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Original Article

Metabolic syndromes increase significantly with the accumulation of bad dietary habits

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A R T I C L E I N F O

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Bad dietary habits
Metabolic syndrome (MetS)
Obesity

A B S T R A C T

Background: The association between dietary habits and metabolic syndrome (MetS) has not been well documented, due to the complexity and individualization of dietary culture in the Chinese population.
Objective: To construct a composite score from various bad dietary habits and to evaluate their comprehensive association with the prevalence of MetS and its components among Chinese men and women across various age groups.
Setting: Serial cross-sectional studies.
Methods: Twenty-three dietary habits were assessed through face-to-face interviews with 98,838 males and 83,099 females in health check-up programs from 2015 to 2021, among which eighteen bad dietary habits were observed to be associated independently with total MetS. The total score of bad dietary habits was composed of four categories via variable clustering analysis, including irregular dietary habits, unhealthy dietary flavors, unbalanced dietary structure, and high-fat diet. The 2016 Chinese guideline for the management of dyslipidemia in adults was used to define MetS.
Results: Men had a higher score of bad dietary habits than women (9.63 ± 3.11 vs. 8.37 ± 3.23), which decreased significantly with increasing age in both males and females ($P_{interaction}$<0.01). The prevalence of total MetS increased significantly with the cumulative score of bad dietary habits in both males (highest quintile vs. lowest quintile: OR, 1.90; 95% confidence interval [CI], 1.80–2.00; P_{linear}<0.01) and females (OR, 2.23; 95% CI, 2.02–2.46; P_{linear}<0.01) after adjusted for age, education, smoking status, alcohol consumption, and physical activities. These linear trends were also observed for each MetS component (all P_{linear}<0.01). The role of irregular dietary habits and high-fat diet on MetS prevalence are much higher in males than in females, while unhealthy dietary flavors and unbalanced dietary structure had a greater influence on females.
Conclusions: The accumulation of bad dietary habits contributes to the MetS developments. Thus, individualized lifestyle interventions are needed to correct bad dietary habits with regard to gender differences.

1. Introduction

Non-communicable chronic diseases (NCDs), largely due to unhealthy dietary patterns, have shown a notable increase in prevalence in developed and under-developed countries, especially cardiovascular diseases (CVD), hypertension, and type 2 diabetes mellitus (T2DM) [1–3]. Metabolic syndrome (MetS) is a cluster of risk factors in parallel with CVD, T2DM, and total mortality, which has been defined differently by various organizations [4,5]. The prevalence of MetS increased from 13.7% to 31.1% during 2000–2017 in China, although the definition of MetS slightly varied, mainly due to the modification to waist circumference cutoffs [5–9]. As a well-known environmental factor, lifestyle, especially involving changes in Chinese dietary patterns, has played an important role in facilitating the development of MetS and exacerbating its consequences [10–13].

Dietary patterns determined via factor analyses are often used to assess the overall associations of dietary habits with MetS development using proxy indicators of real food consumption and availability, which could provide a more realistic representation of daily eating patterns. A "healthy" dietary pattern, characterized by a high yield of vegetables,

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fruits, poultry, fish, and whole grains, is associated with reducing MetS developments, particularly in Asia. In contrast, an increased risk of MetS has been found to be associated with the "Meat/Western" dietary pattern, which consists of a high yield of red meat, processed meat, animal fat, eggs and sweets [1,14,15]. A small number of Chinese studies also determined that a higher prevalence of MetS was strongly associated with a diet rich in animal offal, animal blood, meats, and sausages [16–19], while traditional Chinese dietary patterns demonstrated preventative countermeasures against the development of MetS, as they are high in whole grains, tubers, vegetables, fruits, pickled vegetables, mushrooms, bacon and salted fish, salted and preserved eggs, soy and its products, miscellaneous beans, vegetable oil, and tea based on a factor analysis [18]. Of course, inconsistent findings may be found for dietary patterns in relation to MetS due to the diversity of food sources in Chinese foods.

Dietary habits were defined as the habitual decisions in food selection, of which one or more were capable of affecting total MetS and its components [15,18,20,21], including late-night eating [22], fried foods [23], high-fat meat or animal offal [19], skipping meals, dining out, and fast foods [24]. However, dietary habits are not cultivated in isolation but in several different combinations. It may not be efficient to evaluate the association of any one dietary habit with the risk of disease if several dietary habits are simultaneously present within one person, especially those that pertain to bad dietary habits. Therefore, developing a composite score of bad dietary habits may better assess the association of the prevalence of total MetS with the combined impacts of dietary habits. Thus, we aimed to construct a composite score from twenty-three bad dietary habits via a questionnaire in health check-up programs from 2015 to 2021, and to evaluate the comprehensive influence of these habits on the prevalence of MetS and its components among Chinese men and women across various age groups.

2. Methods

2.1. Study subjects

Serial cross-sectional studies were conducted during 2015 and 2021. 98,838 males and 83,099 females attended a routine health check-up at the Health Management Center at the Third Xiangya Hospital, Changsha, China, and completed face-to-face questionnaire interviews regarding the twenty-three bad dietary habits by trained physicians or nurses. For multiple check-ups, only the earliest check-up data was adopted using a Chinese residential ID card number unique to each participant.

2.2. Inclusive criteria

Participants were included into final analyses if the following criteria were met: (1) aged 18 years or older; (2) twenty-three bad dietary habits were provided; 3) relevant data for MetS diagnosis was accessible, including age, sex, systolic blood pressure (SBP), diastolic blood pressure (DBP), waist circumference (WC), triglyceride (TG), high-density lipoprotein cholesterol (HDL-C), fasting blood glucose (FBG), as well as medical history and drug treatments of hypertension and diabetes; (4) presented with reasonable blood pressures: SBP $\geq$ 70 and $\leq$260 mmHg; DBP $\geq$ 40 and $\leq$140 mmHg; (5) presented with plausible blood liquids: TG $\geq$ 0.2 and $\leq$30 mmol/L; HDL-C$\geq$0.1 and $\leq$10.0 mmol/L.

2.3. Data collection

Sociodemographic characteristics and behavioral factors were collected via a structured questionnaire, which included age, sex, education level, smoking status, drinking status, and physical activities. Physical activities were defined as exercise $\geq$ 3 times/week and lasting more than 30 min/day. Physical examinations were performed by trained physicians to measure weight, height, WC, hip circumference (HC), SBP, and DBP. Based on the Guidelines for Blood Pressure Measurement in China, blood pressure readings were taken on both arms using an OMRON automatic digital BP monitor (OMRON HBP-9021, OMRON Healthcare, Scarborough, ON, Canada).

Fasting blood samples were collected to test for FBG, total cholesterol (TC), TG, low-density lipoprotein cholesterol (LDL-C), and HDL-C levels using LEADMAN test kits (Beijing LEADMAN Biochemical Co., Ltd. China). More details on the procedures followed for conducting physical examinations, blood collections, and measurements have been published previously [25–27].

