Prevalence of and lifestyle factors associated with metabolic syndrome determined using multi-level models in Chinese adults from a cross-sectional survey

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**Abstract**

People living in the same area are more likely to experience similar socioeconomic characteristics, which leads to cluster effect and influences the generalizability of data regarding metabolic syndrome (MetS). However, previous studies did not consider or adjust for the cluster effect of living circumstances. The aim of this study was to determine the prevalence of MetS and associated lifestyle factors in Chinese adults 18 to 80 years of age, using multi-level generalized estimation equation (GEE).

The participants came from a large-scale cross-sectional population survey. A total of 28,062 participants underwent all the blood tests. Participants meeting at least 3 of the 5 diagnostic criteria were defined as having MetS. Multi-level GEE was used to evaluate the relationship between MetS and lifestyle covariates to control the cluster effect of living circumstances. Odds ratios (ORs) and their 95% confidence intervals (CIs) were used to assess the strength of each relationship.

A total of 65.70% of the participants had at least 1 clinical feature of MetS, and 2926 were diagnosed with MetS (prevalence 14.03%). 32.74%, 18.93%, 10.25%, 3.25%, and 0.53% of the participants had 1, 2, 3, 4, and 5 components, respectively. The prevalence of MetS in men (12.31%) was lower than in women (15.57%). After controlling for the cluster effect of living circumstances, many demographic and lifestyle characteristics were associated with MetS. Overweight (OR = 1.070, 95% CI: 1.060–1.143), obesity (OR = 2.287, 95% CI: 2.136–2.449), current alcohol consumption (OR = 1.053, 95% CI: 1.020–1.086), physical labor (OR = 1.070, 95% CI: 1.040–1.101), a high-salt diet (OR = 1.040, 95% CI: 1.000–1.071), hyperuricemia (OR = 1.264, 95% CI: 1.215–1.316), short sleep duration (OR = 1.032, 95% CI: 1.009–1.055), and a family history of cardiovascular disease (OR = 1.065, 95% CI: 1.019–1.113), or cerebrovascular disease (OR = 1.065, 95% CI: 1.007–1.104) increased the risk of MetS. The risk of MetS increased 6.9% (OR = 1.069, 95% CI: 1.053–1.085) with each 5% increase in body fat percentage.

MetS has become a serious public health challenge in China. Many lifestyle factors have been found to be closely associated with MetS, including obesity, a high-salt diet, alcohol consumption, and short sleep duration. Therefore, changes in lifestyle are very important for adults to reduce the prevalence of MetS.

**Abbreviations:** BMI = body mass index, CI = confidence interval, DBP = diastolic blood pressure, HDL-C = high density lipoprotein cholesterol, MetS = metabolic syndrome, NCEP ATP III = National Cholesterol Education Program Adult Treatment Panel III, OR = odds ratio, PBF = percentage of body fat, SBP = systolic blood pressure, SD = standard deviation, WGOC = working Group on Obesity in China.

**Keywords:** body fat percentage, body mass index, metabolic syndrome, sleep duration
1. Introduction

The inhabitants of China and most countries around the world are currently achieving their highest life expectancy in history. As a result of economic growth and the associated sociodemographic changes, the burden of infectious disease has diminished, but changes in lifestyles have led to a greater burden of cardiovascular disease, diabetes, and other chronic diseases. Metabolic syndrome (MetS), a cluster of cardiovascular risk factors that include dyslipidemia, abdominal obesity, hypertension, and hyperglycemia, is associated with the development of diabetes, cardiovascular disease, and kidney disease, which are the leading causes of mortality worldwide. As overweight and obesity has increased worldwide, MetS has become common, not only in developed countries, but also in less developed countries. Sherling et al have stated that the overlap of several components of MetS in each disease state, resulting in atherogenesis, should be considered a broader entity, rather than these factors being considered separately. The incidence of MetS often parallels the incidences of obesity and type 2 diabetes. However, prevalence estimates vary depending on the criteria used for the definition of MetS. Global data regarding MetS are hard to collect, but Saklayen estimated the global prevalence of MetS to be 25%, implying that over a billion people around the world now have MetS. It has been reported that about one third of US adults have MetS, and Gu has reported that the prevalence of MetS in China is 9.8% in men and 17.8% in women aged 35 to 74 years, while Wang reported that the prevalence of MetS in China in 2017 was 15.5%. In the absence of a national program for the prevention and control of MetS in China, its prevalence is likely to continue to increase in the near future.

