Diabetes, Metabolic Syndrome and Obesity

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ORIGINAL RESEARCH

Influence of Central Obesity on Associations Between Physical Activity, Sitting Time, and Metabolic Syndrome Among Middle-Aged and Older Adults in Urban China: A Cross-Sectional Study

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Objective: This study assessed possible associations among physical activity (PA), sitting time (ST), metabolic syndrome (MetS), and the individual components thereof. We analyzed the entire study sample and subpopulations stratified by visceral fat area (VFA). We hypothesized that individuals with elevated VFA might respond differently to modifiers of metabolic health, including PA and ST.

Methods: This cross-sectional study, conducted between March and May 2010, enrolled 957 adults with abdominal magnetic resonance imaging (MRI) aged 40–65 years living in the urban communities in Hangzhou, China. PA and ST were recorded using the standard International Physical Activity Questionnaire (IPAQ) and categorized into three levels. The ethnicity-specific cutoff for central obesity was VFA $\geq$ 80 cm^2 on MRI according to Chinese population-based research. Multiple logistic regression models were used to analyze the associations between PA, ST, MetS and its components.

Results: In the total subject population, participants reporting high level of PA were at a lower risk of MetS (OR = 0.46, 95% CI: 0.25, 0.86) than those declaring low PA. In the subgroup population with VFA $\geq$ 80 cm^2 (ie, with central obesity), moderate-to-high PA levels were associated with a lower risk of MetS (p for trend < 0.05) and a lower risk of decreased high-density lipoprotein cholesterol (HDL-C) concentrations (p for trend < 0.05). In addition, ST > 3 h/day was a risk factor for both MetS (p for trend < 0.05) and hypertriglyceridemia (p for trend < 0.05) in the total subject population. While in the central obesity subgroup, ST > 3 h/day was found a stronger risk factor.

Conclusion: Our study suggests that moderate-to-high levels of PA may have a role in prevention of MetS, and ST > 3 h/day was associated with a higher risk of MetS, particularly in individuals with central obesity.

Keywords: metabolic syndrome, physical activity, sitting time, central obesity, visceral fat area

Introduction

Non-communicable diseases (NCDs) are rapidly increasing in prevalence in both developed and underdeveloped countries, imposing a major burden on health systems worldwide. Notably, metabolic syndrome has become the major NCD. MetS is defined as a cluster of risk factors for both cardiovascular disease and type 2 diabetes mellitus. Although various institutions have presented slightly different definitions of MetS over the past decade, MetS can be broadly summarized as a combination of central obesity, abnormal glycemia, dyslipidemia, and hypertension.[1] Recent research indicates that, together with obesity, MetS affects more than 30% of all adults and approximately 5% of all adolescents worldwide.[2,3]

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Both observational and interventional studies suggest that PA significantly reduces the risk of cardiometabolic issues and insulin-resistance.[4–6] Regular PA aids weight loss, lowers blood pressure, and improves dyslipidemia by raising the level of HDL-C and reducing that of triglycerides (TGs).[7–9] Emerging evidence shows that less sedentary time may also reduce metabolic risk.[10–12] Recently, the American Diabetes Association and equivalent bodies in other countries have added sedentary behavior guidelines to their PA recommendations.[13–15]

Many researchers have shown that overweight and obesity are associated with a greater risk of MetS than is normal weight. Inappropriate body fat distribution constitutes a strong metabolic and cardiovascular risk factor. Larger VFA is associated with the development of obesity-related comorbidities and increased all-cause mortality; the level of abdominal subcutaneous adipose tissue (SAT) is a much weaker indicator of cardiovascular risk.[16,17] Although the underlying mechanisms are not fully understood, three plausible suggestions have been made. First, the metabolic properties of visceral adipose tissue (VAT) may differ from those of SAT; second, excess VAT may induce inflammation; and third, VAT may be a marker of increased ectopic fat.[18,19] Hence, identifying individuals with central obesity is important, and it is essential to initiate effective behavioral interventions at an early stage.

To date, no study has explored whether the two separate health consciousness behavior of PA and ST independently affect MetS risk by VFA status. Our study aims to evaluate associations among different PA, ST levels, and the risk of MetS and components thereof in Chinese Han individuals stratified by central obesity status.

Methods

Study Subjects

This population-based cross-sectional study was conducted between March and May 2010, located in Caihe Streets of Hangzhou, Zhejiang province, China, as documented previously.[20] Stratified cluster random sampling method was used. All residents aged 40–65 (residing for over 5 years) in the 15 communities of Caihe streets were stratified by gender. Within each gender, each community was divided into five groups according to age (40–45, 45–50, 50–55, 55–60, 60–65). Initially, stratified cluster random sampling was conducted in 10 communities. Then, the remaining 5 communities were also included in the sampling due to insufficient samples. A total number of 1181 Chinese Han participants aged 40–65 were enrolled in this study. The followings were excluded: 1) previous cardiovascular events, 2) oral or intravenous corticosteroids, 3) cirrhosis and ascites, 4) known hyperthyroidism or hypothyroidism, 5) malignant tumor, 6) severe disability or mental illness, 7) pregnancy. Written informed consent was signed with participants based on the inclusion and exclusion criteria. Of the 1181 participants, 140 were excluded with missing data on weight, height, waist circumference (WC) and blood pressure; 8 were excluded with missing data on blood measurements; 76 were further excluded due to refusing MRI examination. Finally, 957 participants (386 males and 571 females) with MRI data were included in the primary analysis (Figure 1). The study protocol was approved by the Ethics Committee of Sir Run Run Shaw Hospital on 14 January 2010 and was conducted in accordance with the Declaration of Helsinki.

This study was part of the multicenter study on Abdominal Obesity and Metabolic Syndrome in China, which was conducted over a 3-year prospective period in populations from different regions of the country.[21] The baseline survey selected urban communities in eastern (Shanghai, Hangzhou), central-western (Chengdu), northern (Shenyang, Beijing), and southern (Guangzhou) cities. The total sample size was approximately 5000, including 1000 each in Shanghai and Hangzhou, and 750 each in Chengdu, Shenyang, Beijing and Guangzhou.