2.4. Construction of a bad dietary habit score

A structured questionnaire was used to collect information on the twenty-three bad dietary habits, among which eighteen individual components were associated significantly with the prevalence of total MetS after adjusted for age, education, smoking status, alcohol consumption, and physical activities (Appendix Table S1). Four independent categories were defined using a cluster analysis, including (1) Irregular dietary habits (5 specifications): often skipping meals, often late-night eating, often over-eating, often dining out for business, and often eating fast foods; (2) Unhealthy dietary flavors (four specifications): preference for salty, spicy, pickled, or fried foods, which were defined as the four unhealthy dietary flavors due to "Light Eating Possesses Health Benefits" in traditional Chinese concepts; (3) Unbalanced dietary structure (six specifications): lack of eating coarse cereals, drinking milk or yogurt $<$3 times per week, eating eggs $<$3 times per week, eating beans $<$3 times per week, eating fruits $<$3 times per week, and eating vegetables $<$100 grams per day; (4) High-fat diets (3 specifications): eating meats $\geq$50 grams per day (e.g., pork, beef, lamb, poultry), eating fat meats per week, and eating animal offal per week. Besides these eighteen bad dietary habits, five additional bad dietary habits were not found to be significantly related to the risk of total MetS, including preferences for hot scalded foods, preferences for snacks, lack of eating fish or seafood, frequent coffee consumption, and frequent consumption of sweetened beverages. The total score of bad dietary habits was calculated as the sum of each bad dietary habit multiplied by its own full-adjusted sex-specific odds ratio for the risk of total MetS (adjusted for age, education, smoking status, alcohol consumption, and physical activities, Appendix Table S1).

2.5. The definitions for total MetS and its components

Participants with three or more of the following factors were diagnosed with total MetS as per the Guidelines for the Prevention and Treatment of Dyslipidemia in Chinese Adults (revised in 2016) [5]: (1) central obesity: a waist circumference of $\geq$85 cm in females and $\geq$90 cm in males; (2) elevated TG: serum TG level $\geq$1.7 mmol/L; (3) low HDL-C: serum HDL-C level $<$1.0 mmol/L; (4) elevated blood pressure (BP): has been diagnosed with hypertension by a physician, currently uses blood pressure medications, or SBP $\geq$ 130 mmHg or a DBP $\geq$ 85 mmHg; and (5) elevated FBG: has been diagnosed with diabetes by a physician, currently uses anti-diabetic medications, or fasting blood glucose level $\geq$6.1 mmol/L.

2.6. Statistical analyses

The Statistical Analysis System (SAS 9.4 for Windows; SAS Institute Inc., Cary, NC, USA) software was used for all statistical analyses in this study. Continuous variables were represented as the mean $\pm$ standard deviation (SD) and categorical variables as percentages (%) and numbers. As the primary independent variable, the total score of bad dietary habits was divided into five groups using sex-specific quintiles of the overall study population, with reference to the lowest quartile. As secondary independent variables, the four categories, which include irregular dietary habits, unhealthy dietary flavors, unbalanced dietary structure, and high-fat diet, were defined using variable clustering analysis. The comparison among various quintiles of bad dietary habit scores was conducted using the Kruskal-Wallis tests for continuous variables and the Mantel-Haenszel Chi-square tests for categorical variables. Binary logistic

Table 1
The characteristics of overall population by quintiles of bad dietary habit scores.

