dmj
DIABETES & METABOLISM JOURNAL

Trends in Metabolically Unhealthy Obesity by Age, Sex, Race/Ethnicity, and Income among United States Adults, 1999 to 2018

Wen Zeng, Weijiao Zhou, Junlan Pu, Juan Li, Xiao Hu, Yuanrong Yao, Shaomei Shang

Diabetes Metab J 2025;49:475-484 | *https://doi.org/10.4093/dmj.2024.0364*

Trends in Metabolically Unhealthy Obesity by Age, Sex, Race/Ethnicity, and Income among US Adults, 1999-2018

Population

Data from the National Health and Nutrition Examination Survey
(1999–2018, aged > 20 years, non-pregnant)

MUO Definition

BMI ≥ 30 kg/m^2 with any of the following criteria:

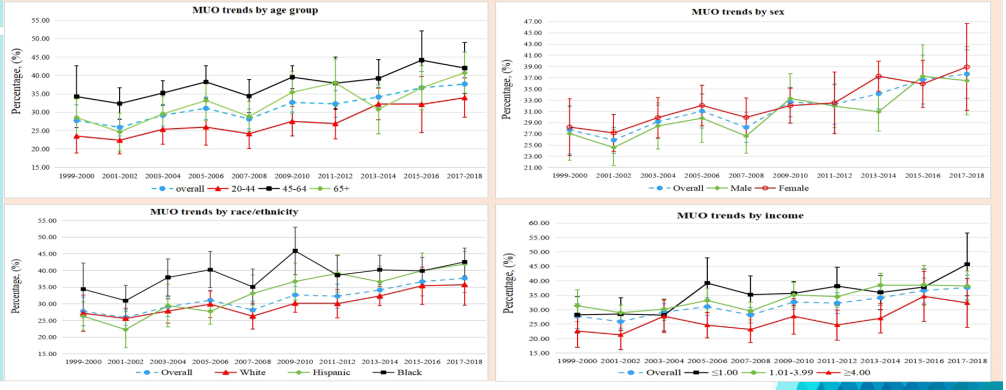
(1) BP ≥ 130/85 mm Hg; or using BP-lowering medication

(2) Fasting plasma glucose ≥100 mg/dL; or HbA1c ≥5.7%; or using glucose-lowering medication

(3) Triglyceride ≥150 mg/dL; or HDL-cholesterol ≤40 mg/L (men) or ≤50 mg/dL (women)

Results

- The age-adjusted percentage of MUO continuously increased in US adults across all subgroups from 1999 to 2018 (all P<0.05 for linear trend).
- It remained consistently higher in adults aged 45–64 years than in the other two age subgroups (P<0.05 for group differences).
- It was continuously higher in Non-Hispanic Blacks than in Non-Hispanic Whites (P<0.05 for group differences).
- It was consistently higher in individuals with high income level than in those with low income (P<0.05 for group differences).



Conclusion

This study found a continuous rise in MUO among US adults from 1999 to 2018, with persistent disparities by age, race/ethnicity, and income.

Highlights

- **This study assesses MUO trends across groups to evaluate long-term disparities.**
- **The age-adjusted percentage of MUO rose across all subgroups from 1999 to 2018.**
- **MUO disparities by age, race/ethnicity, and income persisted among US adults.**
- **The study calls for timely assessment and targeted prevention of MUO.**

How to cite this article:
Zeng W, Zhou W, Pu J, Li J, Hu X, Yao Y, et al. Trends in Metabolically Unhealthy Obesity by Age, Sex, Race/Ethnicity, and Income among United States Adults, 1999 to 2018. Diabetes Metab J 2025;49:475-484. https://doi.org/10.4093/dmj.2024.0364

Original Article
Metabolic Risk/Epidemiology

Diabetes Metab J 2025;49:475-484
https://doi.org/10.4093/dmj.2024.0364
pISSN 2233-6079 · eISSN 2233-6087

dmj
DIABETES & METABOLISM JOURNAL

Trends in Metabolically Unhealthy Obesity by Age, Sex, Race/Ethnicity, and Income among United States Adults, 1999 to 2018

Wen Zeng[1,2], Weijiao Zhou[2], Junlan Pu[2], Juan Li[1], Xiao Hu[1], Yuanrong Yao[1], Shaomei Shang[2]

[1]Guizhou Provincial People's Hospital, Guiyang,
[2]School of Nursing Peking University Health Science Center, Beijing, China

Background: This study aimed to estimate temporal trends in metabolically unhealthy obesity (MUO) among United States (US) adults by age, sex, race/ethnicity, and income from 1999 to 2018.
Methods: We included 17,230 non-pregnant adults from a nationally representative cross-sectional study, the National Health and Nutrition Examination Survey (NHANES). MUO was defined as body mass index ≥30 kg/m^2 with any metabolic disorders in blood pressure, blood glucose, and blood lipids. The age-adjusted percentage of MUO was calculated, and linear regression models estimated trends in MUO.
Results: The weighted mean age of adults was 47.28 years; 51.02% were male, 74.64% were non-Hispanic White. The age-adjusted percentage of MUO continuously increased in adults across all subgroups during 1999–2018, although with different magnitudes (all $P<0.05$ for linear trend). Adults aged 45 to 64 years consistently had higher percentages of MUO from 1999–2000 (34.25%; 95% confidence interval [CI], 25.85% to 42.66%) to 2017–2018 (42.03%; 95% CI, 35.09% to 48.97%) than the other two age subgroups ($P<0.05$ for group differences). The age-adjusted percentage of MUO was the highest among non-Hispanic Blacks while the lowest among non-Hispanic Whites in most cycles. Adults with high-income levels generally had lower MUO percentages from 1999–2000 (22.63%; 95% CI, 17.00% to 28.26%) to 2017–2018 (32.36%; 95% CI, 23.87% to 40.85%) compared with the other two subgroups.
Conclusion: This study detected a continuous linear increasing trend in MUO among US adults from 1999 to 2018. The persistence of disparities by age, race/ethnicity, and income is a cause for concern. This calls for implementing evidence-based, structural, and effective MUO prevention programs.

Keywords: Health inequities; Metabolic diseases; Metabolic syndrome; Obesity; Trends

INTRODUCTION

Obesity, which is traditionally assessed by the body mass index (BMI) with a cut-off value of ≥30 kg/m^2, has become one of the most challenging public health issues globally and within the United States (US) [1] since it is typically linked to an array of metabolic abnormalities or metabolic disorders such as hypertension, dyslipidemia, and impaired blood glucose et al. [2,3] and an increase in the incidence of cardiovascular diseases (CVD) such as stroke, heart failure, and coronary heart disease [4-6].

