BMC Public Health

RESEARCH

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# Association of dietary behavior patterns of middle-aged and older adults with their obesity metabolic phenotype: a cross-sectional study

Fangfang Pu[1†], Jialing Lin[1,2†], Yaoyao Wei[4], Jingjing Li[1], Xinyi Liao[1], Lei Shi[1], Xianchun Zeng[3] and Wen Hu[1*]

## Abstract

**Background** Middle-aged and elderly individuals are the most susceptible groups for metabolic diseases, with their dietary behaviors being significant influencing factors. Exploring the association between overall dietary behaviors and obesity metabolic phenotypes is crucial for early prevention and control of chronic diseases, precision treatment and personalized interventions.

**Methods** We conducted a cross-sectional study of 15,160 middle-aged and older adults between June 2019 and August 2021 to collect information on their body mass index (BMI), biochemical indices and disease history. The population was classified into four categories by the criteria of obesity metabolic phenotypes: metabolically healthy non-obesity (MHNO), metabolically unhealthy non-obesity (MUNO), metabolically healthy obesity (MHO) and metabolically unhealthy obesity (MUO). Scores were calculated based on compliance with healthy eating behavior patterns (appropriate or light dietary taste, moderately soft and hard food, slightly hot food temperature, medium or slow eating speed, daily intake of dietary supplements and eating with others), and the population was categorized into subgroups 0–2 (did not meet and met only 1 or 2), 3–4 (met 3 or 4), 5–6 (met 5 or 6). The relationship between dietary behavior patterns and different obesity metabolic phenotypes in middle-aged and elderly people were analyzed by multi-categorical logistic regression model.

**Results** Compared with the 5–6 subgroup, the dietary behavior patterns of 0–2 and 3–4 scores were risk factors for MUNO, MHO and MUO ($P < 0.05$), and the lower the scores of the dietary behavior patterns, the higher the multiplicity of the occurrence of MUNO, MHO and MUO, especially for females and adults between 45–60 years old. Appropriate or light dietary taste, moderately soft and hard food, and slightly hot food temperature were protective factors for MUNO and MUO ($P < 0.05$); medium or slow eating speed and daily intake of dietary supplements were protective factors for MUNO, MHO and MUO ($P < 0.05$).

**Conclusion** Dietary behavior patterns in middle-aged and older adults are associated with different obesity metabolic phenotypes, and healthy dietary behaviors may be beneficial for the prevention and control of MUNO, MHO and MUO.

**Keywords** Middle-aged and older adults, Dietary behavior, Obesity metabolic phenotype, Metabolic abnormalities

†Fangfang Pu and Jialing Lin are co-first authors.

*Correspondence:
Wen Hu
wendy_nutrition@163.com
Full list of author information is available at the end of the article

## Introduction

According to the World Social Report 2023, the world population has reached 8 billion, while population aging has become one of today's global trends. In 2021, the global population of people aged 65 years and older was 761 million, and this number will increase to 1.6 billion by 2050 [1]. The prolongation of human lifespan has also increased the global burden of diseases in the later years of middle and old age. According to the China Health Statistics Yearbook (2021), the middle-aged and old-aged populations account for a relatively large proportion of the disease prevalence and incidence of chronic diseases, and the prevalence of chronic diseases in the middle-aged and old-aged populations aged 45 years and older is increasing year by year, with the prevalence in the group of people aged 65 years and older having grown to 62.5%. Middle-aged and elderly people are more prone to obesity or metabolic diseases in the long term due to high work and mental stress, sedentary lifestyle and irregular diet, and gradual decline of organ function with age [2], which adversely affects their health outcomes. According to the China Kadoorie Biobank cohort study, among residents aged < 60 years, those with ≥ 4 unhealthy lifestyles had a 0.81- to 1.28-fold increased risk of first-ever diabetes, stroke, or heart disease, compared with those with ≤ 1 unhealthy lifestyle component; those aged ≥ 60 years had a 0.52-fold increased risk of first-ever occurrence of these diseases [3]. It is evident that middle-aged and elderly people with unhealthy lifestyles are more likely to suffer from obesity and metabolic abnormalities, and the more unhealthy their life styles are, the higher the risk for age-related disease. Metabolic disorders or obesity combined with metabolic abnormalities will increase the risk of chronic diseases, and the metabolic heterogeneity associated with obesity is relatively complex. In order to more accurately study the situation of middle-aged and elderly people with different obesity and metabolic statuses, according to the body mass index (BMI) and metabolic status, they can be divided into four different obesity metabolic phenotypes, namely, metabolically healthy non-obesity (MHNO), metabolically unhealthy non-obesity (MUNO), metabolically healthy obesity (MHO) and metabolically unhealthy obesity (MUO).

Studies have shown that long-term metabolic disorders may lead to the development of diabetes mellitus, cardiovascular and cerebrovascular diseases, metabolic syndrome, which seriously affect the health of the population [4, 5]. The occurrence of the obesity metabolic phenotype is usually closely related to genetic factors, ethnic factors, regional factors, lifestyle and dietary factors [6–8]. Dietary behaviors are factors that everyone is exposed to on a daily basis. Unhealthy dietary behaviors are significantly associated with the development of obesity and metabolic abnormalities, and can impact on health outcomes [9–11]. Drinking large amounts of alcohol may promote progression from normoglycemia to prediabetes [12]. Dietary speed is significantly and positively correlated with BMI [13], and slower dietary speeds may lead to greater satiety and decreased appetite, whereas those who eat quickly have poorer gastric hunger hormone suppression and are less likely to feel full [14]. Fast eating speed is associated with the development of metabolic diseases such as diabetes, alcoholic fatty liver and metabolic syndrome, as well as an increased incidence of abnormalities in low and high-density lipoprotein cholesterol indices [15–17]. Dietary tastes also have an impact on more metabolic diseases, with those with salty tastes having an increased risk of metabolic diseases such as hypertension, diabetes and cardiovascular disease [18, 19]. Dietary firmness and softness have been shown to affect appetite, with softer textured foods typically being ingested faster, having a shorter palate exposure time, and tending to be eaten more and less satiating [20]. Increasing the firmness and elasticity of solid foods reduces the amount of chewing, the speed of dietary, and the amount of food ingested [21], which in turn reduces total energy intake [22]. Regarding the effect of dietary temperature on food consumption, it was found that dietary temperature affects food aroma perception and flavor intensity [23], influencing consumer decision-making about food, dietary intake and pleasure [24, 25]. When consumers buy cold food, they choose more complementary foods because cold food is less satiating [26], and increased temperature of hot food can change the balance of taste compared to cold food, making the pleasurable sensory attributes more prominent, which increases satiety and reduces energy intake [27]. A Korean study found that middle-aged adults who ate all three meals alone had the highest probability of developing metabolic syndrome, 50.1% and 36.8% for men and women, respectively, and the risk of metabolic syndrome in men who ate dinner alone was 1.51 times higher than that of men who did not eat alone, and that eating alone may be a potential risk factor for metabolic diseases [28]. A dry and hard diet is a risk factor for esophageal cancer [29], and esophageal cancer has been correlated with spicy food, fast eating speed and high eating temperature [30]. Different dietary behaviors can affect the health status individually or synergistically. However, most of the current studies focus on the effects of individual dietary behaviors on a specific disease, and there is a lack of investigation on the overall dietary behavior pattern, and most of the middle-aged and elderly population have obesity metabolism phenotypic heterogeneity

rather than obesity or metabolism abnormality. Therefore, it is important to explore the effects of synergistic patterns of eating behavior consisting of multiple eating behaviors on the development of different obesity metabolic phenotypes. Considering that different ethnicities, geographic regions, dietary cultures, age groups and differences in the prevalence of obesity and metabolic diseases can influence the results, it is necessary to analyze the association between eating behavior patterns and obesity metabolic phenotypes in different national and ethnic populations.

