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Trends and key disparities of obesity among US adolescents: The NHANES from 2007 to 2020

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Abstract

This study aimed to estimate the trends in the body mass index (BMI) and prevalence of obesity among United States (U.S.) adolescents (10–19 years) and to examine the associations between sociodemographic factors and both BMI and obesity prevalence. The 2007–2020 National Health and Nutrition Examination Survey (NHANES), a nationally representative repeated cross-sectional survey data (n = 9,826) were used. Outcomes included: 1) Mean BMI and 2) obesity (yes/no; defined as BMI ≥95% percentile). Sociodemographic variables included age, sex, race/ethnicity, and poverty income ratio (PIR; low-income <1.3, middle-income ≥1.3 and <3.5, high-income ≥3.5). By accounting for the complex survey design, weighted generalized linear/Poisson models were used to conduct the analyses. Girls constituted 49% of the sample. From 2007–2008 to 2017–2020, there was an increase in BMI and obesity prevalence, particularly among Black and Hispanic adolescents, and those from low- and middle-income families. Additionally, there was an increase in obesity prevalence among both boys and girls. However, there were no significant changes in BMI and obesity prevalence in the other race and ethnic adolescents. Girls had a 12% (Adjusted Prevalence Ratio [APR] = 0.88; 95% CI, 0.81–0.96) lower likelihood of being obese than boys. Compared to White adolescents, Black and Hispanic adolescents had 22% (APR = 1.22; 95% CI, 1.06–1.40) and 19% (APR = 1.19; 95% CI, 1.05–1.36) greater risk of being obese. Compared to high-income families, adolescents from low- and middle-income families had 62% (APR = 1.62; 95% CI, 1.39–1.90) and 47% (APR = 1.47; 95% CI, 1.24–1.76) greater risk of being obese, respectively. The results indicated persistent disparities in obesity prevalence among different race/ethnic and sociodemographic groups. Future obesity intervention should address key disparities by targeting specific race/ethnic adolescents from low-income families and promoting health equality.

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Introduction

The increasing prevalence of childhood obesity in the United States (U.S.) has become a significant public health concern, elevating the risk of developing cardiometabolic comorbidities among U.S. adolescents [1–4]. Recent data from the Centers for Disease Control and Prevention (CDC) [5] showed that the prevalence of obesity among children and adolescents aged 2–19 years increased from 12 million (16.9%) in 2010 to 14.7 million (19.7%) in 2020. These concerning trends have long-term implications for the health and well-being of adolescents as they transition into adulthood [6–8]. The economic burden of obesity in the U.S. healthcare system was estimated to be $173 billion in 2021 [9]. Thus, monitoring national trends and examining the association between sociodemographic factors and weight-related outcomes among adolescents are critical to increase awareness and prevent childhood obesity.

Obesity among adolescents (aged 10–19 years) is defined as age- and sex-specific body mass index (BMI) greater than or equal to the 95th percentile based on the 2000 CDC growth chart [4]. Sociodemographic factors, such as age, sex, race/ethnicity, and socioeconomic status, have been associated with the prevalence of childhood obesity [1,10–12]. For example, a recent study showed a 4.5% increase in obesity prevalence among adolescents aged 12–19, from 17.7% in 2009–2010 to 21.5% in 2017–2020 [13]. Research showed a higher prevalence of obesity in boys than girls [14].

This increased rate is particularly pronounced among certain racial and ethnic minorities [15,16]. The most recent 2020 CDC data indicated that the prevalence of obesity among Black and Hispanic children was 24.8% and 26.2%, respectively, compared to 16.6% among White children [5]. In addition, youth from lower socioeconomic backgrounds are more likely to be obese than those from higher socioeconomic backgrounds [15,17], and families with lower incomes were 1.39 times more likely to have children who are obese than those from families with higher incomes [18].

Nevertheless, most studies on sociodemographic factors in relation to childhood obesity were cross-sectional reporting point prevalence estimates [19–21], with limited studies examining the key disparities in sociodemographic factors with long-term trends in mean BMI and obesity prevalence. Thus, there are a limited amount of studies on the most recent trends in obesity prevalence among U.S. adolescents aged 10–19 years. To address these gaps, we used a nationally representative sample from the National Health and Nutrition Examination Survey (NHANES) from 2007 to 2020. The aims of this study were two-fold: 1) to illustrate trends in mean BMI and obesity prevalence among U.S. adolescents, and 2) to examine how sociodemographic factors were associated with the mean BMI and obesity prevalence among this sample of U.S. adolescents. We hypothesized that there is a significant increasing trend in mean BMI and obesity prevalence among U.S. adolescents from 2007 to 2020. Additionally, we hypothesized the sociodemographic factors have a significant association with mean BMI and obesity prevalence among the sample of U.S. adolescents.

Methods

Study sample

This study utilized data from the NHANES from 2007 to 2020 [22], including the cross-sectional survey waves for years 2007–2008, 2009–2010, 2011–2012, 2013–2014, 2015–2016, and 2017–2020. To maintain a nationally representative estimates, the 2017–2020 period included the data until the beginning of the COVID-19 pandemic in March 2020 [5]. NHANES uses a stratified multistage sampling method to represent the US population. The sampling frame included a total of 11,357 participants aged 10–19 years. Participants were excluded due to 990

missing sociodemographic data (e.g., age, sex, race and ethnicity, poverty income ratio [PIR]), and 541 participants lacking outcome data (BMI). The final analytical sample resulted in n = 9,826 across the six NHANES waves spanning from 2007 to 2020 (S1 Fig). The NHANES protocol was approved by the National Center for Health Statistics research ethics review board, and all participants provided written informed consent.

