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Trends in the prevalence of metabolically healthy and unhealthy obesity in the US adult population: analysis of eight NHANES cross-sectional survey cycles, 1999–2014

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ABSTRACT

Objective To exam the time trend of the prevalence of metabolically healthy obesity (MHO) in the US adult population.

Design Eight cross-sectional survey cycles.

Setting National Health and Nutrition Examination Survey (NHANES), 1999–2014.

Participants 16 459 NHANES participants aged 20 years and older.

Primary outcome measure MHO was defined as central obesity (waist circumference ≥102 cm for men and ≥88 cm for women) without any of the following conditions: elevated levels of blood pressure (≥130/85 mm Hg), glucose (≥100 mg/dL) and triglycerides (≥150 mm/dL); reduced levels of high-density lipoprotein cholesterol (<40 mg/dL for men and <50 mg/dL for women) or any medication use for high cholesterol, hypertension or diabetes.

Results The prevalence of central obesity significantly increased from 45.2% in 1999–2000 to 56.7% in 2013–2014 (p=0.003). Over the same period, MHO prevalence among those with central obesity only slightly and non-significantly increased from 11.0% to 15.7% (p=0.38). However, MHO prevalence among women increased significantly (p=0.04) from 7.1% to 13.7%. Female gender, a younger age, being Hispanic and non-Hispanic black and high education (some college or above) were significantly (p<0.05) associated with higher prevalence of MHO.

Conclusions While the prevalence of central obesity in the US population has increased since 1999, the prevalence of MHO among those who are centrally obese remained fairly stable.

STRENGTHS AND LIMITATIONS OF THIS STUDY

⇒ A nationally representative sample of US adults was used to ensure a high generalisability of the study findings.
⇒ The large sample size allowed us to estimate the prevalence of metabolically healthy obesity (MHO) for minority groups.
⇒ The survey response rates were high.
⇒ Due to the serial cross-sectional design, we are not able to track the dynamic changes of MHO, as could be done in a longitudinal study.
⇒ We did not include data regarding insulin resistance or inflammation criteria, potentially limiting the detection of cardiometabolic abnormalities.

INTRODUCTION

Obesity, defined as body mass index (BMI) ≥30.0 kg/m^2, is an important risk factor for chronic diseases.[1] It has been associated with heightened risk of cardiovascular disease, type 2 diabetes, dyslipidaemia, osteoarthritis, sleep apnoea, certain types of cancer and all-cause mortality.[2–5] However, accumulating evidence suggests that obesity is not a homogeneous condition, and individual differences exist in cardiometabolic responses to obesity.[6] This unexpected phenotype is referred to as metabolically healthy obesity (MHO).[7] Individuals with MHO are a subgroup of obese individuals who meet the standard for obesity, but are considered as metabolically healthy because they do not demonstrate the panoply of other major cardiometabolic risk factors.[8] Therefore, this subgroup of obese individuals is at much lower risk for cardiometabolic morbidity and mortality compared with those with metabolically unhealthy obesity (MUO).[6] The prevalence of MHO was estimated to be between 10.0% and 55.2% according to different definitions,[9–12] and the prevalence varied by gender, age and race/ethnicity groups.[13]

During the past decade, lower all-cause and cardiovascular mortality have been observed among overweight/obese adults with cardiovascular disease, especially elderly, compared with normal-weight individuals with cardiovascular disease.[14] Given this unexpected 'obesity paradox',[15] studies on the trends of different obese phenotypes may shed important insights into this phenomenon.

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Such analyses will also provide more comprehensive estimates of the national burden of obesity, and aid in the development of intervention programme to individualise the management of MHO or MUO individuals, which is missing in the current guidelines.[16]

Therefore, the purpose of this study was to determine the prevalence and trends of different obesity phenotypes among a nationally representative sample of the US adult population, stratified by gender, race/ethnicity, age group. Since educational level is an important socioeconomic factor and reflects access to healthcare and health literacy, and higher education correlates to significantly better metabolic health,[17] we also explore the prevalence and time trends of MHO across levels of education.