Measurements

Demographic variables and anthropometric data

Before the study began, the project working group established a well-trained research team (including medical investigators, community doctors, nurses and volunteers) and standardized operating procedures and quality control systems. We used questionnaires to collect the information about marital status, education, dietary pattern, physical activity, sitting time, sleep duration, history of alcohol consumption, smoking, tea drinking and disease including diabetes as well as hypertension. All participants were interviewed face-to-face by trained medical investigators. The main socio-demographic factors included: sex (men; women), age (40–65), marital status (married or remarriage; single or divorce/

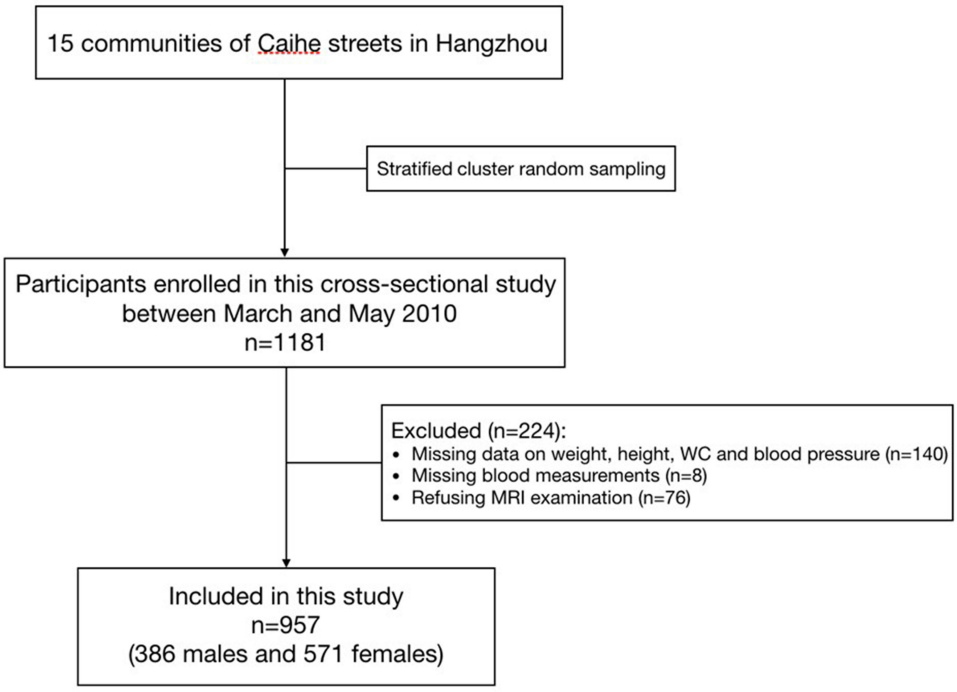

Figure 1 Flow chart of study population.
Abbreviations: WC, waist circumference; MRI, magnetic resonance imaging.

widowhood), education (illiterate or primary, junior high school, high school or university level), dietary pattern (meat-base, half meat half vegetarian or vegetarian).

Participants were informed in writing of the precautions to be taken (including fasting blood sampling, the OGTT test and the collection of urine samples) in advance. The project working group provided the standard instruments for basic anthropometric data, including height and weight measuring instruments, WC meters and blood pressure measurements. For 75-g oral glucose tolerance test (OGTT), participants were instructed to fast overnight for at least 10 h, and then blood samples were taken in central laboratory of Sir Run Run Shaw Hospital. Fasting plasma glucose (FPG), 2-hour post-load plasma glucose (2hPG), TG and HDL-C were measured with enzymatic method by auto analyzer (Aeroset, Chicago, IL, USA). Fasting serum insulin (FINS) levels were measured by chemiluminescent enzyme-linked immunosorbent assay using an insulin detection kit (Beijing North Institute Biological Technology, China). Insulin sensitivity was assessed by homeostatic model assessment for insulin resistance (HOMA-IR), calculated as: [FINS (mU/L) × FBG (mg/dl)/18] / 22.5.[22] Body Mass Index (BMI) was calculated by weight (kg) to the square of height (m).

After the demographic survey and the collection of blood and urine samples were completed, MRI examinations were carried out in batches by trained medical investigators. All subjects underwent MRI using a Signa 1.5 T MRI device equipped with an abdominal coil (SMT-100; Shimadzu Corp., Kyoto, Japan). The abdominal subcutaneous fat area (SFA) and abdominal VFA were obtained from the MRI scans at the umbilical level between L4 and L5, measured by two trained investigators using SliceOmatic image analysis software (version 5). The above measurement was based on the 2-D pixels in DICOM images fitting the "adipose shading threshold".

Physical activity level and sitting time

Exercise data were collected by the International Physical Activity Questionnaire Short Form (IPAQ-SF),[23] the validity and reliability of which has been well established.[24,25] Three specific types of activity namely walking, moderate and vigorous activity, were measured by the questionnaire. All subjects were asked to declare the duration in minutes per day and the average number of days per week of three physical activities. The volume of physical activity was computed by weighting each type of activity based on its energy requirements defined as metabolic equivalents (MET), and was

presented in MET-min/week units. The MET score for each activity was defined as: walking = 3.3 MET, moderate PA = 4.0 MET, vigorous PA = 8.0 MET. And total MET-min/week units for each activity were calculated as: MET score × duration (min) × frequency (days). According to the criteria from IPAQ Research Committee, PA levels were classified into three groups: low, moderate, and high.[23] Since individual health benefits from regular physical activity, the grouping criteria consider not only the overall level of PA but also the frequency per week and duration per day. Sitting time during the last week was measured by IPAQ-SF as well. Then, we calculated the average number of hours spent sitting per day. Overall declared sitting time daily was categorized as ≤3 h/day, 3–6 h/day, and >6 h/day.

