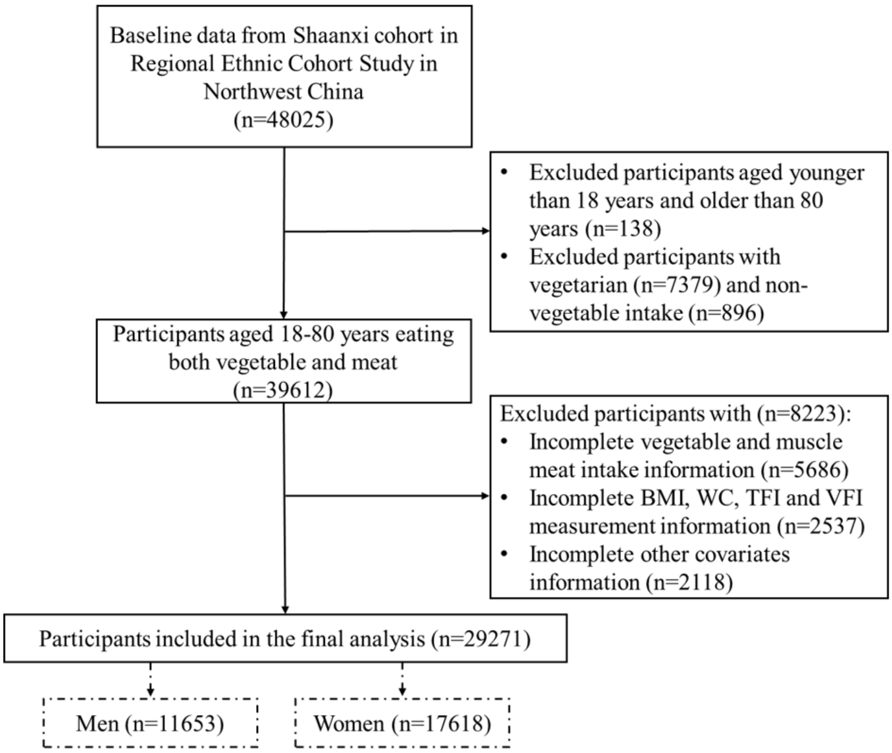

Figure 1. The flow chart for study participant selection

their shoes. WC was measured to the nearest 0.1 cm at the midpoint between the lowest rib and the iliac with a medical tape measure. TBF% and VF grade were measured using bioelectrical impedance analysis, and the difference of the impedance values between the fat and non-fat tissues of the body were used to indicate body composition.

Covariates

As determined through a literature review, covariates correlated with muscle meat and vegetable intake and with health outcomes were controlled for. These covariates pertained to sociodemographic characteristics (age, gender, socioeconomic status [SES], residence, and marital status), lifestyle (smoking, drinking, physical activity, and sleeping problems), dietary habits (staple food consumption, diet diversity score [DDS], and unhealthy eating behaviors), and nutrition-related diseases.[32-37] SES was indicated using a comprehensive index based on family income, education level, and occupation, and was divided by tertiles (high, medium, and low). Residence was either urban or rural. Marital status was either married or unmarried. Smoking was defined daily smoke or not. Drinking was defined at least once every week or not. The physical activity was assessed using metabolic equivalents.[38] Sleeping problem was defined if participants had a history of one of the following: typically requiring more than half an hour to fall asleep, waking up early in the morning and having trouble getting back to sleep, taking sleeping pills at least once a day to help with sleep, and impaired functioning during the day due to a lack of sleep. We estimated the energy intake and whole diet quality based on the participant's intake of staple foods and DDS. Staple food intake was defined as the cumulative intake of rice, wheat, and cereals. DDS was assessed using such nine major food groups as white tubers and roots, vegetables, fruits, meat, eggs, seafood, legumes, nuts and seeds, dairy products, and sweets according to the recommended daily intake for adults of Chinese descent.[39] A single DDS unit was defined as the consumption of any food group at least five times a week with no consideration of minimum intake; cereals and oils were not included in the DDS because almost everyone in China consumes these two food groups daily.[40] Unhealthy eating behaviors covered the cumulative intake frequency of snacks, convenience foods, midnight snacks, cured meats, processed foods, fried foods, and fast food and the frequency of skipping breakfast or eating out. Nutrition-related diseases were defined as the occurrence of one of the following: diabetes, stroke, and myocardial infarction.

Statistical analysis

Data were presented as mean ± standard deviation (for continuous data) or percentage (for categorical data) by gender. The log MMV ratio was visualized using a histogram and density curve by gender. Multivariable linear regression model was employed to estimate β coefficients and 95% confidence intervals (CI) for associations of muscle meat, vegetable consumption, and MMV ratio (as independent variables) with BMI, WC, TBF%, and VF (as dependent variables). Gender-specific models were established to account for gender differences in nutrition. All models had adjustments for age, SES, marital status, residence, smoking, drinking, physical activity, sleeping problem, staple food intake, DDS, and unhealthy eating behaviors. Restricted cubic splines with three knots were used for dose–response analyses to explore the potential dose–response associations of MMV ratio with body fat mass or fat distribution.[41] Knots were placed at the 10th, 50th, and 90th percentiles of the log MMV ratio. A series of subgroup analyses by MMV ratio (lower vs. higher) were conducted to determine the relationship between fat mass markers and MMV ratio. A series of sensitivity analyses were conducted to confirm the robustness of the findings. First, the linear regression analysis were repeated in the participants without nutrition-related disease (n = 27,390), and in all participants among them missing values were filled in by multiple imputation (n = 31,389). Second, an exploratory subgroup analysis was conducted with the main covariates. Finally, we further explored the association of intake of each type of muscle meat with fat mass. Statistical analysis was performed using R 4.0 and SPSS 18.0 software. Significance was indicated by a two-tailed p value <0.05.