METHODS

Study design and participants

The National Health and Nutrition Examination Survey (NHANES) is a programme of studies designed to assess the health and nutritional status of adults and children in the USA. Since 1999, the NHANES has been conducted in 2-year cycles without a break between cycles. In each survey cycle, a nationally representative sample of the US civilian, non-institutionalised population was selected using a stratified, multistage, probability cluster sampling design. Surveys include demographic information, standardised physical examinations, laboratory results and other health-related interviews and questionnaires.[18] For the purpose of the study, we pooled publicly available data for 19 537 participants aged 20 years and older from eight survey cycles conducted between 1999 and 2014 (1999–2000, 2001–2002, 2003–2004, 2005–2006, 2007–2008, 2009–2010, 2011–2012 and 2013–2014 cycles).[19] Of the 19 537 participants, 3078 were excluded because of missing data on waist circumference, blood pressure (BP), high-density lipoprotein cholesterol (HDL-C), triglycerides (TG) or fasting plasma glucose. Therefore, the final study sample included 16 459 participants for the analyses.

Definitions of MHO and MUO

Obesity was measured as having waist circumference ≥102 cm among men and 88 cm among women.[20] Participants who met all the following five criteria were considered metabolically healthy: (1) systolic BP <130 mm Hg and diastolic BP <85 mm Hg; (2) fasting plasma glucose <100 mg/dL; (3) TG <150 mg/dL; (4) HDL-C at least 40 mg/dL in men and at least 50 mg/dL in women and (5) not taking medications for treatment of hypertension, diabetes or dyslipidaemia. According to obesity and cardiometabolic status, participants were categorised into one of the four groups[13]: (a) MHO, obese individuals who were metabolically healthy; (b) MUO, obese individuals with abnormality in at least one of the five cardiometabolic healthy criteria; (c) metabolically healthy normal weight, non-obese individuals who were metabolically healthy and (d) metabolically unhealthy normal weight, non-obese individuals with abnormality in at least one of the five cardiometabolic healthy criteria.

Data collection

Trained interviewers conducted household interviews, collecting demographic, sociodemographic, dietary and health-related data. Age, gender, race/ethnicity, educational level and medication use for treatment of hypertension, diabetes or dyslipidaemia were assessed by self-reported responses to specific interview questions. Race/ethnicity was categorised as Mexican American, other Hispanic, non-Hispanic white, non-Hispanic black and other races, including multiracial origin. Educational level was categorised as less than 9th grade, 9–11th grade (including 12th grade with no diploma), high school graduates, some college or associate degree and college degree or above.

Waist circumference was measured by a trained health technologist using a non-elastic tape midway between the last rib and the top of the iliac crest. BP was measured by a trained physician using a mercury sphygmomanometer following the recommendations for BP measurement in humans.[21] Three BP readings were obtained at 30 s intervals after participants resting for 5 min. For diastolic BP, if one or two readings were zero, the readings were set as missing, and the non-zero readings were used. If all readings were zero, the diastolic BP was zero. Average systolic and diastolic BP were then calculated using the following protocol[22]: If only one BP reading was obtained, that reading was the average; if two BP readings were obtained, the second BP reading was the average and if there were three BP readings, the first reading was excluded, and the mean of the remaining readings was used. HDL-C and TG were measured enzymatically in serum or plasma using a series of coupled reactions that hydrolyze cholesteryl esters and oxidise the 3-OH group of cholesterol, and fasting plasma glucose was also measured enzymatically via a hexokinase reaction.[23]

Statistical analyses

Participant characteristics were presented by survey cycles without consideration of the survey design and non-response rate. Continuous variables are presented as means and SD, and categorical variables are shown in frequencies and percentages.

