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Association of body mass index and other factors with metabolically unhealthy status: Results from the national health examination survey IV

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Abstract

Increasing evidence about non-proportionally high cardiovascular risk in individuals with normal body mass index (BMI) suggested a need for alternative approaches to risk classification, one of which is metabolic health status (MHS). This study aimed to estimate the prevalence of MHS, and examine the association of BMI, other factors and being metabolically unhealthy in a contemporary Thai population, using data on 19,640 participants in the National Health Examination Survey IV (NHES IV) in 2009. Metabolically unhealthy (MUH) was defined as individuals having abnormality in at least one metabolic parameter based on the International Diabetes Federation (IDF) criteria. The prevalence was estimated for the overall population and across BMI categories. Multivariable logistic regression was performed to examine the association between BMI categories, other characteristics and MUH status. The results show that the prevalence of MUH individuals in the Thai population is 73.1%. The prevalence of metabolic parameter abnormalities rose significantly with increasing BMI category, from the prevalence of 54.1%, 63.6%, 75.9% and 87.4% with corresponding odds ratios of 1.55, 2.77, and 6.31 for BMI ≥18.5-22.9 kg/m^2, 23-24.9 kg/m^2 and ≥25 kg/m^2, respectively. The odds of being MUH tends to increase when BMI level increases. Other characteristics associated with MUH were being female, being older, having a low level of education, living in a rural area and currently smoking tobacco. In this national representative sample of the Thai general population, the prevalence of MUH was high and rose continuously with increasing BMI levels. MUH was also prevalent in normal weight and underweight individuals.

Keywords: Metabolically unhealthy, Prevalence, Body mass index, Cross-sectional analytical study

1. Introduction

The number of people that are overweight and obese has been increasing in both developed and developing countries, and this increasing trend is observed in both men and women. In Year 2014 almost 2.1 billion adults in the world were obese [1]. Being obese or overweight contributes to the increasing public health burden of metabolic abnormalities [2], non-communicable diseases, and all-cause mortality as well as cardiovascular and cancer mortality [3-5]. The body mass index (BMI) assessment approach has been widely used to define level of obesity in population-based studies. However, high BMI does not necessarily reflect an increased fat mass, while not all subjects with normal and lower range BMI have normal metabolic components too [2,6,7]. Epidemiological studies have shown that not only obese and overweight people have a high risk of cardiometabolic disorders, but people with normal weight can have these disorders as well [3,6,7]. It may also include underweight persons. Therefore, a better metabolic parameter to predict the risk of cardiometabolic disorders is needed. Metabolic health status is one of such parameters.

The metabolic health status (MHS) approach can be categorized into two groups, i.e. metabolically healthy (MH) and metabolically unhealthy (MUH) [6,8]. In fact, recent cohort studies have indicated a higher risk of type 2 diabetes, stroke, hypertension and mortality among metabolically unhealthy normal weight individuals [5,9-11]. Determining factors associated with being metabolically unhealthy within each BMI category are necessary, as they may inform appropriate preventive strategies. However, many of these previous studies have been done in western populations [5,12], where the background of cardiovascular risk, including lifestyle, culture factors and body fat composition may be different from those of Asian populations. Little evidence exists to describe metabolic health in relation to levels of an overall measure of obesity and BMI. Therefore, this study aims to describe the prevalence of metabolically unhealthy persons across different BMI levels, and examine the association of BMI, other factors and MUH among the Thai population aged 15 years and older.