Definition

Metabolic syndrome was defined according to the Chinese Guidelines for the Prevention and Treatment of Type 2 Diabetes (2020 Edition),[26] wherein MetS was diagnosed when meeting three or more criteria. Five criteria were as follows: 1) abdominal obesity: WC ≥ 90 cm for men and ≥85 cm for women; 2) hyperglycemia: FPG ≥ 110 mg/dL or 2hPG ≥ 140 mg/dL and (or) those who have been diagnosed with diabetes and treated; 3) hypertension: blood pressure ≥ 130/85 mmHg and (or) confirmed hypertension and treated; 4) fasting TG ≥ 150 mg/dL; (5) fasting HDL-C < 40 mg/dL.

A history of smoking was defined as currently smoking or ever smoked. Alcohol use and tea drinking were defined as frequent or occasional drinking. Chinese population survey found that the optimal VFA cutoff was near 80 cm^2 in identifying the MetS with two or more components (not including overweight/obesity by either of the two definitions).[27,28] Therefore, we defined central obesity as VFA ≥ 80 cm^2 in our study.

Statistical Analysis

Data were analyzed using SPSS Statistics 25.0 (IBM Corp., Armonk, NY, USA). Normally distributed continuous variables were presented as means ± standard deviation (SD), while the vast majority did not have satisfactory distribution of normality resulting in being presented as median (interquartile range). Categorical variables were presented in absolute and relative frequency. To compare means between subjects with and without MetS or central obesity, the *t*-test or Mann–Whitney *U*-test was applied. Differences among normally distributed continuous variables of three categories according to PA or ST were analyzed using one-way analysis of variance (ANOVA). Comparisons between non-normally distributed variables were performed by the non-parametric Kruskal–Wallis test. Categorical variables across different groups were compared using the Chi-squared test. Associations of three levels of PA and ST with the MetS as well as its components were examined using binary multivariable logistic regression analysis: model 1 without adjustment; model 2, adjusted for confounding variables (sex, age, BMI, smoke, alcohol use, tea drinking, sleep duration, education, dietary pattern, marital status, serum uric acid, total cholesterol, low-density lipoprotein cholesterol). Initially, demographic and behavioral risk factors were considered as potential confounders. Then variables associated with the MetS at $p < 0.2$ were retained as confounders. For avoiding multicollinearity, the risk factors strongly correlating with each other were not included. Three levels of ST and PA levels were also added as a confounder for each other's exposure. A two-side p value < 0.05 was considered at a statistically significant level.

Results

Both PA and ST Were Associated with the Risk of MetS and Its Components

A total of 957 participants (386 males and 571 females) were included in the primary analysis; the mean age was 53.1 ± 6.8 years. Sociodemographic and lifestyle characteristics are listed in Table 1 by MetS status. The prevalence rates of MetS in the overall sample, men and women were 16.4%, 25.4% and 10.3%, respectively. MetS patients smoked more, consumed more alcohol and tea, slept longer, and were older than those without MetS. Low PA was more common in those with than without MetS (29.9% vs 20.9%); more participants without MetS engaged in high PA compared to those with MetS (29.9% vs 19.7%). The daily ST was longer in patients with than without MetS; the proportion of individuals with MetS who sat for >6 h/day was much higher than that of those without MetS (32.5% vs 23.4%). Each MetS component occurred at a significantly higher frequency in those with than without MetS.

Table 1 Sociodemographic Characteristics, Lifestyle and Metabolic Parameters of the Total Sample and Across MetS Status

Characteristic	All N=957	Non-MetS N=800	MetS N=157	*P* value
Sex: male, N (%)	386 (40.3%)	288 (36.0%)	98 (62.4%)	**0.000***
Age (y)	53.1 ± 6.8	52.8 ± 6.7	54.6 ± 6.7	**0.003***[a]
Smoke, N (%)	295 (30.8%)	215 (26.9%)	80 (51.0%)	**0.000***
Alcohol use, N (%)	411 (42.9%)	324 (40.5%)	87 (55.4%)	**0.001***
Drink tea, N (%)	667 (69.7%)	541 (67.6%)	126 (80.3%)	**0.002***
Sleep duration (≥8 h/day), N (%)	450 (47.0%)	364 (45.5%)	86 (54.8%)	**0.033***
Marital status: married, N (%)	900 (94.0%)	753 (94.1%)	147 (93.6%)	0.811
Education, N (%)[#]				0.688
Illiterate or primary	94 (9.8%)	76 (9.5%)	18 (11.5%)	
Junior high school	431 (45.1%)	364 (45.5%)	67 (42.9%)	
High school or higher	431 (45.1%)	360 (45.0%)	71 (45.5%)	
Dietary pattern, N (%)				0.243
Meat-based diet	75 (7.8%)	58 (7.2%)	17 (10.8%)	
Half meat half vegetarian	659 (68.9%)	551 (68.9%)	108 (68.8%)	
Vegetarian diet	223 (23.3%)	191 (23.9%)	32 (20.4%)	
Physical activity, N (%)				**0.008***
Low	214 (22.4%)	167 (20.9%)	47 (29.9%)	
Moderate	473 (49.4%)	394 (49.3%)	79 (50.3%)	
High	270 (28.2%)	239 (29.9%)	31 (19.7%)	
Sitting time (h/day)	4.0 (3.0,6.0)	4.0 (2.6,6.0)	5.0 (3.0,8.0)	**0.008***[b]
Sitting time, N (%)				**0.029***
≤3 (h/day)	370 (38.7%)	321 (40.1%)	49 (31.2%)	
3–6 (h/day)	349 (36.5%)	292 (36.5%)	57 (36.3%)	
>6 (h/day)	238 (24.9%)	187 (23.4%)	51 (32.5%)	
Abdominal WC, N (%)	162 (16.9%)	69 (8.6%)	93 (59.2%)	**0.000***
Increased glucose concentration, N (%)	191 (20.0%)	102 (12.8%)	89 (56.7%)	**0.000***
Elevated blood pressure, N (%)	514 (53.7%)	372 (46.5%)	142 (90.4%)	**0.000***
Increased TG concentration, N (%)	294 (30.7%)	157 (19.6%)	137 (87.3%)	**0.000***
Decreased HDL-C concentration, N (%)	88 (9.2%)	26 (3.3%)	62 (39.5%)	**0.000***

