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American Indian Alaska Native (AIAN) adolescents and obesity: the influence of social determinants of health, mental health, and substance use

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OBJECTIVE: To explore the prevalence of obesity among American Indian and Alaska Native (AIAN) adolescents aged 12–19 years in association with social determinants of health (SDOH), and mental health and substance use disorders.

METHODS: Guided by the World Health Organization's Social Determinants of Health Framework, we examined data from the Indian Health Service (IHS) Improving Health Care Delivery Data Project from Fiscal Year 2013, supplemented by county-level data from the U.S. Census and USDA. Our sample included 26,226 AIAN adolescents ages 12–19 years. We described obesity prevalence in relationship to SDOH and adolescents' mental health and substance use disorder status. We then fit a multivariable logit generalized linear mixed model to estimate the relationships after adjusting for other individual and county level characteristics.

RESULTS: We observed a prevalence of 32.5% for obesity, 13.8% for mental health disorders, and 5.5% for substance use disorders. Females had lower odds of obesity than males (OR = 0.76, $p < 0.001$), which decreased with age. Having Medicaid coverage (OR = 1.09, $p < 0.01$), residing in a county with lower education attainment (OR = 1.17, $p < 0.05$), and residing in a county with higher rates of poverty (OR = 1.51, $p < 0.001$) were each associated with higher odds of obesity. Residing in a county with high access to a grocery store (OR = 0.73, $p < 0.001$) and residing in a county with a higher proportion of AIANs (OR = 0.83, $p < 0.01$) were each associated with lower odds of obesity. Those with mental health disorders had higher odds of obesity (OR = 1.26, $p < 0.001$); substance use disorders were associated with decreased odds of obesity (OR = 0.73, $p < 0.001$).

CONCLUSIONS: Our findings inform future obesity prevention and treatment programs among AIAN youth; in particular, the need to consider mental health, substance use, and SDOH.

INTRODUCTION

The obesity rate among American Indian and Alaska Native (AIAN) adolescents is 33.8%, ~50% higher than that of all adolescents in the United States (20.6%) [1, 2]. Obesity in adolescence adult obesity [3], youth- and adult-onset type 2 diabetes mellitus (T2DM) [2], cardiovascular disease, cancer, and non-alcoholic fatty liver disease [4, 5]. These chronic diseases ultimately lead to higher rates of mortality for AIAN peoples as compared to other racial/ethnic groups in the United States. For instance, in 2019, AIANs were 2.5 times more

likely than non-Hispanic whites to die from T2DM, 1.2 times more likely to die of heart diseases, and more than 4 times more likely to die from diseases of the liver [6]. These rates underscore the need to identify risk and protective factors that influence obesity rates among AIAN adolescents to reduce morbidity and mortality among AIAN people across the lifespan.

Many have addressed AIAN health risks and protective factors with a focus on the social determinants of health (SDOH), which are the social and environmental conditions in which people are born, work, and age [7–10]. SDOH are, in fact, strong drivers of racial/ethnic health inequities, compromising health in vulnerable communities through decreased resources and increased stressors [8, 10]. Inequities in the social and physical environment have been seen to influence health outcomes across the lifespan. For instance, gender has been found associated with AIAN obesity, with AIAN male adolescents experiencing higher rates of severe obesity than females [1]. Socioeconomic inequities, such as limited education and income, are also associated with higher obesity rates among AIAN adolescents compared to their non-Hispanic white counterparts [11].

The sociopolitical and historical contexts for Indigenous peoples further play a role in current health outcomes. The extant research indicates that SDOH related to a history of colonization and oppression may additionally influence AIAN health risks [12]. Specifically, colonization has been associated with AIAN having increased rates of adverse childhood events, lifetime traumas [13, 14] and racial discrimination [15, 16]. These risks are further associated with increased risks for obesity [17–19], as well as higher rates of mental health disorders [20–22] and substance use [20, 23] among AIAN adolescents, as compared to the general US population. Prior research has indicated that a complex relationship exists among mental health disorders, substance use, and obesity. Mental health disorders increase in prevalence during adolescence and appear to influence adolescents' risk for obesity [24, 25], with limited findings among AIAN adolescents [11, 26]. The unique life stressors that become apparent in adolescence also independently increase the risk of obesity (e.g., identity development and increased autonomy) [27]. Moreover, substance use disorders tend to correlate with reduced physical activity and less nutritious diets [28], and there is evidence that substance use is associated with obesity among adolescents [29]. Furthermore, exposure to obesogenic factors in the social and physical environmental may compound obesity risk, as found among limited samples of AIAN youth [30, 31]. Yet, little research exists examining the complex relationship of these factors among AIAN youth on obesity.