2. Materials and methods

2.1 Study design and study population

In this cross-sectional analytical study, data on 19,640 participants aged 15 years and older in the National Health Examination Survey IV (NHES IV) were used. Details about the NHES IV study are described elsewhere [13]. Briefly, NHES IV was a nationally representative population-based cross-sectional survey study aimed at investigating the prevalence of diseases and essential health risk factors among Thai people. Four-stage sampling was used to identify and recruit study participants. Bangkok and five provinces in each of the four geographic regions of Thailand were selected. In each province, two to three districts were randomly selected, and 24 enumeration areas were randomly chosen, equally from urban and rural areas. This constituted a total of 540 enumeration areas from 21 provinces. Finally, individuals of both sexes from each age group (15-29, 30-44, 45-59, 60-69, 70-79 and 80 years or more) were randomly selected from each enumeration area. A total of 20,426 individuals participated in the NHES IV. In face-to-face interviews with research nurses, who were trained and verified about the standard of the study protocol, participants were questioned about their socioeconomic data, medical history (diabetes, hypertension, dyslipidemia and medications used), health-related behaviors (physical activity, smoking and alcohol consumption), and a physical examination was made, including blood pressure (BP), body weight, height, and waist and hip circumference. Based on fasting blood samples obtained, fasting plasma glucose (FPG), high-density lipoprotein cholesterol (HDL-c), and triglyceride (TG) were determined. We included in this analysis only those people with complete data on metabolic parameters, which included FPG, HDL-c, TG and BP, and other potential risk factors for metabolic health status, leaving 19,640 individuals as a final study population. Anthropometric parameters (weight, height and waist circumference) were measured using standardized procedures and calibrated instruments. BMI was calculated as an individual's weight (in kilograms) divided by height (in meters) squared. BMI was then categorized into four groups according to the Asia-Pacific body mass index classifications: underweight <18.5 kg/m2, normal weight ≥18.5 - 22.9 kg/m2, overweight 23 - 24.9kg/m2 and obese ≥ 25kg/m2. Blood pressure was measured using a standardized automatic blood pressure monitor model A100.FPG, while TG and HDL-c were determined using standard methods described previously [13].

2.2 Health-related behaviors

Physical activity (PA) was assessed using the Global Physical Activity Questionnaire (GPAQ) [14] and categorized into three groups; high, moderate and low. Alcohol consumption was assessed using a simple, self-reported question calculated according to the WHO guide and then classified into two groups: current alcohol drinkers and non-drinkers described previously [13]. Smoking was assessed using a self-report simple question and categorized into two groups: current tobacco smokers and non-smokers.

2.3 Definitions of metabolically unhealthy

Metabolic health status was classified into being metabolically healthy (MH) and metabolically unhealthy (MUH). Metabolically unhealthy individuals were defined as those who had one or more abnormalities of the following metabolic parameters: 1) fasting plasma glucose (FPG) ≥100 mg/dL or antidiabetic medication use, 2) triglyceride ≥150 mg/dL, 3), HDL-cholesterol<40 mg/dL in men or <50 mg/dL in women or lipid-lowering medication use and 4) blood pressure ≥130/85 mmHg or antihypertensive medication use. Cut-off points used to define abnormality of metabolic parameters were based on the harmonized definition of the joint interim statement of the International Diabetes Federation criteria [8].

2.4 Statistical analysis

Statistical analyses were performed using Stata software version 15.0 (Texas, USA). The prevalence was estimated for the overall population and across BMI categories. Participant characteristics were presented as median (interquartile range, IQR) and number (%) for continuous and categorical variables, respectively. A Chi-squared test was used to compare the prevalence of being metabolically unhealthy across BMI category. Differences in the metabolic parameter abnormalities and the number of metabolic abnormalities between BMI levels were assessed. Univariable and multivariable logistic regression was performed to estimate the association between sex, age, educational level, residence area, smoking, alcohol consumption, physical activity, body mass index levels and being metabolically unhealthy, and odds ratios (OR) with 95% confidence intervals (CIs) were calculated. The multivariable logistic regression model was performed using enter model. Included variables were those with significant predictors at p-value ≤0.2 in the univariable analysis.

All analyses accounted for the complex survey design. A p-value of <0.05 was considered statistically significant.

3. Results and discussion

The characteristics of participants are shown in Table 1. The prevalence of MUH in Thai people aged ≥15 years was 73.1% (95%CI 71.9-74.3). According to BMI category, the MUH was found in 87.4% (95%CI 86.4-88.3) of the obese, 75.9% (95%CI 73.7-77.9) of the overweight, 63.6% (95%CI 61.5-65.7) of the normal weight and 54.1% (95%CI 50.4-57.9) of the underweight (Table 2). The prevalence was significantly different across BMI levels (p<0.001) (Table 3).

Prevalence of being metabolically unhealthy in the Thai population aged 15 and older across socioeconomic, health-related behavior and BMI category is presented in Table 2. The prevalence of being metabolically unhealthy was higher in females than males, in those with older age, low level of education, individuals living in a rural area, and the prevalence increased with increasing BMI as shown in the previous section. Nevertheless, individuals with MUH and without MUH were similar regarding smoking, alcohol consumption and physical activity.

Table 1 Socioeconomic, health-related behaviors, anthropometric and laboratory data of study population (NHES IV) n= 19,460.