Notes: Values are presented as mean ± standard deviation (SD), median (interquartile range), or percent prevalence. P values calculated by chi-square test unless otherwise indicated. Versus the group of Non-MetS, *$P<0.05$. [#]Education was missing for 1 participant; therefore, total add up to 956. [a]T-test P value. [b]Mann–Whitney *U*-test P value. Variables with statistical significance are shown in boldface. Abdominal WC was defined as WC ≥ 90 cm for men and ≥85 cm for women; increased glucose concentration was defined as FPG ≥ 110 mg/dL or 2hPG ≥ 140 mg/dL and (or) those who have been diagnosed with diabetes and treated; elevated blood pressure was referred to as blood pressure ≥ 130/85 mmHg and (or) confirmed hypertension and treated; increased TG concentration was referred to as fasting TG ≥ 150 mg/dL; and decreased HDL-C concentration means fasting HDL-C < 40 mg/dL.[26]

Abbreviations: MetS, metabolic syndrome; WC, waist circumference; TG, triglyceride; HDL-C, high-density lipoprotein cholesterol.

Tables 2 and 3 list parameters of metabolic health according to PA level and ST. Participants declaring high PA exhibited superior health profiles, ie, smaller WC, lower VFA, TG, fasting insulin, HOMA-IR levels, and higher HDL-C concentrations, wherein WC, TG and HDL-C levels showed statistically significant differences with increased activity levels. A significant decrease in HDL-C was apparent in subjects with ST > 6 h/day compared to those with ST ≤ 3 h/day. Notably, the MetS prevalence rates were 22.0%, 16.7%, and 11.5% in those reporting low, moderate, and high PA levels, respectively ($p = 0.008$). Consistently, the MetS incidence increased with longer ST, being 13.2%, 16.3% and 21.4% among subjects reporting three levels of ST respectively ($p = 0.029$).

Table 2 Prevalence of Metabolic Parameters and MetS According to Physical Activity Levels

Parameter	Low N=214	Moderate N=473	High N=270	P value
BMI (kg/m^2)	23.7 ± 3.1	23.5 ± 2.8	23.3 ± 3.0	0.355[a]
WC (cm)	79.9 ± 9.4	78.5 ± 8.8	77.8 ± 9.3*	**0.037**[a]
VFA (cm^2)	76.7 (51.5, 115.5)	70.1 (46.5, 109.7)	67.5 (43.8, 107.5)	0.059
SFA (cm^2)	152.7(118.2, 206.4)	154.6(118.4, 198.3)	148.7(115.3, 203.9)	0.689
TG (mg/dL)	125.0 (87.5, 176.5)	115.0 (84.0, 166.0)	112.0(80.8, 152.5)*	**0.015**
HDL-C (mg/dL)	53.0 (45.0, 62.5)	55.0 (47.0, 64.0)	56.0 (48.0, 66.0)*	**0.021**
FPG (mg/dL)	88.0 (81.0, 96.0)	88.0 (81.0, 97.0)	87.0 (80.0, 95.0)	0.393
2hPG (mg/dL)	99.0 (82.0, 130.0)	98.0 (82.0, 124.0)	97.5 (81.0, 116.0)	0.327
Fasting insulin (mmol/L)	18.5 (14.7, 23.6)	17.8 (13.6, 23.3)	17.4 (13.3, 22.5)	0.099
HOMA-IR	4.0 (3.1, 5.5)	3.8 (2.9, 5.5)	3.7 (2.7, 5.2)	0.125
SBP (mmHg)	124.4 ± 17.1	124.6 ± 17.0	123.6 ± 15.8	0.796[a]
DBP (mmHg)	81.3 ± 10.3	81.1 ± 9.9	80.6 ± 9.9	0.620[a]
MetS, N (%)	47 (22.0%)	79 (16.7%)*	31 (11.5%)*#	**0.008**[b]

Notes: Values are presented as mean ± SD, median (interquartile range), or percent prevalence. P values calculated by non-parametric Kruskal–Wallis test unless otherwise indicated. Versus the group of Low PA, *P<0.05. Versus the group of Moderate PA, #P<0.05. [a]ANOVA P value. [b]Chi-square P value. Variables with statistical significance are shown in boldface.
Abbreviations: SFA, subcutaneous fat area; VFA, visceral fat area; FPG, fasting plasma glucose; 2hPG, 2-hour post-load plasma glucose; HOMA-IR, homeostatic model assessment of insulin resistance; SBP, systolic blood pressure; DBP, diastolic blood pressure.

Table 3 Prevalence of Metabolic Parameters and MetS According to Sitting Time

Parameter	≤3h N=370	3–6h N=349	>6h N=238	P value
BMI (kg/m^2)	23.6 ± 3.2	23.4 ± 2.9	23.4 ± 2.6	0.610[a]
WC (cm)	78.4 ± 9.4	78.3 ± 9.1	79.4 ± 8.6	0.305[a]
VFA (cm^2)	71.0 (44.8, 114.2)	67.7 (45.3, 106.9)	74.0 (48.2, 113.5)	0.307
SFA (cm^2)	153.2(116.6, 206.1)	152.8(117.4, 199.2)	154.4(117.5, 198.7)	0.918
TG (mg/dL)	113.0 (83.3, 151.8)	119.0 (85.3, 164.5)	118.0 (85.0, 177.5)	0.133
HDL-C (mg/dL)	56.0 (48.0, 65.0)	54.0 (45.0, 63.0)	54.0 (46.0, 63.0)*	**0.029**
FPG (mg/dL)	88.0 (81.0, 97.0)	87.5 (80.0, 95.0)	87.0 (81.5, 94.5)	0.202
2hPG (mg/dL)	100.0 (83.0, 129.0)	97.0 (80.0, 118.0)	97.0 (81.0, 123.0)	0.121
Fasting insulin (mmol/L)	17.5 (13.3, 22.8)	17.6 (13.7, 22.9)	18.5 (14.4, 23.7)	0.234
HOMA-IR	3.8 (2.9, 5.5)	3.7 (2.9, 5.2)	4.1 (3.1, 5.5)	0.255
SBP (mmHg)	125.6 ± 16.9	123.3 ± 16.3	123.4 ± 16.8	0.115[a]
DBP (mmHg)	80.6 ± 10.2	80.5 ± 9.4	82.2 ± 10.2	0.086[a]
MetS, N (%)	49 (13.2%)	57 (16.3%)*	51 (21.4%)*#	**0.029**[b]