However, it was increasingly debated that obesity classification based on BMI status alone may not provide adequate information about current health status [2] because the risk of

Corresponding author: Yuanrong Yao https://orcid.org/0000-0002-3594-1180
Neurological Ward of Guizhou Provincial People's Hospital, No. 83, Zhongshan East Road, Nanming District, Guiyang 550002, China
E-mail: yaoyuanrong@qq.com

Shaomei Shang https://orcid.org/0009-0001-0751-0797
School of Nursing Peking University Health Science Center, No. 38, Xueyuan Road, Haidian District, Beijing 100191, China
E-mail: shangshaomei0104@126.com

Received: Jul. 5, 2024; Accepted: Sep. 27, 2024

developing obesity-related complications in people with obesity is interindividual heterogeneous [5-7]. In other words, not all individuals with obesity exhibit metabolic disorders [8]. Under the rationale, metabolically healthy obesity (MHO) and metabolically unhealthy obesity (MUO) are developed by incorporating metabolic health status and BMI. Although there has not been a universally accepted definition [3], MHO is typically used to describe a subgroup of individuals who are with obesity but free from cardiometabolic disorders, including elevated triglycerides (TG), reduced high-density lipoprotein cholesterol (HDL-C), elevated blood pressure (BP), elevated fasting glucose, or drug treatment for those disorders [5,9]. In contrast to MHO, MUO refers to obesity with any metabolic disorders. Such novel concepts provide promising insight for stratifying people in the clinical treatment and management of obesity [7].

In recent years, MUO has received considerable attention, and results from empirical evidence suggest that MUO develops because MHO is not stable and is transient over time [10]. Schroder et al. [11] reported that nearly 50% of individuals with MHO converted to MUO. As emphasized in previous studies, each metabolic factor has been confirmed to be associated with an increased risk of CVD, and the excess in CVD-related mortality might result from the cluster of those metabolic factors [12]. Under the rationale of the obesity epidemic and the high risks of MUO-associated unfavorable health outcomes, shedding light on trends in MUO might be beneficial for the stratification and treatment of obesity and inform policy efforts.

Moreover, population factors such as age, sex, race/ethnicity, and family income lead to considerable disparities in obesity or metabolical health conditions [13-17]. To our knowledge, rooted causes of health inequality and health disparities in America are complicated, including social, economic, environmental, and structural factors. Among those factors, disparities based on race/ethnicity, especially between Whites and Blacks, are the most persistent and challenging to emphasize in the US [18] because they play a fundamental role in structuring socioeconomic disparities [19]. Another critical factor that impacts health inequity and health disparities is income and wealth. People with more income could get more opportunities to receive quality healthcare services and greater resources to afford a healthy lifestyle, housing, quality education, and so on [20]. However, few studies have examined the trends in the percentage of MUO among US adults by age, sex, race/ethnicity, and family income, making it unclear how MUO changed over time and leaving a knowledge gap in understanding and differentiating disparities of MUO trends by those factors. Therefore, a comprehensive understanding of the changes in secular trends in the prevalence of MUO helps provide evidence to inform more precise, novel policy strategies and targeted interventions for the stratification, treatment, and management of obesity to eliminate health disparities [21].

Therefore, the primary objective of this study was to use data from the National Health and Nutrition Examination Survey (NHANES) 1999-2018 to estimate trends in the percentage of MUO among US adults in different age and sex groups, the three largest racial/ethnic groups and different socioeconomic levels to determine long-term differences in changes in health inequities.

METHODS

Data source and study population

We used the most recent 10 cycles' data from a sequential series of nationally representative cross-sectional surveys, NHANES, from 1999–2000 to 2017–2018, with a response rate ranging from 48.8% to 76.0% [22]. Selecting participants using a complex, stratified, multistage probability cluster sampling design, the NHANES has been conducted every 2 years to assess noninstitutionalized people's health and nutritional status through questionnaires, physical examinations, and laboratory blood tests. In this study, we included non-pregnant adults aged 20 years and older. We excluded participants if they had missing data in demographic information (i.e., age, sex, self-reported race/ethnicity, education level, marital status, and family income-to-poverty ratio) and missing data on MUO (Supplementary Fig. 1).

Data collection

Demographic information was collected through a questionnaire during household interviews. Weight, height, and BP were measured through standard protocols. Well-trained laboratory staff members tested a blood sample for fasting plasma glucose, glycosylated hemoglobin level, TG, total cholesterol, and HDL-C.

The current analysis collected demographic data, including age, sex, race/ethnicity, educational background, marital status, and family poverty income ratio (FPIR) that represents annual family income compared to the federal poverty level [16,23]. This study separated participants into three age groups (20–44,

45–64, ≥65 years). We mainly included three racial groups (non-Hispanic White, non-Hispanic Black, and Hispanic) because of the relatively small numbers in other races/ethnicities, and Asians were not categorized until 2011. Socioeconomic status was stratified into three levels: at or below the poverty level if FPIR ≤100%, middle-income level if FPIR was from 101% to 399%, and high-income level if FPIR ≥400% [16,23].

Measurement of MUO

We collected medication, physical examination, and blood data to define MUO based on harmonized criteria. Participants were defined as MUO if they were with obesity (BMI ≥30 kg/m^2), and with any of the following criteria: (1) elevated BP, (2) elevated blood glucose, and (3) dyslipidemia [9,24]. More details are demonstrated in Supplementary Table 1.

Statistical analysis

We used SAS version 9.4 (SAS Institute Inc., Cary, NC, USA) and SUDAAN Release 11.0.4 (RIT International, Research Triangle Park, NC, USA) to perform the statistical analyses under the analytic guidelines of the NHANES. The analytic process incorporated the sample weights that accounted for the differential probabilities of the sampling selection, survey non-response, and post-stratification adjustment. We used the Taylor series linearization to estimate the variance (sampling errors). Firstly, the age-adjusted percentage of MUO was calculated using a direct standardization method based on the 2000 US Census population (20–44, 45–64, and ≥65 years) [25]. Then, we used the orthogonal polynomial option to test the nonlinearity of the trends by adding quadratic effects. If the trends were found to be nonlinear, the joinpoint regression modeling through the Joinpoint Desktop Software version 5.0.2 (National Cancer Institute, Bethesda, MD, USA) was used to estimate the number and location of possible joinpoints. Once the joinpoints were identified, a joint regression model with one or more joints was used to obtain the final slope of the trends. If the trends were found to be linear, a linear regression model was fit to obtain the final slope of the trends. We also compared FPIR by race/ethnicity. All statistical tests were two-sided, and the significance was *P* less than 0.05.