In addition, dietary behavior is also influenced by factors such as race, region, culture, age and chronic diseases [31, 32]. The dietary characteristics of residents in Sichuan region are a preference for pickled products such as sausages, cured meat and Sichuan pickles, with a preference for spicy flavors and a preference for cooking methods with a large amount of oil, salt and spices. These unique dietary characteristics have to some extent shaped the dietary behavior of middle-aged and elderly residents in the region. Therefore, it would be informative to analyze the relationship between dietary behavior patterns and obesity metabolic phenotypes among middle-aged and elderly populations in this region. Based on the current situation of dietary behavior research, we conducted a multifaceted study on the basic situation, dietary behavior pattern, nutritional status and metabolic profile of the middle-aged and elderly population, and to explore the relationship between their overall dietary behavior pattern and obesity metabolic phenotype, which can provide a scientific basis for macroeconomic policy control of health management in Sichuan and other regions, and is of great significance for the early prevention and control of chronic diseases, precise treatment and individualized intervention.

## Subjects and methods

### Study population

From June 2019 to August 2021, middle-aged and elderly people who met the inclusion and exclusion criteria were screened by the convenience sampling method from all the study subjects who participated in the project of "Natural Population Cohort Study of West China Hospital of Sichuan University" in the three districts of Mianzhu, Longquanyi, and Pidu in Sichuan Province, using the same method as that of reference [33]. The flowchart for the screening of research subjects is shown in Fig. 1.

We included 1) those who were ≥ 45 years old and 2) those who signed an informed consent form. We excluded 1) people with serious and terminal illnesses; 2) people who could not communicate normally due to severe cognitive impairment, mental disorder, visual or hearing impairment; 3) people who could not cooperate with the questionnaire, laboratory tests or other required tests.

The study was registered with the China Clinical Trial Registry: Natural Population Cohort Study of West China Hospital of Sichuan University (Date of Registration: 19/07/2019; ID: ChiCTR1900024623). The study was approved by the Biomedical Ethics Review Committee of West China Hospital of Sichuan University

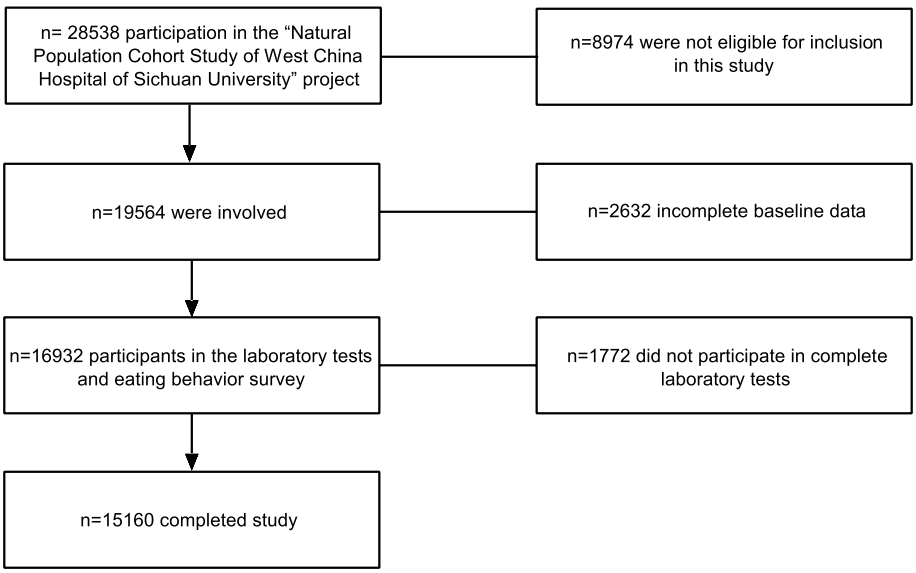


**Fig. 1** the flowchart for the screening of research subjects

(NO.2021–752), and all participants signed a written informed consent.

## Data collection

### *Questionnaire surveys*

*Sociodemographic characteristics* The baseline questionnaire developed by the cohort project was used to collect information on the basic situation of the subjects through one-on-one question-and-answer sessions by uniformly trained investigators. The content mainly includes age, gender, marital status, education level, in-service situation, family history of disease (family history of diabetes mellitus, hypertension and hyperlipidemia), personal chronic disease and other basic information.

*Lifestyle survey* A baseline questionnaire developed uniformly by the cohort project was used to collect information on the subjects' lifestyles in a one-on-one question-and-answer format by uniformly trained investigators. The contents are mainly shown in Table 1.

### *Eating behavior survey*

Adopting the eating behavior questionnaire formulated uniformly by the cohort project (the eating behavior questions in the questionnaire were formulated by experts in clinical related fields and dietitians with more than 5 years of working experience after 3 rounds of discussion, used after validation), the uniformly trained investigators were asked in a face-to-face one-on-one question and answer mode, and the contents are mainly shown in Table 2.

### *Dietary evaluation*

Dietary survey was conducted using the Simplified Food Frequency Questionnaire (SFFQ) [37]; the energy of each type of food was calculated according to the sixth edition of the Standard Edition of the Chinese Food Composition Table.

**Table 1** Lifestyle questionnaire for study participants

| Question | Single choice / fill in the blank | Note |
|---|---|---|
| Smoking | 1-Yes<br>2-No | Smoking refers to the presence of smoking behavior in the last six months and ≥ 4 cigarettes per week |
| Alcohol consumption | 1-Yes<br>2-No | Alcohol consumption refers to the existence of drinking behavior in the last six months, and ≥ 1 time per week |
| Time of exercise per week | minutes | Minimum ≥ 10 min |
| Whether they have sleep problems | 1-Yes<br>2-No | Reference [34] Pittsburgh Sleep Quality Index Scale (PSQI) assessment criteria for assessing the presence of sleep problems, we categorized a score of 0–10 as no sleep problems and a score of 11–21 as having sleep problems |
| Whether anxiety | 1-Yes<br>2-No | Based on the criteria of the Generalized Anxiety Disorder-7 (GAD-7) from the literature [35], which assesses the presence or absence of anxiety, we categorized a score of 0–4 as no anxiety and a score of 5–21 as anxiety |
| Whether depressed | 1-Yes<br>2-No | The presence of depression was assessed according to the criteria of the Patient Health Questionnaire-9 (PHQ-9) of the literature [36], where we categorized a score of 0–4 as no depression and a score of 5–27 as depression |

**Table 2** Dietary behavior questionnaire

| Dietary behavior | Options | Note |
|---|---|---|
| Dietary tastes | 1-greasy; 2-spicy; 3-salty; 4-ligh; 5-sweet; 6-moderate | Single options or multiple options are available |
| Dietary softness | 1-hard; 2-soft; 3-mediu | |
| Dietary temperature | 1-warm; 2-normal; 3-cool | |
| Dietary speed | 1-slow (> 45 min); 2-fast (< 15 min); 3-moderate (15-45 min) | |
| Whether dietary supplements were consumed in addition to the daily diet | 1-Yes<br>2-No | Dietary supplements refer to vitamins, minerals, probiotics, cerebrolytes, protein powder, dietary fiber and other nutritional element supplementation methods |
| Eating with others | 1-Yes<br>2-No | |

#### *Physical and laboratory examinations*

(1) Physical measurements

Height, weight and blood pressure were be measured by the method of reference [2].