Characteristics (Mean ± SD)	Total	Quintiles of bad dietary habits scores (males/females)					P value
		Q1 (<6.91/ <5.58)	Q2 (6.91–8.83/5.58 −7.41)	Q3 (8.84−10.39/7.41 −9.10)	Q4 (10.40−12.32/9.11 −11.17)	Q5 (>12.32/ >11.17)	
Males (sample sizes)	**98,838**	**19,931**	**19,039**	**20,499**	**19,603**	**19,766**	
Bad dietary habit score	9.63 ± 3.11	5.29 ± 1.35	7.91 ± 0.52	9.60 ± 0.49	11.30 ± 0.54	14.01 ± 1.44	<0.01
Age (years)	42.25 ± 12.82	47.42 ± 14.45	43.76 ± 13.11	42.43 ± 12.46	40.08 ± 11.34	37.56 ± 10.06	<0.01
Height (cm)	168.62 ± 6.26	167.89 ± 6.32	168.29 ± 6.29	168.42 ± 6.29	169.03 ± 6.19	169.47 ± 6.09	<0.01
Weight (kg)	70.93 ± 10.81	69.12 ± 9.89	70.00 ± 10.29	70.46 ± 10.64	72.01 ± 11.11	73.07 ± 11.56	<0.01
BMI (kg/m^2)	24.92 ± 3.31	24.49 ± 3.00	24.69 ± 3.15	24.81 ± 3.26	25.18 ± 3.43	25.42 ± 3.58	<0.01
WC (cm)	85.79 ± 9.27	84.69 ± 8.50	85.15 ± 8.75	85.50 ± 9.98	86.48 ± 9.27	87.12 ± 9.53	<0.01
HC (cm)	95.85 ± 6.04	95.08 ± 5.62	95.43 ± 5.87	95.62 ± 6.02	96.31 ± 6.15	96.79 ± 6.33	<0.01
WHR	0.89 ± 0.16	0.89 ± 0.06	0.89 ± 0.25	0.89 ± 0.21	0.90 ± 0.09	0.90 ± 0.06	<0.01
SBP (mmHg)	125.64 ± 14.70	127.06 ± 15.27	126.00 ± 14.97	125.59 ± 14.86	125.14 ± 14.30	124.39 ± 13.90	<0.01
DBP (mmHg)	77.99 ± 10.96	77.93 ± 10.76	77.96 ± 10.91	78.05 ± 11.02	78.10 ± 11.02	77.88 ± 11.07	0.03
FBG (mmol/L)	5.59 ± 1.46	5.67 ± 1.48	5.59 ± 1.41	5.59 ± 1.47	5.59 ± 1.53	5.51 ± 1.42	<0.01
TC (mmol/L)	5.05 ± 1.00	4.95 ± 0.94	5.00 ± 0.97	5.04 ± 0.99	5.11 ± 1.00	5.16 ± 1.06	<0.01
TG (mmol/L)	2.15 ± 2.00	1.80 ± 1.54	1.98 ± 1.80	2.14 ± 1.98	2.32 ± 2.16	2.51 ± 2.34	<0.01
HDL-C (mmol/L)	1.25 ± 0.28	1.28 ± 0.28	1.26 ± 0.27	1.25 ± 0.27	1.24 ± 0.27	1.23 ± 0.29	<0.01
LDL-C (mmol/L)	2.84 ± 0.83	2.85 ± 0.81	2.85 ± 0.82	2.84 ± 0.83	2.83 ± 0.84	2.81 ± 0.86	<0.01
College or higher, % (n)	56.09 (55,434)	55.58 (11,077)	53.41 (10,168)	52.56 (10,775)	57.44 (11,259)	61.49 (12,155)	<0.01
Current smokers[b], % (n)	49.38 (48,808)	29.91 (5,962)	42.79 (8,146)	50.01 (10,251)	57.56 (11,284)	66.60 (13,165)	<0.01
Current drinkers, % (n)	48.84 (48,275)	30.21 (6,021)	41.41 (7,884)	46.24 (9,478)	58.38 (11,444)	68.04 (13,448)	<0.01
Physical activities, % (n)	60.37 (59,672)	77.78 (15,502)	66.83 (12,723)	58.94 (12,082)	54.23 (10,630)	44.19 (8,735)	<0.01
Total MetS, % (n)	22.71 (22,451)	19.30 (3,847)	20.87 (3,974)	22.26 (4,563)	25.06 (4,913)	26.08 (5,154)	<0.01
Central obesity, % (n)	33.00 (32,612)	27.25 (5,431)	30.21 (5,751)	31.98 (6,555)	36.34 (7,124)	39.21 (7,751)	<0.01
Elevated TG, % (n)	46.70 (46,158)	37.21 (7,417)	42.47 (8,086)	46.63 (9,558)	51.27 (10,050)	55.89 (11,047)	<0.01
Low HDL-C, % (n)	15.20 (15,023)	12.64 (2,519)	14.29 (2,721)	15.02 (3,079)	16.63 (3,259)	17.43 (3,445)	<0.01
Elevated BP, % (n)	42.32 (41,830)	47.03 (9,373)	43.51 (8,284)	42.07 (8,624)	40.85 (8,008)	38.15 (7,541)	<0.01
Elevated FBG, % (n)	14.71 (14,543)	17.75 (3,537)	14.62 (2,783)	14.62 (2,996)	14.08 (2,760)	12.48 (2,467)	<0.01
Females (sample sizes)	**83,099**	**16,658**	**16,639**	**16,601**	**16,390**	**16,811**	
Bad dietary habit score	8.37 ± 3.23	3.93 ± 1.20	6.55 ± 0.54	8.28 ± 0.50	10.09 ± 0.57	12.96 ± 1.60	<0.01
Age (years)	41.64 ± 13.04	45.79 ± 13.61	43.36 ± 12.85	41.65 ± 12.76	39.84 ± 12.36	37.58 ± 12.02	<0.01
Height (cm)	157.12 ± 5.64	156.96 ± 5.68	156.93 ± 5.67	156.99 ± 5.62	157.21 ± 5.58	157.52 ± 5.62	<0.01
Weight (kg)	55.65 ± 7.98	55.39 ± 7.42	55.29 ± 7.63	55.68 ± 7.99	55.66 ± 8.08	56.21 ± 8.69	<0.01
BMI (kg/m^2)	22.56 ± 3.13	22.49 ± 2.85	22.46 ± 2.96	22.6 ± 3.13	22.54 ± 3.18	22.68 ± 3.47	0.02
WC (cm)	75.01 ± 8.77	75.03 ± 8.23	74.87 ± 8.38	75.12 ± 8.78	74.86 ± 8.89	75.18 ± 9.50	0.01
HC (cm)	91.36 ± 5.72	91.28 ± 5.40	91.17 ± 5.46	91.36 ± 5.71	91.34 ± 5.78	91.65 ± 6.20	<0.01
WHR	0.82 ± 0.08	0.82 ± 0.06	0.82 ± 0.07	0.82 ± 0.10	0.82 ± 0.07	0.82 ± 0.10	<0.01
SBP (mmHg)	117.16 ± 16.28	118.85 ± 16.51	117.88 ± 16.47	117.54 ± 16.49	116.49 ± 15.94	115.05 ± 15.68	<0.01
DBP (mmHg)	70.97 ± 10.22	71.23 ± 10.14	71.13 ± 10.23	71.24 ± 10.35	70.93 ± 10.23	70.34 ± 10.15	<0.01
FBG (mmol/L)	5.29 ± 1.03	5.33 ± 1.01	5.31 ± 1.00	5.31 ± 1.02	5.27 ± 1.03	5.25 ± 1.07	<0.01
TC (mmol/L)	4.89 ± 0.97	5.00 ± 0.98	4.93 ± 0.98	4.88 ± 0.97	4.85 ± 0.96	4.81 ± 0.94	<0.01
TG (mmol/L)	1.27 ± 1.01	1.26 ± 0.89	1.27 ± 0.98	1.28 ± 1.03	1.27 ± 1.06	1.27 ± 1.09	<0.01
HDL-C (mmol/L)	1.51 ± 0.31	1.54 ± 0.32	1.52 ± 0.31	1.50 ± 0.31	1.50 ± 0.31	1.49 ± 0.30	<0.01
LDL-C (mmol/L)	2.79 ± 0.81	2.87 ± 0.82	2.81 ± 0.82	2.79 ± 0.81	2.75 ± 0.79	2.72 ± 0.79	<0.01
College or higher, % (n)	48.34 (40,174)	49.37 (8,224)	46.76 (7,780)	45.41 (7,539)	47.16 (7,729)	52.95 (8,902)	<0.01
Current smokers[b], % (n)	5.36 (4,454)	2.53 (421)	3.35 (557)	4.71 (782)	6.07 (995)	10.11 (1,699)	<0.01
Current drinkers, % (n)	8.22 (6,832)	4.44 (739)	5.55 (923)	7.17 (1,190)	9.08 (1,489)	14.82 (2,491)	<0.01
			61.94 (10,306)	54.71 (9,082)	46.41 (7,606)	36.94 (6,210)	<0.01

(continued on next page)

Table 1 ***(continued)***

Characteristics (Mean ± SD)	Total	Quintiles of bad dietary habits scores (males/females)					P value
		Q1 (<6.91/ <5.58)	Q2 (6.91–8.83/5.58 –7.41)	Q3 (8.84–10.39/7.41 –9.10)	Q4 (10.40–12.32/9.11 –11.17)	Q5 (>12.32/ >11.17)	
Physical activities, % (n)	54.90 (45,620)	74.53 (12,416)					
Total MetS, % (n)	6.75 (5,611)	6.48 (1,079)	6.39 (1,064)	7.07 (1,173)	6.96 (1,140)	6.87 (1,155)	0.03
Central obesity, % (n)	13.92 (11,569)	12.40 (2,066)	12.70 (2,113)	14.18 (2,354)	14.14 (2,318)	16.17 (2,718)	<0.01
Elevated TG, % (n)	18.43 (15,315)	18.29 (3,047)	18.08 (3,009)	18.81 (3,123)	18.51 (3,034)	18.45 (3,102)	0.43
Low HDL-C, % (n)	2.80 (2,324)	2.30 (383)	2.54 (422)	3.00 (498)	2.97 (486)	3.18 (535)	<0.01
Elevated BP, % (n)	23.38 (19,430)	27.24 (4,537)	24.88 (4,139)	24.15 (4,009)	22.07 (3,617)	18.61 (3,128)	<0.01
Elevated FBG, % (n)	8.03 (6,676)	9.14 (1,523)	8.32 (1,385)	8.16 (1,355)	7.51 (1,231)	7.03 (1,182)	<0.01

Note: SD, standard deviance; MetS, metabolic syndrome; BMI, body mass index; WC, waist circumference; HC, hip circumference; WHR, waist to hip ratio; SBP, systolic blood pressure; DBP, diastolic blood pressure; FBG, fasting blood glucose; SCr, serum creatinine; TC, total cholesterol; TG, triglycerides; HDL-C, high density lipoprotein cholesterol; LDL-C, low density lipoprotein cholesterol;

[1]P value was obtained by Kruskal-Wallis tests for continuous variables and Mantel-Haenszel Chi-square tests for categorical variables;

[b] Passive smokers included.

regression models were used to calculate the odds ratios (OR) and their confidence intervals (CIs) of the prevalence of total MetS and the five components with quintiles for the total score of bad dietary habits. Separated models were fitted to females and males due to the sex difference in dietary habits and the prevalence for MetS. Multivariate logistic regression models were used to assess the above-mentioned associations, in which six covariates were considered, including age (continuous variable), sex (female vs. male), education (college or higher vs. high school or lower), smoking status (current smokers vs. never/former smokers), alcohol consumption (current drinkers vs. never/former drinkers), and physical activities (yes vs. no). Restricted cubic splines (RCS) were used to detect the possible nonlinear dependency of the associations between total MetS and its components with the total score of bad dietary habits, using 3 knots at the 10th, 50th, and 90th percentiles [26]. Scatter plots of the total score of bad dietary habits and its four categories were created with increase age using a penalized B-spline for both females and males. Subgroup analyses and interaction tests were conducted to evaluate the consistency of the overall associations in each category, specifically on sex (females and males), age group (<30, 30–39, 40–49, 50–59, 60–69 years and ≥70 years), and education (college or higher vs. high school or lower).