Ethics approval

The NHANES was approved by the National Center for Health Statistics Research Ethics Review Board (Protocol #98-12, Protocol #05-06, Protocol #2011-17, Protocol #2018-01, https://www.cdc.gov/nchs/nhanes/irba98.htm), and written informed consent was obtained from all participants. This analysis was exempt from an institutional ethical review because we used a publicly available, de-identified dataset. For the current study, we used data from 1999 to 2018, publicly available at https://wwwn.cdc.gov/nchs/nhanes/Default.aspx.

RESULTS

Sociodemographic characteristics

We included 17,230 non-pregnant participants with a weighted mean±standard error age of 47.28±0.23 years in the final trend analysis, representing 178,994,217 US adults aged 20 years and older. Across all years from 1999–2000 to 2017–2018, 8,664 (51.02%) were male, 8,787 (74.64%) were non-Hispanic White, 8,542 (58.66%) were at an education background of high school or below, 8,390 (65.71%) were married or living with a partner, and 9,378 (50.48%) were at a middle-income level. More details are displayed in Table 1. As shown in Supplementary Table 2, non-Hispanic Whites had the highest proportion of high income among three racial/ethnic groups from 1999–2000 to 2017–2018 ($P<0.001$).

MUO trends by age

Tables 2, 3, and Fig. 1A illustrate the age-adjusted percentage of MUO in adults of different ages. Surprisingly, the age-adjusted percentage of MUO in adults aged 45–64 years was significantly higher than those aged 20–44 or ≥65 years from 1999–2000 through 2017–2018 ($P<0.05$ for group differences). The age-adjusted percentage of MUO increased in US adults across all age subgroups from 1999–2000 through 2017–2018 (all $P<0.05$ for linear trend). Specifically, during 1999–2018, the age-adjusted percentage of MUO in adults aged 20–44 years increased by 1.24% points per survey cycle from 23.51% (95% confidence interval [CI], 18.94% to 28.07%) in 1999–2000 to 33.95% (95% CI, 28.58% to 39.32%) in 2017–2018 ($P<0.001$ for linear trend). A similar linear trend was also observed in adults aged 45–64 and ≥65 years, although with different magnitudes during the same period.

MUO trends by sex

An increasing trend in the age-adjusted percentage of MUO was observed in both male and female adults. MUO among male adults increased at 1.27% points per survey cycle from 27.06% (95% CI, 22.27% to 31.85%) in 1999–2000 to 36.49% (95% CI,

Table 1. Sociodemographic characteristics of the included participants in the NHANES, 1999 to 2018

Characteristic	1999–2000 (*n*=1,299)	2001–2002 (*n*=1,769)	2003–2004 (*n*=1,637)	2005–2006 (*n*=1,619)	2007–2008 (*n*=1,992)	2009–2010 (*n*=2,148)	2011–2012 (*n*=1,705)	2013–2014 (*n*=1,848)	2015–2016 (*n*=1,674)	2017–2018 (*n*=1,539)	1999–2018 (*n*=17,230)
Age, yr	46.24±0.78	46.02±0.80	46.46±0.66	46.93±0.89	46.88±0.59	47.71±0.62	47.77±0.69	47.77±0.65	47.98±0.62	48.65±0.76	47.28±0.23
Age group, yr											
20–44	536 (51.62)	753 (49.12)	654 (49.55)	674 (45.75)	764 (45.95)	877 (45.28)	734 (45.36)	755 (45.81)	627 (43.00)	555 (41.84)	6,929 (46.14)
45–64	418 (31.94)	590 (36.15)	499 (34.15)	532 (36.85)	698 (36.97)	734 (35.60)	584 (37.29)	638 (34.47)	612 (37.20)	571 (36.84)	5,876 (35.86)
≥65	345 (16.44)	426 (14.73)	484 (16.30)	413 (17.40)	530 (17.08)	537 (19.12)	387 (17.35)	455 (19.72)	435 (19.80)	413 (21.32)	4,425 (18.00)
Sex											
Male	651 (48.07)	912 (49.65)	841 (49.58)	865 (49.49)	979 (48.83)	1,014 (48.65)	854 (49.42)	889 (48.89)	807 (48.23)	754 (48.83)	8,566 (48.98)
Female	648 (51.93)	857 (50.35)	796 (50.42)	754 (50.51)	1,013 (51.17)	1,134 (51.35)	851 (50.58)	959 (51.11)	867 (51.77)	785 (51.17)	8,664 (51.02)
Race/ethnicity											
Non-Hispanic White	621 (74.24)	998 (78.08)	938 (76.81)	871 (77.06)	1,040 (75.81)	1,138 (75.45)	816 (72.86)	987 (72.75)	697 (72.19)	681 (71.46)	8,787 (74.64)
Hispanic	438 (15.28)	465 (11.85)	378 (11.12)	365 (11.46)	568 (13.03)	641 (13.24)	429 (15.11)	465 (15.26)	592 (15.93)	443 (16.87)	4,784 (13.91)
Non-Hispanic Black	240 (10.48)	306 (10.07)	321 (12.06)	383 (11.48)	384 (11.16)	369 (11.31)	460 (12.02)	396 (11.99)	385 (11.89)	415 (11.68)	3,659 (11.45)
Education level											
High school or below	485 (23.26)	510 (18.09)	466 (17.87)	417 (16.53)	585 (19.53)	594 (18.24)	408 (16.65)	413 (15.86)	393 (14.08)	319 (10.95)	4,590 (16.90)
High school	290 (28.01)	409 (26.02)	412 (26.78)	399 (25.78)	508 (25.13)	484 (22.71)	382 (19.80)	420 (21.19)	399 (22.81)	395 (27.64)	4,098 (24.44)
College or above	524 (48.73)	850 (55.89)	759 (55.35)	803 (57.69)	899 (55.34)	1,070 (59.05)	915 (63.54)	1,015 (62.95)	882 (63.11)	825 (61.42)	8,542 (58.66)
Marital status											
Partnered[a]	840 (67.66)	1,161(67.51)	1,017 (65.96)	1,038 (66.88)	1,212 (63.61)	1,294 (64.56)	979 (62.75)	1,118 (64.29)	994 (64.47)	874 (61.37)	10,527 (64.80)
Not partnered[b]	459 (32.34)	608 (32.49)	620 (34.04)	581 (33.12)	780 (36.39)	854 (35.44)	726 (37.25)	730 (35.71)	680 (35.53)	665 (38.63)	6,703 (35.20)
Income[c]											
FPIR ≤1.00	227 (12.18)	280 (12.65)	268 (12.09)	254 (9.25)	378 (13.21)	460 (14.04)	415 (15.83)	439 (16.88)	397 (14.17)	298 (12.06)	3,416 (13.31)
FPIR 1.01–3.99	699 (50.21)	936 (49.17)	923 (51.26)	916 (53.70)	1,098 (48.67)	1,155 (51.95)	889 (50.23)	962 (49.07)	903 (49.52)	897 (10.49)	9,378 (50.48)
FPIR ≥4.00	373 (37.61)	553 (38.18)	446 (36.65)	449 (37.05)	516 (38.11)	533 (34.01)	401 (33.94)	447 (34.05)	374 (36.31)	344 (36.84)	4,436 (36.21)