Measures

All body measurements were assessed in accordance with a standardized protocol using calibrated instruments [5]. The standing height of the participants was measured using a portal stadiometer, and weight was measured using a portal digital weight scale. BMI was calculated by dividing weight in kilograms by squared height in meters. We further calculated their BMI percentile based on the relevant CDC growth charts for children and adolescents including ages 10 to 19 [23]. The adolescent's obesity was evaluated as their BMI percentile to classify into underweight (less than 5th percentile), normal weight (5th to 84th percentile), overweight (85th to 94th percentile), and obesity (at or above 95th percentile). A binary adolescent obesity outcome (Yes, No) was defined as BMI at or above the 95th percentile (Yes) and below the 95th percentile (No) [23].

Sociodemographic variables included age, sex (girls/boys), race/ethnicity, and PIR. Age was self-reported during the interview and was divided into two age groups: 10 to 14 years and 15 to 19 years [24]. Race/ethnicity was categorized as non-Hispanic White (referent, referred to as White), non-Hispanic Black (referred to as Black), Hispanic (including Mexican American and other Hispanic), and other adolescents (including other multi-racial and ethnic groups) [25,26]. The PIR is a measure of family income relative to poverty guidelines, which was determined by dividing family income by the poverty threshold specific to a family size and geographic location income levels were defined based on the PIR and coded as low income (PIR <1.3), middle income (PIR ≥ 1.3 and <3.5), and high income (PIR ≥ 3.5) [27].

Statistical analyses

Preparing the data involved several steps, such as removing missing values, examining the distribution, and identifying and removing outliers. Survey analysis procedures were used to derive nationally representative estimates, accounting for sampling weights, strata, and primary sampling units (PSU) in the NHANES complex sampling design [28].

In response to aim one, survey-weighted linear regression analysis was conducted to evaluate BMI trends, both overall and stratified by the subgroups (age, sex, race/ethnicity, and PIR), 2007 through 2020. Subsequently, Survey-weighted Poisson regression analysis was employed to evaluate the prevalence of obesity trends, both overall and by the subgroups (age, sex, race/ethnicity, and PIR) from 2007 through 2020. Finally, to evaluate the statistical heterogeneity of trends by subgroups, we used a survey-weighted Wald test for an interaction term between the survey cycle and sociodemographic factors such as age, sex, race/ethnicity, and PIR. For each survey cycle, we report 95% confidence intervals (CI) for all estimates.

To address the second aim, we used multivariate survey-weighted generalized linear/Poisson regression models with a Poisson distribution family and a log link function and robust standard errors to examine the association between sociodemographic factors and mean BMI and obesity prevalence, adjusting for survey wave [29]. Statistical significance was determined by p-value <0.05 (2-tailed). All analyses were conducted using the R statistical software "Survey" package (e.g., "svymean" and "svyglm"), taking into account the complex sampling design (version 4.2.2; www.r-project.org).

Results

Characteristics of study population

The nationally representative sample characteristics from 2007–2008 through 2017–2020, and the characteristics were presented in Table 1. The total sample comprised 9,826 adolescents with mean age of 14.29 years (SD ± 2.78), of which 49.0% were girls. The mean BMI increased from 22.85 (95% CI: 22.40–23.29) in 2007–2008 to 23.66 (95% CI: 23.15–24.03) in 2017–2020. Furthermore, the prevalence of obesity increased from 20.71% (95% CI: 17.16–24.27) in 2007–2008 to 23.99% (95% CI: 21.31–26.67) in 2017–2020. In the overall analyses, the results revealed a statistically significant increase in both BMI and obesity prevalence from 2007 to 2017 (Tables 1, S1 and S2). Fig 1 showed overall obesity prevalence weighted proportions stratified by age, sex, race/ethnicity, and PIR. Notably, Black and Hispanic adolescents showed higher obesity prevalence proportion rates than other race/ethnicity. Moreover, adolescents from low-income demonstrated the highest prevalence.

The Wald test analysis did not reveal any significant interaction between the survey cycle and both BMI and obesity prevalence concerning age groups and sex. However, a significant

Table 1. Descriptive table of children and adolescents aged 10–19 years old, by overall, sex, and race/ethnicity from 2007 to 2020.

Characteristics	N = 9,826 (survey weighted %)[a]						
	All (n = 9,826)	2007–2008 (n = 1,455)	2009–2010 (n = 1,546)	2011–2012 (n = 1,468)	2013–2014 (n = 1,671)	2015–2016 (n = 1,507)	2017–2020 (n = 2,179)
Age group, n (%)							
10–14	6,312 (62.0)	936 (60.7)	966 (61.8)	949 (62.8)	1060 (61.2)	991 (64.4)	1,410 (60.9)
15–19	3,514 (38.0)	519 (39.3)	580 (38.1)	519 (37.2)	611 (38.8)	516 (35.6)	769 (39.1)
Sex, n (%)							
Boys	5,013 (51.0)	770 (52.6)	810 (50.7)	736 (50.8)	838 (51.0)	762 (51.1)	1097 (49.5)
Girls	4,813 (49.0)	685 (47.4)	736 (49.3)	732 (49.2)	833 (49.0)	745 (48.9)	1082 (50.5)
Race/Ethnicity, n (%)							
White	2,934 (56.8)	475 (62.1)	519 (59.1)	351(56.6)	438 (54.6)	446 (55.7)	705 (52.1)
Black	2,472 (14.0)	377 (14.3)	345 (14.5)	455 (15.2)	423 (14.1)	321 (13.0)	551 (13.0)
Hispanic	3,099 (20.9)	535 (17.9)	585 (19.3)	420 (20.8)	545 (22.1)	490 (21.1)	524 (24.1)
Other race[b]	1,321 (8.3)	68 (5.7)	97 (7.1)	242 (7.4)	265 (9.2)	250 (10.2)	399 (10.8)
PIR,[c] n (%)							
PIR ≥3.5 (high-income)	2,125 (32.0)	328 (35.1)	322 (34.2)	312 (29.6)	342 (29.0)	312 (30.7)	509 (33.8)
PIR 1.35 to <3.5 (middle-income)	3,520 (36.5)	516 (33.4)	553 (35.8)	486 (35.5)	549 (36.8)	608 (42.1)	808 (37.3)
PIR <1.3 (low-income)	4,181 (31.5)	611 (31.5)	671 (30.0)	670 (34.9)	780 (34.2)	587 (27.2)	862 (28.8)
Outcomes							
BMI (Mean ± SD)	23.20 ± 6.0	22.85 ± 5.7	23.03 ± 5.7	23.14 ± 6.0	23.41 ± 6.4	23.20 ± 5.9	23.59 ± 6.3
Obesity (%)							
Yes	2,346 (22.0)	341 (20.7)	347 (20.4)	329 (21.9)	385 (22.9)	361 (21.9)	583 (24.0)
No	7,480 (78.0)	1,114 (79.3)	1,199 (79.6)	1,139 (78.1)	1,286 (77.1)	1,146 (78.1)	1,596 (76.0)