Notes: Values are presented as mean ± SD, median (interquartile range), or percent prevalence. P values calculated by non-parametric Kruskal–Wallis test unless otherwise indicated. Versus the group with ST of ≤3h, *P<0.05. Versus the group with ST for 3–6h, #P<0.05. [a]ANOVA P value. [b]Chi-square P value. Variables with statistical significance are shown in boldface.

Correlations of PA and ST with MetS Were Stronger When the VFA Level Was Considered

Individuals with VFA ≥ 80 cm^2 (ie, with central obesity) had a significantly higher prevalence of MetS (34.5% vs 4.2%) and its components than those without central obesity (Table S1). Subjects of central obesity had fewer performance of high-level activities (25.9% vs 29.8%), comparable moderate activities (49.0% vs 49.7%), and more low-level activities (25.1% vs 20.5%) than those without central obesity. Likewise, there was a trend toward a higher performance of ST > 6 h/day in participants with central obesity (both p for trend were close to 0.1).

The odds ratios for MetS and components thereof after stratification by central obesity status are listed in Table 4. In both the total subject population and the central obesity subgroup, high PA was related to a lower risk of MetS compared to those declaring low PA. After adjustment, using low PA as the reference, a lower OR for MetS was found in high-PA individuals in the overall sample (OR = 0.46, 95% CI: 0.25, 0.86, p = 0.014), and this became even more significant in those with central obesity (OR = 0.33, 95% CI: 0.16, 0.70, p = 0.003). Notably, even moderate (compared to low-level) PA was significantly related to a lower MetS risk in the central obesity subgroup (OR = 0.54, 95% CI: 0.29, 0.99, p = 0.046). Moreover, high PA was

Table 4 Odds Ratio for the MetS and Its Components Depending on Physical Activity (or, 95% CI)

PA	Total		Non-central obesity		Central obesity	
	OR (95% CI)	P	OR (95% CI)	P	OR (95% CI)	P
Model1 unadjusted						
Metabolic syndrome						
Low	1.00		1.00		1.00	
Moderate	0.71 (0.48, 1.07)	0.100	1.97 (0.56, 6.99)	0.294	0.63 (0.38, 1.04)	0.071
High	**0.46(0.28, 0.76)**	**0.002**	1.63 (0.41, 6.45)	0.485	**0.38 (0.21, 0.70)**	**0.002**
P for trend		**0.009***		0.570		**0.008***
Abdominal WC						
Low	1.00		1.00		1.00	
Moderate	0.74 (0.49, 1.12)	0.152	1.68 (0.46, 6.05)	0.430	0.70 (0.43, 1.16)	0.167
High	0.63 (0.40, 1.12)	0.059	0.68 (0.14, 3.44)	0.644	0.74 (0.42, 1.31)	0.296
P for trend		0.151		0.339		0.365
Increased glucose concentration						
Low	1.00		1.00		1.00	
Moderate	0.95 (0.65, 1.40)	0.799	1.69 (0.86, 3.32)	0.127	0.71 (0.43, 1.20)	0.200
High	0.62 (0.39, 0.98)	0.042	1.37 (0.65, 2.87)	0.406	**0.37 (0.19, 0.72)**	**0.003**
P for trend		0.068		0.293		**0.012***
Elevated blood pressure						
Low	1.00		1.00		1.00	
Moderate	1.12 (0.81, 1.55)	0.482	1.36 (0.87, 2.13)	0.171	1.04 (0.61, 1.79)	0.884
High	1.06 (0.74, 1.52)	0.749	1.34 (0.83, 2.18)	0.232	0.99 (0.54, 1.84)	0.983
P for trend		0.773		0.364		0.981
Increased TG concentration						
Low	1.00		1.00		1.00	
Moderate	0.84 (0.60, 1.12)	0.330	1.03 (0.59, 1.79)	0.932	0.82 (0.50, 1.34)	0.435
High	0.66 (0.45, 0.98)	0.038	1.02 (0.55, 1.88)	0.951	0.53 (0.30, 0.94)	0.028
P for trend		0.110		0.996		0.076

(*Continued*)

Table 4 (Continued).

