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Metabolic health status in Chinese children and adolescents: Evidence from national adult and students' surveys

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Abstract

Globally rising metabolic syndrome (MS) prevalence underscores the need to understand component changes, especially in China's aging population. This study projects metabolic burden trends from 2000-2030 in Chinese children and adolescents using overweight/obesity (OWOB) and hypertension (HTN) as markers, addressing a critical knowledge gap. Analyzing data from three adult surveys (n=38,725) and five national student surveys (n=1,106,416), we found a 100% increase in adult MS cases, driven primarily by rising high blood pressure, blood glucose, and waist circumference. Projections for 2030 indicate a 34.4% decline in the youth population but a 180.6% surge in OWOB and a 131.5% increase in HTN cases. A significant negative correlation was found between the Population Development Index (PDI) and metabolic risk. Decomposition analysis confirmed rising prevalence as the main driver of increasing case numbers, partially offset by population decline. We conclude that China's deteriorating adult metabolic health, reflected in worsening pediatric trends, portends a rising non-communicable disease burden, demanding urgent public health resource allocation. *(Afr J Reprod Health 2025; 29 [12s]: 165-182).*

Keywords: Components; Metabolic Syndrome; Prevalence Trend

Résumé

L'augmentation mondiale de la prévalence du syndrome métabolique (SM) souligne la nécessité de comprendre les changements de ses composantes, particulièrement dans la population vieillissante de la Chine. Cette étude projette les tendances du fardeau métabolique de 2000 à 2030 chez les enfants et adolescents chinois, utilisant le surpoids/obésité (OWOB) et l'hypertension (HTN) comme marqueurs, comblant ainsi une lacune critique des connaissances. En analysant les données de trois enquêtes sur les adultes (n=38 725) et de cinq enquêtes nationales auprès des étudiants (n=1 106 416), nous avons constaté une augmentation de 100 % des cas de SM chez les adultes, principalement due à la hausse de l'hypertension artérielle, de la glycémie et du tour de taille. Les projections pour 2030 indiquent une baisse de 34,4 % de la population jeune, mais une augmentation de 180,6 % de l'OWOB et une hausse de 131,5 % des cas d'HTN. Une corrélation négative significative a été observée entre l'Indice de Développement de la Population (PDI) et le risque métabolique. L'analyse de décomposition a confirmé que la prévalence croissante était le principal moteur de l'augmentation du nombre de cas, partiellement compensée par le déclin démographique. Nous concluons que la détérioration de la santé métabolique des adultes en Chine, reflétée par l'aggravation des tendances pédiatriques, laisse présager un fardeau croissant des maladies non transmissibles, exigeant une allocation urgente des ressources de santé publique. *(Afr J Reprod Health 2025; 29 [12s]: 165-182).*

Mots-clés: Composants, Syndrome Métabolique, Tendance de la Prévalence

Introduction

A person's metabolic health state is typically defined by metabolic syndrome (MS), a group of cardio-metabolic risk factors that includes abdominal obesity, hypertension, dyslipidemia, and insulin resistance. metabolic syndrome (MS) has been on the rise globally[1,2], and this trend has not gone unnoticed in China, a nation that has seen a fast dietary shift in recent decades, marked by an increase in sedentary lifestyles and high-energy food consumption. The worldwide MS epidemic may have placed a large public health burden on both industrialized and developing nations[1], due to the strong links between MS and the risk of type 2 diabetes mellitus, cardiovascular disease (CVD), and all-cause mortality[4-6].

Growing research in recent years suggests that metabolic health status -which includes MS components - has a complex and diverse impact on the risk of cardiovascular disease (CVD) and death from any cause. The Framingham Heart Study discovered that a particular cluster of MS components -such as central obesity, high blood pressure, and hyperglycemia- increased the risk of cardiovascular events by 2.36 times and mortality by 3 times. Furthermore, metabolic health status appears to be a more accurate predictor of CVD risk than BMI, which measures general overweight or obesity. People who are overweight or obese have a lower risk of cardiovascular disease when MS components are not present, but normal-weight people have a higher risk when one or more MS components are present[810]. The manifestation of metabolic syndrome and its components also differed according to ethnicity and race[11]. To illustrate the greater significance of metabolic health status in Asian populations, consider that at the same BMI[12], the prevalence of metabolic syndrome was higher among Asian Americans compared to non-Hispanic Whites.

Individual and population-level observations of MS reveal a status that is dynamic and subject to change over time. It is possible for an individual's metabolic health status to deteriorate or improve over time, and for a population's cluster of MS components to alter over time as a result of changes in risk exposure, sex distribution, and age[13–15]. The increasing incidence of metabolic syndrome during the last several decades has been extensively studied and documented [2,16,17]. Additionally, an imbalanced shift in MS components was noted. Nonetheless, the influence of MS component shifts on the illness burden of non-communicable diseases (NCDs) has not been investigated in any prior research. Hence, we postulated that metabolic health status might evolve with time, influencing the CVD disease burden.

We used data from three cross-sectional studies that analyzed the population in Shanghai, China, to determine the trend of MS and its components by age group and sex in order to evaluate the hypothesis. Our findings could pave the way for better estimates of the disease burden caused by CVD, more focused interventions for certain high-risk populations, and the identification of trend factors.

Methods

Study population

This study utilized adult data collected through three extensive cross-sectional, population-based surveys conducted in Shanghai, China, during 2002–2003, 2009, and 2017. The primary objectives of these surveys were to estimate the prevalence of type 2 diabetes, identify undiagnosed cases, and examine modifiable risk factors[18-20]. All three surveys adopted a comparable multistage stratified random sampling method to select representative samples from the non-institutionalized adult population in Shanghai.

Briefly, in the 2002–2003 survey, a total of 12,329 permanent residents aged 35–74 years were selected and examined[18- 20]. The 2009 survey recruited 7,423 adults using an almost identical sampling frame and the same age range (35–74 years[18,19]. In the 2017 survey, which employed an updated sampling frame accounting for Shanghai's urban development, the sample size was expanded to include 21,625 participants under the same inclusion criteria (permanent residents aged 35–74 years, living in Shanghai for at least five years)[20].

Among this cohort, 1,789 individuals from the 2009 survey were reexamined. All three surveys excluded individuals who were pregnant, had known type 1 diabetes or cancer, had severe mental or physical disabilities, or were unable to provide informed consent. Response rates varied across the surveys: 82.2% in 2002–2003, 62.6% in 2009, and 90.1% in 2017. For this analysis focusing on metabolic syndrome and its components, the dataset was restricted to participants aged 35–74 years at the time of each survey to maintain consistency. After applying these restrictions, the final sample sizes included 12,302 participants from 2002–2003, 7,400 from 2009 (3,454 men and 3,946 women), and 19,023 from 2017 (7,616 men and 11,407 women).

Additionally, data on Chinese children and adolescents was analyzed from five cycles (2000, 2005, 2010, 2014, and 2019) of the Chinese National Surveys on Students' Constitution and Health (CNSSCH). This nationwide serial cross-sectional survey is conducted every five years across 30 mainland provinces/autonomous regions/municipalities (excluding Hong Kong, Macao, and Taiwan) [21,22] and employs a multistage stratified cluster sampling design based on urban/rural residence and socioeconomic status to ensure representativeness of Han Chinese students aged 7–18 years. Altogether, the five cycles included a total of 1,106,416 participants (ranging from approximately 200,000–230,000 per cycle)[21].