Despite the existing information, more evidence is needed regarding the prevalence of MetS in Chinese populations that cover a broader age range and include more minorities and cover more regions. People living in the same area are more likely to experience similar environmental influences, which influences the generalizability of data regarding MetS and its components. However, most previous studies of MetS did not consider or adjust for the cluster effect of living circumstances, which would have influenced their findings. Therefore, the aim of the present study was to determine the prevalence of MetS and associated lifestyle factors in Chinese adults across a broad age range, from 18 to 80 years, using a national, large-scale, cross-sectional survey. A multi-level generalized estimation equation (GEE) was constructed to evaluate the relationship between MetS and lifestyle factors, controlling for the cluster effect of living circumstances.

2. Material and methods

2.1. Sampling and participants

The study sample was obtained from a large-scale cross-sectional population survey regarding physiologic constants and health characteristics that was conducted in China in 2007 to 2011. A 2-stage cluster sampling method was used to recruit eligible individuals. Briefly, this survey was carried out in 6 provinces or autonomous regions of China: Hunan Province, Yunnan Province, Heilongjiang Province, Inner Mongolia Autonomous Region, Sichuan Province, and Ningxia Hui Autonomous Region. Two or 3 cities were sampled on the basis of their economic status, then several communities were randomly selected within each city. In these selected communities, all the eligible individuals were surveyed. The inclusion criteria of individuals included 3 aspects. First, individuals aged from 18 to 80 years old. Second, individuals did not suffer from severe chronic diseases, such as cancer, cardiovascular diseases, cerebrovascular diseases, chronic kidney diseases, diabetes, etc. Third, individuals did not experience a high fever in the preceding 15 days.

After providing written informed consent, the participants attended temporary physical examination centers voluntarily to take part in the survey and interview. The study was approved by the ethics review board of the Institute of Basic Medical Sciences, Chinese Academy of Medical Sciences (No. 005-2008).

2.2. Survey and interview

The survey and interview were conducted in 6 provinces at different time frames by the same team of trained investigators. 20 investigators were involved in the realization of interviews. About 100 subjects were surveyed and interviewed by 20 investigators per day. The survey and interview lasted about 1 hour for each subject. In each province, about 3500 subjects took part in the survey and interview, and it took 1 and half months for investigators to complete all the survey and interview.

The survey included clinical laboratory tests, blood pressure measurement, body composition analyzing and face to face interview. The content of the interview included demographic characteristics such as birth date, gender, occupation, ethnicity, etc and lifestyle factors such as smoking, alcohol drinking, high-salted diet, sleep duration, etc.

2.3. Clinical laboratory tests

All clinical laboratory tests were performed following a 9 to 12-hour overnight fast, when a blood sample was drawn from an antecubital vein. Total cholesterol, low-density lipoprotein-cholesterol (LDL-C), high-density lipoprotein-cholesterol (HDL-C), and triglyceride concentrations were measured using a Beckman AU Series automated biochemical analyzer (Japan) and Sekisui Medical (Japan) reagents. Fasting blood glucose, creatinine, blood urea nitrogen, and uric acid were measured with the same instrument and with Beckman AU reagents.

2.4. Blood pressure measurement

Systolic blood pressure (SBP) and diastolic blood pressure (DBP) were measured in the morning after the participants had rested for 5 minutes in a seated position, with their back supported, feet on the floor, and right arm supported, with the cubital fossa at the level of the heart. The appropriate cuff was chosen for each participant’s arm circumference. OMRON HEM-7000 electronic sphygmomanometers (OMRON Health-Care, Kyoto, Japan) were used to measure SBP and DBP.