RESULTS

Participant characteristics

Among the 29,271 participants, 60.2% were women and the average age was 50.02 ± 12.85 years. Women tended to be older, have lower SES, be married, live in rural areas, have more sleeping problem, eat more staple foods, consume less alcohol, smoke less, have less physical activity, and have fewer unhealthy eating behaviors than men. The mean (SD) muscle meat and vegetable consumption were 6.0 (5.2) and 6.5 (1.3) times/week for men, 4.6 (4.5) and 6.7 (1.0) times/week for women. There was 47.9% of men whose MMV ratio was greater than or equal to 1 and this figure was about 35.7% for women. Additionally, women had lower BMI, WC, and VF but higher TBF compared with men (Table 1, Figure 2).

Association of body fat mass and fat distribution with muscle meat intake, vegetable intake, and MMV ratio

The adjusted associations between MMV ratio and measures of body fat mass (BMI, WC, TBF%, and VF) were presented by gender in Table 2. Among men, higher muscle meat intake was associated with higher TBF (ß,

Table 1. Baseline characteristics of the participants (n = 29,271)†

Variables	Total (n=29271)	Men (n=11653)	Women (n=17618)
Age (years), mean ± SD	50.02±12.8	49.7±13.9	50.2±12.1
Age (years), %			
<40	6578 (22.5)	3153 (27.1)	3425 (19.4)
40~49	6479 (22.1)	2175 (18.7)	4304 (24.4)
50~59	8864 (30.3)	3015 (25.9)	5849 (33.2)
60~69	5848 (20.0)	2585 (22.2)	3263 (18.5)
≥70	1502 (5.1)	725 (6.2)	777 (4.4)
SES, %			
Low	10679 (36.4)	3205 (27.5)	7474 (42.4)
Median	8886 (30.4)	3438 (29.5)	5448 (30.9)
High	9706 (33.2)	5010 (43.0)	4696 (26.7)
Married, %	25718 (87.9)	10067 (86.8)	15651 (89.3)
Urban, %	8726 (29.8)	4600 (39.5)	4126 (23.4)
Drinking, %	2757 (9.4)	1478 (20.4)	379 (2.2)
Smoking, %	4978 (17.0)	4887 (41.9)	91 (0.5)
Physical activity (METs, h/d), mean ± SD	13.6±11.8	16.3 ± 12.9	11.8 ± 10.6
Sleeping problem, %	9555 (32.6)	3589 (31.6)	5966 (34.3)
Frequency of unhealthy eating behaviors (times/week), mean ± SD	4.3±6.4	5.0±7.1	3.8±6.0
Nutrition-related diseases, %	1181 (6.4)	851 (7.3)	1030 (5.8)
DDS, mean ± SD	3.1±1.3	3.1±1.2	3.0±1.2
Food intake (times/week), mean ± SD			
Staple food	11.8±4.4	11.7±4.4	11.9±4.4
Vegetable	6.6±1.2	6.5±1.3	6.7±1.0
Muscle meat	5.2±4.9	6.0±5.2	4.6±4.5
Pork	3.2±2.6	3.5±2.6	3.0±2.6
Mutton	0.4±1.1	0.6±1.2	0.3±1.0
Beef	0.5±1.2	0.7±1.3	0.4±1.1
Poultry	0.6±1.3	0.7 ±1.4	0.5±1.2
Seafood	0.4±1.0	0.5±1.0	0.4±0.9
Eggs	2.5±2.4	2.7±2.6	2.4±2.5
Dairy	2.5±3.6	2.5±3.5	2.4±3.7
Log MMV ratio, mean ± SD	-0.3±0.5	-0.2±0.5	-0.4±0.5
High MMV ratio	11873 (40.6)	5585 (47.9)	6288 (35.7)
Body fat mass and fat distribution index, mean ± SD			
BMI (kg/m^2)	23.8±3.4	24.3±3.4	23.5±3.4
WC (cm)	82.2±9.8	85.0±9.5	80.4±9.5
TBF, %	29.1±8.2	23.2±6.2	32.5±7.2
VF, level	8.0±4.0	11.0±4.3	6.3±2.5

MMV ratio, muscle meat–vegetable intake ratio; SES, socioeconomic status; DDS, diet diversity score; BMI, body mass index; WC, waist circumference; TBF, total body fat; VF, visceral fat
†Data are mean ± SD, n (%) unless otherwise indicated.