The surveys adhered to standardized protocols for measurement of height, weight, and blood pressure by trained health professionals. Overweight and obesity were classified using age- and sex-specific BMI thresholds: overweight as ≥85th percentile and obesity as ≥95th percentile of the national reference. Hypertension was defined as systolic or diastolic blood pressure ≥95th percentile for age, sex, and height based on references adapted for Chinese youth.[22]

Age- and sex-standardized prevalence estimates were calculated using data from the population of Chinese youth in 2019. Future projections of overweight/obesity (OWOB) and hypertension (HTN) cases up to 2030 were conducted using logistic generalized additive models that incorporated observed prevalence trends alongside United Nations population projections for individuals aged 7–18 years (reflecting a predicted decline in this demographic from 276 million in 2000 to 181 million in 2030) [21]. Decomposition analysis identified contributions of prevalence increases versus population decline. Additionally, Spearman's correlation was applied to examine associations between the Population Development Index (PDI) and metabolic risks[21].

ll CNSSCH surveys adhered strictly to ethical standards outlined in the Declaration of Helsinki and Chinese guidelines for pediatric research. Institutional review boards at institutions such as Peking University Health Science Center granted necessary approvals [22, 24]. Informed consent from parents and verbal assent from students were obtained prior to examinations in each survey cycle to uphold participant autonomy and privacy[24].

Data collection

The three surveys followed a comparable approach. At community healthcare centers in the participants' neighborhoods, qualified interviewers gathered data on participants' demographics and socioeconomic status, blood pressure, cholesterol levels, smoking and alcohol use, level of physical activity, and family history of diabetes. A lifetime consumption of more than 100 cigarettes was deemed as smoking. In this context, "drinking" meant consuming alcoholic beverages on a monthly basis for a minimum of six months. Only the 2002- 2003 and 2009 surveys provided information on occupations, whereas the 2009 and 2017 surveys collected information on mental diseases.

Trained staff measured each participant's weight, standing height, waist circumference (WC), blood pressure (BP), and body weight at the interview. After a minimum of five minutes of rest, blood pressure was taken on the right arm while seated using a conventional mercury sphygmomanometer. For thirty minutes prior to the test, participants were asked to abstain from caffeine, tea, and alcohol, as well as from smoking cigarettes and engaging in strenuous physical activity. Systolic blood pressure (BP) and diastolic blood pressure (DP) were recorded as the first two Korotkoff sounds, respectively. While the patient wore loose-fitting clothing and did not wear shoes, their weight and height were measured while standing. To the nearest 0.1 kg, body weight was measured using electronic scales. Using a stadiometer, the subjects' heights were recorded to within one tenth of an inch. WC was measured on a naked subject in the horizontal plane, halfway between the lower edge of the ribs and the iliac crest, after a normal expiration. The measurement was recorded to the nearest 0.1 cm using a cloth tape. Using the direct measurements, the body mass index (BMI) was determined by dividing the weight in kilograms by the square of the height in meters (kg/m2).

These analyses were based on the mean of the two measurements that were taken. The time interval between the two blood pressure readings was at least two minutes.

Laboratory measurements

The biochemical assays were carried out in all three surveys using the same methodology. At least three days prior to the measurements, all subjects were instructed to continue with their regular eating and exercise routines. For the measurement of plasma glucose, a 1-1.5 mL non-anticoagulated venous blood specimen was collected after at least 10 hours of overnight fasting. For the measurement of triglyceride (TG) and high-density lipoprotein cholesterol (HDLC), a 3-3.5 mL non-anticoagulated venous blood specimen was collected. Serum cholesterol and triglyceride levels were evaluated enzymatically using commercial reagents, and fasting plasma glucose (FPG) was determined using the glucose oxidase-peroxidase (GOD-PAP) method. We used the PTA-Mg technique to measure HDLC. In order to initiate therapy promptly, the subjects and their primary care physicians were notified of any abnormal test results.

The relationship between metabolic health and obesity The World Health Organization Western Pacific Regional Office[25] criteria were used to define overweight, which is defined as a body mass index (BMI) of 25 kg/m2 or more. As per the updated NCEP ATP III criteria for Asian-Americans, metabolic syndrome is characterized as having three or more of the following: (i) A high white blood cell count (HWC) is defined as WC ≥ 90 cm in men and ≥ 85 cm in women; (ii) High blood pressure (HBP) is defined as systolic/diastolic BP ≥ 130/85 mmHg or the use of antihypertensive medication; (iii) High blood glucose (HBG) is defined as FPG ≥ 5.6 mmol/L or the use of antidiabetic drugs; (iv) High total cholesterol (HTG) is defined as TG ≥1.70 mmol/L; or (v) Low HDLC (LHC) is defined as HDLC < 1.03 mmol/L in men and <1.30 mmol/L in women[25-27].

Subjects were divided into four categories according to their body mass index (BMI) (non-overweight <25 kg/m2 vs. overweight > 25 kg/m2) and whether they had metabolic syndrome (MS) or not. (i) wholesome, normal weight (MHNW); (ii) unhealthy, normal weight (MUNW); (iii) overweight, metabolically healthy (MHO); and (iv) unhealthy, metabolically overweight (MUO).

Statistical analyses

The data is displayed either as a percentage for categorical variables or as the median (Interquartile range, IQR) for continuous variables. We analyzed the prevalence and 95% CI of MS and each component in each survey based on sex and age group. The direct technique, which was improved by Doll et al.[28] and reported by Segi[29], was used to calculate age-standardized prevalence using the World Standardized Population. Percentile curves for body mass index and waist circumference were profiled across all three surveys using the distribution curve and LMS (lambda, mu, sigma) methods[19,30]. All individuals including those with MS had their MS component clusters shown using a Nightingale diagram. We utilized the generalized estimating equations (GEE) to examine the temporal pattern of the prevalence because there was subject overlap in the 2009 and 2017 surveys. Using a workable working correlation matrix [31], the GEE model included time as a continuous independent variable. The rising prevalence of MS and its associated complications among adult Chinese residents of Shanghai has led us to estimate an increase in the monetary toll of cardiovascular disease (Methods S1).

By removing respondents who had already filled out the survey in 2009, we were able to use the 2017 data for sensitivity analysis. To examine the pattern of prevalence, the Cochran- Armitage trend test was employed. Statistical significance was indicated by a two-sided P value less than 0.05. We used SAS 9.4 from the SAS Institute in Cary, NC, USA, and R 4.0.0 from the R Foundation for Statistical Computing in Vienna, Austria, to analyze all of the data.

Ethical considerations

The three population-based surveys conducted in Shanghai in 2002, 2009, and 2017 were reviewed and approved by the Institutional Review Board of the Shanghai Municipal Center for Disease Control and Prevention (Ethics Approval Nos. SCDC2002-IRB-015, SCDC2009-IRB-021, and SCDC2017-IRB-033). Written informed consent was obtained from all participants at the time of each survey. The present study analyzed fully anonymized data from these surveys and received additional approval for secondary data analysis (Approval No. SCDC2023-IRB-098). All procedures complied with the ethical standards of the institutional research committee and the principles of the Declaration of Helsinki.