Values are presented as mean±standard error or number (%).
NHANES, National Health and Nutrition Examination Surveys; FPIR, family poverty income ratio.
[a]Married or living with a partner, [b]Widowed, divorced, separated, or never married, [c]Evaluated by family poverty income ratio.

Table 2. Age-adjusted prevalence of MUO among adults aged 20 years and older by races/ethnicities and income, NHANES 1999 to 2018[a]

Variable	1999–2000 (*n*=1,299)	2001–2002 (*n*=1,769)	2003–2004 (*n*=1,637)	2005–2006 (*n*=1,619)	2007–2008 (*n*=1,992)	2009–2010 (*n*=2,148)	2011–2012 (*n*=1,705)	2013–2014 (*n*=1,848)	2015–2016 (*n*=1,674)	2017–2018 (*n*=1,539)	*P* value[b]	*P* value[c]
By age group, % (95% CI)												
20–44 years	23.51 (18.94–28.07)	22.39 (18.68–26.11)	25.36 (21.25–29.46)	25.95 (21.06–30.85)	24.15 (20.22–28.07)	27.52 (23.52,31.53)	26.90 (22.79–31)	32.24 (27.94–36.53)	32.13 (24.49–39.76)	33.95 (28.58–39.32)	<0.001	0.264
45–64 years	34.25 (25.85–42.66)	32.35 (28.06–36.64)	35.23 (31.89–38.56)	38.25 (33.84–42.67)	34.37 (29.88–38.86)	39.55 (36.41–42.68)	37.90 (30.80–45.01)	39.20 (34.05,44.35)	44.15 (36.22–52.08)	42.03 (35.09–48.97)	0.005	0.752
≥65 years	28.55 (23.5–33.59)	24.64 (19.51–29.77)	29.56 (24.69–34.44)	33.20 (27.73–38.67)	28.85 (24.77–32.92)	35.44 (29.78–41.11)	38.01 (31.57–44.45)	30.80 (24.12–37.47)	36.65 (30.62–42.67)	40.74 (35.15–46.33)	<0.001	0.819
P value[d]	<0.05	<0.001	<0.001	<0.001	<0.001	<0.001	<0.05	<0.05	<0.05	<0.05		
By sex, % (95% CI)												
Male	27.06 (22.27–31.85)	24.58 (21.39–27.76)	28.41 (24.31–32.52)	29.81 (25.53–34.08)	26.62 (23.58–29.65)	33.32 (28.90–37.73)	31.96 (28.16–35.76)	30.95 (27.49–34.41)	37.28 (31.72–42.85)	36.49 (30.39–42.59)	<0.001	0.466
Female	28.21 (23.18–33.24)	27.18 (23.92–30.44)	29.90 (26.33–33.47)	32.07 (28.47–35.67)	29.95 (26.49–33.41)	32.05 (28.95–35.15)	32.53 (27.03–38.03)	37.28 (34.62–39.95)	35.92 (31.76–40.08)	38.93 (31.19–46.67)	<0.001	0.529
P value[d]	>0.05	>0.05	>0.05	>0.05	>0.05	>0.05	>0.05	<0.001	>0.05	>0.05		
By race/ethnicity, % (95% CI)												
Non-Hispanic White	27.17 (21.72–32.63)	25.60 (22.51–28.69)	27.85 (24.22–31.49)	29.89 (25.91–33.87)	26.30 (22.43–30.16)	30.15 (27.47–32.83)	30.05 (25.82–34.28)	32.36 (29.52–35.20)	35.41 (29.81–41.01)	35.74 (29.55–41.93)	<0.001	0.248
Hispanic	26.27 (22.00–30.54)	22.27 (16.86–27.67)	29.47 (23.11–35.83)	27.73 (23.89–31.57)	33.13 (27.56–38.70)	36.70 (31.17–42.23)	39.15 (33.56–44.75)	36.57 (31.84–41.30)	39.95 (34.67–45.24)	41.92 (38.09–45.74)	<0.001	0.648
Non-Hispanic Black	34.38 (26.56–42.20)	30.96 (26.43–35.50)	37.92 (32.35–43.50)	40.24 (34.82–45.67)	35.08 (29.68–40.49)	45.89 (38.75–53.03)	38.59 (32.65–44.53)	40.20 (35.78–44.61)	39.89 (35.86–43.91)	42.59 (38.46–46.72)	0.003	0.324
P value[d]	>0.05	<0.05	<0.05	<0.001	<0.05	<0.001	<0.05	<0.001	>0.05	>0.05		
By income, % (95% CI)												
FPIR ≤1.00	28.24 (21.88–34.60)	28.54 (22.89–34.19)	28.11 (22.60–33.62)	39.22 (30.49–47.94)	35.22 (28.78–41.67)	35.67 (31.63–39.71)	38.17 (31.63–44.72)	35.98 (30.07–41.89)	37.85 (31.69–44.01)	45.74 (34.89–56.60)	<0.001	0.945
FPIR 1.01–3.99	31.38 (25.83–36.92)	28.98 (26.33–31.63)	30.19 (26.85–33.53)	33.22 (29.01–37.43)	29.57 (26.52–32.62)	35.13 (30.86–39.39)	34.54 (30.86–38.22)	38.50 (34.29–42.70)	38.58 (31.80–45.36)	38.22 (33.03–43.42)	<0.001	0.433
FPIR ≥4.00	22.63 (17.00–28.26)	21.31 (16.23–26.38)	27.75 (22.04–33.45)	24.67 (20.19–29.14)	23.16 (18.68–27.64)	27.72 (21.61–33.83)	24.71 (19.51–29.90)	27.03 (21.96–32.11)	34.64 (25.98–43.30)	32.36 (23.87–40.85)	0.004	0.349
P value[d]	<0.05	<0.05	>0.05	<0.05	<0.001	>0.05	<0.001	<0.05	>0.05	>0.05		

MUO, metabolically unhealthy obesity; NHANES, National Health and Nutrition Examination Surveys; CI, confidence interval; FPIR, family poverty income ratio.
[a]Age-adjusted for the entire United States (US) population by the direct standardization method to the US 2000 Census population using the following age categories: 20–44, 45–64, 65 years or older, [b]*P* values for orthogonal polynomial contrasts—Linear contrast, [c]*P* values for orthogonal polynomial contrasts—Quadratic contrast, [d]*P* value for group differences.