Abbreviations: BMI, body mass index.

Values are presented as frequency (weighted %) and mean ± SD.

[a]Data were weighted to be nationally representative.

[b]Other race include individuals self-identifying as non-Hispanic Asian, other, or being from more than one race or ethnic group.

[c]PIR: Poverty income ratio.

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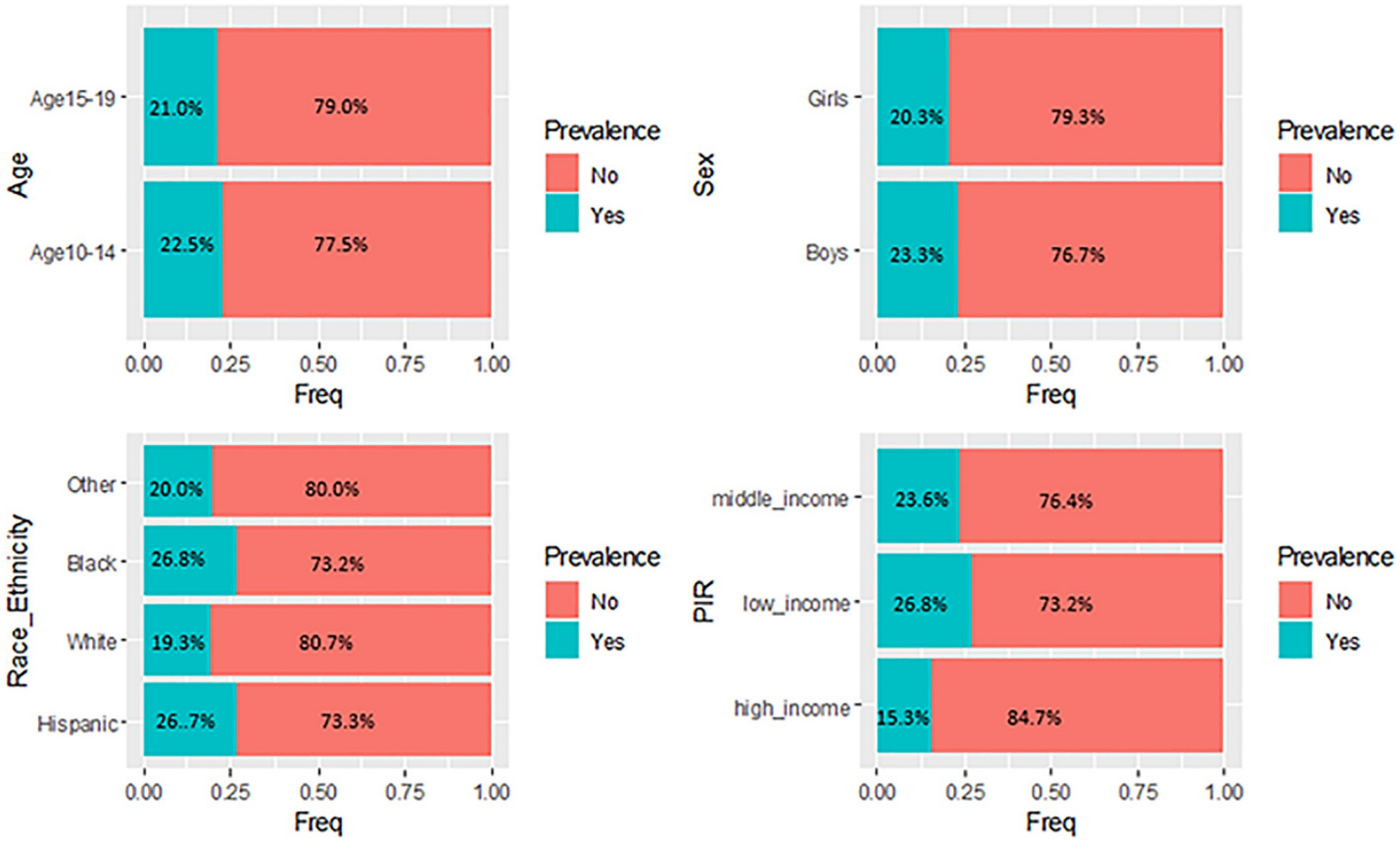

Fig 1. Weighted proportions in obesity prevalence stratify by sex, age and race/ethnicity and poverty income ratio from 2007–2008 to 2017–2020.

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interaction effect between survey cycle and both BMI and obesity prevalence was observed across various race/ethnic and PIR groups (S1 and S2 Tables).