Variable	n(%)
Sex*	
Male	9,285(48.8)
Female	10,175(51.2)
Age group, years*	
<40	4,949(39.8)
40-59	5,751(45.6)
≥60	8,760(14.6)
Educational level*(n=19,426)	
No education	1,249(3.7)
Elementary/secondary	14,191(74.3)
Diploma and over	3,986(22)
Residential area*	
Rural	8,998(70)
Urban	10,462(30)
Smoking*	
Non-smoker	15,328(76)
Current smoker	4,132(24)
Alcohol consumption*(n=19,443)	
Non-drinker	11,982(54.6)
Drinker	7,461(45.4)
Physical activity*(n=19,245)	
Lowly active	4,720(18.4)
Moderately active	5,399(25.4)
Highly active	9,126(56.2)
Obesity level*(n=19,346)	
Underweight	1,975(8.6)
Normal weight	7,276(39.8)
Overweight	3,417(17.2)
Obese	6,678(34.4)
SBP, mmHg‡	123.5(112, 137.5)
DBP, mmHg‡	75(67.5, 83)
FPG, mg/dL‡	87(80, 97)
HDL-C, mg/dL‡	45.9(39, 54)
TG, mg/dL‡	124(87.7, 179)

Note: Data in the table are presented as number (%), mean (SD) and median (IQR) for categorical (*), normally (†) and non-normally (‡) distributed continuous variables respectively.

Table 2 Prevalence of MUH and 95% confidence interval in the Thai adults, overall and by BMI category, socioeconomic and health related behavior.

Variable	Prevalence of MUH, %	(95%CI)
Overall	73.1	(71.9-74.3)
BMI, kg/m^2		
Underweight	54.2	(50.4-57.9)
Normal weight	63.6	(61.5-65.7)
Overweight	75.9	(73.7-77.9)
Obese	87.4	(86.4-88.3)
Sex		
Male	71.0	(69.4-72.5)
Female	75.2	(73.5-76.8)
Age, years		
<40	62.3	(60.5-64.1)
40-59	78.3	(76.8-79.7)
≥ 60	86.4	(85.1-87.6)
Educational level		
No education	82.7	(78.7-86.1)
Elementary/secondary	76.2	(75.2-77.2)
Diploma and over	61.1	(59.2-62.8)
Residence area		
Rural area	74.2	(72.7-75.5)
Urban area	70.7	(69.1-72.4)
Smoking		
Non-smoker	73.1	(71.8-74.4)
Current tobacco smoker	73.2	(70.9-75.3)
Alcohol consumption		
Non-drinker	74.5	(73.0-76.0)
Current alcohol drinker	71.4	(70.0-72.7)
Physical activity		
Lowly active	73.9	(72.0-75.6)
Moderately active	73.1	(71.5-74.6)
Highly active	72.9	(71.4-74.5)

The most common abnormal parameter found in all subjects and across BMI levels was low HDL-c. The proportion of abnormal HDL-c among all subjects, the obese, the overweight, the normal weight and the underweight were 46.5%, 58.9%, 45.0%, 39.0% and 34.4%, respectively. The abnormal parameters found among obese individuals was low HDL-c, followed by abnormal TG, BP and FPG (58.9%, 49.9%, 44.8% and 23.7%, respectively). Similar findings were found among overweight, normal weight, and underweight individuals. Abnormal HDL-c, TG, BP and FPG among the overweight were 45%, 39.7%, 33.3% and 17.5%, respectively. Abnormal HDL-c, TG, BP and FPG among the normal weight were 39%, 27.7%, 21.7% and 9.9%, respectively. Abnormal HDL-c, TG, BP and FPG among the underweight were 34.4%, 18.3%, 15.4% and 9.4%, respectively. The metabolic parameter abnormalities were significantly different across BMI levels ($p<0.001$) (Table 3).

The prevalence of Thai people aged ≥15 years with one or more metabolic parameter abnormalities are presented in Table 3. Overall subjects with one, two, three and four abnormal metabolic parameters were 34.9%, 23.6%, 11.7% and 2.9%, respectively.

The prevalence of one metabolic parameter abnormality was found commonly across BMI category. One metabolic parameter abnormality was found in the normal weight and underweight groups (38.1% and 36.4%), higher than that found in the obese and the overweight groups (30.5% and 35.2%, respectively) with statistical significance ($p<0.001$).