(2) Laboratory examination

Fasting venous whole blood was drawn from the study subjects, and Beckman automatic biochemical analyzer (AU5800) was used to detect Total Cholesterol (TC), Triglyceride (TG), Low Density Lipoprotein Cholesterol (LDL-C), High Density Lipoprotein Cholesterol (HDL-C) and Fasting Blood Glucose (FBG).

### Criteria for determining indicators

#### *Obesity metabolic phenotype*

BMI is calculated by dividing weight in kilograms by the square of height in meters. This item was grouped according to the adult BMI standard recommended by the Chinese Expert Consensus on Medical Nutritional Treatment of Overweight/Obesity (2016 edition), with BMI < 28 $kg/m^2$ as the non-obese group and BMI ≥ 28 $kg/m^2$ as the obese group [38]. According to the diagnostic criteria of the 3rd report of the National Cholesterol Education Program Adult Treatment Group [39], metabolic abnormalities were defined as those who met ≥ 2 of the following indicators: 1) TG ≥ 1.7 mmol/L or use of lipid-lowering drugs; 2) HDL-C < 1.04 mmol/L for men, < 1.29 mmol/L for women; 3) FBG ≥ 5.6 mmol/L or use of medications for diabetes; 4) systolic blood pressure ≥ 130 mmHg or diastolic blood pressure ≥ 85 mmHg or use of antihypertensive drugs. In this study, the subjects were categorized into 4 groups according to obesity and metabolic status: MHNO, MUNO, MHO and MUO.

#### *Judgment of healthy eating behavior pattern*

Through the clinical work experience and discussion of the recommendations of experts in the Department of Clinical Nutrition of West China Hospital, Sichuan University, we defined healthy dietary behaviors as follows: 1) appropriate dietary tastes (appropriate or light dietary taste); 2) appropriate degree of dietary hardness and softness (moderately soft and hard food); 3) appropriate dietary temperatures (slightly hot food temperature); 4) appropriate dietary speeds (medium or slow eating speed); 5) daily intake of dietary supplements; and 6) eating with others. For each dietary behavior, the study subjects scored 1 point if they met the criteria for healthy dietary behavior, otherwise they scored 0. The total score ranges from 0–6, with higher scores indicating healthier dietary behaviors.

Based on the dietary behavioral index scores, we categorized the population into three groups: 0–2, 3–4, and 5–6.

### Statistical analysis

EpiData 3.1 was used for data entry, Excel 2016 was used for data cleaning, and IBM SPSS 26.0 software was used for statistical analysis. Measurement data were expressed as the mean ± standard deviation ($\overline{X} \pm S$) , and t-test or ANOVA was used for between-group comparisons, and LSD or Tambane's T2 was used for post hoc multiple comparisons; count data were expressed as rate (%), and the chi-squared test was used for between-group comparisons; factor analysis was used to analyze dietary patterns; multi-categorical logistic regression analyses were used to study the associations between the patterns of healthy dietary behaviors and the metabolic phenotypes of obesity, ANOVA analysis was used to explore whether there was an interaction between the two categorical variables and the differences were considered to be statistically significant with $P < 0.05$.

### Quality control

Before the formal survey, the investigators were given two unified trainings and assessments by the researcher to ensure the consistency of the questionnaire survey and measurement operation; the relevant measuring instruments were calibrated before measurement; the quality control team personnel were responsible for the worksite inspection and supervision; the questionnaires were checked and entered by a pair of people and manually cleaned up and computerized logic check for errors, and questionnaires that did not pass the audit were eliminated.

### Sample size calculation

In order to ensure the study was appropriately powered to achieve the research aims, the sample size was powered on the basis of prevalence estimates from previous research [38]. The rate of obesity among middle-aged and elderly Chinese is 13%. Therefore, with 10,000 middle-aged and older adults, it was predicted there would be more than 1300 obese individuals, which would be sufficient to meet the analytical needs of the study.

## Results

### Distribution of obesity metabolic phenotypes in the study population

Eventually 15,160 people were enrolled in the study, including 4663 males, accounting for 30.8% of the total number of participants, and the number of females was 10,497, accounting for 69.2%. In the age grouping,

there were 9,851 people in the group of 45–60 years old, accounting for 65%, and 5,309 people in the group of 60 years old and above, accounting for 35%. According to the BMI obesity standard, the population was divided into non-obese and obese groups, with 13,129 cases (86.6%) in the non-obese group and 2,031 cases (13.4%) in the obese group. According to the diagnostic criteria of metabolic abnormalities, the population was divided into metabolically normal and metabolically abnormal groups, with 9103 cases (60.0%) in the metabolically normal group and 6057 cases (40.0%) in the metabolically abnormal group. According to the metabolic phenotype of obesity, the study population was divided into 4 groups, with 8340 cases (55.0%) of MHNO, 4789 cases (31.6%) of MUNO, 763 cases (5.0%) of MHO and 1268 cases (8.4%) of MUO.

Comparison of the basic profiles of people with different obesity metabolic phenotypes is shown in Table 3. Four obesity metabolic phenotypes were evident when considering the effects of gender, age group, BMI, education level, in-service situation, family history of disease, time of exercise per week, smoking, alcohol consumption, whether anxiety, dietary tastes, softness and hardness, speed, intake of dietary supplements. TC, TG, LDL-C, HDL-C and FBG were significantly different between the 4 groups, $P < 0.05$.

### Distribution characteristics of the population grouped by different dietary behavior index scores

Table 4 shows the baseline characteristics of the populations in each group after grouping according to the dietary behavior index scores; there were 1,292 cases (8.5%) in the 0–2 score group, 9,643 cases (63.6%) in the 3–4 score group and 4,225 cases (27.9%) in the 5–6 score group. Four different dietary patterns were identified by factor analysis, namely, "plant preference" pattern, "grain-meat preference" pattern, "meat preference" pattern and "Egg and dairy preference" pattern.