2.5. Definition of MetS

According to the National Cholesterol Education Program Adult Treatment Panel III (NCEP ATP III), individuals meeting at least 3 of the following 5 criteria were defined as having MetS: fasting hyperglycemia, hypertension, low HDL-C concentration, hypertriglyceridemia, and abdominal obesity. The definitions are provided below in more detail.
1) Hyperglycemia: fasting blood glucose $\geq 110$ mg/dL or a diagnosis of diabetes;
2) Hypertension (SBP $\geq 130$ mm Hg and/or DBP $\geq 85$ mm Hg) or a history of hypertension;
3) Low HDL-C: serum HDL-C concentration $< 40$ mg/dL in men and $< 50$ mg/dL in women;
4) Hypertriglyceridemia: serum triglyceride concentration $\geq 150$ mg/dL;
5) Abdominal obesity: waist circumference $\geq 102$ cm in men and $\geq 88$ cm in women, as measured to the nearest 0.1 cm at the level of the navel, using a flexible steel tape.

2.6. Definition of covariates

Participants were categorized into 3 age groups, young (18–34 years old), middle-aged (35–59 years old), and older adults (60–80 years old).

Body mass index (BMI) was defined as body mass (kg) divided by the square of height (m$^2$). Body mass was measured to the nearest 0.1 kg. Height and waist circumference were measured to the nearest 1 mm. According to Chinese Guidelines for the Prevention and Control of Adult Overweight and Obesity,[16] normal weight is defined by the BMI $< 24$ kg/m$^2$, overweight by a BMI $\geq 24$ kg/m$^2$, but < 28 kg/m$^2$, and obesity by a BMI $\geq 28$ kg/m$^2$. The percentage of body fat (PBF) was defined as the percentage of total body mass that was fat, and was measured using the bioelectric impedance method (Biodynamics Bl-310 body composition analyzer; American Biodynamics Corporation). Participants were too fast, refrain from strenuous exercise at least 4 hours before measuring and refrain from drinking 24 hours before measuring.

2.7. Quality control

First, the project survey questionnaires, operation manual, and training manual were developed to guarantee the quality of the study. Before the survey was formally conducted, all investigators and medical professionals were trained based on training manuals and pilot survey was conducted to ensure that all of them were proficient in the survey process. Trained medical professionals carried out the survey and face to face interview and the responsibilities of the research team members were clarified and established. The training content included clinical laboratory tests, blood pressure measurement, body composition analyzing and face to face interview.

Second, the same brand and model of body composition analyzer, biochemical analyzer and sphygmomanometers were used at each center, and these were adjusted every day before measurements were made to minimize measurement errors. All survey and interview were conducted by the same team of trained investigators.

Finally, the survey questionnaires and the raw data were double-checked to guarantee the authenticity and accuracy including effective data logic control and editing checks. The database was constructed using EPI3.02 software (the EpiData Association, Odense, Denmark), and data were entered twice, by 2 data managers, to guarantee its accuracy and integration.

2.8. Statistical analysis

Statistical analyses were conducted using SAS9.4 software (SAS Institute Int. Cary, NC, USA) software. Two-tailed analyses were conducted, in which $P<0.05$ was defined as indicating statistical significance. Continuous data are summarized using means and standard deviations (SDs) and were compared using Student t test. Categorical data are summarized using numbers and percentages and were compared using the Chi-squared test.

Given that participants living in the same area were more likely to experience similar living circumstances and socioeconomic characteristics, we used the residence area to reflect subjects' living circumstances and socioeconomic characteristics. The residence area was defined as the community, city and province where subjects resided for a long time. A multi-level GEE model was used to determine the relationship between MetS and lifestyle factors to control for the cluster effect of living circumstances and socioeconomic characteristics. Odds ratios (ORs) and their 95% confidence intervals (CIs) were used to assess the strength of each relationship.