Two or more metabolic parameter abnormalities vary significantly within the BMI category. Individuals with obesity had two or more disorders of metabolic parameters more than individuals who were overweight, normal weight and underweight (30.9 %, 25.8%, 18.6% and 13.3%, respectively) with statistical significance ($p<0.001$).

Table 3 Prevalence of being metabolically unhealthy, metabolic parameter abnormalities and numbers of abnormal metabolic parameters overall and across obese, overweight, normal weight and underweight individuals.

Items	Overall (%)	Obese (%)	Overweight (%)	Normal weight (%)	Underweight (%)	*P*-value*
Metabolically unhealthy	73.1	87.4	75.9	63.6	54.1	<0.001
Metabolic parameter abnormalities						
FPG	15.9	23.7	17.5	9.9	9.4	<0.001
BP	30.9	44.8	33.3	21.7	15.4	<0.001
HDL-C	46.5	58.9	45.0	39.0	34.4	<0.001
TG	36.6	49.9	39.7	27.7	18.3	<0.001
Number of metabolic abnormalities						
0	26.8	12.5	24.1	36.3	45.8	<0.001
1	34.9	30.5	35.2	38.1	36.4	
2	23.6	30.9	25.8	18.6	13.3	
3	11.7	20.3	11.9	5.8	3.8	
4	2.9	5.6	2.9	1.0	0.6	

Note: Obesity, being overweight, normal weight and underweight were defined as BMI of ≥ 25kg/m^2, 23-24.9kg/m^2, ≥18.5 to 22.9kg/m^2 and <18.5 kg/m^2, respectively.

Metabolic parameter abnormalities: FPG = hyperglycemia (fasting plasma glucose ≥ 100 mg/dL or diabetes); BP =high blood pressure (≥130 or 85 mmHg or hypertension); HDL-C = low high-density lipoprotein-cholesterol (< 40 mg/dL in men and < 50 mg/dL in women); TG =triglyceride (triglyceride ≥150 mg/dL) *Using Chi-squared test. The prevalence and adjusted odds ratios computed to estimate the independent effects of each of the socioeconomic, health-related behavior and BMI categories are shown in Table 4. BMI level was associated with being metabolically unhealthy, with dose response relationship ($_{adj}$OR 6.31, 95% CI 5.39-7.39; 2.77, 95%CI 2.34-3.29 and 1.55, 95% CI 1.36-1.77, for those obese, overweight and normal weight, as compared to underweight). Females were independently associated with increasing odds of MUH ($_{adj}$OR 1.17,95%CI 1.04-1.30). Older individuals and current tobacco smokers were associated with increasing odds of MUH ($_{adj}$OR 3.64,95%CI 3.28-4.04, and $_{adj}$OR 1.27,95%CI 1.15-1.41, respectively). In addition, highly educated people living in an urban area had decreasing odds of MUH ($_{adj}$OR 0.56,95%CI 0.42-0.74, and $_{adj}$OR 0.75,95%CI 0.65-0.85, respectively). Being metabolically unhealthy tended to increase the odds when BMI levels were increasing. The adjusted odds ratio among the obese, the overweight and the normal weight when compared to the underweight were 6.31, 2.77 and 1.55, respectively. However, alcohol drinking and physical activity were not found to be associated with MUH.

Table 4 BMI and other factors associated with being metabolically unhealthy (MUH) in Thai adults.

Variable	Crude OR (95%CI)	*P*-value	Adjusted OR*(95%CI)	*P*-value
BMI, kg/m^2				
Underweight	1.00		1.00	
Normal weight	1.47 (1.29-1.68)	<0.001	1.55 (1.36-1.77)	<0.001
Overweight	2.66 (2.27-3.12)	<0.001	2.77 (2.34-3.29)	<0.001
Obese	5.88 (5.06-6.84)	<0.001	6.31 (5.39-7.39)	<0.001
Sex				
Male	1.00		1.00	
Female	1.24 (1.11-1.38)	0.001	1.17 (1.04-1.30)	0.004
Age, years				
<40	1.00		1.00	
40-59	2.18 (2.01-2.36)	<0.001	1.62 (1.49-1.77)	<0.001
≥ 60	3.85 (3.45-4.25)	<0.001	3.64 (3.28-4.04)	<0.001
Educational level				
No education	1.00		1.00	
Elementary/secondary	0.67 (0.52-0.86)	0.004	0.88 (0.66-1.67)	0.332
Diploma and over	0.32 (0.15-0.42)	<0.001	0.56 (0.42-0.74)	0.001
Residence area				
Rural area	1.00		1.00	
Urban area	0.84 (0.75-0.94)	0.004	0.75 (0.65-0.85)	<0.001
Smoking				
Non-smoker	1.00		1.00	
Current tobacco smoker	1.00 (0.88-1.12)	0.198	1.27 (1.15-1.41)	<0.001
Alcohol consumption				
Non-drinker	1.00		1.00	
Current alcohol drinker	0.85 (0.78-0.92)	0.001	1.01 (0.94-1.09)	0.948
Physical activity				
Lowly active	1.00		1.00	
Moderately active	0.96 (0.85-1.07)	0.151	0.90 (0.80-1.01)	0.074
Highly active	0.95 (0.86-1.05)	0.201	0.98 (0.88-1.09)	0.795