30.39% to 42.59%) in 2017–2018, while MUO among female adults increased at 1.29% points per survey cycle at the same period ($P<0.001$ for linear trend) (Tables 2, 3, and Fig. 1B).

Table 3. Parameter estimates for joinpoints regression models fit trends in MUO among United States adults aged 20 years or over by age and sex: 1999–2000 through 2017–2018[a]

Variable[b]	Slope	SE	*P* of test that slope=0
By age group			
20–44 years (0 joinpoints)	1.24	0.29	<0.001
45–64 years (0 joinpoints)	1.10	0.37	0.003
≥65 years (0 joinpoints)	1.33	0.32	<0.001
By sex			
Male (0 joinpoints)	1.27	0.28	<0.001
Female (0 joinpoints)	1.29	0.30	<0.001

MUO, metabolically unhealthy obesity; SE, standard error.
[a]Running joinpoints regression models with 0 joinpoints to estimate the slope of linear trend, [b]Linear regression model with zero joinpoint.

MUO trends by race/ethnicity

Tables 2, 4, and Fig. 1C present an overview of MUO trends by

Table 4. Parameter estimates for linear regression models fit trends in MUO among United States adults aged 20 years or over by race/ethnicity and income: 1999–2000 through 2017–2018[a]

Variable[b]	Slope	SE	*P* of test that slope=0
By race/ethnicity			
Non-Hispanic White (0 joinpoints)	1.13	0.27	<0.001
Hispanic (0 joinpoints)	2.05	0.27	<0.001
Non-Hispanic Black (0 joinpoints)	1.09	0.30	<0.001
By income			
FPIR ≤1.00 (0 joinpoints)	1.51	0.43	0.001
1.00< FPIR ≤3.99 (0 joinpoints)	1.18	0.28	<0.001
FPIR ≥4.00 (0 joinpoints)	1.29	0.37	0.001

MUO, metabolically unhealthy obesity; SE, standard error; FPIR, family poverty income ratio.
[a]Running joinpoints regression models with 0 joinpoints to estimate the slope of linear trend, [b]Linear regression model with zero joinpoint.

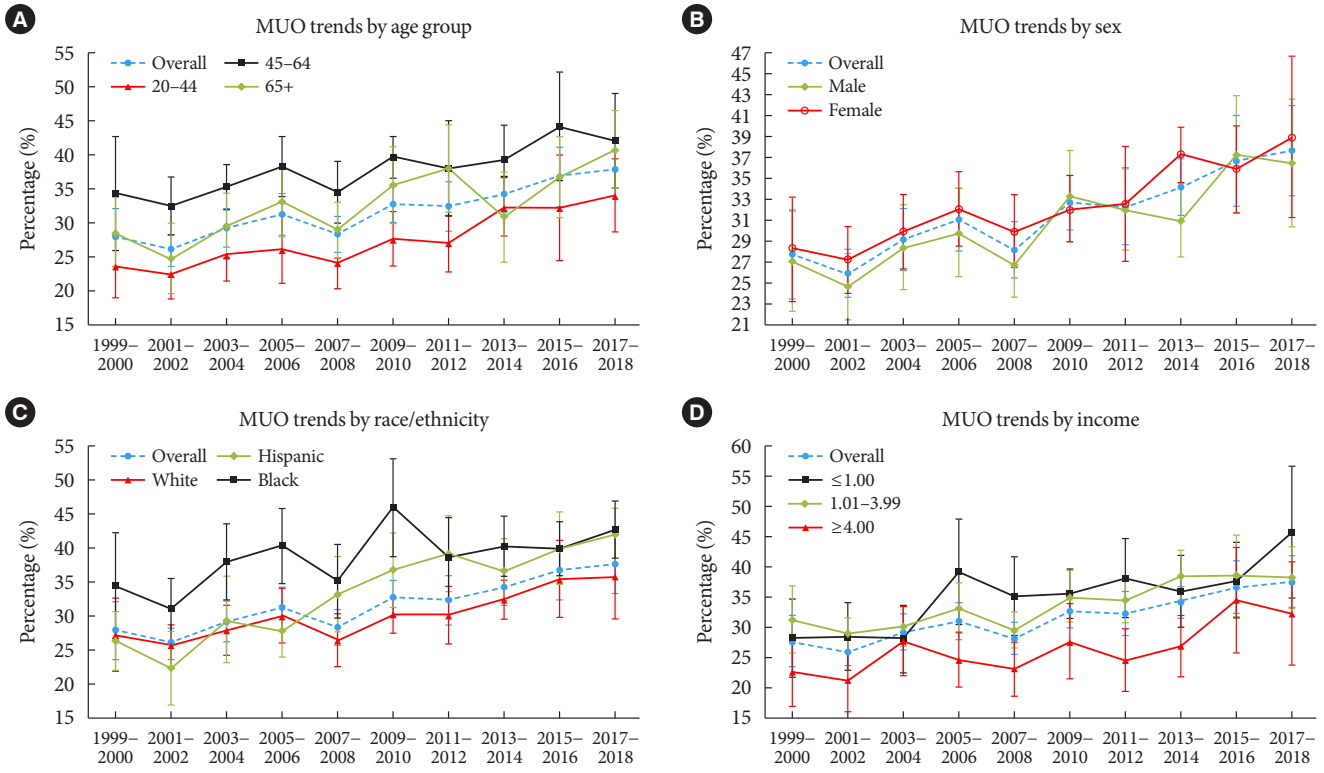


Fig. 1. Trends in metabolically unhealthy obesity (MUO) by (A) age, (B) sex, (C) race/ethnicity, and (D) income from 1999–2000 to 2017–2018.

race/ethnicity. It is apparent that the age-adjusted percentage of MUO in non-Hispanic Black adults was the highest, while that in non-Hispanic White adults was the lowest in most survey cycles. Moreover, a clear increasing trend in the age-adjusted percentage of MUO was observed among the study population (all $P<0.05$ for linear trend). Specifically, the age-adjusted percentage of MUO in non-Hispanic Black adults increased by a slope of 1.13% points per cycle from 34.38% (95% CI, 26.56% to 42.20%) in 1999–2000 to 42.59% (95% CI, 38.46% to 46.72%) in 2017–2018 ($P=0.003$ for linear trend). Notably, MUO in Hispanic adults increased at 2.05% points per survey cycle, much higher than in the other two racial/ethnic adults.