Sociodemographic stratified trends and disparities in the BMI and prevalence of obesity

For the 15–19 age group, the mean BMI level significantly increased from 24.48 (95% CI: 23.84–25.13) in 2007–2008 to 25.53 (95% CI: 24.94–26.12) in 2020 ($p < 0.001$) (S2A Fig and S1 Table). However, the prevalence of obesity did not significantly increase from 18.7 (95% CI: 13.25–24.15) to 22.11 (95% CI: 18.29–25.94) (Fig 2A, Table 2). Additionally, there was no significant increase in BMI levels or obesity prevalence for the 10–14 age group. For girls (boys [reference]), mean BMI levels did not significantly increase from 22.11 (95% CI: 22.33–23.50) in 2007–2008 to 23.78 (95% CI: 23.23–24.33) in 2017–2020 ($p \geq 0.05$) (S2B Fig and S1 Table). However, there is a significant increase in the prevalence of obesity for girls (boys [reference]), from 19.37 (95% CI: 15.46–23.29) in 2007–2008 to 22.35 (95% CI: 18.47–26.22) in 2017–2020 ($p < 0.01$) (S2B Fig and S2 Table). Similar trends in mean BMI and obesity prevalence were observed in boys.

Among race/ethnic groups, Black adolescents had the highest increase in mean BMI from 23.90 (95% CI: 23.28–24.53) to 25.92 (95% CI: 24.28–25.56) ($p<0.001$) between 2007 and 2020 (S2C Fig). Hispanic adolescents also had an increase in mean BMI from 22.54 (95% CI: 22.89–24.18) to 24.07 (95% CI: 23.31–24.83) ($p < 0.001$). Yet, there was no significant trend in the

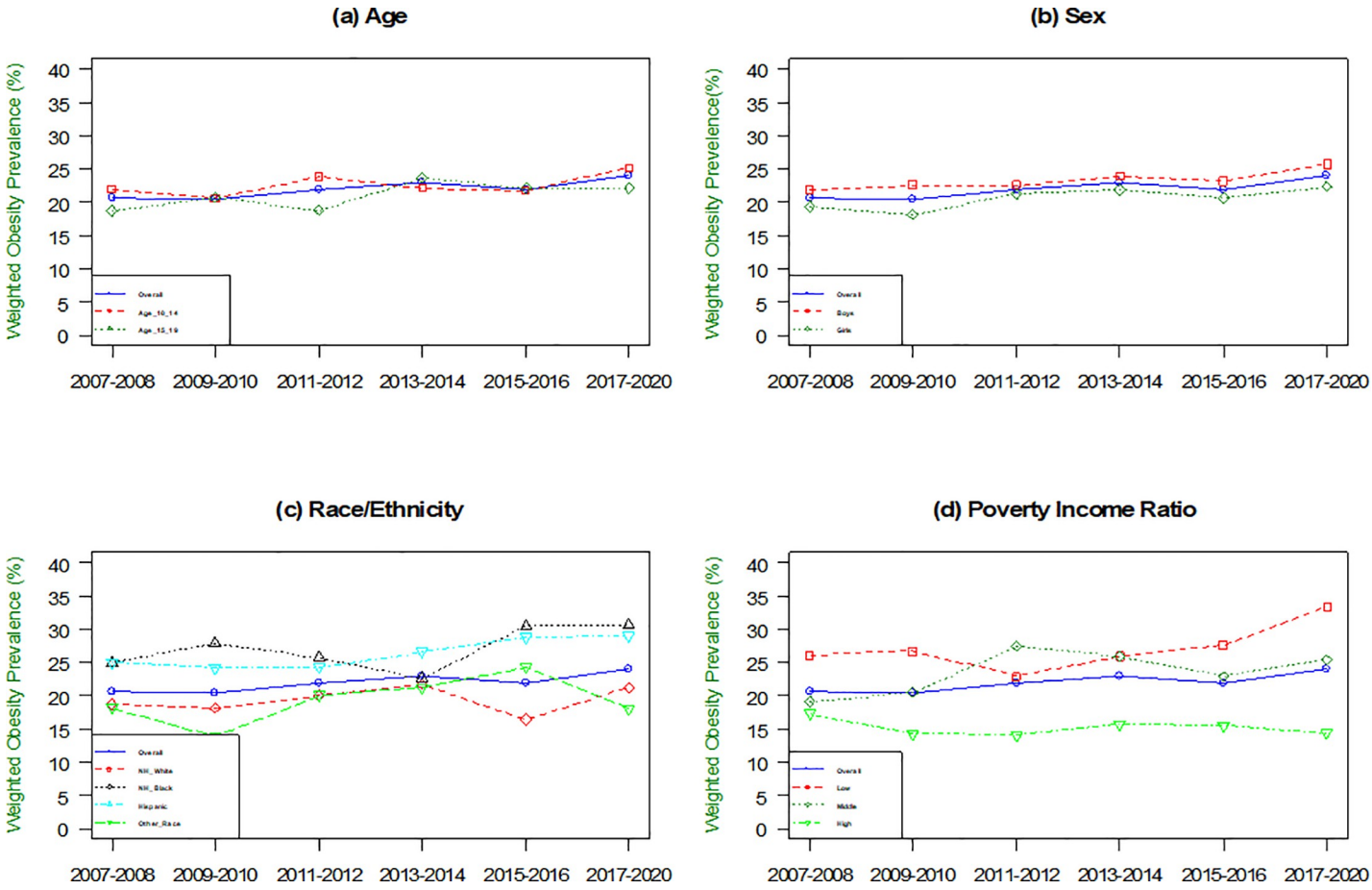

Fig 2. Trends in prevalence of obesity among US adults (aged 10–19), NHANES 2007–2020 by (a)Age, (b) Sex, (c) Race/ethnicity, and (d) Poverty Income Ratio.

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other race group. Similarly, for the obesity prevalence (Fig 2C), Black adolescents also had the highest increase, with a rise of 5.66% from 24.96 (95% CI: 22.07–33.45) to 30.62 (95% CI: 27.18–34.06) ($p < 0.001$) in 2007–2020. In addition, Hispanic adolescents had an increase from 24.21 (95% CI: 20.78–28.67) to 29.05 (95% CI: 22.97–35.13) ($p < 0.001$). However, there were no significant changes in BMI and obesity prevalence in the other race and ethnic adolescents.