The differences among different gender, age group, BMI, education level, marital status, in-service situation, family history of disease, time of exercise per week, smoking, alcohol consumption, sleep, anxiety, TC, TG, HDL-C, FBG, obesity metabolic phenotypes, dietary pattern groups and energy level were statistically significant in each grouping of dietary behavioral index scores ($P<0.05$). With the increase of the dietary behavior index, BMI, TG and FBG levels gradually decreased, while TC and HDL-C levels increased.

### Correlation analysis of dietary behavior patterns and obesity metabolic phenotypes

Multi-categorical logistic regression analysis was performed with obesity metabolic phenotype as the dependent variable, and dietary behavior index as the independent variable. The fit of the crude model, model 1, model 2 and model 3 were statistically significant, and the results of the analyses are shown in Table 5. Compared with the healthy dietary behavior pattern with a score of 5–6, the dietary behavior patterns with scores of 0–2 versus scores of 3–4 were the most important risk factors in the occurrence of MUNO, MHO and MUO, and the lower the dietary behavior pattern score was, the higher the multiplicity of occurrence of MUNO, MHO and MUO ($P < 0.05$).

### Stratified analysis of the association between dietary behavior patterns and obesity metabolic phenotypes

Table 6 shows the associations between dietary behavior patterns and obesity metabolic phenotypes in subgroups stratified according to gender and age group. We found an interaction between gender and age group in the dietary behavior patterns with obesity metabolic phenotypes.

Compared with the dietary behavior index 5–6 subgroup, subgroups 0–2 and 3–4 were risk factors for MUNO, MHO and MUO in female, and the lower the dietary behavior index score was, the higher the risk multiplier for the development of the obesity metabolic phenotype ($P<0.05$). In male, subgroups 0–2 were risk factors for MUNO and MUO, and subgroups 3–4 were risk factors for MUO ($P<0.05$). For the 45–60-year-old group, subgroups 0–2 and 3–4 were risk factors for MUNO, MHO and MUO, and the lower the dietary behavior index score was, the higher the risk multiplier for the development of the obesity metabolic phenotype ($P<0.05$). For the over 60-year-old group, subgroups 0–2 were risk factors for MUNO, MHO and MUO, and subgroups 3–4 were risk factors for MUNO and MUO ($P<0.05$).

### Association of individual dietary behavior with obesity metabolic phenotypes

Multi-categorical logistic regression analyses of the six dietary behaviors that comprise the healthy dietary behavior model individually with the obesity metabolic phenotype indicated that, after adjusting for all potential confounders, appropriate or light dietary taste, moderately soft and hard food and slightly hot food temperature were protective factors for MUNO and MUO ($P<0.05$); medium or slow eating speed and daily intake of dietary supplements were protective factor for MUNO, MHO and MUO ($P<0.05$). In addition, no association between eating with others and each obesity metabolic phenotype was found in this study. The results are shown in Table 7.

**Table 3** Basic information of people with different obesity metabolic phenotypes/n (%) or ($\overline{X}\pm S$)

| | MHNO | MUNO | MHO | MUO | *P*-value |
|---|---|---|---|---|---|
| Gender | | | | | < 0.001 |
| Male | 2347 (28.10) | 1651 (34.50) | 205 (26.90) | 460 (36.30) | |
| Female | 5993 (71.90) | 3138 (65.50) | 558 (73.10) | 808 (63.70) | |
| Age group | | | | | < 0.001 |
| 45–60 years old | 5862 (70.30) | 2714 (56.70) | 513 (67.20) | 762 (60.10) | |
| ≥ 60 years old | 2478 (29.70) | 2075 (43.30) | 250 (32.80) | 506 (39.90) | |
| BMI ($kg/m^2$) | $23.35 \pm 2.36^{(a,b,c)}$ | $24.38 \pm 2.13^{(b,c)}$ | $29.74 \pm 1.78^{(c)}$ | $30.14 \pm 3.63$ | < 0.001 |
| Literacy | | | | | < 0.001 |
| Elementary school and below | 2946 (35.30) | 1928 (40.30) | 386 (50.60) | 599 (47.20) | |
| Secondary school and vocational high school | 4961 (59.50) | 2667 (55.70) | 351 (46.00) | 614 (48.40) | |
| College and above | 433 (5.20) | 194 (4.10) | 26 (3.40) | 55 (4.30) | |
| Marital status | | | | | 0.970 |
| Married | 7684 (92.10) | 4414 (92.20) | 702 (92.00) | 1173 (92.50) | |
| Others (Unmarried / Divorced / Separated / Widowed) | 656 (7.90) | 375 (7.80) | 61 (8.00) | 95 (7.50) | |
| In-service situation | | | | | < 0.001 |
| Incumbency | 1965 (23.60) | 862 (18.00) | 169 (22.10) | 225 (17.80) | |
| Non-working | 6375 (76.40) | 3927 (82.00) | 594 (77.90) | 1043 (82.20) | |
| Family history of disease-Diabetes | | | | | < 0.001 |
| Yes | 682 (8.20) | 525 (11.00) | 59 (7.70) | 133 (10.50) | |
| No | 7658 (91.80) | 4264 (89.00) | 704 (92.30) | 1135 (89.50) | |
| Family history of disease-Hypertension | | | | | 0.020 |
| Yes | 1518 (18.20) | 953 (19.90) | 127 (16.60) | 257 (20.30) | |
| No | 6822 (81.80) | 3836 (80.10) | 636 (83.40) | 1011 (79.70) | |
| Family history of disease-Hyperlipidemia | | | | | 0.581 |
| Yes | 102 (1.20) | 63 (1.30) | 6 (0.80) | 13 (1.00) | |
| No | 8238 (98.80) | 4726 (98.70) | 757 (99.20) | 1255 (99.00) | |
| Time of exercise per week (minutes) | $262.41 \pm 279.37^{(a)}$ | $286.22 \pm 291.31^{(b,c)}$ | $262.54 \pm 308.43$ | $266.23 \pm 276.34$ | < 0.001 |
| Smoking | | | | | < 0.001 |
| Yes | 1201 (14.40) | 829 (17.30) | 83 (10.90) | 199 (15.70) | |
| No | 7139 (85.60) | 3960 (82.70) | 680 (89.10) | 1069 (84.30) | |
| Alcohol consumption | | | | | < 0.001 |
| Yes | 1855 (22.20) | 1276 (26.60) | 171 (22.40) | 352 (27.80) | |
| No | 6485 (77.80) | 3513 (73.40) | 592 (77.60) | 916 (72.20) | |
| Sleep problems | | | | | 0.255 |
| Yes | 1672 (20.0) | 1011 (21.10) | 140 (18.30) | 258 (20.30) | |
| No | 6668 (80.0) | 3778 (78.90) | 623 (81.70) | 1010 (79.70) | |
| Anxiety | | | | | 0.001 |
| Yes | 720 (8.60) | 344 (7.20) | 76 (10.0) | 85 (6.70) | |
| No | 7620 (91.40) | 4445 (92.80) | 687 (90.0) | 1183 (93.30) | |
| Depression | | | | | 0.851 |
| Yes | 455 (5.50) | 260 (5.40) | 47 (6.20) | 72 (5.70) | |
| No | 7885 (94.50) | 4529 (94.60) | 716 (93.80) | 1196 (94.30) | |
| Dietary tastes | | | | | < 0.001 |
| Oily | 328 (3.90) | 182 (3.80) | 43 (5.60) | 76 (6.00) | |
| Spicy | 1320 (15.80) | 837 (17.50) | 135 (17.70) | 283 (22.30) | |
| Salty | 524 (6.30) | 351 (7.30) | 55 (7.20) | 116 (9.10) | |
| Light | 3925 (47.10) | 2239 (46.80) | 323 (42.30) | 527 (41.60) | |
| Sweet | 186 (2.20) | 92 (1.90) | 13 (1.70) | 39 (3.10) | |
| Moderate | 2765 (33.20) | 1510 (31.50) | 262 (34.30) | 396 (31.20) | |