MUO trends by income

As demonstrated in Tables 2, 4, and Fig. 1D, adults with high-income levels generally had lower MUO percentages from 1999–2000 (22.63%; 95% CI, 17.00% to 28.26%) to 2017–2018 (32.36%; 95% CI, 23.87% to 40.85%) compared with the other two groups. This study also found an increasing trend in the age-adjusted percentage of MUO in adults with different income levels (all $P<0.05$ for linear trend). The results of the linear regression model indicated that adults at or below the poverty level (FPIR ≤1.00) increased at a greater slope (1.51% points per cycle) than those in the other two income groups.

DISCUSSION

Principal findings

The current study aimed to estimate and compare the temporal trends in MUO among US adults aged 20 years and older across age, sex, race/ethnicity, and income from 1999–2000 through 2017–2018 using a nationally representative sample. The core finding of this study is that we detected a continuous linear increase in MUO percentage in US adults. Furthermore, our study highlights emerging age, race/ethnicity, and income disparities that persisted in temporal MUO trends. The key findings of this study update and add additional information to the literature on MUO trends among US adults and complement research detailing disparities in MUO prevalence by providing temporal sociodemographic and socioeconomic components.

The most unexpected finding of this study is that the age-adjusted percentage of MUO was consistently higher in adults aged 45 to 64 years than those in the other two age subgroups from 1999 to 2018. This finding is contrary to that of Liu et al. [26] who found that adults aged 65 years and older had the highest prevalence of MUO. A possible explanation for this might be the differences in defining MUO. For example, we used more strict criteria to define MUO as obesity with any of the metabolic disorders in our study. In contrast, it was described as obesity with three or more metabolic disorders in the study of Liu et al. [26]. From this aspect, a universally accepted definition of MUO is needed. We also found a significant increasing trend in MUO across all age groups in the study, consistent with earlier reports [26]. Such a finding suggests that greater attention and efforts for MUO prevention must begin early.

There is an ongoing controversy on sex differences in the prevalence of MUO. A report by Marcus et al. [27] suggested men were more likely to be with MUO than women, whereas Wen et al. [28] reported that the prevalence of MUO was consistently higher in females than males from 1999 to 2014. However, our study did not observe sex differences in the prevalence of MUO, which was in line with the results of Liu et al. [26]. Furthermore, our study detected a rising linear trend at a similar slope in the prevalence of MUO in both male and female adults, contrary to Wen et al.'s results. [28] the prevalence of MUO demonstrated a logarithmic increase in females while an inverse U-shape increase in males. So far, the association and mechanism between sex and MUO disparities are unclear [15]. More studies are needed to explore sex or gender differences related to MUO.

Racial/ethnic and socioeconomic disparity in metabolic disorders and associated obesity has received continuous attention in recent years. In line with previous reports [26,28], our study confirms MUO differences related to racial/ethnic disparities, particularly between non-Hispanic Blacks and non-Hispanic Whites, as well as socioeconomic disparities. We found that non-Hispanic Blacks had higher percentages of MUO. In comparison, non-Hispanic Whites had lower percentages of MUO in most survey cycles, and we also observed that MUO prevalence was consistently lower in low-income adults during the entire study period. The intertwined association between income and health inequality [29] might explain those findings. As shown in our study, non-Hispanic White had significant higher proportion of high income than non-Hispanic Black, such disparities in MUO trends by race/ethnicity and income might result from widened disparities in obesity and metabolic disorders prevention and control rooted in diet intake (including frequency of fast food, consumption of sugar-sweetened beverages, diet quality, and food security), physical activities (including leisure-time and work-related

physical activity), sleep quality, smoking behavior, environmental exposure [14], and access to high quality of health services [30,31]. Our findings provide clues for developing novel, evidence-based, structural, and practical strategies to eliminate racial and socioeconomic disparities in MUO is a high priority.

Strengths and limitations of the study

The main strength of the current study is the use of extensive, nationally representative, standardized serial cross-sectional survey data from 1999–2000 to 2017–2018 to estimate the temporal trends and disparities in MUO percentages among US adults across age, sex, race/ethnicity, and income. This ensures the validity of our results. However, we have to acknowledge that this study has limitations. First, the nature of the cross-sectional research prevents us from estimating longitudinal changes in MUO over time. Second, there are different definitions used to define MUO so far, and there is no universally accepted definition of MUO. The criteria in our study are several commonly used, which might limit the generalizability and interpretation of our findings. Different defining approaches might explain the heterogeneous findings on the prevalence and clinical outcomes of MUO. For instance, Liu et al. [32] compared the prevalence of obesity phenotypes using five different MUO definitions for the same population. They found that the prevalence of MUO in the same population was inconsistent and varied greatly based on different definitions of MUO. Therefore, longitudinal studies with a globally accepted definition of MUO would allow researchers to better understand the changes in MUO.

Clinical implications

The finding of continuous linear increase in the age-adjusted prevalence of MUO from 1999 to 2018 highlighted that MUO remains a major public health issue in the US. In other words, it is a huge challenge to face with combined burden of obesity and metabolic problems. Therefore, early recognition of metabolic disorders in obese people is of importance. We suggest that people with obesity should participate in assessment for metabolic health status as much as possible. Additionally, health professionals should deliver interventions including weight management, physical activity, dietary modification, smoking cessation, and drug treatment et al., as soon as possible to address the underlying metabolic disorders and coexistent risk factors [12]. Regarding the disparities in the prevalence of MUO by age, sex, race/ethnicity, and income in our study, we suggest that evidence-based, effective, accessible policies or strategies such as income allocation, health services accessibility, health insurance coverage, food environment and safety et al. [33,34] should be informed and implemented to eliminate the health disparities in the US.

Conclusion

In summary, our study found a sustained increasing trend in MUO percentage among US adults aged 20 years and older. Age, race/ethnicity, and income disparities persisted in the temporal trends in MUO. Particularly, middle-aged, non-Hispanic Black and low-income adults appear to have the greatest need for MUO prevention. Those findings suggest that MUO is a significant health concern, and addressing MUO disparities among US adults is a high priority in research, clinical practice, and policymaking. From a public health point of aspect, our study highlights disparate groups that require timely assessment of MUO and implementation of evidence-based, structural policy.

SUPPLEMENTARY MATERIALS

Supplementary materials related to this article can be found online at https://doi.org/10.4093/dmj.2024.0364.