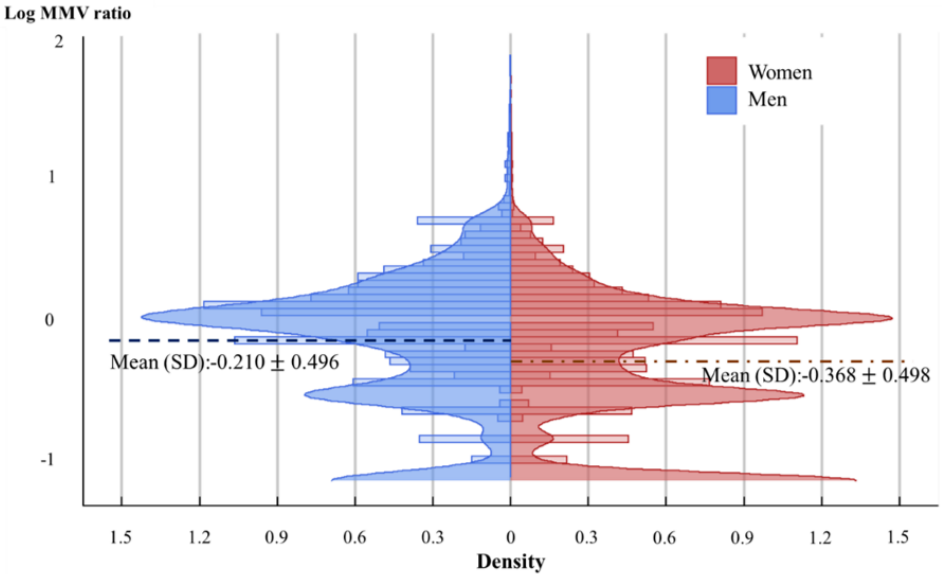

Figure 2. Log MMV ratio histogram plot by gender.

Table 2. Associations of muscle meat intake, vegetable intake, and MMV ratio with body fat mass and fat distribution by gender†

Variables	Men (N=11653)			Women (N=17618)		
	ß	(95% CI)	*p*	ß	(95% CI)	*p*
Muscle meat‡						
BMI, kg/m^2	0.159	(-0.003, 0.320)	0.054	0.148	(0.030, 0.265)	0.014
WC, cm	0.366	(-0.112, 0.844)	0.134	0.676	(0.345, 1.006)	<0.001
Total body fat, %	0.508	(0.187, 0.829)	0.002	0.581	(0.315, 0.846)	<0.001
Visceral fat, level	0.096	(-0.122, 0.314)	0.388	0.105	(0.017, 0.192)	0.014
Vegetable						
BMI, kg/m^2	-0.047	(-0.103, 0.009)	0.101	0.027	(-0.024, 0.078)	0.098
WC, cm	-0.109	(-0.297, 0.079)	0.256	0.136	(-0.021, 0.292)	0.090
Total body fat, %	-0.073	(-0.220, 0.074)	0.328	-0.121	(-0.253, 0.012)	0.075
Visceral fat, level	-0.109	(-0.206, -0.011)	0.029	-0.021	(-0.064, 0.022)	0.344
MMV ratio‡						
BMI, kg/m^2	0.195	(0.039, 0.350)	0.014	0.129	(0.015, 0.244)	0.027
WC, cm	0.402	(-0.061, 0.866)	0.089	0.584	(0.260, 0.908)	<0.001
Total body fat, %	0.523	(0.209, 0.838)	0.001	0.630	(0.369, 0.890)	<0.001
Visceral fat, level	0.152	(-0.061, 0.366)	0.162	0.113	(0.027, 0.199)	0.010

†Models had adjustments for age, SES, marital status, smoking and drinking, residence, physical activity, sleeping problem, stable food intake, unhealthy eating behaviors and DDS
‡Variables are log transformed

0.508; 95% CI, 0.187–0.829), higher vegetable intake was associated with lower VF (ß, -0.109; 95% CI, -0.206–-0.011), and higher log MMV ratio was associated with higher BMI (ß, 0.195; 95% CI, 0.039–0.350) and VF (ß, 0.523; 95% CI, 0.209–0.838). Among women, higher muscle meat intake was associated with higher BMI (ß, 0.148; 95% CI, 0.030–0.265), WC (ß, 0.676; 95% CI, 0.345–1.006), TBF (ß, 0.581; 95% CI, 0.315–0.846), and VF (ß, 0.105; 95% CI, 0.017–0.192). No significant associations between vegetable intake and BMI, WC, TBF, and VF were observed. MMV ratio was positively associated with BMI (ß, 0.129; 95% CI, 0.015–0.244), WC (ß, 0. 584; 95% CI, 0.260–0.908), TBF (ß, 0.630; 95% CI, 0.369–0.890), and VF (ß, 0.113; 95% CI, 0.027–0.199).

Restricted cubic splines were used to explore the dose–response association and visualize the relationship of MMV ratio with BMI, WC, TFI, and VF by gender in Figure 3. The nonlinear trend was nonsignificant for all associations (*p* for non-linearity > 0.05). However, the dose-response relationship indicated such that a higher log MMV ratio was associated with higher BMI (p = 0.050) and TBF (p = 0.003) among men and with higher BMI (p = 0.004), WC (p < 0.001), TBF (p < 0.001), and VF (p = 0.006) among women.