PA	Total		Non-central obesity		Central obesity	
	OR (95% CI)	**P**	**OR (95% CI)**	**P**	**OR (95% CI)**	**P**
Decreased HDL-C concentration						
Low	1.00		1.00		1.00	
Moderate	**0.58 (0.35, 0.94)**	**0.029**	1.03 (0.39, 2.73)	0.950	**0.48 (0.26, 0.88)**	**0.019**
High	**0.35 (0.18, 0.66)**	**0.001**	0.45 (0.12, 1.62)	0.219	**0.36 (0.16, 0.77)**	**0.009**
P for trend		**0.004***		0.324		**0.013***
Model2 adjusted						
Metabolic syndrome						
Low	1.00		1.00		1.00	
Moderate	0.73 (0.44, 1.21)	0.221	2.73 (0.68, 11.01)	0.157	**0.54 (0.29, 0.99)**	**0.046**
High	**0.46 (0.25, 0.86)**	**0.014**	2.31 (0.50, 10.68)	0.285	**0.33 (0.16, 0.70)**	**0.003**
P for trend		**0.049***		0.368		**0.012***
Abdominal WC						
Low	1.00		1.00		1.00	
Moderate	0.85 (0.48, 1.54)	0.599	2.24 (0.48, 10.51)	0.308	0.67 (0.34, 1.32)	0.247
High	0.66 (0.33, 1.33)	0.244	0.94 (0.12, 7.42)	0.950	0.68 (0.30, 1.54)	0.359
P for trend		0.500		0.430		0.488
Increased glucose concentration						
Low	1.00		1.00		1.00	
Moderate	0.93 (0.61, 1.41)	0.731	1.79 (0.87, 3.67)	0.112	0.64 (0.37, 1.12)	0.120
High	0.60 (0.36, 0.98)	0.042	1.39 (0.63, 3.06)	0.413	**0.31 (0.15, 0.64)**	**0.002**
P for trend		0.074		0.259		**0.007***
Elevated blood pressure						
Low	1.00		1.00		1.00	
Moderate	1.10 (0.77, 1.57)	0.619	1.25 (0.78, 2.02)	0.361	0.98 (0.55, 1.77)	0.950
High	1.16 (0.77, 1.74)	0.477	1.25 (0.74, 2.11)	0.405	1.01 (0.51, 2.00)	0.976
P for trend		0.774		0.628		0.995
Increased TG concentration						
Low	1.00		1.00		1.00	
Moderate	0.81 (0.54, 1.22)	0.314	0.90 (0.47, 1.71)	0.740	0.73 (0.41, 1.29)	0.277
High	0.75 (0.47, 1.19)	0.214	0.98 (0.48, 1.99)	0.949	0.56 (0.29, 1.09)	0.089
P for trend		0.439		0.927		0.234

(*Continued*)

Table 4 (Continued).

PA	Total		Non-central obesity		Central obesity	
	OR (95% CI)	P	OR (95% CI)	P	OR (95% CI)	P
Decreased HDL-C concentration						
Low	1.00		1.00		1.00	
Moderate	**0.55 (0.31, 0.97)**	**0.038**	0.87 (0.29, 2.67)	0.812	**0.42 (0.21, 0.85)**	**0.015**
High	**0.38 (0.18, 0.78)**	**0.009**	0.51 (0.12, 2.17)	0.359	**0.31 (0.13, 0.76)**	**0.011**
P for trend		**0.021***		0.619		**0.016***

Notes: Model 1: unadjusted. Versus the group of Low PA, *P<0.05. Model 2: adjusted for gender, age, BMI, smoke, alcohol use, tea drinking, sleep duration, education, dietary pattern, marital status, serum uric acid, total cholesterol, low-density lipoprotein cholesterol and sitting time. Versus the group of Low PA, *P<0.05. Variables with statistical significance are shown in boldface.
Abbreviations: OR, odds ratio; CI, confidence interval.

inversely associated with hyperglycemia, and moderate-to-high PA correlated with a lower risk of decreased HDL-C concentrations in the central obesity subgroup both before and after adjustment.

ST > 6 h/day (compared to ≤3 h/day) was associated with a significantly higher MetS risk in the overall sample (Table 5). In adjusted analysis, participants who sat for 3–6 and >6 h/day exhibited 1.8-fold (95% CI: 1.06, 2.99) and almost 3-fold increased odds (95% CI: 1.69, 5.19) of MetS than those who sat for ≤3 h/day, respectively. STs of 3–6 and >6 h/day were even more closely correlated with an increased risk of MetS in individuals with central obesity.

A longer ST (>3 h), both in the total subject population and in the central obesity subgroup, was associated with an increased TG concentration. After adjustment for confounders, the odds of hypertriglyceridemia were even higher for

Table 5 Odds Ratio for the MetS and Its Components Depending on Sitting Time (or, 95% CI)

ST h/day	Total		Non-Central Obesity		Central Obesity	
	OR (95% CI)	P	OR (95% CI)	P	OR (95% CI)	P
Model1 unadjusted						
Metabolic syndrome						
≤3	1.00		1.00		1.00	
3–6	1.28 (0.85, 1.93)	0.244	0.94 (0.32, 2.73)	0.909	**1.86 (1.12, 3.07)**	**0.016**
>6	**1.79 (1.16, 2.75)**	**0.008**	2.31 (0.86, 6.23)	0.097	**1.87 (1.10, 3.18)**	**0.020**
P for trend		**0.030***		0.124		**0.022***
Abdominal WC						
≤3	1.00		1.00		1.00	
3–6	0.88 (0.60, 1.30)	0.529	1.92 (0.57, 6.46)	0.294	0.98 (0.61, 1.59)	0.942
>6	0.86 (0.56, 1.33)	0.496	2.39 (0.66, 8.63)	0.184	0.70 (0.41, 1.18)	0.177
P for trend		0.737		0.398		0.353
Increased glucose concentration						
≤3	1.00		1.00		1.00	
3–6	0.67 (0.46, 0.97)	0.035	0.52 (0.30, 0.91)	0.022	0.94 (0.56, 1.56)	0.799
>6	0.79 (0.53, 1.18)	0.254	0.79 (0.44, 1.42)	0.421	0.79 (0.45, 1.38)	0.412
P for trend		0.102		0.071		0.712

(*Continued*)

Table 5 (Continued).