Note: CI, confidence interval; OR, odds ratio

*ORs were adjusted for all factors in the table.

The present study is a report of the national prevalence of cardio-metabolic abnormality using the metabolic health status approach in the Thai population. About three-quarters of the Thai people were MUH. Also, the prevalence of MUH is likely to increase with obesity level. Obese subjects had a higher prevalence of MUH than those who were overweight, normal weight or underweight. It was found that more than two-thirds of the normal weight people and more than half of the underweight group were MUH.

The most common abnormal metabolic parameters was dyslipidemia (low HDL-c). Abnormality of one metabolic parameter is common and varies significantly in the BMI category, with more than a third of the normal weight and the underweight groups experiencing this disorder. Previous studies found considerable variability in the prevalence of MUH among those who are obese and overweight ranging from 14 to 88% [7,12,15].

It was found that the prevalence of MUH among obese Thai people was less than that of American and Brazilian people, which were 93.2% and 88.0%, respectively [6,12], but higher than that of Chinese people (4.2%-13.6%) [16], while it was found that the prevalence of MUH among the overweight Thai group was less than that of American people (85%) and similar to that of Chinese people (74.5%), but was higher than that of Iranian people (55.6%) [17]. The reason for higher prevalence of MUH among the Thai population than in the Asian population may come from health behaviors, such as consuming higher proportions of carbohydrates which is more common in rural areas.This study accounts for more than two-thirds of the rural population, which may also include over half of the Thai population who were overweight and obese. Additionally, cultures linked to disease promoting lifestyles may differ from other countries.

The prevalence of MUH within the normal weight subgroup was higher in comparison to results of a study in Iran (37.5%) [18], Brazil (48.6%) [7], Finland (20.4-23.8%) [19] and China (16%) [20], while similar to that of the US (66.5%)[12], but was lower than that of the Netherlands (97.3%) [17], and Spain (93.5%) [21]. This may be due to the criteria used for diagnosing metabolic health. When using different criteria, the prevalence is also likely to be different [16]. In addition, the age range of the majority of the population studied was in the age group of 35 years or more [2,7,16,22]. Health behaviors including the culture of each population can make the results of each study different.

This study is probably the first to report the prevalence of the MUH in the underweight group in Asia. The underweight group had the lowest MUH ratio compared to other BMI levels, but more than half had MUH. Most previous studies combined the underweight and the normal weight groups together [2,7,22]. In addition, more than two-thirds of the normal weight groups had MUH. Therefore, if we use only the BMI approach to identify cardiometabolic risk group, we will miss this group.

Based on the BMI approach guidelines, these groups will be ignored without measures to reduce risk factors. But recent studies have found that MUH in normal weight may lead to type 2 diabetes, cardiovascular disease, stroke and mortality [9-11]. This is consistent with the idea that not all subjects with normal range BMI have a decreased risk of cardiometabolic disease and lower all-cause mortality [6]. Yet, the study of Hosseinpanah [23] found that normal weight subjects with dysmetabolic status had a higher risk for predicted cardiovascular diseases compared to obese subjects without dysmetabolic status.

The study of Ting Huai Shi [24] also found that normal weight adults with metabolic syndrome (MetS) had a higher risk for predicted cardiovascular mortality and all-cause mortality. It can be seen that if the screening measures for risk groups are overlooked, this group may affect the incidence of chronic diseases, disability and premature death.

Being metabolically unhealthy was more common in females compared to males, except in the obese and overweight subgroups, where it appeared that males tended to be more commonly, which is not consistent with the studies by Diniz [7] and Araujo [12] which found that men were more likely to have MUH than females in all BMI categories.