The adjusted associations between MMV ratio and measures of body fat mass (BMI, WC, TBF%, and VF) in both low and high MMV ratio groups by gender were presented in Table 3. Among men, a higher log MMV ratio was associated with higher VF (β, 0.959; 95% CI, 0.090–1.829) in the high MMV ratio group. Among women, a higher log MMV ratio was associated with higher WC (β,1.603; 95% CI, 0.082–3.125), TBF (β, 1.896; 95% CI, 0.527–3.265), and VF (β, 0.524; 95% CI, 0.082–0.966) in the high MMV ratio group.

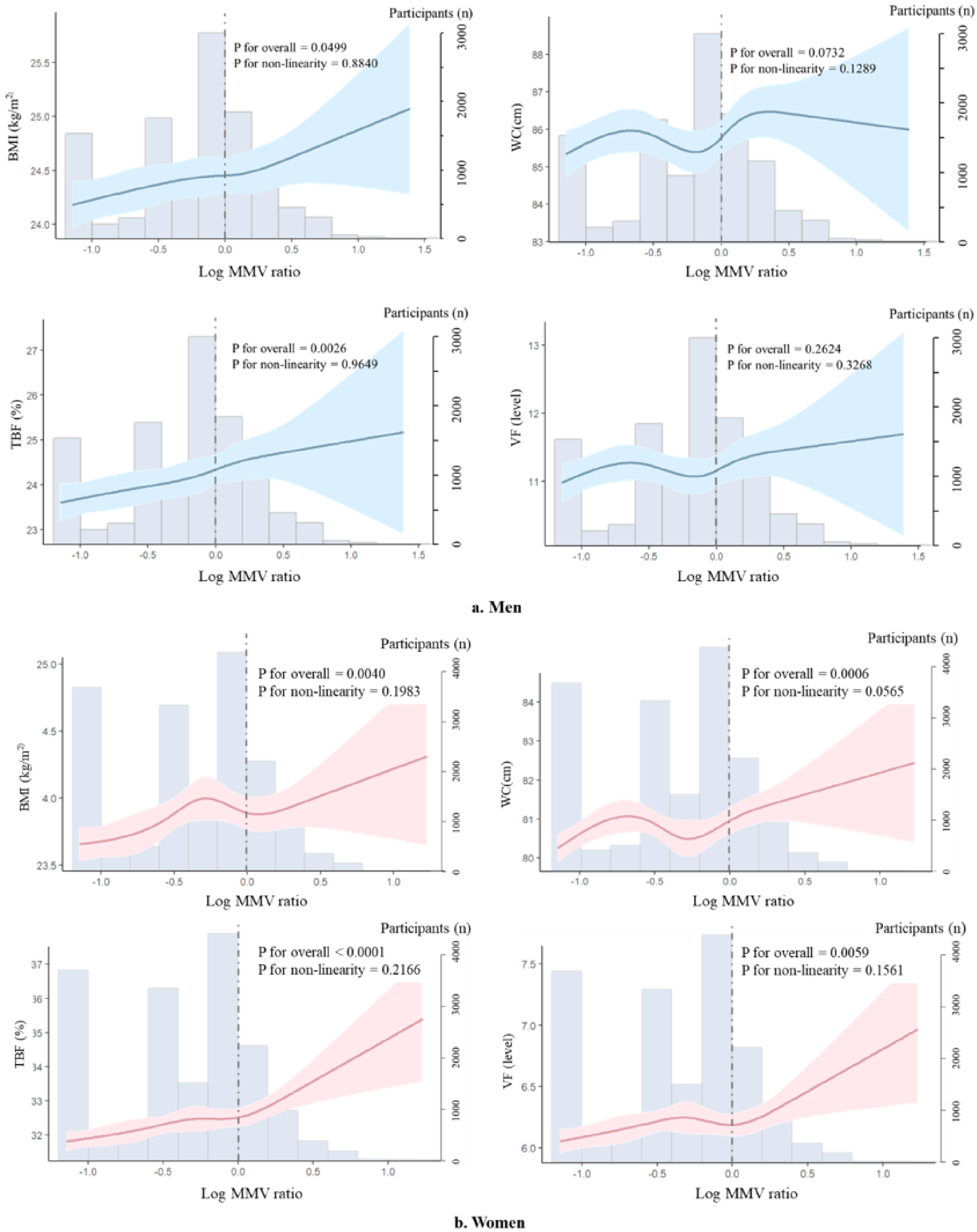

Figure 3. Non-linear relationship between log MMV ratio and body fat mass and fat distribution by gender

Sensitivity analyses and subgroup analyses

Several sensitivity analyses were performed to observe the robustness of the association of interest. MMV ratio was still associated with higher BM and VF in man and higher all fat mass in women, even after excluding the participants with nutrition-related diseases (Supplementary Table 1). When our analysis included all participants, whose missing values were imputed, the results were also similar to main analysis (Supplementary Table 2). The exploratory subgroup analysis based on the main covariates (Supplementary Figure 1) indicated a robust association of muscle meat intake, vegetable intake, and MMV ratio with fat mass and distribution regardless of gender. Moreover, we also found that the consumption of pork, beef or mutton had a positive relationship with fat mass makers, separately, while intake of poultry and seafood was not significantly associated with those makers (Supplementary Table 3).