3. Results

The mean age of the 20,862 participants was 43.4±16.1 years, that of the 9864 men was 43.3±16.7 years, and that of the 10,998 women was 43.4±15.6 years. The participants were of dozens of ethnicities, including Han (13,279; 63.7%), Yi (2031; 9.7%), Miao (343; 1.6%), Mongolian (1143; 5.5%), Tibetan (608; 2.9%), Korean (717; 3.4%), Hui (1808; 8.7%), Tujia (625; 3.0%), and others (308; 1.5%).

A total of 65.70% (n=13,707) of all the participants had at least 1 clinical feature of MetS. Specifically, 32.74%, 18.93%, 10.25%, 3.25%, and 0.53% of the participants had 1, 2, 3, 4, and 5 components, respectively. These components, listed in order of their prevalence, were hypertension (41.90%), hypertriglyceridemia (28.14%), low HDL-C concentration (27.14%), hyperglycemia (10.82%), and abdominal obesity (9.21%). The most common pair of components occurring together were hypertension and low HDL-C concentration (9.64%) and the most common grouping of 3 components comprised hypertension, hypertriglyceridemia, and low HDL-C concentration (5.56%).

In total, 2926 participants were diagnosed with MetS (prevalence 14.03%). The prevalence of MetS in men (12.31%) was lower than in women (15.57%, $P<.0001$). The mean age of participants with MetS was 53.4±12.9 years and that for participants without MetS was 41.8±16.0 years. The prevalence of MetS was 3.59% in young participants, 16.72% in middle-aged participants, and 26.13% in older adult participants. The prevalence of MetS increased gradually with age ($P<.0001$). Among the minorities studied, Tibetan participants had the lowest prevalence of MetS (5.59%) and Korean participants the highest (20.50%). Physical laborers had a higher prevalence (17.39%) of MetS than their counterparts. Participants with hyperuricemia (26.56%) or who habitually consumed a high-salt diet (15.74%) had higher prevalences of MetS than their counterparts. Compared with participants without a family history, those with a family history of cardiovascular disease (17.41%) or cerebrovascular disease (17.75%) had higher prevalence rates of MetS. Participants who normally slept for < 6 hours a day had a higher prevalence (15.50%) of MetS than their counterparts. Compared with participants with normal body mass, those who were overweight or obese had higher prevalences (21.10% and 46.40%, respectively) of MetS. The mean PBF was 26.9%±7.9% for participants with MetS and 21.0%±8.6% for those without
MetS. The prevalences and factors related to MetS, classified according to demographic characteristics, are listed in Table 1. Table 2 shows the results of the univariate and multivariate multi-level GEE models constructed using the factors associated with MetS. After controlling for the cluster effect of living circumstances and other covariates, no significant associations were found between sex or smoking status and MetS. Compared with young participants, middle-aged (OR = 1.461, 95% CI: 1.371–1.557), and older adult participants (OR = 1.667, 95% CI: 1.535–1.812) had higher prevalences of MetS. Compared with normal-weight participants, overweight (OR = 1.670, 95% CI: 1.600–1.743) and obese participants (OR = 2.287, 95% CI: 2.136–2.449) had higher prevalences of MetS. Thus, being older or having a higher BMI increases the risk of MetS. Compared with Hans, Koreans were more likely to have MetS (OR = 1.264, 95% CI: 1.215–1.316), those who typically slept for < 6 hours a day (OR = 1.032, 95% CI: 1.009–1.055), and those with a family history of cardiovascular disease.
(OR = 1.065, 95% CI: 1.019–1.113) or cerebrovascular disease (OR = 1.055, 95% CI: 1.007–1.104) had higher prevalences of MetS. We found that the risk of MetS increased by 6.9% (OR = 1.069, 95% CI: 1.053–1.085) with each 5% increase in PBF. In contrast to the results of the univariate analysis, the multivariate model did not show a significant association between current smoking status and MetS.