CONFLICTS OF INTEREST

No potential conflict of interest relevant to this article was reported.

AUTHOR CONTRIBUTIONS

Conception or design: W.Z., S.S.
Acquisition, analysis, or interpretation of data: W.Z., W.Z., J.P., J.L., X.H., Y.Y.
Drafting the work or revising: W.Z.
Final approval of the manuscript: all authors.

ORCID

Wen Zeng *https://orcid.org/0000-0001-5454-8504*
Yuanrong Yao *https://orcid.org/0000-0002-3594-1180*
Shaomei Shang *https://orcid.org/0009-0001-0751-0797*

FUNDING

This study was supported by the Ministry of Science and Technology of the People's Republic of China (2020YFC2008801 and 2020YFC2008800) and the National Natural Science Foundation of China (81860245). The funders had no role in designing and conducting the study, data collection, management, analysis, interpretation, preparation, review, or approval of the manuscript or the decision to submit the manuscript for publication.

ACKNOWLEDGMENTS

None

REFERENCES

1. Lavie CJ, Neeland IJ. Is Metabolically healthy obesity really healthy for the heart? JACC Cardiovasc Imaging 2023;16:902-4.
2. Smith GI, Mittendorfer B, Klein S. Metabolically healthy obesity: facts and fantasies. J Clin Invest 2019;129:3978-89.
3. Petersen MC, Smith GI, Palacios HH, Farabi SS, Yoshino M, Yoshino J, et al. Cardiometabolic characteristics of people with metabolically healthy and unhealthy obesity. Cell Metab 2024;36:745-61.
4. Despres JP. Taking a closer look at metabolically healthy obesity. Nat Rev Endocrinol 2022;18:131-2.
5. Cuthbertson DJ, Wilding JP. Metabolically healthy obesity: time for a change of heart? Nat Rev Endocrinol 2021;17:519-20.
6. April-Sanders AK, Rodriguez CJ. Metabolically healthy obesity redefined. JAMA Netw Open 2021;4:e218860.
7. Stefan N, Haring HU, Hu FB, Schulze MB. Metabolically healthy obesity: epidemiology, mechanisms, and clinical implications. Lancet Diabetes Endocrinol 2013;1:152-62.
8. Iacobini C, Pugliese G, Blasetti Fantauzzi C, Federici M, Menini S. Metabolically healthy versus metabolically unhealthy obesity. Metabolism 2019;92:51-60.
9. Lavie CJ, Laddu D, Arena R, Ortega FB, Alpert MA, Kushner RF. Healthy weight and obesity prevention: JACC health promotion series. J Am Coll Cardiol 2018;72:1506-31.
10. Tsatsoulis A, Paschou SA. Metabolically healthy obesity: criteria, epidemiology, controversies, and consequences. Curr Obes Rep 2020;9:109-20.
11. Schroder H, Ramos R, Baena-Diez JM, Mendez MA, Canal DJ, Fito M, et al. Determinants of the transition from a cardiometabolic normal to abnormal overweight/obese phenotype in a Spanish population. Eur J Nutr 2014;53:1345-53.
12. Liberopoulos EN, Mikhailidis DP, Elisaf MS. Diagnosis and management of the metabolic syndrome in obesity. Obes Rev 2005;6:283-96.
13. Krueger PM, Reither EN. Mind the gap: race/ethnic and socioeconomic disparities in obesity. Curr Diab Rep 2015;15:95.
14. Garcia-Alexander G, Poston DL Jr. International handbook of the demography of obesity. Cham: Springer; 2022. Chapter 9, Race/ethnic and socioeconomic disparities in obesity; p153-72.
15. D'Archivio M, Coppola L, Masella R, Tammaro A, La Rocca C. Sex and gender differences on the impact of metabolism-disrupting chemicals on obesity: a systematic review. Nutrients 2024;16:181.
16. Kanjilal S, Gregg EW, Cheng YJ, Zhang P, Nelson DE, Mensah G, et al. Socioeconomic status and trends in disparities in 4 major risk factors for cardiovascular disease among US adults, 1971-2002. Arch Intern Med 2006;166:2348-55.
17. Kibria GM, Crispen R, Chowdhury MA, Rao N, Stennett C. Disparities in absolute cardiovascular risk, metabolic syndrome, hypertension, and other risk factors by income within racial/ethnic groups among middle-aged and older US people. J Hum Hypertens 2023;37:480-90.
18. Williams DR, Mohammed SA. Discrimination and racial disparities in health: evidence and needed research. J Behav Med 2009;32:20-47.
19. Farmer MM, Ferraro KF. Are racial disparities in health conditional on socioeconomic status? Soc Sci Med 2005;60:191-204.
20. Weinstein JN, Geller A, Negussie Y, Baciu A. Communities in action: pathways to health equity. Washington (DC): National Academies Press; 2017. Chapter 3, The root causes of health inequity; p99-184.
21. Bailey ZD, Feldman JM, Bassett MT. How structural racism works: racist policies as a root cause of U.S. racial health inequities. N Engl J Med 2021;384:768-73.
22. Centers for Disease Control and Prevention. About the National Health and Nutrition Examination Survey [Internet]. Atlanta: CDC; 2023 [cited 2024 Dec 12]. Available from: https://www.cdc.gov/nchs/nhanes/about_nhanes.htm.
23. Odutayo A, Gill P, Shepherd S, Akingbade A, Hopewell S, Tennankore K, et al. Income disparities in absolute cardiovascular risk and cardiovascular risk factors in the United States, 1999-2014. JAMA Cardiol 2017;2:782-90.