DISCUSSION

This study on the association of body fat mass with muscle meat and vegetable consumption involved a large

Table 3. Associations of log MMV ratio with body fat mass and fat distribution in low and high MMV ratio groups by gender (n = 29,271)†

Variables	Men (N=11653)			Women (N=17618)		
	ß	(95% CI)	*p*	ß	(95% CI)	*p*
Low MMV ratio group						
BMI, kg/m^2	0.255	(0.002, 0.507)	0.049	0.052	(-0.128, 0.232)	0.572
WC, cm	0.513	(-0.219, 1.245)	0.170	0.354	(-0.152, 0.860)	0.170
Total body fat, %	0.355	(-0.144, 0.855)	0.163	0.402	(0.005, 0.800)	0.047
Visceral fat, level	0.336	(-0.002, 0.675)	0.051	0.125	(-0.007, 0.258)	0.063
High MMV ratio group						
BMI, kg/m^2	0.214	(-0.285, 0.712)	0.401	0.208	(-0.388, 0.604)	0.669
WC, cm	1.139	(-0.557, 2.834)	0.188	1.603	(0.082, 3.125)	0.039
Total body fat, %	0.200	(-1.090, 1.490)	0.761	1.896	(0.527, 3.265)	0.007
Visceral fat, level	0.959	(0.090, 1.829)	0.031	0.524	(0.082, 0.966)	0.020

†Models had adjustments for age, SES, marital status, smoking and drinking, residence, physical activity, sleeping problem, stable food intake, unhealthy eating behaviors and DDS

population-based sample of Chinese adults. Among men, higher muscle meat intake was associated with higher TBF and a higher MMV ratio was associated with higher BMI and VF. However, among women, higher muscle meat intake and MMV ratio were associated with all higher body fat mass. Further, intake of pork, beef and mutton was associated significantly with body fat mass but such association was not found for poultry and seafood. A protective association of vegetable intake with VF was observed only among men.

Obesity is a multifactorial disease caused by biological, behavioral, and environmental factors,[42,43] but it is mainly attributed to low physical activity and a high consumption of energy-dense food over a prolonged period.44 Increased fruit and vegetable intake is widely recommended for preventing and treating obesity, whether at an individual or policymaking level.[45,46] In epidemiological research demonstration, a review study indicated that most types of fruit had anti-obesity effects and another review concluded that fruit type played an important role in body weight.[47,48] More observational studies indicated that vegetables were beneficial to physical and mental health.[49-53] However, the relationship between vegetable intake and obesity remains unclear. Fruit contains large amounts of simple sugars (e.g., glucose, fructose, and sucrose), which are well known to induce obesity. The present study indicated that vegetable intake was not associated with a lower likelihood of body fat mass or fat distribution in Chinese, which could be attributed to the different dietary pattern. Western dietary pattern includes more muscle meat and fewer vegetables while there are more vegetables and staple foods but less muscle meat in Chinses diet.[27,54,55]

Greater muscle meat intake and higher MMV ratio were observed largely be associated with increased body fat mass and fat distribution in both men and women. This is consistent with the results of previous studies.56 Generally, longitudinal studies have reported increased body weight, abdominal fat, and WC with increases in the intake of dietary animal protein.[57,58] Some studies also found impact of intake of egg and milk on body fat mass but the results were inconsistent.[59-62] In our participants, egg and milk were found inversely associated with BMI and TBF in both men and women (Supplementary Table 4). The present study mainly focused on muscle meat foods which were main source of animal protein in Chinese, and all analysis was adjusted for egg and milk which were integrated into DDS. There were four notable findings. First, compared with the influence on WC and VF, the influence of muscle meat intake and MMV ratio on BMI and TBF were greater in men. A study conducted in China reported that that the body composition indicators of waist-to-hip ratio, body fat percentage, and VF area predict the occurrence of T2D.[63] Our results indicated that muscle meat intake may induce fat gain in men, but not necessarily around the waist or in a manner that leads to unhealthier VF. Second, although muscle meat intake and MMV ratio had positive associations with BMI, WC, TBF, and VF in women, the increase was more in evidence when MMV > 1. For example, a higher log MMV ratio was associated with a higher TBF (β, 0.402; 95% CI: 0.005–0.800) in the low MMV ratio group but the β was about 1.896 (95% CI, 0.527–3.265) in the high MMV ratio group. This indicated that the participants consuming more muscle meat than vegetables tended to have greater body fat. Conversely, for participants with higher vegetable intake, increased muscle meat consumption had little influence on body fat. This implied that the extent to which muscle meat affected body fat could be related to the proportion of muscle meat to vegetables in the diet. Muscle meat contains protein containing essential amino acids, the proportion of nitrogen acid is close to human body, and easy to be digested and absorbed by human body.[17] Muscle meat is believed to enrich the blood in fibrin and corpuscles and to increase mineral salts, especially phosphates; it both repairs old tissue and aids the growth of new tissue. It improves the condition of the muscles, which are firmer than those of individuals on a vegetable-based diet. A recent study reported that every essential nutrient was present in animal-sourced foods but not always in high levels in commonly eaten animal products.[64] Another study with a larger sample reported that greater meat consumption was associated with cardiometabolic benefits, particularly improved central adiposity, independent of other dietary factors.[65] Crucially, although muscle meat intake within a certain range increases body weight and fat, muscle meat possesses peculiar advantages. Therefore, the relative merits of muscle meat intake require recognition. The MMV ratio reflects structural dietary problems. Therefore, dietary pattern, especially the ratio of muscle meat to vegetables, should be considered in nutritional interventions, and a biodiverse nutritious diet should be advocated. Third, the MMV ratio had a relatively weak influence, even a negative influence, among older participants for various reasons. For example, the sample size of older adults was limited and the older may have their own specific nutritional needs. In Korean adults aged 60 years or older, a higher protein intake was associated with more favorable obesity index scores. The effect was similar among both men and women and for both animal and plant proteins.[56] A varied intake of animal-based and plant-based foods provides greater nutritional security. Fourth, the effect of muscle meat on fat mass was still largely determined by the amount of pork, beef and mutton consumed (Supplementary Table 3). The present results seemed to stand by previous research findings that high red meat consumption was positively associated with the obesity and metabolic syndrome in Chinese adults.[66,67]