Results

Participant characteristics

Here are the participant characteristics, as shown in Table 1. Differences in age, education, income per capita, alcohol consumption, and the presence or absence of hypertension, type 2 diabetes, and dyslipidemia were statistically significant among the three surveys' subjects. Additionally, there was a significant difference between the participants in terms of average body measurements, biochemical tests such as FPG and HDLC, and all trend P values

Table 1: Survey takers' personal details from 2002- 2003, 2009, and 2017

	Men The 2002- 2003 survey (*n* = 5,023)	The 2009 survey (*n* = 3,454)	The 2017 survey (*n* = 7,616)	*P* for trend	Women The 2002-2003 survey (*n* = 7,279)	The 2009 Survey (*n* = 3,946)	The 2017 survey (*n* = 11,407)	*P* for trend
Age (years) (median, IQR)	54.0 (46.0, 64.0)	55.0 (48.0, 61.0)	63.0 (56.0, 68.0)	<0.001	51.0 (45.0, 61.0)	55.0 (49.0, 61.0)	62.0 (55.0, 66.0)	<0.001
Education (*n*, %)								
Primary school and below	1,112 (22.3)	619 (17.9)	1,539 (20.2)	<0.001	2,996 (41.4)	1,066 (27.0)	3,261 (28.6)	<0.001
Middle school	1,768 (35.4)	1,576 (45.6)	3,687 (48.4)		2,254 (31.1)	1,784 (45.2)	4,935 (43.3)	
High school	1,376 (27.5)	955 (27.7)	1,684 (22.1)		1,633 (22.6)	940 (23.8)	2,558 (22.4)	
College or above	739 (14.8)	303 (8.8)	706 (9.3)		357 (4.9)	154 (3.9)	653 (5.7)	
Monthly income *per capita* (USD) (*n*, %)								
<154	1,838 (37.0)	170 (4.9)	53 (0.7)	<0.001	3,088 (42.4)	159 (4.0)	76 (0.7)	<0.001
154–461	1,911 (38.5)	1,445 (41.9)	2,935 (38.6)		2,793 (38.4)	1,845 (46.8)	4,404 (38.6)	
462–769	1,110 (22.3)	1,146 (33.2)	3,923 (51.5)		1,302 (17.9)	1,312 (33.3)	5,978 (52.4)	
>769	109 (2.2)	691 (20.0)	701 (9.2)		92 (1.3)	629 (15.9)	944 (8.3)	
Alcohol drinking (*n*, %)								
Former	291 (5.9)	122 (3.5)	375 (4.9)	0.011	8 (0.1)	7 (0.2)	20 (0.2)	0.039
Current	1540 (31.0)	1416 (41.0)	1640 (21.6)		112 (1.5)	122 (3.1)	122 (1.1)	
Cigarette smoking (*n*, %)								
Former	444 (8.9)	256 (7.4)	1340 (17.6)	<0.001	18 (0.2)	11 (0.3)	28 (0.2)	0.110
Current	2645 (52.8)	2039 (59.1)	3847 (50.5)		109 (1.5)	64 (1.6)	100 (0.9)	
Measurements (median, IQR) BMI (kg/m^2)	24.3 (22.1,26.3)	24.2 (22.2, 26.3)	25.1 (23.1, 27.2)	<0.001	24.0 (21.9, 26.5)	24.0 (21.9, 26.3)	24.5 (22.5, 26.7)	<0.001
WC, cm	84.0 (77.0, 90.0)	85.0 (79.0, 91.0)	89.0 (83.0, 94.2)	<0.001	78.0 (72.0, 84.0)	80.0 (74.0, 87.0)	83.0 (77.5, 89.0)	<0.001
Systolic BP, mmHg	126 (116, 138)	125 (115, 137)	139 (128, 151)	<0.001	119 (109, 138)	122 (111, 135)	136 (125, 150)	<0.001
Diastolic BP, mmHg	78 (73, 88)	80 (73, 87)	84 (78, 91)	<0.001	78 (70, 86)	79 (71, 83)	82 (75, 88)	<0.001
FPG, mmol/L	5.0 (4.5, 5.6)	5.0 (4.6, 5.6)	5.7 (5.2, 6.6)	<0.001	5.0 (4.5, 5.5)	5.0 (4.7, 5.5)	5.5 (5.2, 6.2)	<0.001

	Men The 2002- 2003 survey (*n* = 5,023)	The 2009 survey (*n* = 3,454)	The 2017 survey (*n* = 7,616)	*P* for trend	Women The 2002- 2003 survey (*n* = 7,279)	The 2009 Survey (*n* = 3,946)	The 2017 survey (*n* = 11,407)	*P* for trend
TG, mmol/L	1.4 (1.0, 2.0)	1.4 (0.9, 2.2)	1.4 (1.0, 2.0)	0.906	1.3 (0.9, 1.8)	1.4 (0.9, 2.0)	1.3 (1.0, 1.8)	0.511
HDLC, mmol/L	1.3 (1.1, 1.6)	1.2 (1.0, 1.5)	1.3 (1.1, 1.5)	<0.001	1.4 (1.2, 1.7)	1.4 (1.2, 1.6)	1.5 (1.3, 1.8)	<0.001
Previous metabolic disorders (*n*, %)								
Hypertension†	952 (19.0)	1101 (31.9)	3490 (45.8)	<0.001	1161 (15.9)	1115 (28.3)	4647 (40.7)	<0.001
Type 2 diabetes†	368 (7.3)	362 (10.5)	1266 (16.6)	<0.001	418 (5.7)	334 (8.5)	1445 (12.7)	<0.001
Dyslipidemia‡	337 (6.7)	358 (10.4)	1432 (18.8)	<0.001	422 (5.8)	395 (10.0)	2291 (20.1)	<0.001
Overweight (BMI ≥ 25 kg/m^2)	2,034 (40.6)	1,365 (39.6)	3,922 (51.5)	<0.001	2,795 (38.4)	1,510 (38.3)	4,873 (42.7)	<0.001

were less than 0.001. Over the course of the three polls, however, there was no discernible gender gap in TG levels.

In the 2009 survey, a higher percentage of men (26.0%) and women (20.2%) were involved in professional jobs compared to the 2002- 2003 study (17.3% for men and 10.3% for women) (all P values <0.001). Women (1.8, 41.4, 4.8 and 10.0% vs 0.1, 9.9, 2.3 and 7.1%, respectively) and men (1.0, 33.2, 2.5 and 8.1% vs 0.1, 4.7, 1.2 and 4.6%, respectively) had a higher prevalence of mental disorders in the 2017 survey compared to the 2009 survey (all P values <0.001) (data not shown in tables).

Prevalence and trend of MS

Three studies found that the prevalence of metabolic syndrome was much greater in males than in women (Figure 1a). In 2002- 2003, the crude and age-adjusted prevalence rates for men were 23.0% (95% CI: 21.9-24.2) and 21.5% (95% CI: 20.2-22.9), respectively. In 2009, the rates were 29.6% (95% CI: 28.0-31.1) and 26.6% (95% CI: 24.8-28.5), while in 2017, the rates were 45.3% (95% CI: 44.2-46.4) and 44.2% (95% CI: 41.8-46.7). The age-adjusted prevalence of metabolic syndrome in women was significantly lower than the crude prevalence. In 2002- 2003, it was 20.2% (95% CI: 19.1-21.2) vs 21.8% (95% CI: 20.8-22.7), in 2009, it was 25.3% (95% CI: 23.7-27.1) vs 29.6% (95% CI: 28.2-31.0), and in 2017, it was 32.3% (95% CI: 30.8-33.9) vs 41.5% (95% CI: 40.6-42.4).