Moreover, this condition was also associated with older age within the BMI subgroup as demonstrated by others studies [7,12]. Higher educational level was associated with decreased MUH in the present study, similarly to Diniz's study and Araujo’s study [12]. Educational level, which is a proxy for socioeconomic and cultural status, influences living conditions and opportunities for having a healthy lifestyle.

This study also found that people living in rural areas appeared to have an increased risk of MUH. This was consistent with Wichai’s study [25]. The higher prevalence of dyslipidemia among rural populations is likely due to the difference in dietary patterns, in which people consume higher proportions of carbohydrates[13]. Dietary glycemic index and carbohydrates were associated with increased triglyceride levels and decreased HDL-c [26].

Regarding health behaviors, smoking appeared to increase MUH. Still, drinkers were not different between MUH and MH groups, and physical activity was not found to be associated with MUH in this study. In other studies [11,12,27], it was found that moderate and vigorous physical activity levels had a beneficial impact on the risk of metabolic syndrome, and decreased the prevalence of MUH in all BMI categories [7].

Another interesting point is that all metabolic parameter abnormalities tended to increase according to the BMI subgroup, which corresponds to the study of Abolfotouh et al.[28], which found that the proportion of metabolic parameter abnormalities increased significantly with increasing BMI.

In terms of the number of abnormal metabolic parameters each participant was having, it was found that the most common number was one metabolic parameter abnormality. It was interesting to find that more than one-third of the normal weight group and of the underweight group had one metabolic parameter abnormality, which was greater than other BMI ranges. HDL-c was the most common abnormal parameter at all levels of BMI. This is consistent with a study in Iranian people aged 35-70 years that found that people with MUH-Lean and MUH-Obese have abnormalities of HDL-c as well [2].Disorders of only one metabolic parameter may lead to a combination of metabolic parameter abnormality, metabolic syndrome and chronic disease [29]. In addition, having two or more metabolic parameter abnormalities still tends to increase with BMI level, and was found mostly in females.

The number of abnormal metabolic components has a clinical significance, since it appeared to be strongly associated with cardiovascular incidence as found in a study in an urban Japanese population [30].

The most common abnormal metabolic parameter among the metabolically unhealthy in normal weight and underweight subgroups was low HDL-c, which increases the chances of having the condition of metabolic syndrome by around 27 times. Next was high TG, which increases the chances of having metabolic syndrome by about 31 times, the highest FPG 15 times, and high blood pressure 8 times, which is higher in the metabolically unhealthy obese group [2].

Normal weight individuals had a higher chance of developing metabolic syndrome. So it seems that a decision on initiation of lifestyle modification intervention should be not only based on the BMI, but rather on the metabolic health status [2].

The results of this study highlight the high prevalence of MUH among normal weight and underweight groups. More than half of them were having the condition [6]. They tended to be ignored by health promotion campaigns. This argument is supported by the findings in a number of studies. Normal weight and underweight individuals appeared to have a higher chance of developing metabolic syndrome, type 2 diabetes, cardiovascular disease, stroke and mortality [2,9-11,23,24]. Therefore screening for cardio-metabolic risk using the metabolic health status approach is suggested. It may lead to finding more risk groups and help determine an intervention that better covers risk groups than using the BMI approach. This should be applied to modify existing health programs aiming at preventing and delaying progression of non-communicable disease in the Thai population. The normal weight and underweight groups should be included.

Major strengths of this study are the large number of representative sample sizes used to estimate national prevalence, and tools for evaluating metabolic components are precise and reliable. However, our study has limitations; a cross-sectional design precluded interpreting the causal relationship between independent factors and MUH. This analysis was based on cross-sectional data; hence, the possibility of reverse causality should be of concern. The findings may be just primary hypotheses about the factors that might be related to MUH.

4. Conclusion

In this national representative sample of the Thai general population, the prevalence of MUH was high, and factors associated with being metabolically unhealthy increased with BMI level, being female, older age, low educational level, living in rural areas and currently smoking tobacco. MUH was also prevalent in normal weight and underweight individuals; these subgroups were likely overlooked in routine risk screening and disease prevention practices. Future studies to examine the longitudinal association between MUH and cardiovascular disease and mortality are needed.

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6. Ethic approval

This study was reviewed and approved according to the Declaration of Helsinki by the Ethics Committee in Human Research, Khon Kaen University (HE 621333).

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