Adolescents from low-(PIR <1.3) and middle-income families (PIR 1.3 to <3.5) had significant increases in mean BMI (S2D Fig). Specifically, the low-income group had a mean BMI of 23.57 (95% CI: 22.83–24.31), and the middle-income group had a mean BMI of 22.84 (95% CI: 22.10–23.59) in 2007–2008 to 24.82 (95% CI: 24.22–25.42), and 23.67 (95% CI: 22.96–24.38) in 2017–2020. The prevalence of obesity also increased significantly in the middle-income group, from 19.25 (95% CI: 13.37–25.12) in 2007–2008 to 25.45 (95% CI: 21.32–29.58) in 2017–2020 (Fig 2D, S2 Table). There was a significant decrease in the prevalence of obesity in the high-income group (PIR ≥3.5), from 17.31 (95% CI: 12.51–22.21) in 2007–2008 to 14.44 (95% CI: 11.50–17.38) in 2017–2020, although no significant changes in BMI were found.

Association of sociodemographic factors with BMI and obesity

Table 2 showed that age, sex, race/ethnicity, and PIR were significantly associated with mean BMI. Adolescents aged 15–19 years had a higher BMI (β = 3.27, 95% CI: 2.91–3.62) compared to ones aged 10–14 years. Black and Hispanic adolescents had a higher BMI (β = 1.10, 95% CI:

Table 2. Weighted generalized linear/Poisson models for obesity among US children and adolescents aged 10–19 years old, 2007–2020.

	Mean BMI		Prevalence of obesity	
	Adjusted β (95%CI)	**P-value**	**Adjusted Prevalence Ratio[a] (95% CI)**	**P-value**
Age group				
10–14	reference		1.00 (reference)	
15–19	3.27 (2.91, 3.62)	<0.001	0.95 (0.85, 1.05)	≥0.05
Sex				
Boys	reference		1.00 (reference)	
Girls	0.23 (-0.08, 0.53)	≥0.05	0.88 (0.81, 0.96)	<0.01
Race/Ethnicity				
White	reference		1.00 (reference)	
Black	1.10 (0.59, 1.62)	<0.001	1.22 (1.06, 1.40)	<0.01
Hispanic	0.69 (0.29, 1.09)	<0.001	1.19 (1.05, 1.36)	<0.01
Other Race[b]	-0.37 (-0.95, 0.22)	≥0.05	0.93 (0.82, 1.04)	≥0.05
Poverty Income Ratio				
PIR ≤ 3.5 (high-income)	reference		1.00 (reference)	
PIR < 1.3 (low-income)	1.43 (1.04, 1.83)	<0.001	1.62 (1.39, 1.90)	<0.001
PIR 1.3 to <3.5 (middle-income)	1.09 (0.60, 1.60)	<0.001	1.47 (1.24, 1.76)	<0.001

Models were adjusted for survey year.

[a]A survey-weighted Poisson regression analysis with a Poisson distribution family and a log link function was employed.

[b]Other race include individuals self-identifying as non-Hispanic Asian, other, or being from more than one race or ethnic group.

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0.59–1.62, and β = 0.69, 95% CI: 0.29–1.09, respectively), compared to White counterparts. Furthermore, low and middle-income adolescents had a higher BMI (β = 1.43, 95% CI: 1.04–1.83, β = 1.09, 95% CI: 0.60–1.60, respectively) than those from high-income families.

Table 2 shows no statistically significant relationship between age and obesity prevalence. Girls had a lower likelihood of obesity compared to boys (Adjusted Prevalence Ratio [APR] = 0.88; 95% CI, 0.81–0.96, p <0.01). Furthermore, Black and Hispanic adolescents had a higher risk of obesity than White adolescents (Black; APR = 1.22; 95% CI: 1.06–1.40, p < 0.01; and Hispanic; APR = 1.19; 95% CI, 1.05–1.36, p <0.01, respectively). Additionally, adolescents with low and middle income were 62% and 47% more likely to be obese compared to ones from high-income groups.

Discussion

We examined trends in BMI and obesity prevalence among US adolescents using nationally representative NHANES data from 2007–2008 to 2017–2020. This study provided the most up-to-date available US nationally representative trends over the decade. Our findings indicated that adolescent obesity continued to increase in the US over the past decade. We found the increase in both mean BMI and obesity prevalence from 2007–2008 to 2017–2020 among several subgroups of adolescents, including Black and Hispanic adolescents (compared to White counterparts), and those from low and middle-income backgrounds (compared to high-income backgrounds). Additionally, our findings indicated that obesity prevalence increased significantly among both boys and girls over the past decade. In contrast, we found no significant changes in mean BMI and a significant decrease in obesity prevalence among those from high-income groups. Our analysis also revealed persistent disparities among

certain racial minorities (Black and Hispanic adolescents) and those in low and middle-income groups (PIR $\leq$1.3 and PIR 1.35 to <3.5) who had greater odds of being obese. These findings underscore the importance of targeted interventions to address the growing obesity epidemic among US adolescents, particularly those from minority groups and lower socioeconomic status backgrounds.

The BMI increased from 22.85 kg/m^2 in 2007–2008 to 23.59 kg/m^2 in 2017–2020 among adolescents aged 10–19, while the prevalence of obesity increased by 3.3% from 20.7% to 24% over the same time period. Our findings were consistent with prior research indicating that childhood obesity remained high in the U.S., with approximately 1 in 5 children affected 12- to 19-year-olds [30]. Notably, our study provides updated data on this trend compared to 2017–2020. In addition, our study findings are consistent with a recent study that reported a 4.5% increase in obesity prevalence among adolescents aged 12–19 from 2009–2010 to 2017–2020, yet presented only unadjusted prevalence estimates [13]. Our study included a longer time span than these previous studies through a robust multivariate survey-weighted data analysis, adjusting for key sociodemographic factors and survey cycle. Our findings demonstrated disparities in race/ethnic groups and income levels leading to obesity among U.S. adolescents. Additionally, although both boys and girls have a significant prevalence of obesity, compared to girls, boys had a higher prevalence of obesity, from 22.5% in 2007–2008 to 25.7% in 2017–2020. This finding was consistent with the findings of the previous study, which demonstrated slightly higher obesity prevalence in boys [31]. Considering sex will enable us to develop more effective and tailored strategies to improve the overall well-being and outcomes of this vulnerable population.