In each survey cycle, we calculated the percentage of US adults with MHO and MUO, respectively, taking into account the complex survey design and non-response rate. Such analyses were done for the overall population, obese population and within subgroups defined by 10-year age groups, gender, race/ethnicity and education levels. Differences of MHO and MUO prevalence were compared between men and women and among age groups and race/ethnic groups. All the calculations and comparisons were conducted using the PROC SURVEYFREQ procedure in SAS software (V.9.4, SAS Institute). The SAS PROC SURVEYREG procedure was applied to test for trends across survey cycles. The Excel trendline

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Table 1 Participant characteristics, by survey cycle

	1999–2000	2001–2002	2003–2004	2005–2006	2007–2008	2009–2010	2011–2012	2013–2014
Mean age (SD), years	49.2 (18.1)	48.1 (18.1)	49.2 (18.5)	47.0 (18.1)	48.7 (16.5)	47.6 (16.5)	49.1 (17.8)	49.7 (17.4)
Males, %	48.1	48.2	48.2	47.7	49.2	48.7	47.8	48.1
Race/ethnicity, %								
Mexican Americans	6.4	7.2	7.9	8	8.8	8.8	7.8	8.9
Other Hispanic	8.8	4.9	3.1	3.6	5	5.4	6.4	5.8
Non-Hispanic white	70.5	72.2	71.6	71.5	69.1	67	66.4	66.3
Non-Hispanic black	10.3	10.8	11.5	11.2	11.3	11.6	11.5	11.6
Multiracial origin	4	4.9	5.9	5.8	5.9	7.3	7.8	7.4
Education, %								
<9th grade	7.8	6.7	6.4	6.4	6	6.4	5.9	4.5
9–11th grade	15.4	12	11.3	10.6	13	11.8	11.5	11.7
High school grad	26.8	25.6	26.1	25.9	29.3	22.2	19.7	20.8
Some college	26.8	32.2	32	32.2	28.5	30.2	31.5	32.4
≥College degree	22.9	23.2	24.2	24.7	28.3	29.5	31.3	30.6

function was used to exam the time patterns and the corresponding formulas of obesity phenotypes over time.

Patient and public involvement

Participants and the public were not involved in the present study, which is a secondary analysis of the publicly available de-identified data.

RESULTS

Characteristics of the study sample in each survey cycle are presented in table 1. Mean age of the participants ranged from 47.0 to 49.8 across the eight cycles. There were slightly more women than men in each survey cycle. Participants were predominately non-Hispanic white (>66.0%), and the majority (>80.0%) had an educational level of high school degree or above.

As shown in figure 1 and table 2, the overall prevalence of central obesity increased from 45.1% in 1999–2000 to 56.7% in 2013–2014 (P for trend=0.005). Meanwhile, the proportion of MHO increased from 5.0% to 8.9%

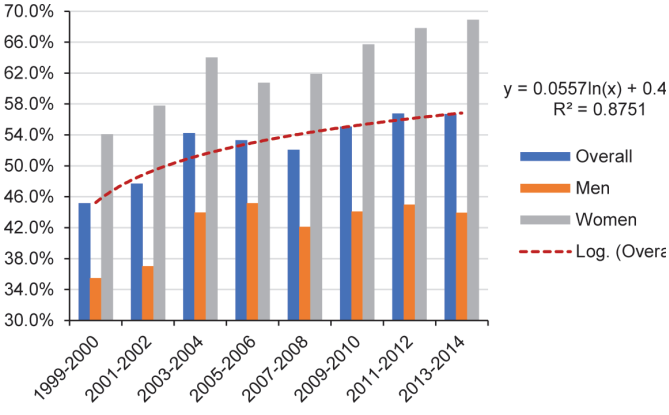

Figure 1 Prevalence and time trends of central obesity, overall and by sex. Trend line and the corresponding formula were generated for obesity among the overall participants using the Excel trendline function.

in the overall population (p=0.13), and from 11.0% to 15.7% in the population with central obesity (p=0.38). As shown in figure 2 and table 2, for both overall and the centrally obese populations, the prevalence of MHO was consistently higher in women than in men in all survey cycles (table 2). There was significant increase in MHO among women over the eight cycles (P for trend=0.04). In addition, the prevalence of MHO in women showed a logarithmic increase over time (figure 2), while in men, MHO prevalence followed an inverse u-shaped pattern, in which the prevalence peaked in 2003–2004 then steadily decreased (figure 2). The gender difference was most apparent in the most recent cycle 2013–2014, in which 13.7% of women were metabolically healthy in comparison with only 3.9% of men with the same phenotype. A similar finding of higher prevalence of MUO was observed in women than men across all eight survey cycles (table 2). In addition, the prevalence of MUO increased over the eight cycles among the overall participants (p=0.002), men (p=0.01) and women (p=0.01), respectively. However, among centrally obese participants, the proportion of MUO decreased from 89.1% in 1999–2000 to 84.3% in 2013–2014, although the trend was not significant (p=0.39).