The prevalence of metabolic syndrome at each age group and sex at each survey is displayed in Figure 1b. In both men and women, the prevalence of MS tended to rise as they got older at each survey (P for trend <0.05). There was an uptick across all age categories over the three surveys, with males showing a more noticeable trend than women, especially in the younger age brackets.

Prevalence and trend of MS components

The three studies showed that HBP was the most common symptom of MS in both men and women (Figure 2a). Across all three surveys, the frequency of high blood pressure, high blood sugar, and high cholesterol (HBG), both unadjusted and adjusted for age, rose in both men and women (P for trend <0.001). The rise was more noticeable from 2009 to 2017 compared to the years 2002 to 2009. However, changes in dyslipidemia prevalence differed by sex; for example, men saw an increase in the age-adjusted prevalence of HDL while women saw a decrease. In 2009, the poll found that LHC had the greatest crude prevalence among both sexes.

Figure 2b shows that in every survey, the prevalence of HWC, HBG, and HBP increased with age in both men and women (P for trend <0.05). Women had an increasing prevalence of HTG as they aged, whereas men showed an increasing and then decreasing prevalence of the dyslipidemia. While the frequency of LHC stayed the same in women, it declined in men as they got older. Table 1

The median (IQR) was used for continuous variables and the percentage for categorial variables. To test for the trend, a generalized estimating equation was employed. Missing values excluded from the analysis for men in the 2002- 2003, the 2009 and the 2017 surveys: Education (n = 28,1,0), Monthly income per capita (n = 55,2,4), Alcohol drinking (n = 54,2,22), Cigarette smoking (n = 9,3,5), BMI and overweight (n = 9,3,0), WC (n = 21,3,0), BP (n = 10,0,2), FPG (n = 0,0,6), TG (n = 7,0,6), HDLC (n = 3,0,6) and diagnosis of dyslipidemia (n = 8,2,0); for women: Education (n = 39,2,0), Monthly income per capita (n = 4,1,5), Alcohol drinking (n = 2,1,10), Cigarette smoking (n = 0,4,9), BMI and overweight (n = 3,1,0), WC (n = 17,1,0), BP (n = 1,0,7), FPG (n = 0,0,12), TG (n = 4,0,9), HDLC (n = 3,0,8), and diagnosis of dyslipidemia (n = 10,0,0). A negative trend was indicated by the bolded P values. diagnosed by doctors using the criteria set by the World Health Organization in 1999. Medical professionals in China make dyslipidemia diagnoses in accordance with official guidelines. BMI, body mass index; BP, blood pressure; FPG, fasting plasma glucose; HDLC, high- density lipoprotein cholesterol; TG, Triglycerides; WC, waist circumstance.

Figure 1. Results from the population-based studies conducted in China in 2002- 2003, 2009, and 2017 show the prevalence of metabolic syndrome in both men and women. (a) The overall prevalence as well as the prevalence adjusted for age; (b) The prevalence each age group separately. The prevalence trend was tested using generalized

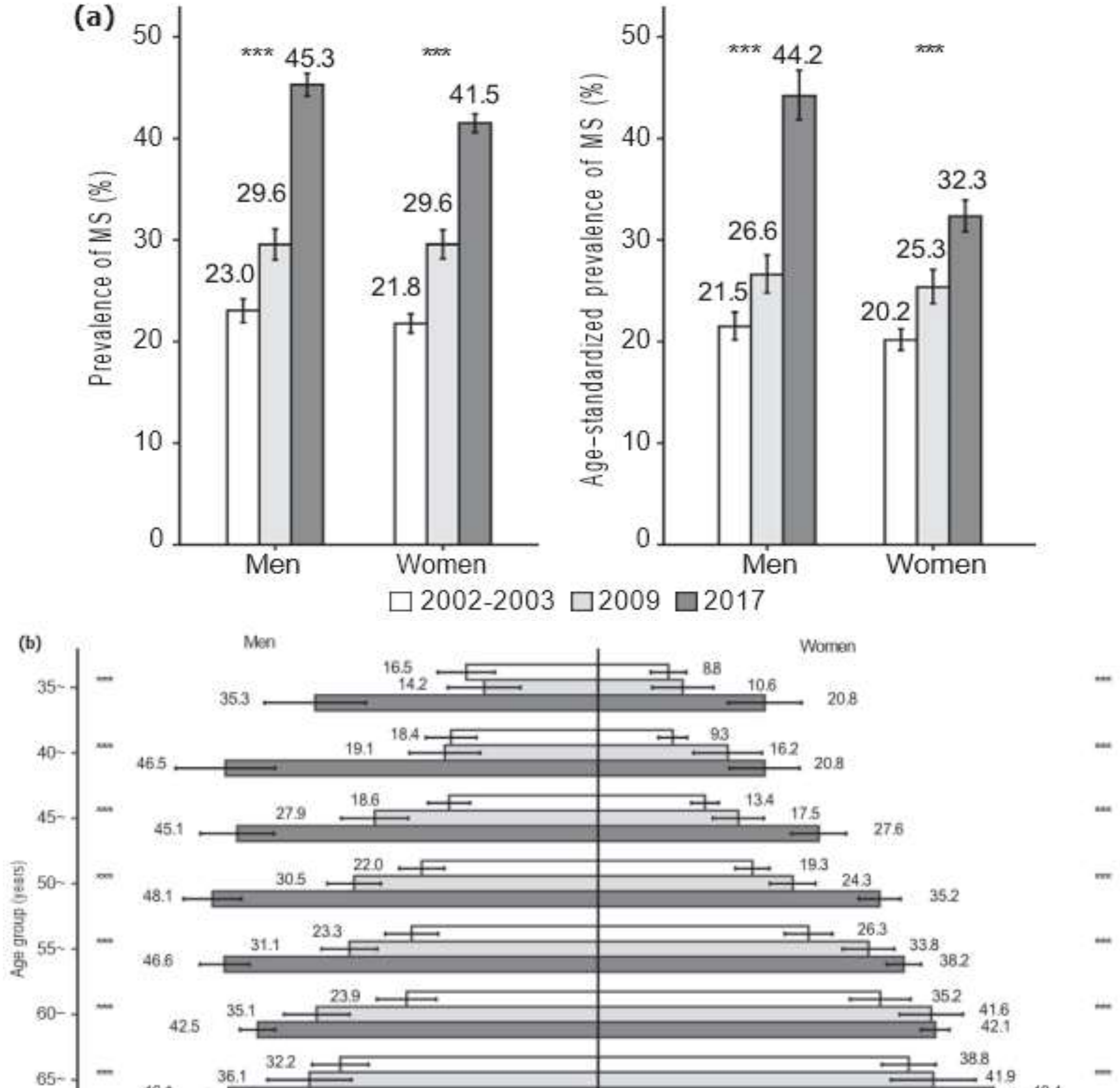

Figure 1: Prevalence of metabolic syndrome in men and women from population-based surveys in Shanghai, China (2002–2003, 2009, 2017); **a)** Crude and age-standardized prevalence; **b)** Age-specific prevalence by sex.

estimating equations. Indicated by bars are the 95% confidence intervals. If the trend is less than 0.001, the corresponding p-values are ** for trend less than 0.01 and * for trend less than 0.05.