In summary, after controlling for the cluster effect of living circumstances, age, sex, occupation, ethnicity, alcohol drinking, high-salt diet, BMI, PBF, sleep duration, and family history of disease were associated with MetS.

**4. Discussion**

Individuals living in the same area were more likely to experience similar socioeconomic characteristics, which has an inevitable effect on the generalizability of findings regarding MetS and its components. The present study used a multi-level GEE to evaluate the relationship between MetS and lifestyle factors, while controlling for the cluster effect of same living areas and similar living circumstances, which substantially improves the accuracy and generalizability of the results. In addition, we conducted the study using standardized protocols and instruments, and strict training processes and vigorous quality control.

| Table 2 |
| Risk factors associated with the metabolic syndrome. |

| Characteristics | Univariate GEE model | Multivariate GEE model |
|-----------------|----------------------|------------------------|
|                  | OR 95%CI              | OR 95%CI                |
| Age (yr)         |                      |                        |
| 18–34           | 1.0 (Ref.)           | 1.0 (Ref.)             |
| 35–59           | 2.000 1.838–2.176    | 1.461 1.371–1.557      |
| 60–80           | 2.570 2.319–2.847    | 1.667 1.535–1.812      |
| Gender          |                      |                        |
| Male            | 1.0 (Ref.)           | 1.0 (Ref.)             |
| Female          | 0.997 0.927–1.073    | 0.993 0.934–1.055      |
| Occupation      |                      |                        |
| Physical laborer| 1.419 1.320–1.526    | 1.070 1.040–1.101      |
| Mental laborer  | 1.0 (Ref.)           | 1.0 (Ref.)             |
| Ethnicity       |                      |                        |
| Han             | 1.0 (Ref.)           | 1.0 (Ref.)             |
| Yi              | 0.835 0.667–1.045    | 0.953 0.923–0.984      |
| Miao            | 0.905 0.747–1.096    | 1.028 0.945–1.118      |
| Mongolia       | 0.904 0.827–0.989    | 0.986 0.939–1.035      |
| Tibetan        | 0.959 0.912–1.009    | 0.853 0.813–0.895      |
| Korean         | 1.194 1.060–1.034    | 1.120 1.043–1.129      |
| Hui             | 0.923 0.831–1.024    | 0.970 0.953–1.005      |
| Tujia          | 0.835 0.667–1.045    | 1.020 0.931–1.119      |
| Others         | 0.837 0.729–1.960    | 0.936 0.854–1.026      |
| Smoker          |                      |                        |
| No              | 1.0 (Ref.)           | 1.0 (Ref.)             |
| Yes             | 1.078 1.018–1.143    | 1.031 0.997–1.066      |
| Alcohol drinker |                      |                        |
| No              | 1.0 (Ref.)           | 1.0 (Ref.)             |
| Yes             | 1.103 1.054–1.153    | 1.053 1.020–1.086      |
| High-salted diet|                      |                        |
| No              | 1.0 (Ref.)           | 1.0 (Ref.)             |
| Yes             | 1.097 1.038–1.159    | 1.040 1.009–1.071      |
| Hyperuricemia   |                      |                        |
| No              | 1.0 (Ref.)           | 1.0 (Ref.)             |
| Yes             | 1.582 1.511–1.655    | 1.264 1.215–1.316      |
| Family history of cardiovascular diseases | | |
| No              | 1.0 (Ref.)           | 1.0 (Ref.)             |
| Yes             | 1.145 1.083–1.211    | 1.065 1.019–1.113      |
| Family history of cerebrovascular diseases | | |
| No              | 1.0 (Ref.)           | 1.0 (Ref.)             |
| Yes             | 1.127 1.048–1.212    | 1.055 1.007–1.104      |
| BMI             |                      |                        |
| Normal          | 1.0 (Ref.)           | 1.0 (Ref.)             |
| Overweight      | 2.077 1.941–2.223    | 1.670 1.600–1.743      |
| Obesity         | 3.183 2.901–3.493    | 2.287 2.136–2.449      |
| sleep duration  |                      |                        |
| >6 h            | 1.0 (Ref.)           | 1.0 (Ref.)             |
| <6 h            | 1.158 1.089–1.230    | 1.032 1.009–1.055      |
| PBF (5%)        | 1.184 1.157–1.212    | 1.069 1.053–1.085      |

*CI = confidence interval, GEE = generalized estimation equation, OR = odds ratio, PBF = percentage of body fat.
assurance programs were put in place to ensure the quality of the data.