We found that the prevalence of obesity continues to increase among certain race/ethnic groups, as well as low-income groups. Compared to White counterparts, Black and Hispanic adolescents had higher obesity rates in 2017–2020 (30.62% and 29.05%, respectively). These findings are consistent with previous studies [12,31,32], that Black and Hispanic adolescents as having the highest obesity rates among all minority groups. other races including Asian adolescents had a lower prevalence of obesity in all age and sex groups, which is also in line the with earlier research [33]. However, it is important to note that Asians have different body compositions, and Asian children with a normal BMI range, meant for White children may still be considered overweight or obese according to Asian-specific criteria [34]. In addition, we found a decreasing trend from 17.31% in 2007–2008 to 14.44% in 2017–2020 among high income groups. Conversely, low-income families (PIR <1.3) and middle-income families (PIR 1.3 to < 3.5) had significant increases in mean BMI and obesity prevalence observed for both groups. Consistent with the pervious result showing that adolescents from low-income families had a greater chance of being obese [15], our study highlights a concerning trend of rising obesity rates among adolescents from low- and middle-income groups [35]. Since adolescents from low-income families often encounter challenges, such as limited access to healthy foods and opportunities for physical activity [36], they may face obstacles in making healthier choices than those from high-income families [37,38].

Our overall analyses examining the association between sociodemographic factors and BMI and obesity revealed persistent disparities among Black and Hispanic adolescents. Black and Hispanic adolescents had 23% and 19% greater odds of being obese compared to White counterparts. Adolescents from low and middle-income groups had higher odds of obesity, while the high-income group had lower odds. These results align with previous studies [39], indicating that socioeconomic inequalities play a significant role in shaping access to neighborhood and social resources. Furthermore, a previous systematic review demonstrated that approximately 40% of studies have identified a widening socioeconomic inequality gap since 2000 [40]. A possible explanation may be that these disparities in obesity prevalence among different

race/ethnic and income groups may be linked to various factors such as residing in unsafe neighborhoods that limit opportunities [41] and limited access to healthy food options [42]. Furthermore, another study indicated that adolescents from low socioeconomic neighborhoods are more exposed to poverty, crime, low social cohesion, higher levels of air pollution, lack of green spaces, and poor quality of the built environment, which can increase the likelihood of obesity [43]. Adolescence is a critical period for preventing obesity, the results of our study underscore the substantial disparities in the prevalence of obesity existing among youth. Therefore, future research should address these disparities and promote health equality.

It is crucial to recognize that BMI and obesity prevalence demonstrated inconsistent trends across age groups. BMI provides a continuous weight assessment in relation to height, offering a comprehensive perspective on weight changes, particularly in adolescent populations. Conversely, obesity is typically defined by specific BMI thresholds and is directly associated with an elevated risk of obesity-related health concerns, including type 2 diabetes, cardiovascular disease [44]. These disparities can result in distinct interpretations when scrutinizing trends within specific demographic groups.

The strengths of this study included assessment of the most up-to-date available data from NHANES to evaluate trends over the past 13 years. In addition, while the survey data were mostly self-reported and were subject to misclassification, a strength of our approach is that the weight and height data collected from NHANES were measured by professional data collectors rather than self-report, increasing the accuracy and reliability of the results by reducing personal bias [17]. Another strength is the large sample size, which provided sufficient statistical power to examine the race- and sex-specific mean BMI and prevalence of obesity, despite not accounting for Asian American adolescents. Lastly, this study employed a rigorous multivariate survey-weighted data analysis and accounted for the key sociodemographic factors and survey cycles. This methodological approach significantly enhances the depth and reliability of the findings, strengthening the validity of the study's conclusions.

There are two limitations. First, the NHANES data are based on repeated cross-sectional surveys, which means that we cannot examine within-child changes over time or imply causality. However, this approach still provides a valuable snapshot of obesity prevalence among US adolescents over time. In addition, including Asian American adolescents in the other group in our analysis raises questions about the validity of current reference ranges for defining obesity [33].

Conclusions

Despite efforts in public health policies and increasing awareness, the prevalence of obesity among children remains high and continues to increase among Black and Hispanic adolescents. Future research should address key disparities suggested through this analysis and promote health equality. The findings of our study suggest that future obesity interventions should target specific race/ethnic minorities and low-income families to prevent obesity. This could involve developing policies and interventions addressing social determinants of health, such as improving access to healthy food options, creating safe environments for physical activity, and promoting culturally appropriate community-based initiatives that support healthy lifestyles [43].

Supporting information

S1 Fig. Sample size flowchart.
(DOCX)

S2 Fig. Trends in mean BMI obesity among US adults (aged 10–19), NHANES 2007–2020 by sex, age, race/ethnicity and poverty income ratio (details see in S1 Table).
(DOCX)

S1 Table. BMI changes in adolescents aged 10–19 years old, stratify by overall, sex, age, race/ethnicity, and poverty ratio from 2007 to 2020 (n = 9,826).
(DOCX)

S2 Table. Prevalence of obesity in adolescents aged 10–19 years old, stratify by overall, sex, age, race/ethnicity, and poverty ratio from 2007 to 2020 (n = 2,346).
(DOCX)

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Author Contributions

Conceptualization: Sami Yli-Piipari, Kosuke Tamura.

Formal analysis: Yangyang Deng, Kosuke Tamura.

Methodology: Yangyang Deng.