The biological mechanisms underlying gender-specific variations between the MMV ratio and increased body fat mass and fat distribution are unclear. With regard to gender-specific physiology, endogenous sex hormones could play different roles in metabolic health in men versus women.[68] Adiposity and mitochondrial dysfunction are related factors contributing to the development of metabolic diseases while distinct sex-dependent associations between monocyte and skeletal muscle mitochondrial metabolism with body composition exhibit.[69] Moreover, men may consume more muscle meat than women; muscle meat is a main source of n-3 polyunsaturated fatty acids (PUFAs), an essential nutrient for the human body. These results suggest that although n-3 PUFAs may not aid weight loss, they may attenuate further weight gain and could help maintain optimal weight whether consumed through supplements or one's diet. Proposed mechanisms through which n-3 PUFAs improve body composition and counteract obesity-related metabolic changes include the modulation of lipid metabolism, regulation of adipokines, alleviation of adipose tissue inflammation, promotion of adipogenesis, or alteration of epigenetic mechanisms.[70]

The strengths of this study are its large sample size and a wide age range. Most studies have focused on effects of diet on body fat mass and fat distribution among adolescents or older adults. Our sample had a large proportion of middle-aged adults. Sensitivity analyses were also conducted. However, several limitations should be noted. First, its cross-sectional design precluded rate, particularly with regard to the temporal sequence of events, and further prospective cohort studies should thus be conducted. Second, the FFQ did not allow us to accurately determine the total energy intake of the participants, and we estimated total energy intake using staple food intake, DDS,[71] age, sex, and physical activity. Third, information on diet was self-reported, and recall bias was thus inevitable. However, this error was mitigated by the fact that dietary information was collected through face-to-face interviews by trained staff. The FFQ was not designed to differentiate types of vegetables, which limited the analysis by specific vegetable. Fourth, women with low SES were overrepresented in the sample, and generalizability may thus be limited. Finally, the complex interactions between food consumption and nutrition could not be fully captured in this study, and our findings should thus be interpreted with caution.

Conclusion

Increased intake of muscle meat and higher MMV ratio may induce body fat accumulation, but this association was gender specific. The positive association between muscle meat intake and body fat accumulation was more pronounced among participants with high MMV ratio. Increasing intake of pork, beef and mutton may be main contributor. Nutritional practice may capitalize on the results of this study to consider the MMV ratio in diet recommendations.

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CONFLICT OF INTEREST AND FUNDING DISCLOSURES

The authors declare no conflict of interest.

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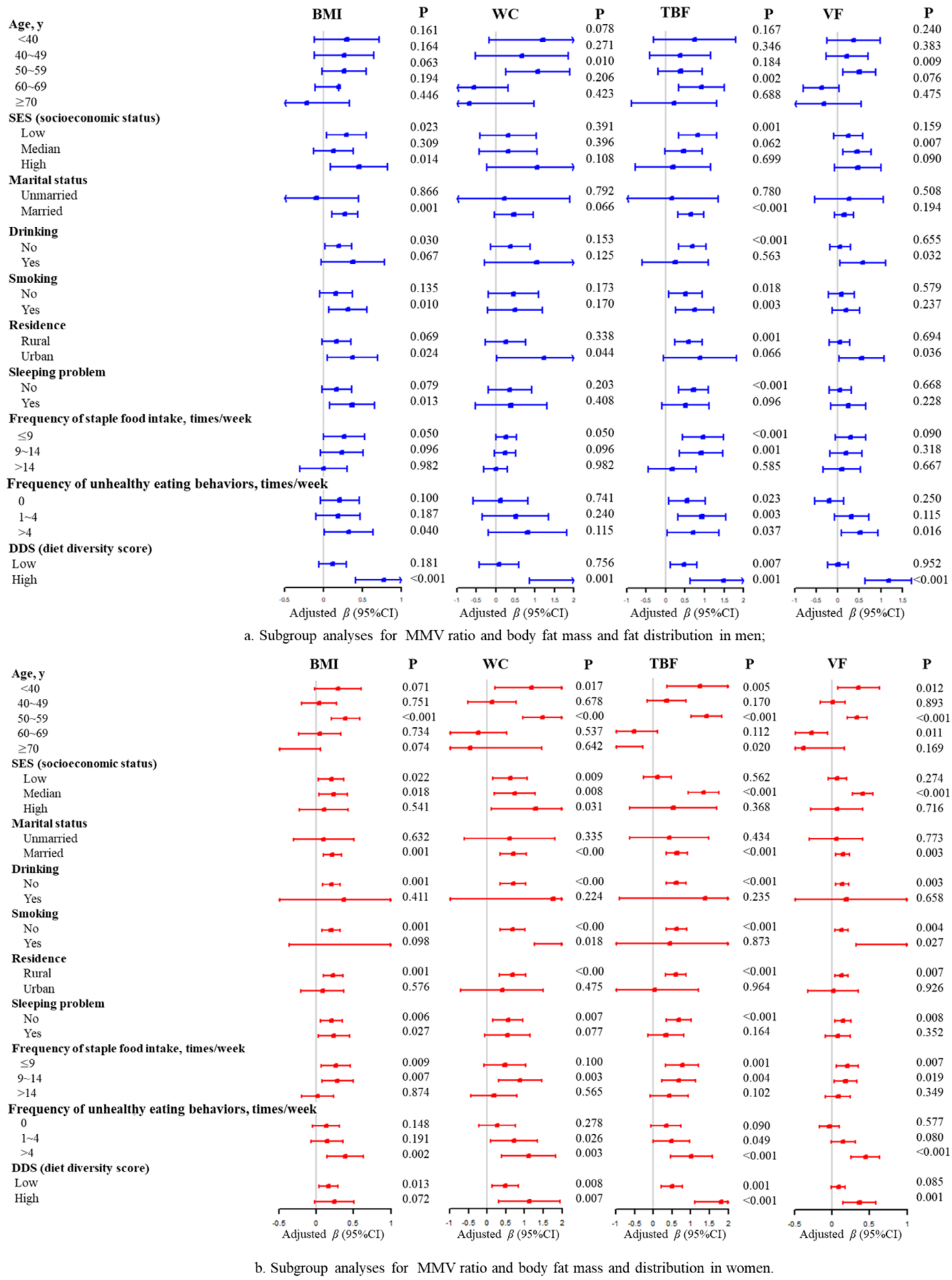