In the most recent survey cycle in 2013–2014, MHO was most prevalent among Mexican Americans (10.7%), followed by non-Hispanic blacks (9.4%), non-Hispanic whites (9.2%), other Hispanics (7.1%) and other ethnic groups (4.5%) (table 3). Although not significant, MHO prevalence increased over time for most of the ethnic groups, except for non-Hispanic blacks, among whom, MHO prevalence decreased from 11.2% in 1999–2000 to 9.4% in 2013–2014 (p=0.39). Meanwhile, the prevalence of MUO was highest among non-Hispanic blacks (52.7%), followed by Mexican Americans (51.2%), non-Hispanic whites (49.0%), other Hispanics (44.9%) and other ethnic groups (26.5%). The prevalence of MUO significantly increased over time for non-Hispanic blacks

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Table 2 Overall prevalence of obesity phenotypes, by survey cycle and sex, in the general adult population

	1999–2000	2001–2002	2003–2004	2005–2006	2007–2008	2009–2010	2011–2012	2013–2014	P value*
Central obesity, %	45.2	47.7	54.3	53.3	51.1	55.1	56.8	56.7	**0.005**
MHO, %									
Overall	5.0	6.0	8.7	8.0	7.4	8.4	6.4	8.9	0.13
Central obese	11.0	12.5	16.0	15.0	14.2	15.3	11.4	15.7	0.38
Male	2.6	3.3	5.4	4.8	3.8	4.2	3.1	3.9	0.80
Female	7.1	8.5	11.8	10.9	10.9	12.6	9.6	13.7	**0.04**
MUO, %									
Overall	40.2	41.8	45.6	45.3	44.7	46.6	50.3	47.8	**0.002**
Central obese	89.1	87.5	84.0	85.0	85.8	84.7	88.7	84.3	0.39
Male	32.9	33.8	38.6	40.4	38.3	39.9	41.9	40.1	**0.01**
Female	47.0	49.3	52.2	49.8	51.0	53.1	58.2	55.2	**0.01**

Significant p-values are indicated in bold.
*P value for time trends.
MHO, metabolically healthy obesity; MUO, metabolically unhealthy obesity.

(p=0.002), non-Hispanic whites (p=0.01) and Mexican Americans (p=0.01).

In general, in all survey cycles, MHO increased till the 30–39 age group then declined with age, and MUO increased with age (table 4). Among participants aged 50 years and older, more than half were MUO. Both MHO and MUO increased over time, and significant time trends were observed for MUO among the 30–39 (p=0.03) and 70–85 (p=0.003) age groups.

As shown in table 5, across the eight survey cycles, higher prevalence of MHO was found in individuals with higher educational level, typically individuals with some college or above. Higher prevalence of MUO was found in individuals with lower educational level, especially those with less than high school degree. In addition, significant increasing trends were found for MUO among individuals with 9–11 years' education (p=0.003) and among those with some college education (p=0.0002).