The objectives of this study were to (1) estimate obesity prevalence among Indigenous adolescents ages 12–19 years and (2) examine the association of SDOH, mental health and substance use disorders with obesity in this population. To achieve these objectives, we analyzed data from the Indian Health Service (IHS) [32]. As guided by the World Health Organization [8] and Healthy People 2020 SDOH Frameworks [33], our analyses investigated SDOH related to the social and community context, access to healthcare, education, economic stability, and neighborhood built environment factors (see Fig. 1). To our knowledge, this is the first investigation of the impact of SDOH in combination with mental health and substance use

disorders as risk factors for obesity among AIAN adolescents using a large geographically diverse sample.

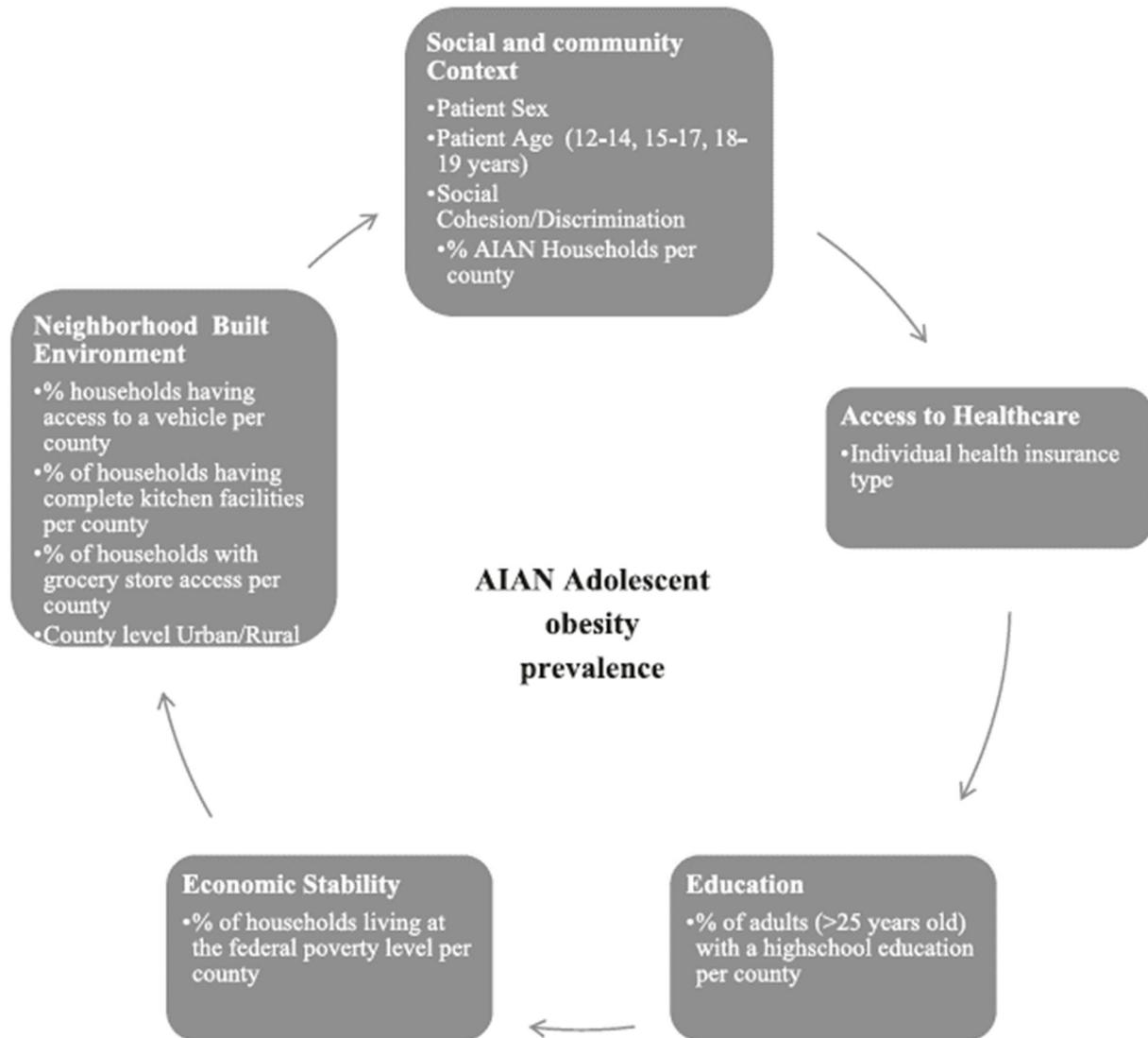


Fig. 1 Study SDOH Conceptual Framework. SDH conceptual framework drawn from the Healthy People 2020 and CSDH and factors potentially influencing AIAN adolescent obesity prevalence.

METHODS

Data source

This analysis used data from the IHS Improving Health Care Delivery Data Project (henceforth, the IHS Data Project). The project established a critical data infrastructure regarding the health status, utilization, and costs of treating chronic diseases among over 640,000 AIAN patient users of the IHS healthcare system [32]. This data infrastructure represents nearly 30% of AIAN users and is comparable to the national IHS service population in terms of age and sex

[34, 35]. [See O’Connell et al. for further information about the data infrastructure [32]. The 15 participating IHS and tribal organizations of the IHS Data Project were engaged by project personnel via a formal Collaborative Network, which included Steering, Project Site, and Patient Committees. Approval for this analysis was obtained from the IHS National Institutional Review Board (IRB), tribal IRBs, tribal councils and tribal authorities, and the University of Colorado IRB.