Supplementary Figure 1. Subgroup analyses for MMV ratio and body fat mass and fat distribution by gender†
†All results were adjusted for variables other than the subgroup variables.

Supplementary Table 1. Associations of muscle meat intake, vegetable intake, and MMV ratio with body fat mass and fat distribution by gender with participations with nutrition-related disease excluded (n = 27,390)†

Variables	Men (N=10802), 39.4%			Women (N=16588), 60.6%		
	ß	(95% CI)	*p*	ß	(95% CI)	*p*
Muscle meat‡						
BMI, kg/m^2	0.222	(0.053, 0.391)	0.010	0.155	(0.035, 0.275)	0.011
WC, cm	0.527	(-0.016, 1.328)	0.079	0.628	(0.289, 0.967)	<0.001
Total body fat, %	0.656	(0.319, 0.994)	<0.001	0.602	(0.329, 0.875)	<0.001
Visceral fat, level	0.174	(-0.055, 0.402)	0.137	0.109	(0.020, 0.198)	0.017
Vegetable						
BMI, kg/m^2	-0.050	(-0.107, 0.008)	0.090	0.032	(-0.019, 0.084)	0.221
WC, cm	-0.124	(-0.316, 0.069)	0.208	0.144	(-0.015, 0.303)	0.076
Total body fat, %	-0.095	(-0.247, 0.056)	0.218	-0.099	(-0.234, 0.037)	0.153
Visceral fat, level	-0.123	(-0.223, -0.022)	0.017	-0.020	(-0.064, 0.024)	0.379
MMV ratio‡						
BMI, kg/m^2	0.257	(0.095, 0.420)	0.002	0.133	(0.016, 0.250)	0.026
WC, cm	0.563	(-0.007, 1.129)	0.053	0.530	(0.198, 0.862)	0.002
Total body fat, %	0.678	(0.347, 1.009)	<0.001	0.643	(0.375, 0.911)	<0.001
Visceral fat, level	0.232	(-0.008, 0.466)	0.052	0.117	(0.029, 0.205)	0.009

†Models had adjustments for age, SES, marital status, smoking and drinking, residence, physical activity, sleeping problem, stable food intake, unhealthy eating behaviors and DDS
‡Variables are log transformed

Supplementary Table 2. Associations of muscle meat intake, vegetable intake and MMV ratio with body fat mass and fat distribution by gender after multiple imputation (n = 31,389)†

Variables	Men (N=12720), 40.5%			Women (N=18669), 59.5%		
	ß	(95% CI)	*p*	ß	(95% CI)	*p*
Muscle meat‡						
BMI, kg/m^2	0.159	(0.003, 0.315)	0.046	0.144	(0.030, 0.257)	0.013
WC, cm	0.401	(-0.055, 0.858)	0.085	0.631	(0.320, 0.942)	<0.001
Total body fat, %	0.511	(0.194, 0.828)	0.002	0.627	(0.379, 0.876)	<0.001
Visceral fat, level	0.126	(-0.087, 0.339)	0.247	0.115	(0.029, 0.201)	0.009
Vegetable						
BMI, kg/m^2	-0.031	(-0.082, 0.021)	0.241	0.020	(-0.028, 0.069)	0.414
WC, cm	-0.073	(-0.217, 0.070)	0.317	0.065	(-0.068, 0.198)	0.338
Total body fat, %	-0.097	(-0.201, 0.007)	0.069	-0.019	(-0.125, 0.088)	0.734
Visceral fat, level	-0.058	(-0.121, 0.005)	0.072	-0.010	(-0.048, 0.029)	0.622
MMV ratio‡						
BMI, kg/m^2	0.201	(0.052, 0.350)	0.008	0.131	(0.020, 0.241)	0.021
WC, cm	0.407	(-0.042, 0.855)	0.075	0.566	(0.262, 0.869)	<0.001
Total body fat, %	0.546	(0.242, 0.851)	<0.001	0.636	(0.393, 0.878)	<0.001
Visceral fat, level	0.171	(-0.037, 0.380)	0.107	0.126	(0.041, 0.210)	0.003