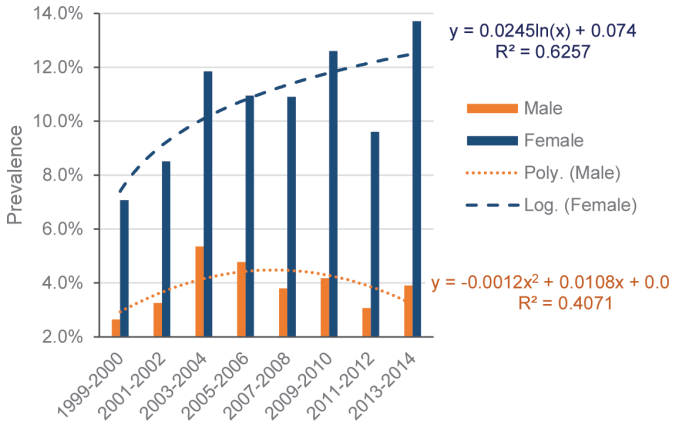

Figure 2 Prevalence and time trends of metabolic healthy obesity by sex. Trend lines and the corresponding formulas were generated using the Excel trendline function.

DISCUSSION

The current study documented the prevalence and time trends of two different obesity phenotypes, MHO and MUO, for US adults from 1999–2000 to 2013–2014. We revealed that more than half of the US adults currently had central obesity, more than 15.0% of the obese population were metabolically healthy, and MHO was more common among women, younger adults, Hispanics and non-Hispanic blacks and individuals with higher education levels. In addition, there was considerable increase in MHO in the past 15 years, particularly among females. The majority of the obese adults were metabolically unhealthy, and there had been significant increase of MUO among both male and female US adults, and among non-Hispanic blacks, non-Hispanic whites and Mexican Americans, respectively. Furthermore, a higher prevalence of MUO was found among women, older adults, non-Hispanic blacks and individuals with less than high school education.

Higher prevalence of MHO and MUO was both observed in women compared with men across all survey cycles. This gender difference in MHO was in line with previous studies in diverse populations.[24–26] Such differences may have been driven by both the body distribution of adipose tissue as well as oestrogen levels.[27 28] Women predominantly have subcutaneous adipose tissue on their lower extremities, while men accumulate significantly more visceral adipose tissue in the abdominal region.[27 28] It has been demonstrated that visceral fat rather than subcutaneous fat is the major predictor of adverse cardiometabolic disorders.[29 30] In addition, oestrogen levels have been reported to protect against adipose accumulation and to reduce inflammatory signalling and improve insulin sensitivity.[31 32] It is unexpected and noteworthy that women also had higher prevalence of MUO. The reason is not clear, but may be in part explained by both behavioural and socioeconomic factors. According

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Table 3 Overall prevalence of obesity phenotypes, by survey cycle and race/ethnicity, in the general adult population

	1999–2000	2001–2002	2003–2004	2005–2006	2007–2008	2009–2010	2011–2012	2013–2014	P value*
MHO, %									
NHB	11.2	7.8	10.9	10.3	10.5	8.1	8.9	9.4	0.39
NHW	3.8	5.6	8.8	7.5	7.0	9.0	6.0	9.2	0.10
OH	4.5	8.5	11.7	14.78	7.5	6.5	9.5	7.1	0.99
MA	6.8	7.4	9.9	8.2	8.2	8.6	7.8	10.6	0.14
Other	6.9	3.3	0.2	5.2	5.0	4.6	2.4	4.5	0.78
MUO, %									
NHB	41.3	41.7	47.2	47.7	48.0	51.4	48.6	52.7	**0.002**
NHW	40.3	43.2	46.3	46.5	46.0	47.5	53.4	49.0	**0.01**
OH	41.2	40.1	31.0	41.6	46.6	42.9	47.6	44.9	0.12
MA	40.2	37.7	46.0	40.6	40.8	47.5	49.3	51.2	**0.01**
Other	35.3	26.2	40.4	34.7	28.3	31.6	30.1	26.5	0.27

Significant p-values are indicated in bold.
*P value for time trends.
MA, Mexican American; MHO, metabolically healthy obesity; MUO, metabolically unhealthy obesity; NHB, non-Hispanic black; NHW, non-Hispanic white; OH, other Hispanics.

to the 2015 National Health Interview Survey data, women were more likely to be physically inactive than men.[33] Furthermore, working women receive lower earnings than working men of comparable educational attainment in almost all occupations.[34] Limited income may impede women's access to nutritious foods.[35]