**Table 3** (continued)

| | MHNO | MUNO | MHO | MUO | *P*-value |
|---|---|---|---|---|---|
| Dietary Firmness | | | | | |
| Hard | 753 (9.00%) | 555 (11.60%) | 88 (11.50%) | 181 (14.30%) | |
| Soft | 2258 (27.10%) | 1177 (24.60%) | 180 (23.60%) | 297 (23.40%) | |
| Moderate | 5329 (63.90%) | 3057 (63.80%) | 495 (64.90%) | 790 (62.30%) | |
| Dietary temperature | | | | | 0.065 |
| Hot | 2860 (34.30%) | 1533 (32.00%) | 263 (34.50%) | 415 (32.70%) | |
| Cold | 104 (1.20%) | 71 (1.50%) | 11 (1.40%) | 25 (2.00%) | |
| Warm | 5376 (64.50%) | 3185 (66.50%) | 489 (64.10%) | 828 (65.30%) | |
| Dietary speed | | | | | < 0.001 |
| Slow (> 45 min) | 539 (6.50%) | 259 (5.40%) | 36 (4.70%) | 59 (4.70%) | |
| Fast (< 15 min) | 2995 (35.90%) | 1846 (38.50%) | 343 (45.00%) | 567 (44.70%) | |
| Moderate (15-45 min) | 4806 (57.60%) | 2684 (56.00%) | 384 (50.30%) | 642 (50.60%) | |
| Intake of dietary supplements | | | | | < 0.001 |
| Yes | 3089 (37.00%) | 1619 (33.80%) | 243 (31.80%) | 372 (29.30%) | |
| No | 5251 (63.00%) | 3170 (66.20%) | 520 (68.20%) | 896 (70.70%) | |
| Eating with others | | | | | 0.767 |
| Yes | 7800 (93.50%) | 4458 (93.10%) | 713 (93.40%) | 1188 (93.70%) | |
| No | 540 (6.50%) | 331 (6.90%) | 50 (6.60%) | 80 (6.30%) | |
| TC (mmol/L) | $5.39 \pm 0.96^{(a,b,c)}$ | $5.59 \pm 1.13^{(b,c)}$ | $5.27 \pm 0.84^{(c)}$ | $5.51 \pm 1.07$ | < 0.001 |
| TG (mmol/L) | $1.26 \pm 0.57^{(a,b,c)}$ | $2.48 \pm 1.92^{(b,c)}$ | $1.43 \pm 0.66^{(c)}$ | $2.58 \pm 1.95$ | < 0.001 |
| HDL-C (mmol/L) | $1.92 \pm 0.47^{(a,b,c)}$ | $1.59 \pm 0.46^{(b,c)}$ | $1.74 \pm 0.37^{(c)}$ | $1.51 \pm 0.39$ | < 0.001 |
| LDL-C (mmol/L) | $3.00 \pm 0.73^{(a,c)}$ | $3.21 \pm 0.82^{(b)}$ | $3.05 \pm 0.65^{(c)}$ | $3.23 \pm 0.80$ | < 0.001 |
| FBG (mmol/L) | $5.00 \pm 0.85^{(a,b,c)}$ | $6.10 \pm 2.00^{(b)}$ | $5.16 \pm 0.78^{(c)}$ | $6.14 \pm 1.76$ | < 0.001 |

[(a)] represents compared with the MUNO group, $P < 0.05$

[(b)] represents compared with the MHO group, $P < 0.05$

[(c)] represents compared with the MUO group, $P < 0.05$

## Discussion

The association between dietary factors and chronic disease has been confirmed as the scope of chronic disease research has developed and deepened, with previous studies concluding that meal timing, frequency of eating, and fasting have an impact on health [40]. However, diet is a complex and variable system that changes with geography, ethnicity and customs. One study showed that dietary risk accounted for 12.2% of the factors affecting the global total disability-adjusted life years for men and 9.0% for women [41]. Dietary factors are the major risk factors for morbidity and mortality in Chinese adults [42]; therefore, rational understanding of the impact of diet on disease has received increasing attention. Dietary behavioral characteristics are considered to be reliable indicators of food-related behaviors [43]; this study analyzed the relationship between dietary behavior patterns and obesity metabolic phenotypes, in order to find healthier and more appropriate dietary strategies for the middle-aged and elderly population.

We found that there is obesity metabolic heterogeneity in the middle-aged and elderly population from the percentage of different obesity metabolic phenotypes, and the average BMI of the MUNO population is in the overweight state ($24.0 \leq BMI < 28.0$ kg/m$^2$ is overweight), although it has not reached clinical criteria for obesity, but there are already metabolic abnormalities. Studies have shown that early metabolic disorders in overweight and obese people, the accumulation of adipose tissue in the liver, causing a large number of unesterified fatty acids into the blood, promoting the synthesis of TG by the liver, exacerbating the imbalance of lipids and leading to hyperlipidemia [44]. Moreover, adipose tissue is positively correlated with many metabolic indicators, such as triglycerides, blood glucose and blood uric acid, indicating that being in an overweight state can also have a certain impact on the body's metabolism, which should be taken seriously [2]. A total of 63.6% of the people in this study belonged to the eating behavior pattern 3–4 subgroup, indicating that most of them actually had more or less poor eating behavior, and their average BMI of overweight may also be associated with it. In addition, this study found that the higher the eating behavior scores, the lower their BMI, TG and FBG levels, and the higher