†Models had adjustments for age, SES, marital status, smoking and drinking, residence, physical activity, sleeping problem, stable food intake, unhealthy eating behaviors and DDS
‡Variables are log transformed

Supplementary Table 3. Associations of each type of muscle meat intake with body fat mass and fat distribution by gender †

Muscle meat‡	Men (N=11653)			Women (N=17618)		
	ß	(95% CI)	*p*	ß	(95% CI)	*p*
Pork						
BMI, kg/m^2	0.007	(-0.019, 0.033)	0.586	0.035	(0.015, 0.055)	0.001
WC, cm	-0.039	(-0.116, 0.038)	0.323	0.077	(0.019, 0.135)	0.009
Total body fat, %	0.085	(0.032, 0.138)	0.002	0.074	(0.027, 0.120)	0.002
Visceral fat, level	-0.021	(-0.057, 0.015)	0.257	0.005	(-0.011, 0.020)	0.539
Mutton						
BMI, kg/m^2	0.076	(0.016, 0.135)	0.013	0.007	(-0.048, 0.062)	0.800
WC, cm	0.407	(0.217, 0.598)	<0.001	0.229	(0.064, 0.395)	0.006
Total body fat, %	0.090	(-0.052, 0.232)	0.214	0.275	(0.137, 0.413)	<0.001
Visceral fat, level	0.191	(0.096, 0.286)	<0.001	0.059	(0.014, 0.105)	0.010
Beef						
BMI, kg/m^2	0.101	(0.045, 0.157)	<0.001	-0.021	(-0.074, 0.031)	0.429
WC, cm	0.432	(0.244, 0.620)	<0.001	0.266	(0.103, 0.429)	0.001
Total body fat, %	0.097	(-0.048, 0.242)	0.190	0.268	(0.128, 0.408)	<0.001
Visceral fat, level	0.174	(0.078, 0.270)	<0.001	0.058	(0.013, 0.104)	0.013
Poultry						
BMI, kg/m^2	-0.022	(-0.078, 0.034)	0.448	-0.049	(-0.102, 0.003)	0.065
WC, cm	-0.035	(-0.229, 0.160)	0.727	0.083	(-0.090, 0.255)	0.346
Total body fat, %	-0.041	(-0.201, 0.118)	0.611	0.110	(-0.050, 0.270)	0.179
Visceral fat, level	0.011	(-0.094, 0.116)	0.840	0.032	(-0.020, 0.084)	0.231
Seafood						
BMI, kg/m^2	-0.026	(-0.099, 0.048)	0.490	-0.056	(-0.121, 0.009)	0.092
WC, cm	-0.005	(-0.260, 0.250)	0.969	0.076	(-0.138, 0.289)	0.488
Total body fat, %	-0.028	(-0.229, 0.174)	0.789	0.100	(-0.096, 0.296)	0.316
Visceral fat, level	0.057	(-0.078, 0.191)	0.409	0.025	(-0.039, 0.089)	0.438

†Models had adjustments for age, SES, marital status, smoking and drinking, residence, physical activity, sleeping problem, stable food intake, unhealthy eating behaviors and DDS
‡Variables are log transformed

Supplementary Table 4. Associations of eggs and dairy intake with body fat mass and fat distribution by gender†

Body Fat Mass	Men (N=11653)			Women (N=17618)		
	ß	(95% CI)	*p*	ß	(95% CI)	*p*
Eggs						
BMI, kg/m^2	-0.035	(-0.061, -0.009)	0.009	-0.051	(-0.072, -0.030)	<0.001
WC, cm	0.004	(-0.076, 0.084)	0.927	-0.031	(-0.092, 0.030)	0.323
Total body fat, %	-0.066	(-0.122, -0.011)	0.019	-0.076	(-0.125, -0.026)	0.003
Visceral fat, level	0.012	(-0.026, 0.049)	0.543	-0.021	(-0.037, -0.005)	0.012
Dairy						
BMI, kg/m^2	-0.056	(-0.076, -0.035)	<0.001	-0.058	(-0.074, -0.042)	<0.001
WC, cm	-0.094	(-0.160, -0.028)	0.005	-0.047	(-0.096, 0.003)	0.064
Total body fat, %	-0.108	(-0.156, -0.060)	<0.001	-0.043	(-0.085, -0.002)	0.042
Visceral fat, level	-0.015	(-0.047, 0.017)	0.360	-0.025	(-0.039, -0.011)	<0.001

†Models had adjustments for age, SES, marital status, smoking and drinking, residence, physical activity, sleeping problem, stable food intake, unhealthy eating behaviors and DDS