2.7. Results

From 2015–2021, 351,867 were enrolled into our check-up program, and 1,615 juveniles were excluded. Another 164,325 were deleted due to missing data on dietary habits (n = 157,809), waist circumference (n = 2,305), blood lipids and glucose levels (n = 1,892), blood pressure (n = 1,345), medical history, and medications (n = 974). 3,990 subjects were not considered, resulting from unreasonable blood pressure and blood

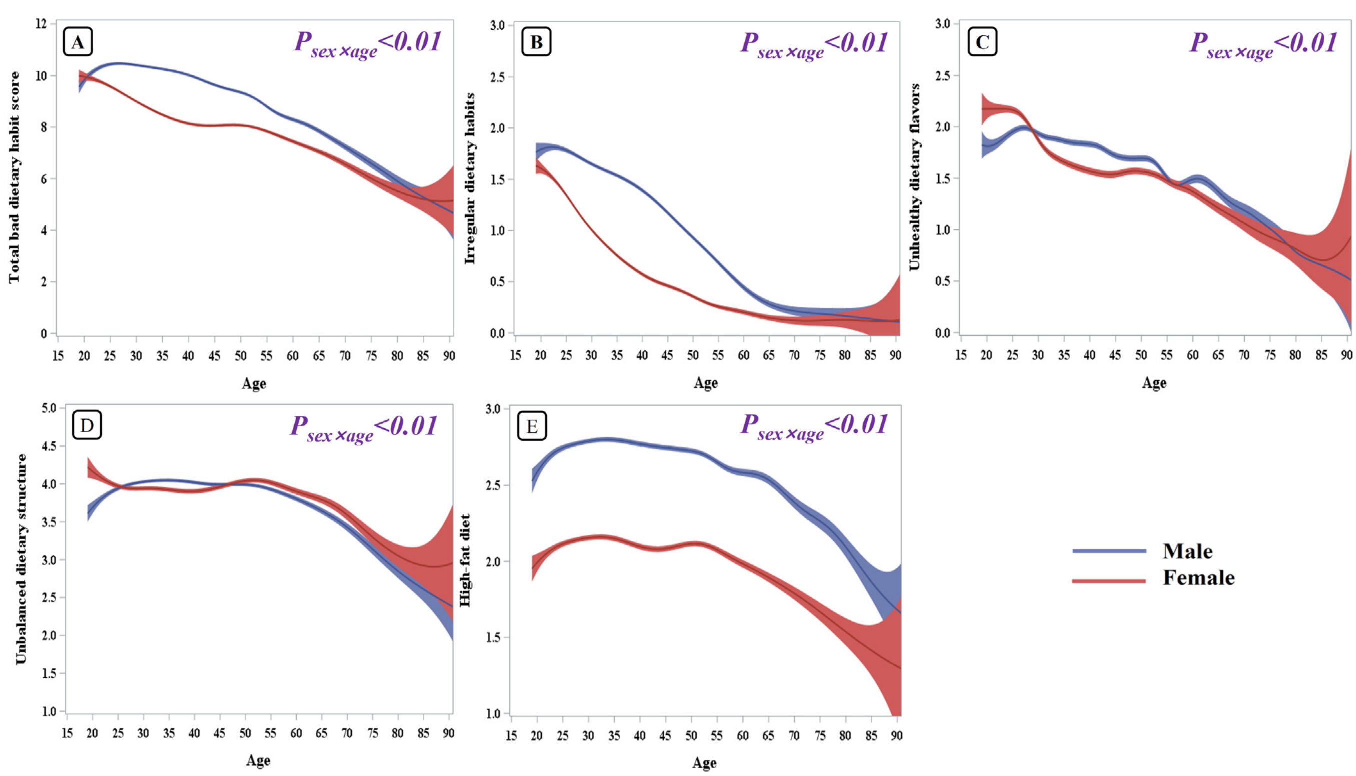

Fig. 1. The trends of total bad dietary habit score and its components with increasing age among females and males.

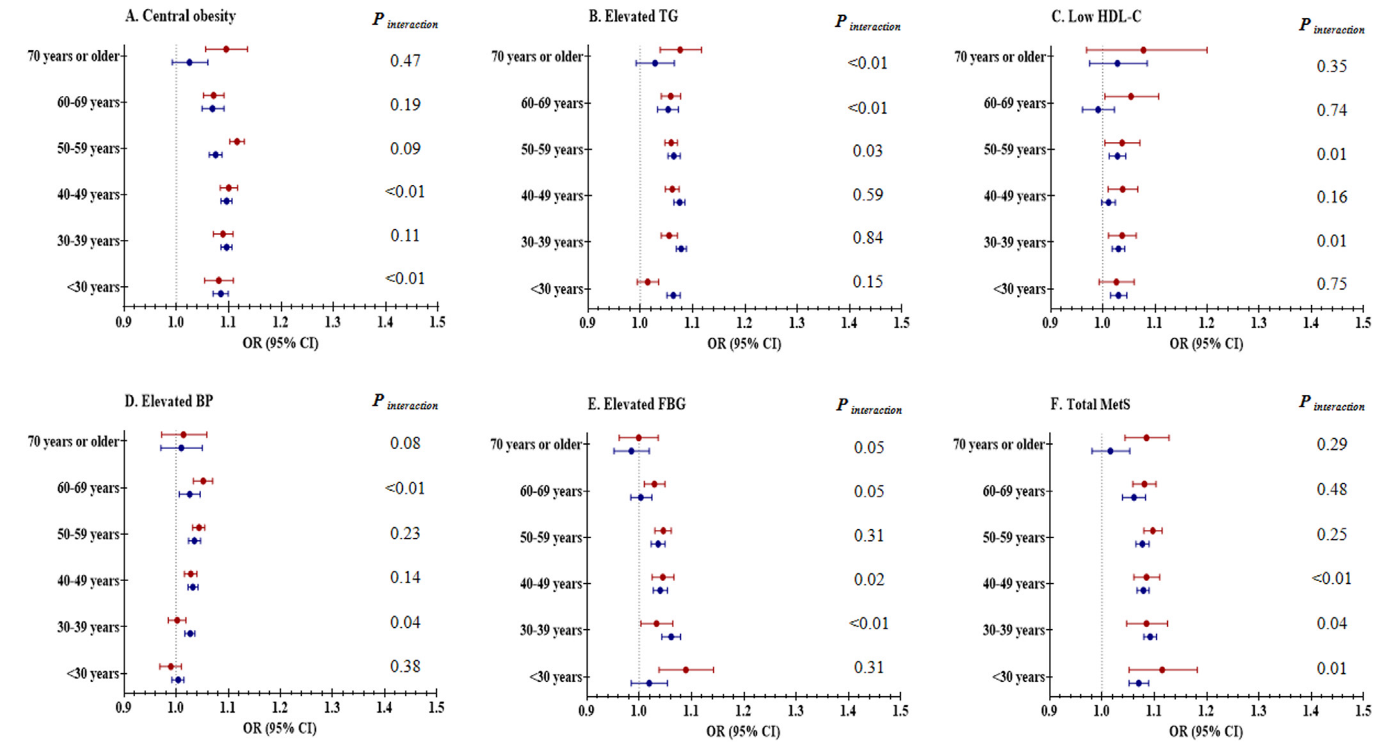

Fig. 2. Adjusted odds ratios and 95% confidence intervals for total MetS and its components with total bad dietary habit score per one unit increase by various age groups and sex (female in purple bars and males in blue bars). (A) Central obesity; (B) Elevated TG; (C) Low HDL-C; (D) Elevated BP; (E) Elevated FBG; (F) Total MetS.