Figure 2. The prevalence of metabolic syndrome components in men and women in China based on population-based surveys conducted in 2002- 2003, 2009, and 2017. (a) The overall prevalence as well as the prevalence adjusted for age; (b) The prevalence each age group separately. The prevalence trend was tested using generalized estimating equations. Indicated by bars are the 95%

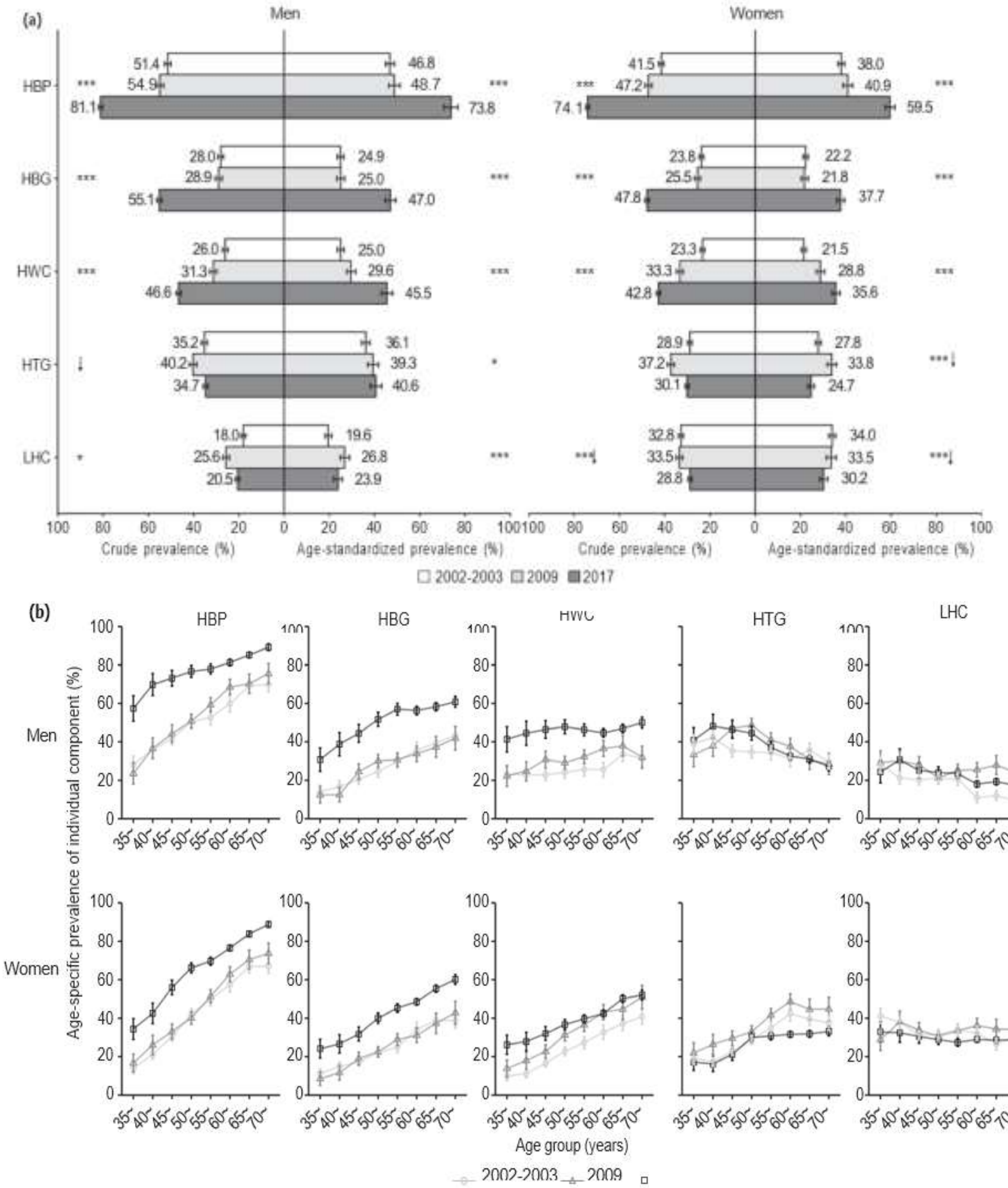

Figure 2: Prevalence of metabolic syndrome components in men and women from population-based surveys in Shanghai, China (2002–2003, 2009, 2017); **a)** Crude and age-standardized prevalence; **b)** Age-specific prevalence by sex.

confidence intervals. The following symbols indicate statistical significance: *P for trend <0.05, **P for trend <0.01, and ***P for trend <0.001. LHC stands for low high-density lipoprotein cholesterol; HBG stands for high blood glucose; HBP for high blood pressure; HTG for high triglycerides; HWC for high waist circumference.

Both men and women may be seen in Figure 3, which displays the curves representing their normal weight and body mass index, respectively.