**Table 4** Distributional characteristics of populations grouped by different dietary behavioral index scores/n (%) or ($\overline{X}\pm S$)

| | Dietary behavioral index scores subgroup | | | $X^2/F$ | *P*-value |
|---|---|---|---|---|---|
| | 0–2 | 3–4 | 5–6 | | |
| Gender | | | | 261.255 | < 0.001 |
| Male | 530 (41.00) | 3220 (33.40) | 913 (21.60) | | |
| Female | 762 (59.00) | 6423 (66.60) | 3312 (78.40) | | |
| Age group | | | | 6.564 | 0.038 |
| 45–60 years old | 881 (68.00) | 6248 (64.80) | 2722 (64.40) | | |
| ≥ 60 years old | 411 (31.8) | 3395 (35.2) | 1503 (35.6) | | |
| BMI (kg/m$^2$) | 25.20 ± 3.18$^{(a,b)}$ | 24.67 ± 3.33$^{(b)}$ | 24.15 ± 3.02 | 64.109 | < 0.001 |
| Literacy | | | | 58.703 | < 0.001 |
| Elementary school and below | 542 (42.00) | 3855 (40.00) | 1462 (34.60) | | |
| Secondary school and vocational high school | 714 (55.30) | 5364 (55.60) | 2515 (59.50) | | |
| College and above | 36 (2.80) | 424 (4.40) | 248 (5.90) | | |
| Marital Status | | | | 24.992 | < 0.001 |
| Married | 1155 (89.00) | 8867 (92.00) | 3951 (93.50) | | |
| Others (Unmarried / Divorced / Separated / Widowed) | 137 (10.60) | 776 (8.00) | 274 (6.50) | | |
| In-service situation | | | | 30.590 | < 0.001 |
| Incumbency | 314 (24.00) | 2127 (22.10) | 780 (18.50) | | |
| Non-working | 978 (75.70) | 7516 (77.90) | 3445 (81.50) | | |
| Family history of disease-Diabetes | | | | 8.911 | 0.012 |
| Yes | 137 (10.60) | 840 (8.70) | 422 (10.00) | | |
| No | 1155 (89.00) | 8803 (91.30) | 3803 (90.00) | | |
| Family history of disease-Hypertension | | | | 16.679 | < 0.001 |
| Yes | 244 (18.90) | 1729 (17.90) | 882 (20.90) | | |
| No | 1048 (81.00) | 7914 (82.10) | 3343 (79.10) | | |
| Family history of disease-Hyperlipidemia | | | | 2.193 | 0.334 |
| Yes | 12.00 (0.90) | 113 (1.20) | 59 (1.40) | | |
| No | 1280 (99.00) | 9530 (98.80) | 4166 (98.60) | | |
| Time of exercise per week (minutes) | 245.08 ± 278.87$^{(a,b)}$ | 263.20 ± 281.04$^{(b)}$ | 294.07 ± 292.97 | 22.876 | < 0.001 |
| Smoking | | | | 251.576 | < 0.001 |
| Yes | 336 (26.00) | 1592 (16.50) | 384 (9.10) | | |
| No | 956 (74.00) | 8051 (83.50) | 3841 (90.90) | | |
| Alcohol consumption | | | | 177.044 | < 0.001 |
| Yes | 452 (35.00) | 2441 (25.30) | 761 (18.00) | | |
| No | 840 (65.00) | 7202 (74.70) | 3464 (82.00) | | |
| Sleep problems | | | | 9.049 | 0.011 |
| Yes | 266 (21.00) | 1892 (19.60) | 923 (21.80) | | |
| No | 1026 (79.40) | 7751 (80.40) | 3302 (78.20) | | |
| Anxiety | | | | 28.144 | < 0.001 |
| Yes | 129 (10.00) | 694 (7.20) | 402 (9.50) | | |
| No | 1163 (90.00) | 8949 (92.80) | 3823 (90.50) | | |
| Depression | | | | 4.786 | 0.091 |
| Yes | 77 (6.00) | 501 (5.20) | 256 (6.10) | | |
| No | 1215 (94.00) | 9142 (94.80) | 3969 (93.90) | | |
| TC (mmol/L) | 5.41 ± 1.06$^{(b)}$ | 5.43 ± 1.02$^{(b)}$ | 5.52 ± 1.04 | 12.785 | < 0.001 |
| TG (mmol/L) | 1.93 ± 1.67$^{(a,b)}$ | 1.78 ± 1.47$^{(b)}$ | 1.68 ± 1.25 | 17.084 | < 0.001 |
| HDL-C (mmol/L) | 1.67 ± 0.46$^{(a,b)}$ | 1.74 ± 0.48$^{(b)}$ | 1.86 ± 0.50 | 114.171 | < 0.001 |
| LDL-C (mmol/L) | 3.10 ± 0.77 | 3.08 ± 0.77 | 3.10 ± 0.77 | 0.781 | 0.458 |
| FBG (mmol/L) | 5.59 ± 1.77$^{(a,b)}$ | 5.46 ± 1.53$^{(b)}$ | 5.38 ± 1.31 | 10.388 | < 0.001 |

**Table 4** (continued)

| | Dietary behavioral index scores subgroup | | | $X^2/F$ | *P*-value |
|---|---|---|---|---|---|
| | 0–2 | 3–4 | 5–6 | | |
| Obesity metabolic phenotypes | | | | 109.046 | < 0.001 |
| MHNO | 604 (47.00) | 5187 (53.90) | 2549 (59.90) | | |
| MUNO | 448 (34.80) | 3071 (31.90) | 1270 (29.90) | | |
| MHO | 79 (6.10) | 502 (5.20) | 182 (4.30) | | |
| MUO | 157 (12.20) | 858 (8.90) | 253 (5.90) | | |
| Dietary pattern groups | | | | 205.409 | < 0.001 |
| "Plant preference" pattern | 224 (17.30) | 1978 (20.50) | 1041 (24.60) | | |
| "Grain-meat preference" pattern | 424 (32.80) | 2615 (27.10) | 796 (18.80) | | |
| "Meat preference" pattern | 347 (26.90) | 2217 (23.00) | 931 (22.00) | | |
| "Egg and dairy preference" pattern | 297 (23.00) | 2833 (29.40) | 1457 (34.50) | | |
| Energy level | 1104.72 ± 526.83[(a,b)] | 1068.24 ± 428.38 | 1077.33 ± 408.73 | 4.240 | 0.014 |

[(a)] represents compared with the eating behavior index 3–4 subgroup, $P < 0.05$

[(b)] represents compared with the eating behavior index 5-6 subgroup, $P < 0.05$

**Table 5** Multi-categorical logistic analysis of healthy dietary behavior patterns and metabolic phenotypes of obesity

| Dietary Behavior Model | MHNO | MUNO | | MHO | | MUO | |
|---|---|---|---|---|---|---|---|
| | | OR (95% CI) | *P*-value | OR (95% CI) | *P*-value | OR (95% CI) | *P*-value |
| Coarse model | | | | | | | |
| 0–2 points | 1.00 | 1.485 (1.291–1.707) | < 0.001 | 1.820 (1.377–2.405) | < 0.001 | 2.588 (2.081–3.218) | < 0.001 |
| 3–4 points | 1.00 | 1.181 (1.089–1.280) | < 0.001 | 1.349 (1.131–1.609) | 0.001 | 1.646 (1.419–1.908) | < 0.001 |
| 5–6 points | - | | | | | | |
| Model 1 | | | | | | | |
| 0–2 points | 1.00 | 1.490 (1.291–1.719) | < 0.001 | 1.771 (1.335–2.348) | < 0.001 | 2.485 (1.990–3.102) | < 0.001 |
| 3–4 points | 1.00 | 1.174 (1.081–1.276) | < 0.001 | 1.321 (1.105–1.579) | 0.002 | 1.598 (1.375–1.856) | < 0.001 |
| 5–6 points | - | | | | | | |
| Model 2 | | | | | | | |
| 0–2 points | 1.00 | 1.482 (1.284–1.711) | < 0.001 | 1.815 (1.367–2.409) | < 0.001 | 2.500 (2.000–3.124) | < 0.001 |
| 3–4 points | 1.00 | 1.170 (1.076–1.272) | < 0.001 | 1.330 (1.113–1.590) | 0.002 | 1.587 (1.366–1.845) | < 0.001 |
| 5–6 points | - | | | | | | |
| Model 3 | | | | | | | |
| 0–2 points | 1.00 | 1.486 (1.287–1.715) | < 0.001 | 1.817 (1.369–2.412) | < 0.001 | 2.508 (2.006–3.135) | < 0.001 |
| 3–4 points | 1.00 | 1.166 (1.073–1.268) | < 0.001 | 1.334 (1.116–1.595) | 0.002 | 1.580 (1.359–1.836) | < 0.001 |
| 5–6 points | - | | | | | | |