MHO prevalence was highest among the age group 30–39 in most survey cycles, then decreased with age, while MUO increased with age. In support of these findings, Kuk and associates[36] showed that body fat distribution typically changes with age, with a reduction in lower body subcutaneous fat and an increase in abdominal fat, in particular, visceral fat. The aforementioned gender differences in visceral adipose depots diminish at older ages, as postmenopausal women have greater visceral fat depots compared with men of the same race and similar age.[37 38] Furthermore, the protective role of estrogens against cardiometabolic abnormalities may diminish as a result of ageing.[39] As shown in online supplemental figure S1, the differences in MUO prevalence between men and women becomes less pronounced at age group of 40–49 or 50–59, when women start having menopause onset.

To the best of our knowledge, this is the first study that reported prevalence of different obesity phenotypes by

Table 4 Overall prevalence of obesity phenotypes, by survey cycle and age group, in the general adult population

	1999–2000	2001–2002	2003–2004	2005–2006	2007–2008	2009–2010	2011–2012	2013–2014	P value*
MHO, %									
20–29	5.7	7.5	10.3	12.2	9.4	10.9	11.1	9.7	0.10
30–39	7.0	8.3	12.3	15.2	13.1	10.6	10.1	15.7	0.13
40–49	6.0	6.1	9.6	5.3	7.1	9.2	6.4	10.7	0.20
50–59	4.0	5.8	6.9	5.9	5.2	9.1	4.4	6.0	0.57
60–69	1.8	2.8	5.3	3.0	1.9	3.6	2.4	6.4	0.29
70–85	0.7	0.6	2.5	1.5	3.4	2.4	1.6	2.1	0.20
MUO, %									
20–29	21.9	25.8	24.9	23.5	19.7	27.9	25.1	25.6	0.44
30–39	32.2	31.6	37.4	34.4	35.3	39.1	34.7	42.8	**0.03**
40–49	39.3	41.1	47.2	50.8	47.6	42.0	51.3	47.0	0.15
50–59	56.4	50.5	55.5	51.3	55.01	58.8	63.1	54.6	0.24
60–69	58.3	65.6	63.7	63.6	64.9	59.5	69.5	59.9	0.73
70–85	56.7	59.3	60.2	63.0	66.9	71.3	68.2	67.1	**0.003**

Significant p-values are indicated in bold.
*P value for time trends.
MHO, metabolically healthy obesity; MUO, metabolically unhealthy obesity.

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Table 5 Overall prevalence of obesity phenotypes, by survey cycle and educational level, in the general adult population

	Survey cycle								
	1999–2000	2001–2002	2003–2004	2005–2006	2007–2008	2009–2010	2011–2012	2013–2014	P value*
MHO, %									
<9th grade	2.8	6.5	4.5	6.5	3.6	4.9	3.0	4.5	0.74
9–11th grade	5.4	4.4	5.0	5.7	7.3	6.5	2.7	5.8	0.98
High school grad	4.9	5.7	7.7	5.1	6.1	9.7	6.3	8.9	0.10
Some college	4.2	6.9	11.4	10.4	8.7	7.6	7.4	9.9	0.36
≥College degree	6.4	5.7	9.1	9.4	8.0	10.0	7.6	9.8	0.09
MUO, %									
<9th grade	47.6	47.8	52.2	55.0	51.2	56.0	59.9	52.0	0.06
9–11th grade	45.7	47.1	45.6	48.4	50.2	56.2	53.1	54.2	**0.003**
High school grad	45.7	42.5	52.2	49.8	47.3	47.9	53.2	53.0	0.06
Some college	40.0	39.8	43.5	47.3	45.6	51.8	53.1	53.0	**0.0002**
≥College degree	28.2	39.1	39.7	34.5	37.9	34.6	42.8	35.8	0.33

Significant p-values are indicated in bold.
*P value for time trends.
MHO, metabolically healthy obesity; MUO, metabolically unhealthy obesity.