To examine SDOH not included in the IHS data infrastructure, we drew statistics from United States Census Bureau (2000 (US Census Bureau. Census 2000 Summary File 1 and Summary File 2—United States. 2001) and 2010 (US Census Bureau. Census 2010 Summary File 1 and Summary File 2—United States; 2015)) data as well as the United States Department of Agriculture (USDA) Food Environment Atlas Data (USDA Food Environment Atlas. USDA. June 6, 2018. <http://www.ers.usda.gov/dataproducts/food-environment-atlas.aspx>). We also obtained county-level education and poverty levels for AIAN persons who reported using HIS services from the 2010–2014 American Community Survey (ACS) 5-year estimates (2010–2014 American Community Survey—United States. Data derived from population estimates, Census of Population and Housing, County Business Patterns, Economic Census, Survey of Business Owners, Building Permits, Census of Governments: US Census Bureau; 2016).

Analytic sample

Of the 62,545 AIAN adolescents aged 12–19 years who were active HIS users during fiscal year (FY) 2013, ~55% of them did not have height and weight measured on the same day and were removed from the analytical sample, which is advised by the CDC algorithm; another 3% of the adolescents were removed due to having biologically implausible BMI measures as determined by the CDC Growth Chart algorithm (CDC C for DC. SAS Program (ages 0 to <20 years) [Internet]. | Resources | Growth Chart Training | Nutrition. 2022 [cited 2022 Jul 19]. Available from: <https://www.cdc.gov/nccdphp/dnpao/growthcharts/resources/sas.htm>). Eventually, 42% (n = 26,226) had a biologically plausible BMI measure and were included in the final sample. An FY2013 active user was defined as a patient who obtained services at least once during fiscal year 2013 or the preceding two years (i.e., fiscal years 2011–2012). Exclusion criteria included [1] pregnancy anytime during FY2013 (n = 146) [2], missing data for SDOH variables (n = 2), or [3] enrolled in Medicare in FY2013 (n = 9).