lipids, which might introduce potential bias. Finally, 98,838 males and 83,099 females were eligible for the analyses of this study (Appendix Figure S1), with a mean age of 42.25 ± 12.82 and 41.64 ± 13.04 years old, respectively. The prevalence of total MetS in males was much higher than in females (22.7% vs. 6.8%), and the mean scores of bad dietary habits were also higher in males than in females (9.63 ± 3.11 vs. 8.37 ± 3.23). The prevalence of total MetS increased more significantly with the increase in total bad dietary habit scores in males (from 19.30% to 26.08%) than in females (from 6.48% to 6.7%). Significance was found for most of the characteristics of the study population across various quintiles of bad dietary habit scores in both males and in females ($P < 0.05$), which are presented in Table 1. Further stratified analyses by education level are also provided in Appendix Table S2. The score of bad dietary habits was lower among groups with lower levels of education than higher levels of education (8.87 ± 3.09 vs. 9.21 ± 3.33), but the prevalence of MetS was contrary (18.3% vs. 12.9%).

Total scores of the bad dietary habits and their four components were fitted against age using a penalized B-spline, which is illustrated in Fig. 1. Total bad dietary habit scores decreased with age in both females and males, but downward trends in males were greater than in females ($P_{interaction}<0.01$, Fig. 1A). Similar downtrends of total bad dietary habit scores were also seen in the irregular dietary habits and high-fat diet categories across females and males (Fig. 1B and E). While the trends of the scores for unhealthy dietary flavors and unbalanced dietary structure were variant with age in females and males, the overall trend was still decreasing (Fig. 1C and D).

Fig. 2 displays the forest plots of various age groups among males and females for the adjusted associations of total MetS and its components with total bad dietary habit scores per one unit increase. A significant difference was observed across different age groups for the associations between MetS prevalence and the accumulation of bad dietary habits, but one-way associations with increasing age were not found for total MetS (Fig. 2F) and its components (Fig. 2A–E). Table 2 provides unadjusted odds ratios and their 95% confidence intervals for total MetS and its components with quintiles of total dietary habit scores in logistic regression models. After adjusted for age, education, smoking status, alcohol consumption, and physical activities, positive trends were observed in both females (the highest quintile vs. the lowest quintile: adjusted OR, 2.23; 95% CI, 2.02–2.46; $P_{trend}<0.01$) and males (OR, 1.90; 95% CI, 1.80–2.00; $P_{trend}<0.01$) between total MetS and total scores of bad dietary habits. Meanwhile, five individual MetS components were also evaluated and similar positive associations were shown in quintiles of total bad dietary habit scores (all $P_{trend}<0.01$), including central obesity (adjusted OR and 95% CI for males vs. females, 2.02 [1.92–2.12] vs. 2.29 [2.14–2.16]), elevated TG (1.81 [1.73–1.90] vs. 1.65 [1.55–1.75]), low HDL-C (1.23 [1.15–1.31] vs. 1.36 [1.18–1.56]), elevated BP (1.21 [1.15–1.26] vs. 1.29 [1.21–1.37]), and elevated FBG (1.34 [1.25–1.43] vs. 1.49 [1.36–1.62]). Appendix Table S3 presents further subgroup analyses by education level, but the associations between dietary habits and the prevalence of MetS among individuals with lower levels and higher levels of education were not significantly different.

In regards to the four categories of bad dietary habit scores, further in-depth analyses were conducted to calculate adjusted odds ratios and 95% confidence intervals for total MetS and its components in females and males. Strong associations of total bad dietary habit scores were shown with total MetS (Fig. 3F) and its components (Fig. 3A, 3C-3E) in females, except for elevated TG (Fig. 3B). The roles of unhealthy dietary flavors and unbalanced dietary structure on the probability of total MetS were much greater in females than in males, while the other two categories exhibited the opposite results (i.e. much greater in males than females). More details on the associations between five MetS components and bad dietary habit components can be found in Fig. 3 and Appendix Table S4, which also includes the results of subgroup analyses by education level. Fig. 4 illustrates the RCS models used to explore the potential non-linear relationship adjusted for age, sex, education, smoking status, alcohol consumption, and physical activities, but only linear trends of total bad dietary habit scores were observed for total MetS (Fig. 4F) and its components (Fig. 4A-4E) (all $P_{linear}<0.01$). Further subgroup analyses of

Table 2
ORs and 95% CIs for total MetS and its components with quintiles of total dietary scores.