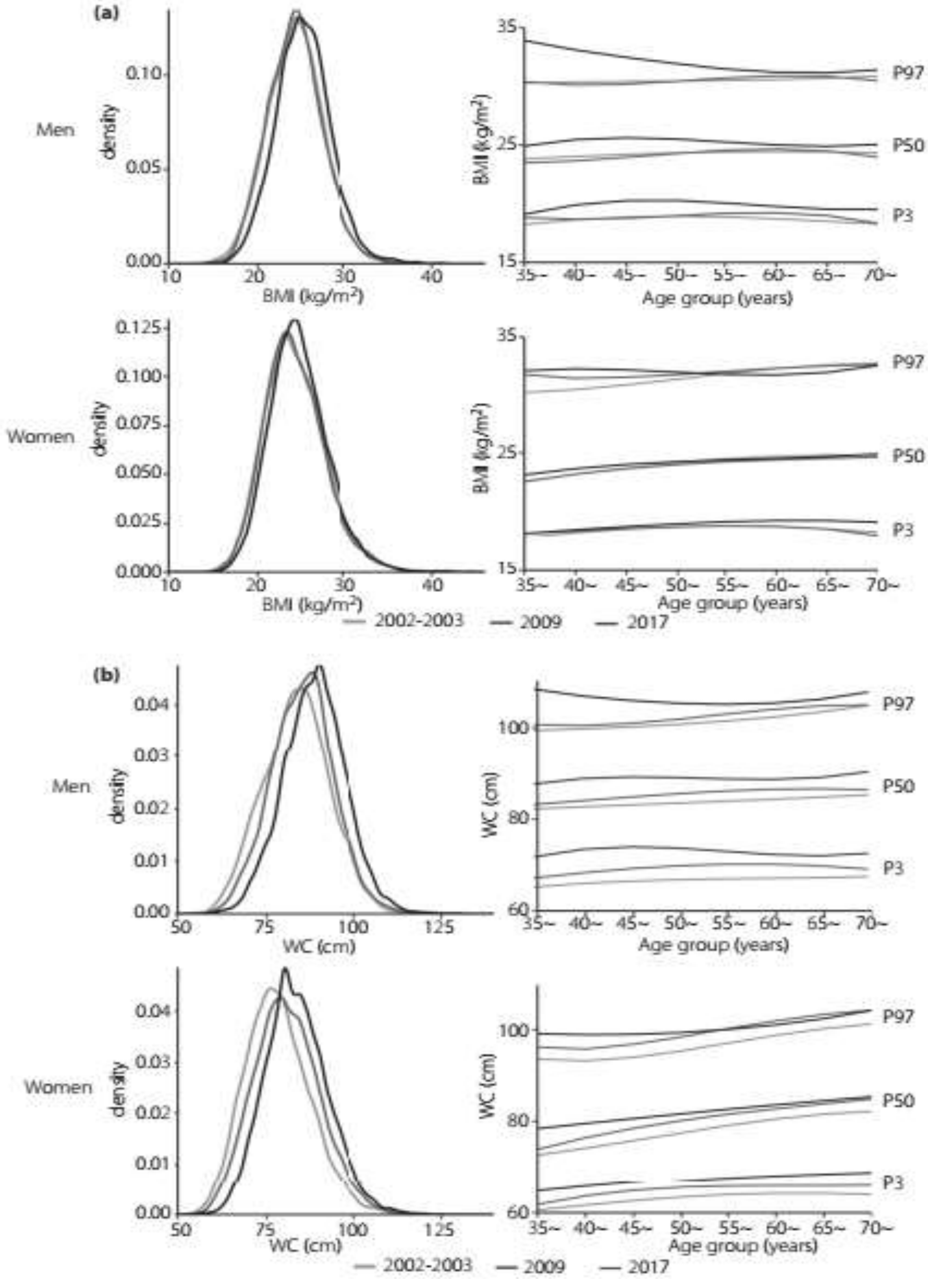

Figure 3: Age- and sex-specific percentile curves for anthropometric measures among Shanghai adults (2002–2003, 2009, 2017); **a)** Body mass index (BMI); **b)** Waist circumference (WC)

Figure 3a shows that the body mass index (BMI) curves from the three surveys nearly overlapped, especially for women, and that the BMI level stayed relevantly consistent with age for both sexes. The mean WC for men increased from 83.0 to 84.8 and 88.2 cm between 2002- 2003 and 2009 and 2017, while for women it increased from 77.7 to 80.3 and 83.1 cm. This change occurred on the right side of the curve for WC in both sexes. Figure 3b shows that when looking at women broken down by age, there was a consistent upward trend in WC and a comparable pattern of change.

Figure 3. Age- and sex-specific percentile curves for body mass index (a) and waist circumference (b)

among Shanghai adults in 2002–2003, 2009, and 2017.

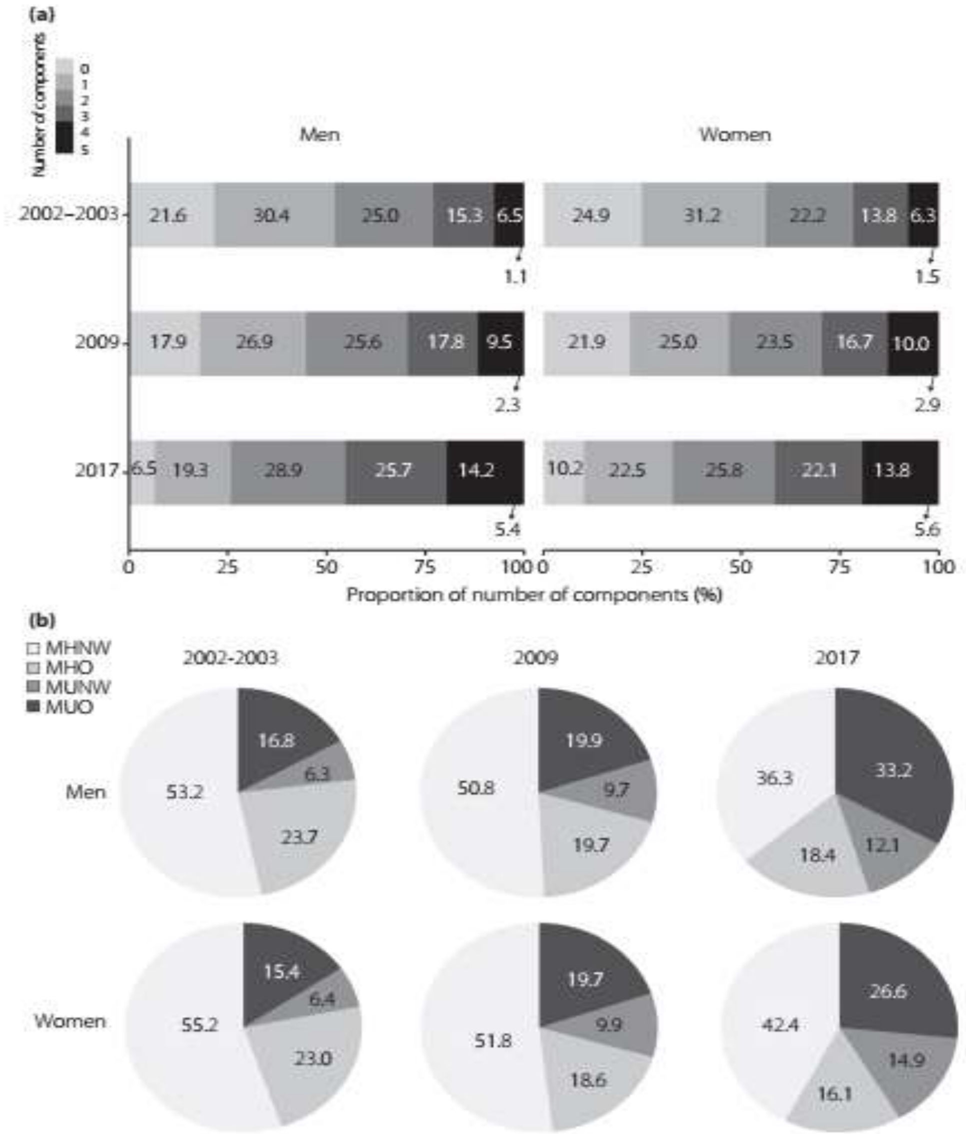

Figure 4: Distribution of metabolic characteristics among Chinese adults from population-based surveys in Shanghai (2002–2003, 2009, 2017); **a)** Percentage of individuals by number of metabolic syndrome components (0 to 5); **b)** Prevalence of metabolic obesity phenotypes by sex

The marked rightward shift in waist circumference distribution reflects increasing central obesity despite relatively stable BMI trends.

Changes in clusters of MS components

The majority of individuals exhibited at least one MS symptom, as shown in Figure 4a. Across all three polls, the percentage of men and women reporting zero or one component decreased, while the percentage reporting two or more components grew.