Dependent variable

Obesity. The primary outcome was obesity, which was computed based on patients’ most recent record in FY2013 for which height and weight were recorded. As is standard practice, we computed BMI as weight in kilograms divided by height in meters squared. As described above, using the age- and sex-specific height, weight, and BMI percentiles from the CDC growth charts (CDC Growth Charts. Accessed November 2018, http://www.cdc.gov/growthcharts/cdc_charts.htm), we excluded adolescents if their BMI or corresponding height or weight was determined to be biologically implausible. We categorized remaining BMI values based on age- and sex-specific percentiles in the CDC growth charts. BMI values above the 95th percentile were defined as obese.

SDOH independent variables

Social and community context

Age and sex: Individual-level predictor variables included patient age and sex. Sex was extracted directly from the data infrastructure. Age was calculated using the patient's birth date and date of height and weight measurement. We examined three age groups (i.e., 12–14, 15–17, and 18–19 years).

Population density: To determine contextual factors related to culture and the density of AIAN population, we examined the decennial Census 2010 to identify the percent of people in each county who identified as “American Indian or Alaska Native” alone or in combination with one or more other races. Across the 72 counties included in the IHS Data Project, the median percentage of the population that identified as AIANs was 14.6%. This value was used as the cutoff to dichotomize counties as being above or below the median for the density of the population self-identifying as AIAN.

Access to healthcare. Using data from the IHS Data Project, we identified individual-level health insurance coverage using three categories: Medicaid coverage, private insurance, or no health coverage other than access to IHS services.

Education. We obtained education level for each county from the American Community Survey (ACS). The educational attainment variable represented the percentage of adults over the age of 25 years living in the county who did not complete high school. Counties were dichotomized into higher and lower educational levels using the median value across counties (46% of adults did not complete high school).

Economic stability. To capture economic stability, we used data from the 2010–2014 ACS to identify counties with higher and lower poverty levels (USDA Food Environment Atlas. USDA. June 6, 2018. <http://www.ers.usda.gov/data-products/food-environment-atlas.aspx>). Across counties, the median percentage of households with an income at or below 100% of the federal poverty level was 27.9%. We defined counties as lower income if they had more than the median percentage of people living in poverty and counties as higher income if they were below the median.

Neighborhood built environment. To operationalize SDOH related to the neighborhood-built environment, we examined several county-level characteristics. First, we determined the “access rate to vehicles” in the county. We drew upon the decennial US Census 2000 to calculate the percentage of single-race AIAN households with no vehicle access within the county (median 12.9%). Similarly, we determined the percentage of households with “incomplete kitchen facilities” in the county (median 1.8%). Counties were identified as being above or below the median on these factors. Finally, using USDA Food Environment Atlas 2015 data [36] (USDA Food Environment Atlas. USDA. June 6, 2018. <http://www.ers.usda.gov/data-products/food-environment-atlas.aspx>), we identified the percentage of people in a county with low “access to a grocery store” (i.e., for rural counties, those more than 10 miles from a supermarket or large store, or more than 1 mile if in an urban area/county). For the 72 counties, the median percentage

of people with low access to a grocery store was 25.3%; counties were classified as having less access (high percentages) and more access (low percentages) to grocery stores using this value.

Urban or rural: Counties were identified as urban or rural using the classifications for metropolitan and non-metropolitan areas as developed by the National Center for Health Statistics (Ingram DD FS. 2013 NCHS Urban–Rural Classification Scheme for Counties. Vol. 2. 2014. Vital Health Stat Accessed June 2, 2019). Metropolitan statistical areas have a population of at least 10,000; whereas, non-metropolitan areas are micropolitan or noncore statistical areas with a population of less than 10,000.

Mental health and substance use disorders. We used Sightlines™ DxCG Risk Solutions software (Sightlines™ DxCG Risk Solutions.) to identify substance use and mental health disorders. The software utilizes ICD-9 diagnosis codes and nationally recognized algorithms to identify these and other acute and chronic conditions. With this software, we identified mental health and substance use disorders, based on diagnostic codes recorded in health service utilization records. The DxCG algorithms are nationally recognized and employed in the private and public sector [37, 38].