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race/ethnicity in a nationally representative sample of the US adult population. Hispanics and non-Hispanic blacks tended to have higher MHO prevalence than individuals from other ethnic groups. An examination of both the extent and body fat distribution provides another insight into ethnic variation in adiposity. For example, using data from the 1999–2006 NHANES, Heymsfield and associates demonstrated that at a given BMI and height, a greater musculoskeletal mass was found in non-Hispanic blacks compared with matched non-Hispanic whites and Mexican Americans. This body composition characteristic was accompanied by correspondingly greater leg mass, smaller trunk mass and less visceral fat in non-Hispanic blacks, with the one exception of a larger waist circumference in the older non-Hispanic black women.[40] Despite overall increased total body fat, Hispanic MHO phenotype has been found to have lower levels of visceral and liver adipose tissue compared with Hispanic MUO phenotype.[41] It is clear that these ethnic differences in body fat distribution and body composition may translate into ethnic differences in cardiometabolic risk. Interestingly, we also found a higher prevalence of MUO among non-Hispanic blacks. The ethnic differences in MUO phenotype could also be partly explained by marked differences in lifestyle habits. Recent evidence from the 2015 National Health Interview Survey revealed that Hispanics (38.8%) and non-Hispanic blacks (39.0%) were more likely to be physically inactive than were non-Hispanic whites (27.0%) based on age-adjusted estimates.[33] In addition, non-Hispanic blacks and Hispanics tended to have fewer metrics at ideal levels for cardiovascular health than non-Hispanic whites or individuals from other ethnic groups.[42]

This is also the first study that reported prevalence of different obesity phenotypes by educational level for the US adults. A higher MHO prevalence was consistently observed in individuals with at least some college or associate degree compared with those with lower educational attainment across all eight survey cycles. Consistent with these findings, data from the 3rd Korean NHANES and the Longitudinal Study of Adult Health (ELSA-Brasil) also supported a strong association between MHO phenotype and higher educational level.[25 43] Inequalities in educational level, which is a measure of socioeconomic status (SES), may influence health behaviours and health outcomes of interest. In particular, those inequalities with a plausible biobehavioral link to cardiovascular disease have been well documented in the literature. Several cross-sectional and longitudinal studies have consistently shown that low SES characteristics (eg, household income, educational level) were associated with an increase in cardiovascular disease and cardiovascular risk factors, especially higher BMI, smoking, limited access to nutritious foods, physical inactivity and lower HDL-C levels.[44–46]

Our study has a number of strengths. First, a nationally representative sample of US adults was used for the study, therefore, the findings of the current study may be generalised to the general US adult population. In addition, the current study included a large sample of US adults, which allowed us to estimate MHO and MUO prevalence for some minority groups, such as Mexican Americans and other Hispanics. Finally, high survey response rates across all eight cycles help to ensure that survey results are less likely to be biased. However, certain limitations should also be acknowledged. First of all, these analyses are, however, cross-sectional, and temporal and causal inferences cannot be established. It is therefore important to conduct more rigorous prospective studies to follow-up MHO and MUO individuals and determine how behavioural, socioeconomic and other factors may impact the prevalence of the different obesity phenotypes. Second, the definition of MHO has not been standardised, and prevalence estimates are subject to change depending on the criteria and cut-off points of these criteria to define MHO. As a final point, unlike other studies,[9 11] we did not include data regarding insulin resistance or inflammation criteria, which therefore may have limited the detection of cardiometabolic abnormalities.

CONCLUSIONS

In summary, this study reported recent trends in the prevalence of different obesity phenotypes in the US population. A high burden of central obesity was found among US adults. While the prevalence of central obesity in the US population has increased, the prevalence of MHO and the proportion of MHO among those who are centrally obese have remained relatively stable since 1999. The paradox between increased obesity prevalence and reduced cardiometabolic mortality may not be due to MHO. Continue surveillance of different obesity phenotypes and longitudinal studies evaluating how one phenotype change to another are warranted. Finally, disparities of both MHO and MUO were observed across education levels, sex and race/ethnic groups. Future studies are needed to longitudinally examine the underlying cause of these disparities. Although MHO remains an interesting research topic, great public health efforts are needed to curb the increasing burden of MUO.