Figure S2A, B shows the specifics of the modified component clusters across all individuals and MS subjects over the three surveys. Clusters of MS components varied over time and between genders, but the most common abnormalities were high blood pressure (HBP) and clusters associated to it. Cluster HBP-HBG-HWC was the most common subgroup among MS subjects in both the 2002- 2003 and 2017 surveys, with prevalence rates of 15.0% (95%CI: 13.0-17.1) and 11.0% (95%CI: 9.4-12.5) for men and 21.5% (95%CI: 20.3-22.7) for women, respectively (Figure S2B).

The frequency of concurrent changes in all five MS components was much lower in the 2002- 2003 survey (5.0% for men and 7.0% for women; 95% CI: 3.7–6.2) but increased in the 2009 and 2017 surveys (11.9 percent for men and 13.6 percent for women, respectively; 9.9 percent for women, and 11.9 percent for men, respectively; 9.8 percent for women, and 9.9 percent for women with a 95% CI: 8.1–11.6).

Figure 4 shows the percentage of Chinese men and women who were overweight or obese in the 2002- 2003, 2009, and 2017 population-based surveys, broken down by metabolic syndrome components (a) and metabolic type (b). The acronyms MHO, MUNW, and MUO stand for metabolically healthy normal weight, metabolically unhealthy overweight, metabolically unhealthy normal weight, and metabolically unhealthy normal weight, respectively.

Overweight people who are metabolically unhealthy: prevalence and trends in Figure 4b, we can see how often MHNW, MUNW, MHO, and MUO were throughout all three polls. For men, the prevalence of MUO was 16.8% (95%CI: 15.7-17.8) in 2002- 2003, 19.9% (95%CI: 18.5-21.2) in 2009, and 33.2% (95% CI: 32.1-34.2) in 2017 (P for trend <0.05). For women, it increased from 15.4% (95% CI: 14.6-16.2) to 19.7% (95% CI: 18.5-20.9) to 26.6% (95% CI: 25.8-27.5) per period (P for trend <0.05). Across all three surveys, the prevalence of MUNW rose in males (6.3%, 9.7%, and 14.9%, respectively) and women (6.4%, 9.9%, and 14.9%, respectively) (with a 95% confidence interval of 5.6-6.9 for men and 8.7-10.7 and 11.4-12.9% for women).

Analysis of increases in medical costs for CVD

We estimated the direct medical costs of CVD in the whole population of Shanghai based on the changes in prevalence of MS, MS components, and metabolic type of overweight, respectively, using previously reported sex- and age-adjusted relative risk (RR) and the calculated population attributable fraction (Table S1). Table 2 shows that among Shanghai's adult Chinese population, MS was a contributing factor in incident CVD at 25.9% in 2002- 2003, 30.6% in 2009, and 39.1% in 2017, resulting in direct medical cost increases of around \$216 million. In terms of direct medical cost, the individual components varied between \$36 million

Table 2: Costs associated with cardiovascular diseases directly attributable to the rising prevalence of metabolic syndrome, its components, and metabolic type of obesity in Shanghai's general population

Direct medical cost each year (USD)				Changes in direct medical cost (USD)		
	In 2002	In 2009	In 2017	From 2002 to 2009	From 2009 to 2017	From 2002 to 2017
MS	24,303,428	71,913,068	240,308,866	47,609,640	168,395,798	216,005,438
Individual components						
HBP	45,288,315	115,389,923	365,072,804	70,101,608	249,682,881	319,784,489
HBG	12,981,349	32,901,404	143,201,958	19,920,055	110,300,555	130,220,609
HWC	8,686,767	27,026,153	92,804,703	18,339,386	65,778,550	84,117,935
HTG	19,618,430	55,462,366	124,763,938	35,843,937	69,301,572	105,145,508
LHC	7,222,705	19,270,822	43,636,648	12,048,117	24,365,826	36,413,943
Main clusters of MS components						
HBP-HWC	12,102,912	38,541,644	156,108,573	26,438,733	117,566,928	144,005,661
HBP-HBG	13,762,182	36,191,544	183,765,603	22,429,362	147,574,059	170,003,421
HBG-HWC	12,786,141	37,601,604	180,692,600	24,815,464	143,090,996	167,906,459
Metabolic type of overweight						
MUO	6,515,356	19,459,777	75,272,511	12,944,422	55,812,734	68,757,156
MUNW	1,314,457	4,890,892	17,997,374	3,576,436	13,106,482	16,682,918
MHO	7,580,646	14,955,569	34,782,210	7,374,923	19,826,641	27,201,564

(HDL-C) to $320 million (hypertension). Approximately $170 million and $69 million of the increase in direct medical spending was attributable to the rising prevalence of HBP-HBG cluster and MUO, respectively.

Sensitivity analysis

Estimates of the prevalence of metabolic syndrome and MS components in 2017 were unaffected by the exclusion of 1,789 respondents from the 2009 survey, who had lower incomes and education levels and were more likely to smoke and drink (in men only). The sensitivity analysis for metabolic syndrome showed results that were highly similar to the main analyses: 45.7% (44.5-46.9%) for males and 44.8% (42.3-47.4%) for women. Prevalence estimates for metabolic type overweight, clusters of components, and individual MS components were relatively unchanged (data not shown). All four of these conditions -MS, HWC, HBG, and HBP- saw dramatic increases in both crude and age-standardized prevalence throughout the course of the three surveys.

Discussion

Using three large, population-based surveys conducted over 15 years in Shanghai, this study shows that the prevalence of metabolic syndrome (MS), as defined by the updated NCEP ATP III criteria, has remained high around 20% in most age and sex groups and has increased substantially over time. In particular, MS and its key components, including high blood pressure, high blood glucose and central obesity, have risen sharply, especially among men and younger age groups. These findings indicate a rapidly worsening cardiometabolic risk profile in a major urban Chinese population and provide quantitative evidence that metabolic health is deteriorating in parallel with China's broader epidemiological and demographic transitions.

CVD, cardiovascular disease; HBG, high blood glucose; HBP, high blood pressure; HTG, high triglyceride; HWC, high waist circumference; LHC, low high-density lipoprotein cholesterol; MHO, metabolically healthy overweight; MS, metabolic syndrome; MUNW, metabolically unhealthy, normal weight; MUO, metabolically unhealthy overweight; PAF, population attributable fraction.

In recent decades, metabolic syndrome has spread around the world. The reported crude prevalence in other populations, according to the NCEP ATP III criteria, varied greatly. For men, it ranged from 9.0 to 52.6% in 2002- 2003, 10.0 to 36.3% in 2009, and 35.1 to 44.4% in 2017. For women, it was 10.3 to 46.9% in 2002- 2003, 14.6 to 62.6% in 2009, and 34.3 to 37.1% in 2017 (Table S2). Economic development, fast urbanization, and the epidemic of sedentary lifestyle[13,14] may be contributing factors to the fast increase of MS in low- and middle-income countries [32,33], while in high-income countries the trend is the opposite or even reverses. Although the worldwide prevalence of metabolic syndrome was at a high level in 2017, indicating a rapidly increasing trend, it was moderate in our community in 2002-2003 and 2009.

An indication that population ageing is a factor is the disparity between the crude and age-standardized prevalence of metabolic syndrome[34]. Due to the fact that a person's chance of developing MS increases with age, this disease is often thought of as an age-related condition. Nevertheless, males younger than 60 years old showed a more significant increase in the prevalence of MS in this investigation. These results were in line with those of a Japanese cohort[35], in which the prevalence of metabolic syndrome in men rose until age 60 and then remained steady thereafter. Both regional and international forces, including cultural, economic, and social considerations, may influence the outcome. The increased prevalence of high-stress occupations in this group may have contributed to the increased risk of MS[36] by disrupting the neuroendocrine system.