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References

1. Wisniewski AB, Chernausek SD. Gender in Childhood Obesity: Family Environment, Hormones, and Genes. Gender Med. 2009; 6:76–85. https://doi.org/10.1016/j.genm.2008.12.001 PMID: 19318220
2. Sanyaolu A, Okorie C, Qi X, Locke J, Rehman S. Childhood and Adolescent Obesity in the United States: A Public Health Concern. Glob Pediatr Health. 2019; 6:2333794X19891305. https://doi.org/10.1177/2333794X19891305 PMID: 31832491
3. Nehus E, Mitsnefes M. Childhood Obesity and the Metabolic Syndrome. Pediatr Clin N Am. 2019; 66 (1):31–+. https://doi.org/10.1016/j.pcl.2018.08.004 PMID: 30454749
4. Grossman DC, Bibbins-Domingo K, Curry SJ, Barry MJ, Davidson K, Doubeni CA, et al. Screening for Obesity in Children and Adolescents US Preventive Services Task Force Recommendation Statement. Jama-J Am Med Assoc. 2017; 317(23):2417–26. https://doi.org/10.1001/jama.2017.6803 PMID: 28632874
5. CDC. National Center for Health Statistics. NHANES questionnaires, datasets, and related documentation. 2020.
6. De Leonibus C, Marcovecchio ML, Chiarelli F. Update on statural growth and pubertal development in obese children. Pediatric Rep. 2012; 4(4):119–23. https://doi.org/10.4081/pr.2012.e35 PMID: 23355935
7. Woo JG, Zhang NH, Fenchel M, Jacobs DR, Hu T, Urbina EM, et al. Prediction of adult class II/III obesity from childhood BMI: the i3C consortium. Int J Obesity. 2020; 44(5):1164–72. https://doi.org/10.1038/s41366-019-0461-6 PMID: 31597933
8. Simmonds M, Burch J, Llewellyn A, Griffiths C, Yang H, Owen C, et al. The use of measures of obesity in childhood for predicting obesity and the development of obesity-related diseases in adulthood: a systematic review and meta-analysis. Health Technol Assess. 2015; 19(43):1–336. https://doi.org/10.3310/hta19430 PMID: 26108433

9. Ward ZJ, Bleich SN, Long MW, Gortmaker SL. Association of body mass index with health care expenditures in the United States by age and sex. Plos One. 2021; 16(3). https://doi.org/10.1371/journal.pone.0247307 PMID: 33760880

10. McLaren L. Socioeconomic status and obesity. Epidemiol Rev. 2007; 29:29–48. https://doi.org/10.1093/epirev/mxm001 PMID: 17478442

11. Ogden CL, Carroll MD, Kit BK, Flegal KM. Prevalence of childhood and adult obesity in the United States, 2011–2012. JAMA. 2014; 311(8):806–14. https://doi.org/10.1001/jama.2014.732 PMID: 24570244

12. Ogden CL, Fryar CD, Hales CM, Carroll MD, Aoki Y, Freedman DS. Differences in Obesity Prevalence by Demographics and Urbanization in US Children and Adolescents, 2013–2016. Jama-J Am Med Assoc. 2018; 319(23):2410–8. https://doi.org/10.1001/jama.2018.5158 PMID: 29922826

13. Hu K, Staiano AE. Trends in Obesity Prevalence Among Children and Adolescents Aged 2 to 19 Years in the US From 2011 to 2020. Jama Pediatr. 2022; 176(10):1037–9. https://doi.org/10.1001/jamapediatrics.2022.2052 PMID: 35877133

14. Shah B, Tombeau Cost K, Fuller A, Birken CS, Anderson LN. Sex and gender differences in childhood obesity: contributing to the research agenda. BMJ Nutr Prev Health. 2020; 3(2):387–90. https://doi.org/10.1136/bmjnph-2020-000074 PMID: 33521549

15. Skelton JA, Cook SR, Auinger P, Klein JD, Barlow SE. Prevalence and Trends of Severe Obesity Among US Children and Adolescents. Acad Pediatr. 2009; 9(5):322–9. https://doi.org/10.1016/j.acap.2009.04.005 PMID: 19560993

16. Wang YC, Gortmaker SL, Taveras EM. Trends and racial/ethnic disparities in severe obesity among US children and adolescents, 1976–2006. International Journal of Pediatric Obesity. 2011; 6(1):12–20. https://doi.org/10.3109/17477161003587774 PMID: 20233157

17. Frederick CB, Snellman K, Putnam RD. Increasing socioeconomic disparities in adolescent obesity. Proc Natl Acad Sci U S A. 2014; 111(4):1338–42. https://doi.org/10.1073/pnas.1321355110 PMID: 24474757

18. Singh GK, Kogan MD, van Dyck PC. Changes in State-Specific Childhood Obesity and Overweight Prevalence in the United States From 2003 to 2007. Arch Pediat Adol Med. 2010; 164(7):598–607. https://doi.org/10.1001/archpediatrics.2010.84 PMID: 20603458

19. Wang Y, Beydoun MA. The obesity epidemic in the United States—Gender, age, socioeconomic, Racial/Ethnic, and geographic characteristics: A systematic review and meta-regression analysis. Epidemiol Rev. 2007; 29:6–28. https://doi.org/10.1093/epirev/mxm007 PMID: 17510091

20. Veugelers PJ, Fitzgerald AL. Prevalence of and risk factors for childhood overweight and obesity. CMAJ. 2005; 173(6):607–13. https://doi.org/10.1503/cmaj.050445 PMID: 16157724

21. Galfo M, D'Addezio L, Censi L, Roccaldo R, Martone D. Overweight and Obesity in Italian Adolescents: Examined Prevalence and Socio-Demographic Factors. Cent Eur J Publ Heal. 2016; 24(4):262–7. https://doi.org/10.21101/cejph.a4367 PMID: 28095279

22. CDC. National Health and Nutrition Examination Survey, Centers for Disease Control and Prevention National Center for Health Statistics. 2022.