Characteristics (Mean ± SD)	ORs (95% CIs) for quintiles of bad dietary habits scores					P_{trend}
	Q1	Q2	Q3	Q4	Q5	
Males (n = 98,838)						
Unadjusted models						
Central obesity	1.00	1.16 (1.11, 1.21)	1.26 (1.20, 1.31)	1.52 (1.46, 1.59)	1.72 (1.65, 1.80)	<0.01
Elevated TG	1.00	1.25 (1.20, 1.30)	1.47 (1.42, 1.53)	1.78 (1.71, 1.85)	2.14 (2.05, 2.23)	<0.01
Low HDL-C	1.00	1.15 (1.09, 1.22)	1.22 (1.15, 1.29)	1.38 (1.30, 1.46)	1.46 (1.38, 1.54)	<0.01
Elevated BP	1.00	0.87 (0.83, 0.90)	0.82 (0.79, 0.85)	0.78 (0.75, 0.81)	0.70 (0.67, 0.72)	<0.01
Elevated FBG	1.00	0.79 (0.75, 0.84)	0.79 (0.75, 0.84)	0.76 (0.72, 0.80)	0.66 (0.63, 0.70)	<0.01
Total MetS	1.00	1.10 (1.05, 1.16)	1.20 (1.14, 1.26)	1.40 (1.33, 1.47)	1.48 (1.41, 1.55)	<0.01
Adjusted models[a]						
Central obesity	1.00	1.27 (1.22, 1.33)	1.43 (1.37, 1.49)	1.86 (1.78, 1.95)	2.26 (2.16, 2.37)	<0.01
Elevated TG	1.00	1.30 (1.25, 1.36)	1.57 (1.51, 1.63)	1.95 (1.87, 2.03)	2.43 (2.33, 2.53)	<0.01
Low HDL-C	1.00	1.12 (1.05, 1.19)	1.17 (1.11, 1.24)	1.31 (1.24, 1.39)	1.37 (1.29, 1.45)	<0.01
Elevated BP	1.00	1.03 (0.99, 1.07)	1.03 (0.99, 1.08)	1.10 (1.06, 1.15)	1.11 (1.07, 1.16)	<0.01
Elevated FBG	1.00	1.02 (0.96, 1.08)	1.13 (1.07, 1.20)	1.30 (1.23, 1.38)	1.37 (1.29, 1.46)	<0.01
Total MetS	1.00	1.27 (1.21, 1.34)	1.46 (1.39, 1.53)	1.89 (1.79, 1.98)	2.20 (2.09, 2.32)	<0.01
Adjusted models[b]						
Central obesity	1.00	1.23 (1.17, 1.28)	1.36 (1.30, 1.42)	1.71 (1.64, 1.79)	2.02 (1.92, 2.12)	<0.01
Elevated TG	1.00	1.18 (1.14, 1.23)	1.35 (1.30, 1.41)	1.57 (1.50, 1.64)	1.81 (1.73, 1.90)	<0.01
Low HDL-C	1.00	1.07 (1.01, 1.14)	1.09 (1.03, 1.15)	1.21 (1.14, 1.28)	1.23 (1.15, 1.31)	<0.01
Elevated BP	1.00	1.06 (1.02, 1.11)	1.09 (1.04, 1.13)	1.17 (1.12, 1.22)	1.21 (1.15, 1.26)	<0.01
Elevated FBG	1.00	1.01 (0.95, 1.07)	1.13 (1.06, 1.19)	1.27 (1.20, 1.36)	1.34 (1.25, 1.43)	<0.01
Total MetS	1.00	1.21 (1.15, 1.27)	1.35 (1.29, 1.42)	1.69 (1.60, 1.78)	1.90 (1.80, 2.00)	<0.01
Females (n = 83,099)						
Unadjusted models						
Central obesity	1.00	1.03 (0.96, 1.10)	1.17 (1.10, 1.24)	1.16 (1.09, 1.24)	1.36 (1.28, 1.45)	<0.01
Elevated TG	1.00	0.99 (0.93, 1.04)	1.04 (0.98, 1.09)	1.02 (0.96, 1.07)	1.01 (0.96, 1.07)	0.52
Low HDL-C	1.00	1.11 (0.96, 1.27)	1.31 (1.15, 1.50)	1.30 (1.13, 1.49)	1.40 (1.22, 1.60)	<0.01
Elevated BP	1.00	0.89 (0.84, 0.93)	0.85 (0.81, 0.89)	0.76 (0.72, 0.80)	0.61 (0.58, 0.64)	<0.01
Elevated FBG	1.00	0.90 (0.84, 0.97)	0.88 (0.82, 0.95)	0.81 (0.75, 0.87)	0.75 (0.69, 0.81)	<0.01
Total MetS	1.00	0.99 (0.90, 1.08)	1.10 (1.01, 1.20)	1.08 (0.99, 1.18)	1.07 (0.98, 1.16)	0.05
Adjusted models[a]						
Central obesity	1.00	1.21 (1.13, 1.30)	1.55 (1.45, 1.66)	1.77 (1.65, 1.90)	2.52 (2.36, 2.70)	<0.01
Elevated TG	1.00	1.14 (1.08, 1.21)	1.33 (1.25, 1.41)	1.46 (1.38, 1.55)	1.70 (1.60, 1.80)	<0.01
Low HDL-C	1.00	1.10 (0.96, 1.27)	1.31 (1.14, 1.50)	1.31 (1.14, 1.50)	1.44 (1.26, 1.65)	<0.01
Elevated BP	1.00	1.09 (1.03, 1.16)	1.22 (1.15, 1.29)	1.27 (1.20, 1.35)	1.24 (1.17, 1.32)	<0.01
Elevated FBG	1.00	1.11 (1.03, 1.21)	1.24 (1.15, 1.35)	1.33 (1.22, 1.45)	1.51 (1.39, 1.65)	<0.01
Total MetS	1.00	1.24 (1.13, 1.37)	1.62 (1.48, 1.78)	1.90 (1.73, 2.09)	2.34 (2.13, 2.58)	<0.01
Adjusted models[b]						
Central obesity	1.00	1.18 (1.10, 1.26)	1.48 (1.39, 1.59)	1.66 (1.54, 1.78)	2.29 (2.14, 2.46)	<0.01
Elevated TG	1.00	1.13 (1.07, 1.20)	1.31 (1.23, 1.39)	1.43 (1.35, 1.52)	1.65 (1.55, 1.75)	<0.01
Low HDL-C	1.00	1.08 (0.94, 1.24)	1.27 (1.10, 1.45)	1.25 (1.09, 1.44)	1.36 (1.18, 1.56)	<0.01
Elevated BP	1.00	1.10 (1.04, 1.16)	1.23 (1.16, 1.30)	1.30 (1.22, 1.38)	1.29 (1.21, 1.37)	<0.01
Elevated FBG	1.00	1.10 (1.02, 1.20)	1.23 (1.13, 1.34)	1.31 (1.20, 1.42)	1.49 (1.36, 1.62)	<0.01
Total MetS	1.00	1.22 (1.11, 1.34)	1.58 (1.44, 1.73)	1.83 (1.66, 2.01)	2.23 (2.02, 2.46)	<0.01

Note: OR, odds ratio; CI, confidence interval; MetS; TG, triglycerides; HDL-C, high density lipoprotein cholesterol; BP, blood pressure; FBG, fasting blood glucose.
[a] Adjusted for age, and education.
[b] Adjusted for age, education, smoke, alcohol drinking, and physical activities.

RCS models were fitted in males (Appendix Figure S2) and females (Appendix Figure S3), and similar linear upward trends were observed (all P_{linear}<0.01).

2.8. Discussions

In our study, bad dietary habit scores were found to decrease with age in both females and males. A significant linear association was found between the accumulation of bad dietary habit scores and MetS after adjusted for potential confounders, but the strength of their association did not present any significant linear changes with increasing age. Compared to those who had the lowest quintile of bad dietary habit scores, those with the highest scores had twice as high of MetS prevalence. Meanwhile, the odds for central obesity, dyslipidemia, hypertension, and hyperglycemia were also significantly higher in those with the highest quintiles of bad dietary habit scores. A strong association was detected in females than in males, although the prevalence of total MetS and its components, as well as the mean levels of total bad dietary habit scores, was much higher in males than in females. Additionally, the contributions of each unhealthy dietary habit to the development of MetS is variant in female and male, so our study was the first to classify dietary habits via variable clustering analyses and divide them into four categories, including irregular dietary habits, unhealthy dietary flavors, unbalanced dietary structure, and high-fat diet.

A moderate number of studies has examined the associations between the risk of MetS and the intake of specific food groups, individual foods and nutrients, as well as different combinations of foods and/or nutrients [3,15,28–30]. In this context, dietary pattern analyses have been widely used as an alternative and complementary approach to assess the complexity of dietary intake, which could facilitate nutritional recommendations [18,19,31]. However, dietary habits were defined as the habitual decisions in food selection, which overlap with dietary patterns, but are a different entity. In addition to promoting balanced diets in nutrient diversity and quality, dietary habits could also focus more on regular eating habits and healthy cooking patterns. Some studies have reported the associations between individual dietary habits and the risk of MetS, including late-night eating [22], fried foods [23], high-fat meat or animal offal [19], skipping meals, dining out, and fast food [24].