Possible drivers of the trend may be shown by the fact that the MS components did not change at the same rate. While the rates of HTG and LHC remained relatively constant, those of HWC, HBG, and HBP rose dramatically across both sexes. This pattern of change was also noted in the Tehran cholesterol and glucose study[37] and the Framingham Heart Study[38]. Dyslipidemia and other components showed equivalent changes in other studies [39,40]. The Korean population[14] saw the greatest increase in LHC, one of the five MS components. various populations are exposed to various risks, according to these studies.

The imbalanced changes in cardio-metabolic risk variables in our population could be due to a number of things. To begin, the disparity could be explained by the varied paths that the metabolic variables take as they age. In contrast to WC, which rises with age in humans[41], TG levels peak around middle age [42, 43], and HDLC levels either keep going down or stay the same [44,45]. Inflammation and hormone levels fluctuate with age, which impacts the character of biological processes as well as the differences in consumption, absorption and meta- bolisms of dietary fat [43,44]. So, while the average levels of TG and HDLC might not change from one survey year to the next, the average levels of WC would rise due to China's rapidly ageing population. The second reason is that western lifestyles, which include less carbs and more protein and fat, lower but still high sodium consumption, and sedentary habits, have been spreading epidemically in China as a result of the country's recent nutritional transition [46,47]. Obesity, hyperglycemia, dyslipidemia, and hypertension were all significantly (albeit to varying degrees) linked to these variables. The development of HDLC may have increased as reports indicate that animal fat consumption has been down in nine Chinese provinces since 2009[48], while plant fat consumption has been on the rise[49]. Men tend to use significantly more tobacco and alcohol than women do, which may explain why there is a gender gap in the incidence trend of metabolic syndrome (MS)[50]. These substances may also contribute to the widespread metabolic phenotypes[51]. Lastly, there was a considerable improvement in the rates of MS recognition, therapy, and control overall, however this improvement varied by metabolic abnormality type [52–54].

Establishing predictive models would not allow us to make a reasonable prediction due to our lack of knowledge regarding the drivers driving the trends in MS prevalence and its components. Time series analysis prevalence projections need the null hypothesis that MS and its components will continue to grow at a constant rate throughout time[55,56]. Nevertheless, the study's findings about the apparent acceleration trends and imbalanced changes in MS components raise questions about the validity and reliability of the predictions. Consequently, time series analysis was also unable to predict the MS prevalence. In order to increase the temporal horizon for making a prediction, further research is necessary.

Limitations

Several limitations are included in this investigation. To begin, selection bias may have been introduced because the three surveys were not comparable with respect to sampling framework, sample size, or response rate of research. For instance, fewer respondents with a bachelor's degree or higher were chosen for the 2009 poll because of changes to the sample framework. The prevalence of MS in the year may have been under-estimated in males and over-estimated in women due to the sex variation in connections of metabolic illness with socioeconomic position (SES)[57,58]. Secondly, we could not rule out batch bias even though we utilized a uniform technique for biochemical assays and body measurements throughout all three surveys. The rising incidence of metabolic syndrome and its components cannot be fully explained by current knowledge due to a lack of data on lifestyle and treatment. The predicted rising trend of MS and its components may have been skewed due to variances in response rates among the three surveys. Lastly, we couldn't directly assess the relationships of MS and its components with these outcomes for disease bur-den estimate and projection because we didn't follow-up the participants for incident CVD and other NCDs, as the study was cross-sectional.

Strengths of this study

This study has several important strengths. First, all three cross-sectional surveys used a comparable multistage stratified sampling framework and standardized field protocols, yielding large, population-representative samples across a 15-year period. Second, the rigorous training of staff, uniform laboratory assays and harmonised definitions ensured high-quality and comparable measurements of MS and its components over time. Third, by stratifying analyses by sex and age and examining both individual components, their clusters and metabolic obesity phenotypes, we provide a nuanced picture of how the cardiometabolic risk profile is evolving in this rapidly urbanising setting. Finally, by combining prevalence trends with established relative risks to estimate CVD-attributable medical costs, the study moves beyond descriptive epidemiology and quantifies the potential economic burden associated with deteriorating metabolic health.

Policy and public health implications

These trends have important implications for public health policy and clinical practice in China. First, the pronounced rise in high blood pressure, high blood glucose and increased waist circumference, together with the large CVD-attributable fractions of these components, supports prioritising integrated MS screening and management within existing hypertension and diabetes programs. In rapidly urbanising settings such as Shanghai, expanding community-based blood pressure and waist circumference monitoring, strengthening dietary and physical-activity interventions, and implementing structural policies such as taxes on sugar-sweetened beverages, sodium-reduction initiatives, and built-environment changes to encourage active transport may be particularly effective in curbing the cardiometabolic burden. Second, the marked increase in metabolically unhealthy overweight and normal-weight phenotypes suggests that risk stratification based solely on BMI is insufficient; clinicians in primary care and hospital settings should routinely assess MS components even in apparently normal-weight adults, and offer early lifestyle or pharmacological interventions when clusters of abnormalities are detected. Finally, by linking MS prevalence trends to direct CVD medical costs, our findings provide an economic rationale for investing in population-level prevention, as relatively modest improvements in MS control could translate into substantial savings in healthcare expenditure and productivity.

Finally, the frequency of metabolic syndrome in adults in China was quite high and had been steadily increasing over the previous several decades. There will be a massive burden of CVD in the population due to the increasing trend of MS, changing clusters of MS components, and heightened metabolically unhealthy over-weight. The urgency of addressing the accumulating metabolic diseases in the population is highlighted by the fact that the population is getting older.

Conclusion

This study highlights alarming evidence of the rapid decline in metabolic health across the lifespan in China. Among adults in Shanghai, the prevalence of metabolic syndrome has doubled from the early 2000s to 2017, primarily due to significant increases in hypertension, hyperglycemia, and central obesity. Meanwhile, national data encompassing over 1.1 million children and adolescents shows similar adverse trends firmly entrenched within younger populations. Despite expectations of a 34.4% reduction in China's youth population by 2030, projections indicate a staggering 180.6% rise in children and adolescents affected by overweight/obesity and a 131.5% increase in hypertension cases, driven predominantly by surging prevalence rates that overshadow the demographic decline. These converging trajectories in both adults and children suggest that the epidemic of cardiometabolic risk factors is no longer limited to older generations but is increasingly taking root early in life. This forebodes a significant future burden from cardiovascular disease, type 2 diabetes, and other non-communicable diseases. By integrating data from high-quality adult surveys with nationally representative pediatric statistics, alongside decomposition analyses and forward projections to 2030, the findings emphasize the critical need for immediate action. Without prompt and comprehensive interventions addressing dietary patterns, physical inactivity, and early-life risk factors—particularly through school-based initiatives, regulation of food environments, and improved screening measures—China risks an unsustainable surge in cardiometabolic disease over the coming decades. The window for impactful primary prevention is rapidly closing and demands urgent action.

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