23. Kuczmarski RJ, Ogden CL, Guo SS, Grummer-Strawn LM, Flegal KM, Mei Z, et al. 2000 CDC Growth Charts for the United States: methods and development. Vital Health Stat 11. 2002(246):1–190.

24. Gavin L, MacKay AP, Brown K, Harrier S, Ventura SJ, Kann L, et al. Sexual and reproductive health of persons aged 10–24 years—United States, 2002–2007. MMWR Surveill Summ. 2009; 58(6):1–58. PMID: 19609250

25. Du Y, Liu BY, Sun YB, Snetselaar LG, Wallace RB, Bao W. Trends in Adherence to the Physical Activity Guidelines for Americans for Aerobic Activity and Time Spent on Sedentary Behavior Among US Adults, 2007 to 2016. Jama Netw Open. 2019; 2(7).

26. Hales CM, Fryar CD, Carroll MD, Freedman DS, Ogden CL. Trends in Obesity and Severe Obesity Prevalence in US Youth and Adults by Sex and Age, 2007–2008 to 2015–2016. Jama-J Am Med Assoc. 2018; 319(16):1723–5. https://doi.org/10.1001/jama.2018.3060 PMID: 29570750

27. Jackson SL, Yang EC, Zhang ZF. Income Disparities and Cardiovascular Risk Factors Among Adolescents. Pediatrics. 2018; 142(5). https://doi.org/10.1542/peds.2018-1089 PMID: 30333131

28. Korn EL, Graubard BI. Epidemiologic Studies Utilizing Surveys—Accounting for the Sampling Design. American Journal of Public Health. 1991; 81(9):1166–73. https://doi.org/10.2105/ajph.81.9.1166 PMID: 1951829

29. Barros AJ, Hirakata VN. Alternatives for logistic regression in cross-sectional studies: an empirical comparison of models that directly estimate the prevalence ratio. BMC Med Res Methodol. 2003; 3:21. https://doi.org/10.1186/1471-2288-3-21 PMID: 14567763

30. Prevention CfDCa. Childhood obesity facts. 2021.

31. Tsoi MF, Li HL, Feng Q, Cheung CL, Cheung TT, Cheung BMY. Prevalence of Childhood Obesity in the United States in 1999–2018: A 20-Year Analysis. Obesity Facts. 2022; 15(4):560–9. https://doi.org/10.1159/000524261 PMID: 35358970

32. Ogden CL, Carroll MD, Lawman HG, Fryar CD, Kruszon-Moran D, Kit BK, et al. Trends in Obesity Prevalence Among Children and Adolescents in the United States, 1988–1994 Through 2013–2014. Jama-J Am Med Assoc. 2016; 315(21):2292–9. https://doi.org/10.1001/jama.2016.6361 PMID: 27272581

33. Skinner AC, Ravanbakht SN, Skelton JA, Perrin EM, Armstrong SC. Prevalence of Obesity and Severe Obesity in US Children, 1999–2016. Pediatrics. 2018; 141(3).

34. Eyre ELJ, Duncan MJ, Nevill A. South Asian Children Have Increased Body Fat in Comparison to White Children at the Same Body Mass Index. Children-Basel. 2017; 4(11). https://doi.org/10.3390/children4110102 PMID: 29165375

35. Lobstein T, Baur L, Uauy R, TaskForce IIO. Obesity in children and young people: a crisis in public health. Obes Rev. 2004; 5 Suppl 1:4–104. https://doi.org/10.1111/j.1467-789X.2004.00133.x PMID: 15096099

36. Burke MP, Martini LH, Blake CE, Younginer NA, Draper CL, Bell BA, et al. Stretching Food and Being Creative: Caregiver Responses to Child Food Insecurity. J Nutr Educ Behav. 2017; 49(4):296–303. https://doi.org/10.1016/j.jneb.2016.11.010 PMID: 28073623

37. Biggs BK, Tolleson E, Millerbernd J, Bronars C, Meiers SJ, Slowiak K, et al. Identifying Opportunities to Promote Physical Activity in a Diverse Low-Income Population: A Mixed-Method Study at a Boys & Girls Club Site. Child Youth Care For. 2020; 49(2):171–200.

38. Chang SH, Kim K. A review of factors limiting physical activity among young children from low-income families. J Exerc Rehabil. 2017; 13(4):375–7. https://doi.org/10.12965/jer.1735060.350 PMID: 29114499

39. Shrewsbury V, Wardle J. Socioeconomic status and adiposity in childhood: A systematic review of cross-sectional studies 1990–2005. Obesity. 2008; 16(2):275–84. https://doi.org/10.1038/oby.2007.35 PMID: 18239633

40. Chung A, Backholer K, Wong E, Palermo C, Keating C, Peeters A. Trends in child and adolescent obesity prevalence in economically advanced countries according to socioeconomic position: a systematic review. Obes Rev. 2016; 17(3):276–95. https://doi.org/10.1111/obr.12360 PMID: 26693831

41. Cohen DA, Han B, Derose KP, Williamson S, Marsh T, Rudick J, et al. Neighborhood poverty, park use, and park-based physical activity in a Southern California city. Soc Sci Med. 2012; 75(12):2317–25. https://doi.org/10.1016/j.socscimed.2012.08.036 PMID: 23010338

42. Drewnowski A, Darmon N. Food choices and diet costs: an economic analysis. J Nutr. 2005; 135(4):900–4. https://doi.org/10.1093/jn/135.4.900 PMID: 15795456

43. Suglia SF, Shelton RC, Hsiao A, Wang YC, Rundle A, Link BG. Why the Neighborhood Social Environment Is Critical in Obesity Prevention. J Urban Health. 2016; 93(1):206–12. https://doi.org/10.1007/s11524-015-0017-6 PMID: 26780582

44. Hruby A, Hu FB. The Epidemiology of Obesity: A Big Picture. Pharmacoeconomics. 2015; 33(7):673–89. https://doi.org/10.1007/s40273-014-0243-x PMID: 25471927