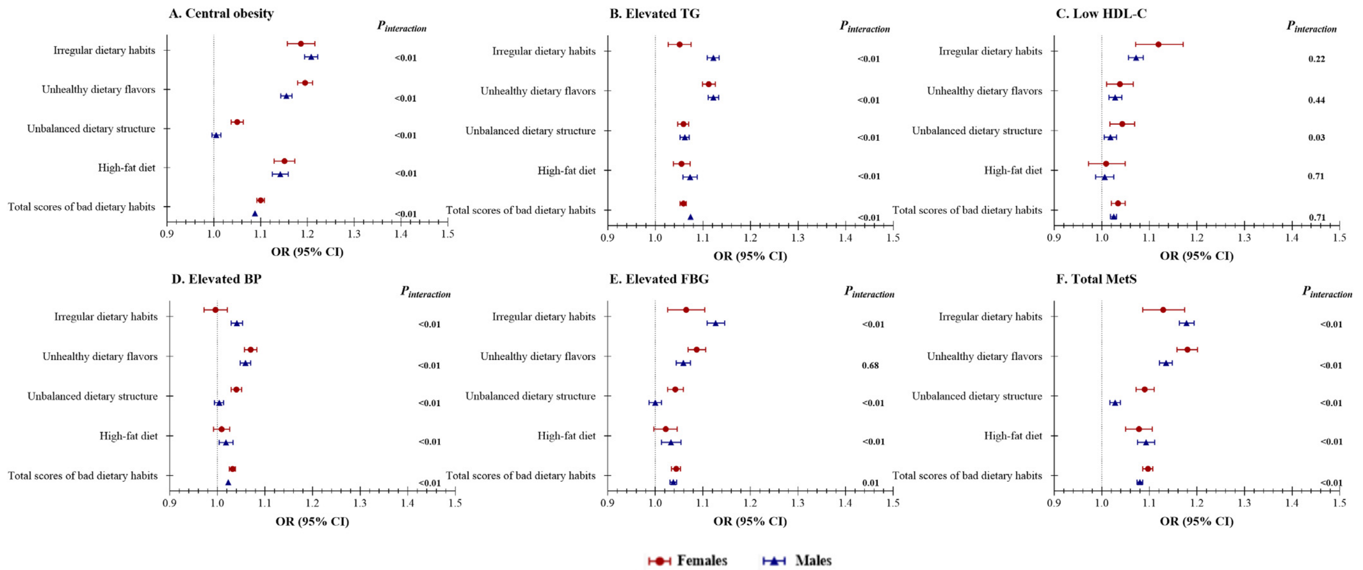

Fig. 3. Adjusted odds ratios and 95% confidence intervals for total MetS and its components with total bad dietary habit score and their four items per one unit increase by sex (female in purple bars and males in blue bars). (A) Central obesity; (B) Elevated TG; (C) Low HDL-C; (D) Elevated BP; (E) Elevated FBG; (F) Total MetS.

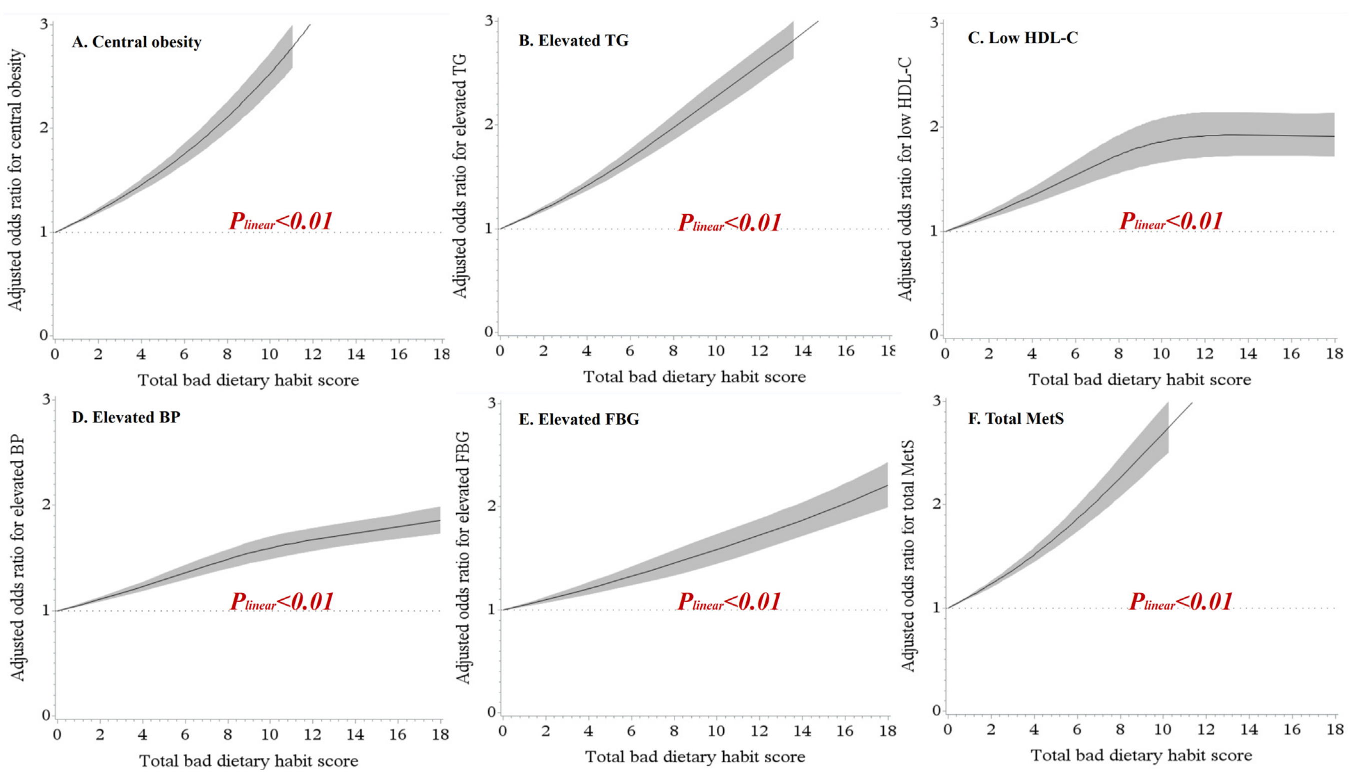

Fig. 4. Adjusted associations of total bad dietary habit score with total MetS and its components using RCS(A) Central obesity; (B) Elevated TG; (C) Low HDL-C; (D) Elevated BP; (E) Elevated FBG; (F) Total MetS.

However, to our knowledge, few studies have evaluated the cumulative effects of multiple dietary habits. Only one study in Iran developed a composite scoring system for dietary habits, which was determined to be significantly associated with MetS risk [20,21]. However, less than two thousand participants was included in the study, so larger studies are needed to further confirm this association in multi-ethnic populations and countries that possess complex and individualized dietary habits in different regions. In our study, more comprehensive dietary habits were considered based on Chinese dietary cultures, and much larger sample sizes were used to calculate a composite dietary habit score, which was found to be strongly associated with MetS. Our findings further confirmed that taking into account the accumulation of multiple dietary habits may provide a more substantial explanation for the association with the disease progression.