The crude model did not adjust for any factors; model 1 adjusted for gender, age, level of education, marital status, in-service situation and family history of disease; model 2 adjusted for time of exercise per week, smoking, alcohol consumption, dietary patterns and energy based on model 1; and model 3 adjusted for sleep, anxiety and depression based on model 2

their HDL-C levels. Dietary behaviors affect the type and amount of food consumed, which in turn affects energy intake [45]. In this study, dietary behavior pattern 5–6 is a healthy dietary behavior pattern, meaning that appropriate or light dietary taste, moderately soft and hard food, slightly hot food temperature, medium or slow eating speed, daily intake of dietary supplements and eating with others, which can contribute to the maintenance of body weight, lipids and blood glucose in the normal range. Further analysis revealed that dietary behaviors with scores of 0–2 and 3–4 were risk factors for MUNO, MHO and MUO compared to healthy dietary behaviors with scores of 5–6, and the lower the dietary behavior score was, the higher the multiplicity of MUNO, MHO and MUO. Separate analyses of the associations between each dietary behavior and the metabolic phenotype of obesity yielded results that provide further support for the conclusion that appropriate dietary behaviors are protective

**Table 6** Multi-categorical logistic analysis of dietary behavioral index scores subgroup and obesity metabolic phenotypes stratified by gender and age group

| Interaction items | MHNO | MUNO | | MHO | | MUO | |
|---|---|---|---|---|---|---|---|
| | | OR (95% CI) | *P*-value | OR (95% CI) | *P*-value | OR (95% CI) | *P*-value |
| Gender and dietary behavioral index scores subgroup | | | | | | | |
| Male[a] | | | | | | | |
| 0–2 points | 1.00 | 1.577 (1.239–2.008) | < 0.001 | 1.048 (0.610–1.799) | 0.865 | 2.704 (1.846–3.961) | < 0.001 |
| 3–4 points | 1.00 | 1.115 (0.947–1.313) | 0.193 | 0.862 (0.606–1.226) | 0.409 | 1.588 (1.184–2.130) | 0.002 |
| 5–6 points | - | | | | | | |
| Female[a] | | | | | | | |
| 0–2 points | 1.00 | 1.411 (1.173–1.697) | < 0.001 | 2.180 (1.563–3.041) | < 0.001 | 2.361 (1.772–3.145) | < 0.001 |
| 3–4 points | 1.00 | 1.176 (1.066–1.296) | 0.001 | 1.509 (1.227–1.856) | < 0.001 | 1.543 (1.292–1.843) | < 0.001 |
| 5–6 points | - | | | | | | |
| Age group and dietary behavioral index scores subgroup | | | | | | | |
| 45–60 years old[a] | | | | | | | |
| 0–2 points | 1.00 | 1.529 (1.280–1.827) | < 0.001 | 1.847 (1.306–2.612) | 0.001 | 2.845 (2.153–3.759) | < 0.001 |
| 3–4 points | 1.00 | 1.139 (1.023–1.268) | 0.017 | 1.403 (1.123–1.752) | 0.003 | 1.624 (1.329–1.984) | < 0.001 |
| 5–6 points | - | | | | | | |
| ≥ 60 years old[a] | | | | | | | |
| 0–2 points | 1.00 | 1.276 (1.001–1.627) | 0.049 | 1.710 (1.040–2.810) | 0.034 | 1.759 (1.193–2.593) | 0.004 |
| 3–4 points | 1.00 | 1.163 (1.018–1.328) | 0.027 | 1.176 (0.869–1.592) | 0.294 | 1.470 (1.167–1.852) | 0.001 |
| 5–6 points | - | | | | | | |

[a] representations adjusted for confounders such as gender, age, level of education, marital status, in-service situation, family history of disease, time of exercise per week, smoking, alcohol consumption, dietary patterns, energy, sleep, anxiety and depression (in addition to stratification variables)

**Table 7** Multi-categorical logistic regression analysis of healthy dietary behaviors and metabolic phenotypes of obesity

| Healthy dietary behaviors | MHNO | MUNO | | MHO | | MUO | |
|---|---|---|---|---|---|---|---|
| | | OR (95% CI) | *P*-value | OR (95% CI) | *P*-value | OR (95% CI) | *P*-value |
| Appropriate or light dietary taste[a] | 1.00 | 0.914 (0.837–0.999) | 0.048 | 0.842 (0.705–1.006) | 0.058 | 0.689 (0.601–0.791) | < 0.001 |
| Moderately soft and hard food[b] | 1.00 | 0.771 (0.683–0.870) | < 0.001 | 0.855 (0.671–1.088) | 0.202 | 0.675 (0.563–0.809) | < 0.001 |
| Slightly hot food temperature[c] | 1.00 | 0.877 (0.811–0.948) | 0.001 | 0.931 (0.794–1.091) | 0.376 | 0.844 (0.742–0.961) | 0.010 |
| Medium or slow eating speed[d] | 1.00 | 0.911 (0.844–0.984) | 0.017 | 0.710 (0.609–0.827) | < 0.001 | 0.741 (0.655–0.839) | < 0.001 |
| Daily intake of dietary supplements[e] | 1.00 | 0.909 (0.840–0.983) | 0.017 | 0.835 (0.709–0.984) | 0.031 | 0.794 (0.694–0.908) | 0.001 |
| Eating with others[f] | 1.00 | 0.887 (0.762–1.032) | 0.121 | 0.951 (0.695–1.303) | 0.757 | 0.970 (0.750–1.255) | 0.818 |

[a] stands for correction of basic condition (gender, age, level of education, marital status, in-service situation, family history of disease, time of exercise per week, smoking, alcohol consumption, dietary patterns, energy, sleep, anxiety and depression), and dietary factors other than dietary tastes

[b] stands for correction of basic condition and dietary factors other than dietary softness or hardness

[c] stands for correction of basic condition and dietary factors other than dietary temperature

[d] stands for correction of basic condition and dietary factors other than dietary speed

[e] stands for correction of basic condition and dietary factors other than whether or not dietary supplements were consumed