Data analysis

Descriptive statistics for the sociodemographic and SDOH variables were calculated for the study sample. Chi-squared tests were performed to test the difference in obesity prevalence by sample demographic characteristics and SDOH. Multivariable logit generalized linear mixed models were fitted to examine the association of obesity with SDOH and mental health disorder and substance use disorder with county-level random intercepts to account for the clustering effect by county. Adjusted odds ratios (ORs) and 95% confidence intervals were reported. We tested for interactions between having a mental health or substance use disorder with SDOH on their relationship with obesity in the multivariable regression models; however, the interactions were not significant and were not retained in the final regression model. All data analyses were performed using SAS software, version 9.4. (SAS software. Version 9.4. 2013.)

RESULTS

Table 1 presents characteristics of the sample (n = 26,226). The overall sample was 52.9% female. Half of adolescents (49.9%) had no health coverage other than access to IHS services. Nearly 40% had Medicaid coverage and 16.4% had private insurance. Half of the adolescents lived in counties with lower educational attainment. Approximately 59% of the sample resided in counties that were above the median (27.9%) for households living in poverty. About a third (30.8%) lived in counties with less access to grocery stores. A large percentage of participants (65%) lived in counties that were above the county median (14.6%) for the percentage of the population identified as AIAN. Most of our participants (65%) resided in an urban, non-rural settings (i.e., populations with more than 10,000).

Table 1. Obesity prevalence by characteristics of AIAN adolescents aged 12–19 years old.

	All		Obesity prevalence	p value ^e
	N	Column %	%	
All	26,226	100.0	32.5	
Gender				***
Female	13,862	52.9	30.0	
Male	12,364	47.1	35.4	
Age group				***
12–14 years	10,545	40.2	34.7	
15–17 years	9,900	37.8	32.0	
18–19 years	5,781	22.1	29.7	
Health insurance coverage				**
Other health coverage				
Had other coverage	13,149	50.1	33.3	
No other coverage	13,077	49.9	31.8	
Medicaid				***
No Medicaid	16,156	61.6	31.7	
Had Medicaid	10,070	38.4	34.0	
Private				
No private insurance	21,929	83.6	32.7	
Had private insurance	4,297	16.4	31.8	
Behavioral health conditions				
Mental health disorder				***
No	22,597	86.2	32.0	
Yes	3,629	13.8	35.7	
Depression				**
No	24,447	93.2	32.3	
Yes	1,779	6.8	35.4	
Substance use disorder				***
No	24,777	94.5	32.8	
Yes	1,449	5.5	28.5	
Alcohol use disorder				**
No	25,546	97.4	32.7	
Yes	680	2.6	27.2	
Drug use disorder				
No	25,381	96.8	32.6	
Yes	845	3.2	30.9	
Tobacco use disorder				*
No	25,881	98.7	32.6	
Yes	345	1.3	27.5	
AIAN IHS educational attainment: % <high school ^a				
Counties below the median (46.0%)	13,033	49.7	32.7	
Counties above the median (46.0%)	13,193	50.3	32.4	
AIAN IHS Income: % <100% FPL ^a				***
Counties below the median (27.9%)	10,606	40.4	28.5	
Counties above the median (27.9%)	15,620	59.6	35.2	
AIAN households with no vehicle access ^b				***
Counties below the median (12.9%)	13,506	51.5	30.6	
Counties above the median (12.9%)	12,720	48.5	34.6	
AIAN households with incomplete kitchen facilities ^b				
Counties below the median (1.8%)	14,062	53.6	32.3	
Counties above the median (1.8%)	12,164	46.4	32.8	
Low access to a grocery store ^c				***

Table 1. continued

	All		Obesity prevalence	p value ^e
	N	Column %	%	
Counties below the median (25.3%)	18,148	69.2	34.2	
Counties above the median (25.3%)	8078	30.8	28.9	
Population AIAN alone or in combination ^d				***
Counties below the median (14.6%)	9122	34.8	36.9	
Counties above the median (14.6%)	17,104	65.2	30.2	
NCHS Urban/rural (2013)				***
Non-rural counties	17,056	65.0	33.6	
Rural counties	9170	35.0	30.6	

AIAN American Indian/Alaska Native, *IHS* Indian Health Service, *FPL* Federal Poverty Level, *NCHS* National Center for Health Statistics.

* $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$.

^aData source: American Community Survey 2010–2014 5-year estimates.