It is worth mentioning that the speed and quantity of eating is unrelated to nutritional disorders. In previous studies, irregular eating habits, such as eating until full, skipping meals, late-night eating, and eating fast were directly related to abdominal obesity, dyslipidemia, impaired blood pressure and blood glucose even if dietary variety and cooking quality had achieved nutritional recommendations, [22,32–34], which were confirmed further by our study. A sex difference was observed in the summed scores of irregular dietary habits, which were much higher in males than in females across the entire age range. Moreover, men also had a higher probability of total MetS due to irregular dietary habits (18% vs. 13%), and similar results were shown with central obesity (21% vs. 19%), elevated TG (12% vs. 5%), and elevated FBG (13% vs. 7%), compared to women. Therefore, it can be concluded that the associations of irregular dietary habits with abdominal obesity, dyslipidemia, impaired blood pressure and blood glucose are significant in both males and females, but irregular dietary habits still have a greater odds on men. Differences in hormone levels and lifestyle may lead to this gender differences. The antioxidant function of estrogen may have a protective role on MetS development [35]. Moreover, men have higher work pressure, more socializing, and unhealthier lifestyle habits than women.

Taste preference was identified as an important determinant of food selection and dietary intake, in which overconsumption of salt and sugar were the most widely studied, due to the perceived pleasure of consuming these tastes, based on their sensory properties [36–40]. A wide range of human and animal studies have identified certain salts and sugars that may play possible roles in metabolic pathways [41–43], although the consumption of sugar-sweetened beverages was found to be unrelated to MetS in our study population. In addition, stir frying with oil, cooking with cayenne pepper, and pickling with salt are traditional cooking practices and food processing techniques in China. Overconsumption of fried foods has been reported to be associated with MetS development, especially for those that are overweight and have hypertension [23,44,45]. To our knowledge, no studies have investigated the associations of preferences for spicy and pickled foods with the prevalence of MetS. Our study is the first to examine the associations of several taste preferences and the prevalence of MetS using the Chinese population, in which each taste preference was more strongly associated with the prevalence of total MetS than the other fourteen individual dietary habits, especially in females. In-depth analyses can be performed to further explore their relationships with total MetS and its components in the future.

Dietary variety has also been one of the most important components in dietary recommendations so as to promote nutrient adequacy and amplify the pleasure associated with eating, though limiting dietary variety has been marketed as a strategy towards reducing energy intake and promoting weight loss, particularly in food groups that are high in energy-density and low in nutrient-density [46,47]. Many epidemiological studies have confirmed that eating more coarse cereals, milk or yogurt, eggs, beans, fruits, and vegetables can decrease mortality and the incidence of chronic diseases [48–50]. “Picky eating” seemed different among women and men at different stages of age in our population. The scores of unbalanced dietary structure were higher in females than in males in the youth stages, while this result was reversed in the middle-age stages. Notably, women surpassed again men in terms of unbalanced dietary structure in the older stages. Traditional Chinese dietary patterns have been associated with a significantly lower prevalence of MetS, which are characterized by the frequent consumption of whole grains, tubers, vegetables, mushrooms, eggs, fruits and beans [16–18]. In accordance with previous studies, our study further confirmed that unbalanced dietary structure may result in an increased prevalence of MetS, and women are at a greater odds than men. Hence, it is necessary to emphasize the importance of rational diets and adequate nutrients, especially for those on a diet.

A high-fat diet, also known as the animal food pattern or the Western dietary pattern, was significantly associated with an increased risk of MetS in our study and several previous studies [18,51,52]. However, there are few studies to examine the heterogeneity of diets between genders in the development of MetS [52]. The findings of this previous study observed that the “animal and fried food” dietary pattern was associated with an enhanced likelihood of MetS in men, while the “high-salt and energy” dietary pattern showed the same effect in women [52]. Gender differences in dietary habits and their association with the prevalence of MetS were also observed in our study. A high-fat diet was more common in men than in women throughout all age stages, so it comes with no surprise that a stronger association of high-fat diet scores was detected in males with total MetS, elevated TG, increased blood pressure, and hyperglycemia. What is more, according to the Dietary Guidelines for Chinese Residents (2016) [53], eating 50–75 g of animal offal was proposed per month, given that they are rich in vitamins and mineral content, but they have a higher content of cholesterol and saturated fats [54,55]. However, the actual intake of animal offal in Chinese adults has exceeded this criteria [56]. To our knowledge, our study is the first to explore the association between eating animal offal per week and the prevalence of MetS in the general population of Chinese adults.

Several potential limitations should be taken into account when explaining our results. Firstly, only twenty-three bad dietary habits were investigated in our study. Of course, the number of bad dietary habits may extend well beyond those that are listed, and some dietary habits were not even included in our survey, such as eating until full, eating quickly, and skipping breakfast. Secondly, our study was not a routine survey using validated food frequency questionnaires (FFQ), and multiple-choice questions were provided for each participant, such as eating fat meats and animal offal. Less than 5% eat them more than three times per week and the quantity for each food was hard to assess during check-ups. Additionally, the judgment criteria for the quality of dietary habits may vary across countries and regions, due to discrepancies in dietary culture and potential social desirability, so the generation of a composite dietary habit score may be different from other studies. Thus, the accumulation of multiple dietary habits should be studied by more research teams to evaluate their associations with MetS and other chronic diseases. Thirdly, only eighteen dietary habits were chosen to compute the total scores of bad dietary habits, as per their own odds ratios for total MetS, resulting in adjusted statistical significance. The other five dietary habits were excluded, due to their lack of significance, including preferences for hot scalded foods, preferences for snacks, lack of eating fish or seafood, frequent coffee consumption, and frequent consumption of sweetened beverages. However, completely different results might be inspected. Fourthly, most of the study participants were urban residents living in or nearby Changsha, China, who may not have the same dietary habits as rural residents. Hence, our results may lack generalizability to other populations outside of urban settings. Fifthly, drug treatments for hypercholesterolemia were not collected for participants with controlled elevated TG or low HDL-C levels during check-ups, so the reported hypercholesterolemia may have been lower than in reality, due to drug control, which may have undermined their true associations with dietary habits. However, the proportion of participants with hypercholesterolemia treated and controlled is less than 5% in China [57]. Finally, our study is a cross-sectional study, which spanned 7 years from 2015 to 2021, so the causality between exposures and outcomes should be further reaffirmed using a cohort study.

3. Conclusions

Ultimately, this was the first study to examine a composite dietary habit score in association with the prevalence of total MetS and its components, including abdominal obesity, hyperglycemia, hypertension, hypertriglyceridemia, and low HDL cholesterol in Chinese adults. More evidence has shown that the highest quintile for the total scores of bad dietary habits is related to an increase in the prevalence of MetS. Moreover, different dietary recommendations targeting the prevention and control of MetS developments should be seriously acknowledged between women and men. Interventions could focus on regular dietary habits and low-fat diets in males, including eating on schedule, avoiding eating at night, and implementing moderate diets and balanced diets, while interventions for women should pay greater attention to reducing overcooked foods and increasing dietary diversity.

Author contributions

Lu Yin, Li Zhang, Ying Li, Xin Huang designed this study; Hao Wu and Pingting Yang collected and cleaned the corresponding database. Ying Li and Yaya analyzed the data. Ying Li and Lu Yin drafted this manuscript. Lu Yin, Li Zhang, Ying Li revised this manuscript.

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Statement of ethics

Study protocol and consent forms were approved by the Ethics Committee of the Third Xiangya Hospital (2020-S498). Written informed consent was obtained from all individual participants included in the study. This study complies with the guidelines for human studies in accordance with the World Medical Association Declaration of Helsinki.

Conflict of interest

None declared.

Data Availability Statement

All data generated or analyzed during this study are included in this article. Further inquiries can be directed to the first author.

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Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.jnha.2023.100017.

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