ST h/day	Total		Non-Central Obesity		Central Obesity	
	OR (95% CI)	P	OR (95% CI)	P	OR (95% CI)	P
Elevated blood pressure						
≤3	1.00		1.00		1.00	
3–6	0.77 (0.57, 1.03)	0.076	0.82 (0.56, 1.20)	0.307	0.81 (0.49, 1.36)	0.428
>6	0.90 (0.65, 1.25)	0.536	0.78 (0.50, 1.21)	0.266	1.12 (0.64, 1.97)	0.698
P for trend		0.203		0.452		0.534
Increased TG concentration						
≤3	1.00		1.00		1.00	
3–6	1.33 (0.96, 1.84)	0.083	0.93 (0.56, 1.54)	0.778	**2.45 (1.51, 3.95)**	**0.000**
>6	**1.73 (1.22, 2.46)**	**0.002**	1.33 (0.78, 2.28)	0.298	**2.39 (1.44, 3.97)**	**0.001**
P for trend		**0.009***		0.399		**0.000***
Decreased HDL-C concentration						
≤3	1.00		1.00		1.00	
3–6	**1.79 (1.04, 3.08)**	**0.036**	2.93 (0.93, 9.23)	0.066	1.84 (0.96, 3.53)	0.065
>6	**2.01 (1.13, 3.58)**	**0.018**	3.67 (1.11, 12.16)	0.034	1.69 (0.85, 3.37)	0.138
P for trend		**0.039***		0.094		0.150
Model2 adjusted						
Metabolic syndrome						
≤3	1.00		1.00		1.00	
3–6	**1.78 (1.06, 2.99)**	**0.029**	0.99 (0.31, 3.11)	0.982	**2.24 (1.22, 4.13)**	**0.010**
>6	**2.96 (1.69, 5.19)**	**0.000**	2.79 (0.89, 8.70)	0.077	**3.09 (1.55, 6.14)**	**0.001**
P for trend		**0.001***		0.105		**0.003***
Abdominal WC						
≤3	1.00		1.00		1.00	
3–6	1.32 (0.75, 2.32)	0.338	8.11 (1.19, 55.18)	0.032	1.29 (0.67, 2.50)	0.451
>6	1.33 (0.70, 2.54)	0.380	8.45 (1.13, 63.50)	0.038	1.19 (0.56, 2.54)	0.648
P for trend		0.559		0.078		0.745
Increased glucose concentration						
≤3	1.00		1.00		1.00	
3–6	0.76 (0.51, 1.13)	0.179	0.58 (0.32, 1.06)	0.075	0.91 (0.52, 1.60)	0.741
>6	1.03 (0.66, 1.60)	0.910	1.09 (0.57, 2.09)	0.800	0.92 (0.49, 1.75)	0.809
P for trend		0.310		0.119		0.941
Elevated blood pressure						
≤3	1.00		1.00		1.00	
3–6	0.87 (0.63, 1.20)	0.394	0.86 (0.57, 1.31)	0.485	0.82 (0.47, 1.45)	0.495
>6	1.09 (0.75, 1.58)	0.658	0.88 (0.54, 1.43)	0.610	1.36 (0.71, 2.57)	0.353
P for trend		0.451		0.766		0.315
Increased TG concentration						
≤3	1.00		1.00		1.00	
3–6	**1.56 (1.06, 2.30)**	**0.024**	0.88 (0.50, 1.55)	0.652	**2.65 (1.51, 4.63)**	**0.001**
>6	**2.07 (1.34, 3.20)**	**0.001**	1.23 (0.65, 2.33)	0.520	**2.92 (1.55, 5.47)**	**0.001**
P for trend		**0.003***		0.563		**0.000***

(*Continued*)

Table 5 (Continued).

ST h/day	Total		Non-Central Obesity		Central Obesity	
	OR (95% CI)	P	OR (95% CI)	P	OR (95% CI)	P
Decreased HDL-C concentration						
≤3	1.00		1.00		1.00	
3–6	1.46 (0.79, 2.67)	0.225	2.14 (0.62, 7.37)	0.229	1.15 (0.55, 2.42)	0.705
>6	1.40 (0.73, 2.71)	0.312	2.58 (0.70, 9.60)	0.157	0.86 (0.38, 1.96)	0.727
P for trend		0.442		0.349		0.761

Notes: Model 1: unadjusted. Versus the group with ST of ≤ 3 h/day, *P<0.05. Model 2: adjusted for gender, age, BMI, smoke, alcohol use, tea drinking, sleep duration, education, dietary pattern, marital status, serum uric acid, total cholesterol, low-density lipoprotein cholesterol and physical activity. Versus the group with ST of ≤3 h/day, *P<0.05. Variables with statistical significance are shown in boldface.

participants in the central obesity subgroup with STs of 3–6 and >6 h/day compared to those in the overall sample. Neither PA nor ST was significantly associated with the risk of MetS or its components in the subgroup without central obesity.

Discussion

We found that high PA may have a role in prevention of MetS and that ST > 3 h/day was associated with a higher risk of MetS in the overall sample; above associations became stronger in those with central obesity.

In this community-based study, the overall prevalence of MetS was 16.4%, with a higher prevalence in males (25.4%) than females (10.3%), consistent with the results of a cross-sectional study on 33,149 employees in northeastern urban China; the rates of MetS in males and females were 24.5% and 15.4%, respectively.[29] The incidence of MetS varies by ethnicity, national development levels and diagnostic criteria of MetS. A recent prospective cohort study included 16,209 subjects in Amsterdam, the Netherlands, reported that the prevalence of MetS in Dutch was 20.6% for men and 9% for women; while for participants from African Surinamese descent, it was 15.4% for men and 14.9% for women; further, MetS occurred the most in Turkish, with 32.4% in men and 18% in women, respectively.[30] In most studies, the prevalence of MetS was higher in men than women aged <50–60 years despite differences in ethnicity and geography, as the proportion of central obesity in males is higher,[30,31] suggesting a close correlation between central obesity and MetS status. Yet in a study among adults aged 18–74 years in rural China, compared to urban male residents, lower prevalence of MetS in rural men (17.5%) was found,[32] probably because rural male residents engage in more PA while working, which is partly indicative of the impact of PA on MetS.

Lifestyle is strongly associated with metabolic risk. In our entire study group, we found significant inverse associations of high PA with the risk of MetS. A cross-sectional study of 1000 subjects aged 20–70 years living in an urban area of northern Iran found that high PA (compared to low PA) was inversely associated with MetS,[33] similar to a large-scale study of 10,367 participants aged 37–66 years conducted in Poland. Suliga et al also found that the risk of MetS in participants reporting low PA was higher than that of those declaring high PA.[34] Moreover, a recent study included 4865 adults in China indicated that higher levels of moderate-to-vigorous PA and total PA were associated with a lower MetS risk.[35] Although all of our subjects were middle-aged or older, and they all lived in the same city, we also found that high PA was associated with a reduced risk of MetS. Our study adds to knowledge on the correlation between PA and MetS status in Han Chinese.