24. Bluher M. Metabolically healthy obesity. Endocr Rev 2020;41: bnaa004.
25. Klein RJ, Schoenborn CA. Age adjustment using the 2000 projected U.S. population. Healthy People 2010 Stat Notes 2001; 20:1-10.
26. Liu J, Zhang Y, Lavie CJ, Moran AE. Trends in metabolic phenotypes according to body mass index among US adults, 1999-2018. Mayo Clin Proc 2022;97:1664-79.
27. Marcus Y, Segev E, Shefer G, Eilam D, Shenkerman G, Buch A, et al. Metabolically healthy obesity is a misnomer: components of the metabolic syndrome linearly increase with BMI as a function of age and gender. Biology (Basel) 2023;12:719.
28. Wen Y, Liu T, Li S, Gong R, Li C. 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. BMJ Open 2022;12:e062651.
29. Chokshi DA. Income, poverty, and health inequality. JAMA 2018;319:1312-3.
30. National Center for Health Statistics. Health, United States spotlight: racial and ethnic disparities in heart disease 2019 [Internet]. Hyattsville: National Center for Health Statistics; 2019 [cited 2024 Dec 12]. Available from: https://www.cdc.gov/nchs/hus/spotlight/HeartDiseaseSpotlight_2019_0404.pdf.
31. Churchwell K, Elkind MS, Benjamin RM, Carson AP, Chang EK, Lawrence W, et al. Call to action: structural racism as a fundamental driver of health disparities: a presidential advisory from the American Heart Association. Circulation 2020; 142:e454-68.
32. Liu C, Wang C, Guan S, Liu H, Wu X, Zhang Z, et al. The prevalence of metabolically healthy and unhealthy obesity according to different criteria. Obes Facts 2019;12:78-90.
33. Min J, Goodale H, Xue H, Brey R, Wang Y. Racial-ethnic disparities in obesity and biological, behavioral, and sociocultural influences in the United States: a systematic review. Adv Nutr 2021;12:1137-48.
34. He J, Zhu Z, Bundy JD, Dorans KS, Chen J, Hamm LL. Trends in cardiovascular risk factors in US adults by race and ethnicity and socioeconomic status, 1999-2018. JAMA 2021;326:1286-98.

Supplementary Table 1. Criteria of metabolically unhealthy obesity

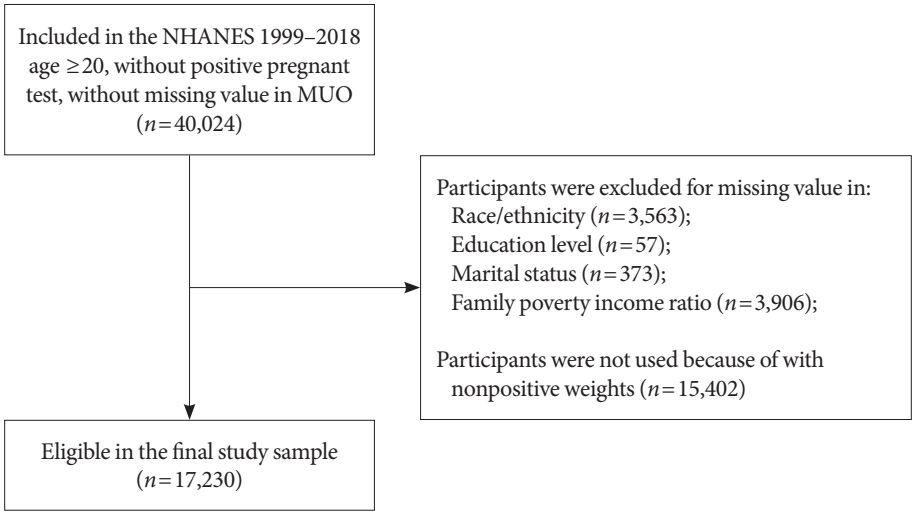
Item	Defining level
Obesity	BMI ≥30 kg/m^2
Metabolic syndrome	
Elevated blood pressure	BP ≥130/85 mm Hg; or using BP-lowering medication
Impaired blood glucose	FPG ≥100 mg/dL or HbA1c ≥5.7%; or using glucose-lowering medication
Dyslipidemia	TG ≥150 mg/dL; or HDL-C ≤40 mg/L (male) or ≤50 mg/dL (female)

BMI, body mass index; BP, blood pressure; FPG, fasting plasma glucose; HbA1c, glycosylated hemoglobin; TG, triglyceride; HDL-C, high-density lipoprotein cholesterol.

Supplementary Table 2. FPIR by race of the included participants in the NHANES, 1999–2018

Characteristic	1999–2000 (*n*=1,299)	2001–2002 (*n*=1,769)	2003–2004 (*n*=1,637)	2005–2006 (*n*=1,619)	2007–2008 (*n*=1,992)	2009–2010 (*n*=2,148)	2011–2012 (*n*=1,705)	2013–2014 (*n*=1,848)	2015–2016 (*n*=1,674)	2017–2018 (*n*=1,539)	1999–2018 (*n*=17,230)
Non-Hispanic White FPIR											
≤1.00	54 (7.77)	83 (8.13)	94 (8.16)	80 (5.88)	177 (10.91)	175 (9.46)	145 (9.92)	168 (10.88)	86 (7.79)	86 (7.90)	1,148 (8.72)
1.01–3.99	308 (47.62)	503 (47.75)	511 (49.43)	476 (51.58)	516 (44.23)	597 (50.82)	442 (50.26)	513 (48.31)	389 (48.06)	401 (48.51)	4,656 (48.68)
≥4.00	259 (44.61)	412 (44.11)	333 (42.40)	315 (42.54)	347 (44.86)	366 (39.72)	229 (39.82)	306 (40.81)	222 (44.15)	194 (43.59)	2,983 (42.60)
Hispanic FPIR											
≤1.00	123 (27.42)	125 (33.20)	102 (25.39)	102 (22.44)	131 (22.67)	205 (33.17)	153 (35.27)	162 (35.28)	214 (35.37)	104 (20.63)	1,421 (29.39)
1.01–3.99	260 (59.72)	272 (55.78)	235 (62.98)	204 (58.59)	348 (63.22)	342 (52.64)	442 (49.88)	239 (50.99)	291 (49.53)	263 (58.40)	2,664 (55.63)
≥4.00	55 (12.86)	68 (11.02)	41 (11.63)	59 (18.97)	89 (14.11)	94 (14.19)	66 (14.85)	64 (13.73)	87 (15.10)	76 (18.47)	699 (14.98)
Non-Hispanic Black FPIR											
≤1.00	50 (21.14)	72 (23.48)	72 (24.82)	72 (18.63)	70 (17.79)	80 (22.16)	117 (27.19)	109 (29.83)	97 (24.53)	108 (25.19)	847 (23.70)
1.01–3.99	131 (54.73)	161 (52.36)	177 (52.05)	236 (63.07)	234 (61.87)	216 (58.67)	237 (50.52)	210 (51.28)	223 (58.34)	233 (56.34)	2,058 (55.90)
≥4.00	59 (24.12)	73 (24.16)	72 (23.13)	75 (18.30)	80 (20.34)	73 (19.17)	106 (22.29)	77 (18.89)	65 (17.13)	74 (18.47)	754 (20.40)
P value	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001

Values are presented as number (%).
FPIR, family poverty income ratio; NHANES, National Health and Nutrition Examination Surveys.



Supplementary Fig. 1. Flowchart of National Health and Nutrition Examination Surveys (NHANES) study population included in the study. MUO, metabolically unhealthy obesity.