The prevalence of MetS was 14.03% across all the participants, and was lower in men (12.31%) than women (15.57%). These prevalences are similar to those previously reported. Changes in lifestyles and diet have led not only to an increase in life expectancy, but also a greater burden of chronic disease. We have shown that over-eating (overweight and obesity), alcohol consumption, a high-salt diet, and a shorter sleep duration increase the risk of MetS.

Overweight and obesity are the major determinants of MetS, a common and serious clinical and public health challenge. Visceral fat tends to account for a higher percentage of total body fat in men, whereas subcutaneous fat tends to predominate in women. Excess visceral body fat in particular is associated with MetS. Visceral adiposity is associated with BMI, must be assessed as a cardiometabolic risk factor, and may serve as a marker and therapeutic target in cardiometabolic disease. Indeed, Djibo found that body adiposity index could distinguish ethnic differences in MetS and Liu found that higher fat mass index was independently and positively associated with the presence of MetS, regardless, of BMI and PBF, when the body composition of a Chinese population attending annual health checks was measured in a single hospital.

Suliga has reported that the daily consumption of alcohol is significantly associated with a higher risk of MetS. However, the association between drinking alcohol and the prevalence of MetS and its components is not consistent. One prospective study found a linear increase in the risk of MetS with an increase in alcohol consumption, whereas another study found that the consumption of 0.1 to 5.0g of alcohol/d was associated with a lower prevalence of MetS and its components, including hypertriglyceridemia and low HDL-C concentration. To better characterize the relationship between alcohol consumption and MetS and its components, large-scale prospective studies should be conducted.

High salt intake was closely associated with hypertension, which was an important component of MetS. For example, Saha showed in a cross-sectional survey that the prevalences of obesity, hypertension, diabetes, dyslipidemia, and MetS, and short-term cardiovascular disease risk score are higher in urban dwellers consuming a high-salt diet.

Smiley has reported an association between MetS and sleep duration; specifically that short sleep duration is associated with a higher risk of MetS and more severe MetS in men. Furthermore, Iftekhar showed a dose-response relationship between short sleep duration and MetS, with individuals who reported a sleep duration of < 5 hours having a 1.5 times higher risk of MetS. This was part of a wider phenomenon because habitual lack of sleep is associated with numerous chronic health conditions, such as hypertension, cancers, depression, obesity, and diabetes, as well as higher mortality.

Several limitations of the present study have to be mentioned. First, owing to its cross-sectional design, it is not possible to draw conclusions with regard to the causality of the relationships between covariates and MetS. Second, given that our analyses excluded individuals with certain severe chronic diseases and those who have experienced a fever in the preceding 15 days, it is likely that the true prevalence of MetS in this Chinese population has been underestimated. Third, because MetS can be defined in several ways, it is difficult to compare the findings of the present study with those of other studies of the prevalence of MetS.

5. Conclusions

Our findings show that MetS has become a serious public health challenge in China. Many lifestyle factors have been found to be closely associated with MetS, including obesity, a high-salt diet, alcohol consumption, and short sleep duration. Therefore, changes in lifestyle are very important for adult population to reduce the prevalence of MetS.

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Author contributions

Tao Xu participated in the design of the study and the field survey, performed the statistical analysis, and drafted the manuscript. Guangjin Zhu conceived the study. Shaomei Han conceived the study and participated in its design. All the authors read and approved the final manuscript.

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