However, the relationships between the PA level and MetS components remain controversial. We found that increased PA was inversely associated with the risk of decreased HDL-C concentrations in the overall sample. A cross-sectional study of 750 patients from central rural India found that PA was negatively correlated with TG and TC levels, but not correlated with HDL-C levels.[36] An observation of Cardiovascular Risk Factors in Luxembourg study reported that those who undertook a medium level of intense PA had significantly higher HDL-C levels and lower TG levels than those who undertook less than this, but the TC and LDL-C levels were not significantly associated with the PA level.[37] In another cross-sectional study, Li et al[38] found that the most-active (compared to the least-active) subjects had a lower risk of

MetS and a lower risk of decreased HDL-C levels, similar to our study. Although PA is well known to benefit metabolism and overall human health, the diverse results among studies may reflect demographic or racial differences, employment of different MetS diagnostic criteria, and the use of various methods to assess PA status.

VFA accumulation, particularly in elderly individuals, is strongly associated with a higher risk of MetS and components thereof.[39] Few studies have explored the relationships among PA, MetS, and its components in middle-aged and older adults stratified by VFA status. We found that the associations between PA and metabolic risk factors were particularly strong in participants with central obesity. In that subgroup, high PA (compared to low PA) was related to a lower risk of MetS components, including hyperglycemia and decreased HDL-C levels. A similar cross-sectional study of adults aged >60 years with BMI ≥ 30 kg/m^2 found that those who engaged in high PA were at a lower risk of MetS.[40] Another 6-year cohort study in 1046 Mexican adults found a different effect of PA pattern: among the overweight or obesity participants adopting an active PA pattern was associated with lower risk of MetS in comparison with an inactive pattern, while maintaining an active lifestyle did not provide additional protection against developing MetS in lean individuals.[41] PA may play a prominent role in central obese populations for the following reasons. First, PA triggers weight loss, particularly VAT loss, and this seems to greatly reduce MetS prevalence.[9,42] Second, the MetS incidence in our patients with central obesity was much greater than that in the overall sample.

We found that, among all participants, those sitting for >3 h/day had a higher risk of MetS and hypertriglyceridemia, independent of PA level. A positive correlation between prolonged ST and the risk of MetS was reported in most previous studies.[10–12,32,43–45] Although most randomized controlled trials found no significant relationship between ST and TG levels,[46,47] a few cross-sectional studies and prospective-observational studies reported a positive association.[36,48–50] Many studies have found that prolonged sitting contributes to the loss of local contractile stimulation, in turn decreasing the activity of skeletal muscle lipoprotein lipase (the enzyme responsible for hydrolysis of TG-rich lipoproteins), TG uptake by red skeletal muscle, and glucose uptake.[51,52] Another reasonable hypothesis is that long STs may increase energy intake due to greater food consumption.[53] This may help explain the positive association between ST and the lipid profile.

Similarly, the associations between ST and the risk of MetS and hypertriglyceridemia were stronger in our participants with central obesity. Few studies have explored the relationship between ST and MetS in such individuals. Wendy C King et al[54] reported that objectively measured indices of ST were positively associated with the risk of MetS in large sample of adults with severe obesity. However, two studies that enrolled overweight and obese participants (BMI ≥ 25 kg/m^2) found no significant associations between ST and lipid concentration.[34,37] The inconsistence may be explained by the fact that BMI does not reliably identify obese individuals with excess VAT on computed tomography (CT) or MRI.[42] Peterson et al[55] examined the extent of obesity misclassification among US adults. Individuals with high body fat levels who were misclassified as non-obese based on BMI had a significantly higher likelihood of MetS than correctly classified normal-BMI subjects with low body fat. We used MRI to assess VFA status because it accurately identifies individuals with central obesity; such individuals have the highest cardiometabolic risk.

To the best of our knowledge, this is one of the first Chinese studies to examine the associations among PA, ST levels, MetS, and its components in middle-aged and older adults varying in VFA status. One strength of our study was that the VFA data were obtained using MRI, which determines abdominal obesity status more accurately than WC and BMI. We adjusted for many potential confounders, including sex, alcohol and tea consumption, smoking, sleep duration, dietary patterns, and other sociodemographic variables.

This study had some limitations. First, self-report measures were used to assess PA and ST status, which can lead to recall bias. Second, the age range of our subjects was narrow, and the conclusions may not be applicable to the general adult population. Third, the study was cross-sectional, so we could not infer causality. Fourth, the study population in this research is from a specific region in China, thus the generalizability of the conclusions to other populations or regions is limited. Future studies should base on multicentric population and use objective measurements derived from accelerometers or movement sensors to prospectively study the causal associations among PA, ST, and metabolic risk.

Conclusion

Our data suggested that moderate-to-high PA may have a role in prevention of MetS, and ST > 3 h/day was associated with a higher risk of MetS both in the overall sample and in individuals exhibiting central obesity; People with central obesity should be encouraged to reduce ST and increase PA to help improve metabolic outcomes and reduce cardiovascular risk.

Abbreviations

PA, physical activity; ST, sitting time; MetS, metabolic syndrome; VFA, visceral fat area; IPAQ, International Physical Activity Questionnaire; NCD, non-communicable disease; HDL-C, high-density lipoprotein cholesterol; LDL-C, low-density lipoprotein cholesterol; TG, triglyceride; WC, waist circumference; FPG, fasting plasma glucose; 2hPG, 2-hour post-load plasma glucose; HOMA-IR, homeostatic model assessment for insulin resistance; BMI, body mass index; VAT, visceral adipose tissue; SAT, subcutaneous adipose tissue.

Data Sharing Statement

The datasets are not publicly available due institution's policy but are available from the corresponding author upon reasonable request.

Ethics Approval and Informed Consent

This study was approved by the Medical Ethics Committee of Sir Run Run Shaw Hospital affiliated to Zhejiang University on 14 January 2010. All participants signed an informed consent prior to participation.

Consent for Publication

All authors approved the publication.

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Disclosure

All authors declare no conflicts of interest.

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