[f] stands for correction of basic condition and dietary factors other than whether or not eating with others

factors for obesity and metabolic diseases, and that the more unhealthy dietary behaviors there are, the higher the odds of developing metabolic diseases. Other studies have confirmed that dietary behaviors have a significant impact on the human body, and that salty, greasy and spicy foods tend to promote appetite and are accompanied by large amounts of fat intake, leading to elevated circulating lipid levels, ectopic lipid deposition, and consequently, hyperlipidemia, which is characterized by elevated TG and TC, and reduced HDL-C levels [46, 47]. It has been found that slow eating significantly reduces dietary energy intake and increases satiety after meals [48], while obese individuals have significantly higher hunger than normal-weight individuals, their eating speed is faster [49], eating speed is

positively correlated with increasing BMI [50], TG levels, diastolic blood pressure, systolic blood pressure, and the prevalence of metabolic syndrome are significantly higher in those who eat fast than in those who eat slowly, and their HDL -C levels are also lower [17, 51]. Cool diet tends to increase the energy intake; however, hot food burning is associated with the occurrence of esophageal cancer [30]. Therefore, the long-term diet is cool or too hot may cause adverse effects on the human body. In addition, studies suggesting that dietary supplements may have health benefits [52, 53]. Vitamin A and B have been associated with glucose metabolism [54], vitamin A improves pancreatic islet's ability to produce B-cells [55], and vitamin $B_6$, as a cofactor, is involved in 150 metabolic reactions regulating glucose, lipids, amino acids, DNA and neurotransmitters, has a role in the regulation of blood glucose [56]. However, supplements' quality, safety and efficacy remain the main issues, the evaluation of dietary supplements is still controversial. Other studies have found that middle-aged adults who ate all three meals alone had the highest probability of developing metabolic diseases, 50.1% and 36.8% for men and women, respectively, and the risk of metabolic syndrome was 1.51 times higher for men eating alone than for eating with others [28]. Furthermore, eating alone may be a potential risk factor for metabolic diseases [28], and is closely associated with overweight [57], depression [58, 59] and cardiovascular diseases [60]. However, we did not find an association between eating alone and each obesity metabolic phenotype, probably due to the differences in the cultural and diet between countries. China, a traditional nation characterized by its high population density and communal lifestyle, typically sees its citizens dining with family or friends. This contrasts with Japan and South Korea, where there are developed economies centered on individuals, and the number of people living and eating alone is notably higher.

Gender and age are important factors affecting the metabolic function of the human body. The analyses were further stratified whether there was any difference in the association between eating behavior patterns and obesity metabolic phenotypes among different genders and age groups. We found that the association still existed in females and the 45–60 age group, but the association of different dietary behavior patterns with MUNO and MUO was stronger among men and people above 60. A result that may be related to the differences in physiological levels and lifestyles. It has been found that men with metabolic syndrome produce excessive amounts of pro-inflammatory cytokines (e.g., interleukin IL-6 and leptin), whereas women show reduced levels of anti-inflammatory adipokines [61]. Middle-aged and older man are more prone to metabolic problems because of higher work stress, more socializing and more risk factors such as alcohol consumption, lack of physical activity or exercise than women [62]. For people over 60 years old, the metabolic level of the body decreases with age, and at the same time, the distribution of body fat changes, which in turn accelerates the aging process and the development of related diseases [63], and makes them more prone to metabolic disorders than middle-aged people.

There were some limitations in this study. Firstly, there was a recall bias and a certain degree of subjectivity in determing dietary tastes, temperatures, and degrees of softness and hardness in the survey. Secondly, the study corrected many potential confounders in the multi-categorical logistic model, but there are still unknown confounders that may interfere with the results of the study. Thirdly, we only collected data from three regions, and the findings cannot be extrapolated to other regions in Sichuan or other provinces in China. Fourthly, as an observational study, the causal relationship between dietary factors and metabolic phenotypes of obesity could not be determined in this study. Therefore, further validation of the results of this study is needed in subsequent cohort and clinical studies. Lastly, only six dietary behaviors were included in this study, and there are still other dietary behaviors that affect health outcomes, so more dietary factors and metabolic diseases can be explored in future studies.

## Conclusions

Overall, the results highlight the relationship between dietary behavior and obesity metabolic phenotype, and provide a theoretical basis for the refinement of more precise interventions aimed at improving the quality of life of middle-aged and elderly people in China as well as other countries.

### Abbreviations

| | |
|---|---|
| BMI | Body Mass Index |
| SFFQ | Simplified Food Frequency Questionnaire |
| FBG | Fasting Blood Glucose |
| HDL-C | High Density Lipoprotein Cholesterol |
| LDL-C | Low Density Lipoprotein Cholesterol |
| TC | Total Cholesterol |
| TG | Triglyceride |
| MHNO | Metabolically Healthy Non-obesity |
| MUNO | Metabolically Unhealthy Non-obesity |
| MHO | Metabolically Healthy Obesity |
| MUO | Metabolically Unhealthy Obesity |
| PSQI | Pittsburgh Sleep Quality Index Scale |
| GAD-7 | Generalized Anxiety Disorder-7 |
| PHQ-9 | Patient Health Questionnaire-9 |

### Acknowledgements

We would like to thank the "Natural Population Cohort Study of West China Hospital of Sichuan University" for their support and help during the process.

### Authors' contributions

PFF and LJL provided the research ideas, completed the data analysis, LJL manuscript writing, WYY, LJJ and LXY provided part of the data analysis, SL, ZXC and HW revised and reviewed the content of this manuscript, and all

authors discussed the results and commented on the manuscript. All the authors have read and approved the final manuscript. PFF, LJL and HW are responsible for its final content.

**Funding**
This study was financially supported by: 1) the West China Hospital of Sichuan University Clinical Research Incubation Project (N0.2021HXFH006); 2) "1·3·5 project for disciplines of excellence-Clinical Research Fund, West China Hospital, Sichuan University" (No.2024HXFH017).

**Availability of data and materials**
The datasets and any other materials of our study are available from the corresponding author on request.

**Data availability**
No datasets were generated or analysed during the current study.

## Declarations

**Ethics approval and consent to participate**
The study was registered with the China Clinical Trial Registry: Natural Population Cohort Study of West China Hospital of Sichuan University (ID: ChiCTR1900024623). The ethical review of this study was approved by the Biomedical Ethics Review Committee of West China Hospital of Sichuan University (NO.2020–145), and all participants signed a written informed consent form.

**Consent for publication**
Not applicable.

**Competing interests**
The authors declare no competing interests.

**Author details**
[1]Department of Clinical Nutrition, West China Hospital, Sichuan University, 37 Guoxue Lane, Wuhou District, Chengdu 610041, Sichuan, China. [2]Laboratory Medicine Center, Sichuan Tianfu New Area People's Hospital, No.97 Zhengbei Shangjie, Huayang Street, Tianfu New Area, Chengdu 610213, Sichuan, China. [3]School of Laboratory Medicine, Chengdu Medical College, No.783, Xindu Avenue, Xindu District, Chengdu 610500, Sichuan, China. [4]Department of Nutrition and Food Hygiene, West China School of Public Health and West China Fourth Hospital, Sichuan University, Chengdu 610041, Sichuan, China.

Received: 16 November 2023 Accepted: 13 August 2024
Published online: 26 August 2024

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