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Patient consent for publication Not applicable.

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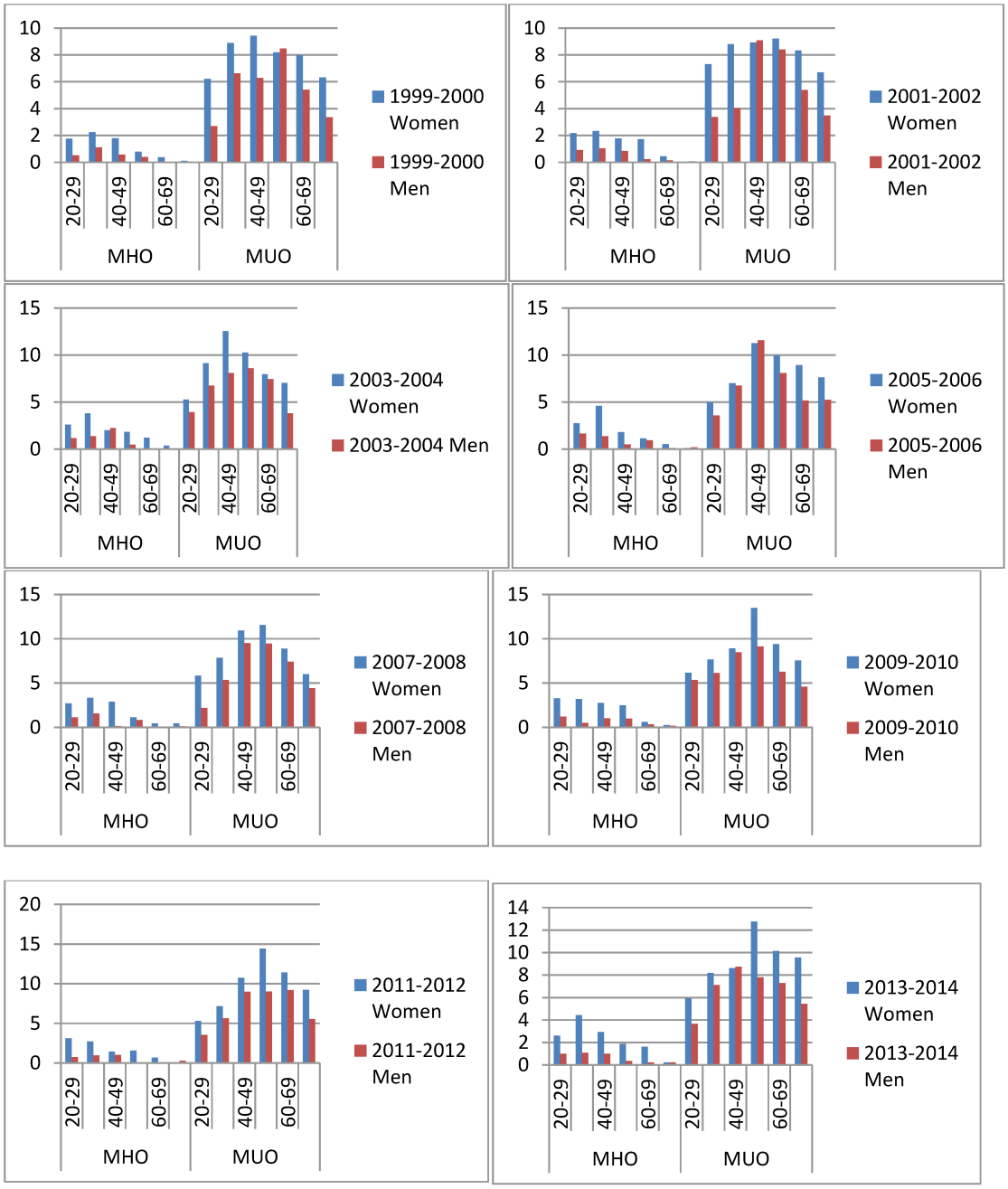
Figure S1. The Prevalence of MHO and MUO by age group and gender in the general population from 1999-2014