^bData source: US Census Bureau 2000.

^cData source: US Department of Agriculture Food Environment Atlas.

^dData source: US Census Bureau 2010.

^ep value from Chi square test testing difference in distribution of obesity prevalence in characteristics categories.

Approximately one-third of adolescents (32.5%) met criteria for obesity. As evident in the Table 1, many SDOH were significantly associated with obesity. In terms of social context, males exhibited higher rates of obesity (35.4%) than females (30%) ($p < 0.001$). Likewise, rates of obesity were significantly associated with age, with obesity rates declining as age increased ($p < 0.001$). With respect to community context, AIAN adolescents who lived in counties with a higher concentration of AIANs had a lower prevalence of obesity (30.2%) than those living in counties with a lower concentration of AIANs (36.9% obesity prevalence, $p < 0.001$). The SDOH of education, derived from the county-level measure, was not significantly associated with differences in obesity rates. Per economic stability, living in a county with higher rates of poverty, as compared to those with lower rates of poverty, was significantly associated with higher rates of obesity (35.2% vs. 28.5%, $p < 0.001$).

The univariate descriptive statistics further indicated that factors related to the neighborhood-built environment and context were significantly associated with obesity. First, counties with less vehicle access were significantly associated with higher rates of obesity (34.6% vs. 30.6%; $p < 0.001$); yet the percent of AIAN households with incomplete kitchen facilities was not. AI/AN adolescents living in counties with less access to grocery stores (counties with values above the median) had lower obesity prevalence than those in counties with more grocery stores access (28.9% vs. 34.2%, $p < 0.001$). Those living in urban counties had higher obesity rates (33.6%) than those living in rural counties (30.6%, $p < 0.001$).

In this sample of AIAN adolescents, 13.8% were diagnosed with mental health disorders. Among those with mental health disorders, 35.7% were obese, a significantly higher rate of obesity than seen among those who did not have a diagnosed mental health disorder (32.0%, $p <$

0.001). The rate of a substance use disorder in the overall sample was 5.5%, with the most common disorder being drug use disorder (3.2%), followed by alcohol disorder (2.6%), and then tobacco use disorder (1.3%). Among those with substance use disorders, 28.5% were obese—a rate that was significantly lower than that of adolescents without a substance use disorder (32.8%, $p < 0.001$). Adolescents 18–19 years old exhibited the highest prevalence of substance use disorders (11.2%, data not shown); 26.2% of these adolescents were obese (data not shown).

Multivariable regression model

Table 2 presents the adjusted ORs from the multivariable generalized linear mixed model used to determine the association of the SDOH and mental health and substance use disorders with obesity. Per social and community context, females were less likely than males to be obese (OR=0.76, $p < 0.001$). In addition, the older age groups had lower odds of obesity than the younger age groups (e.g., OR=0.84 for 18–19 years, $p < 0.001$). Adolescents residing in counties with lower education levels had higher odds of obesity (OR=1.17, $p < 0.05$) than those residing in counties with higher education levels. With respect to healthcare access, Medicaid was associated with higher odds of obesity (OR=1.09, $p < 0.01$). In lower-income counties, the odds of obesity were significantly higher (OR=1.51, $p < 0.001$) than in higher-income counties.

Per neighborhood-built environment, AIAN adolescents living in counties with less access to grocery stores had lower odds of obesity (OR = 0.73, $p < 0.001$) compared to those living in counties with more access to grocery stores. Vehicle access and incomplete kitchen facilities were no longer significantly related to obesity after adjusting for other SDOH. Adolescents living in counties with a higher population density, i.e., higher concentration of AIAN people, had lower odds of obesity (OR = 0.83, $p < 0.01$). Finally, those AIAN adolescents residing in rural and urban areas did not have significantly different odds of obesity.

Considering behavioral health status, AIAN adolescents with mental health disorders had higher odds of obesity (OR = 1.26, $p < 0.001$) than those without a mental health disorder. Participants with substance use disorders had a reduced odds of obesity (OR = 0.73, $p < 0.001$) as compared to those who did not have a substance use disorder.

DISCUSSION

Prior research has found that increased life stressors, including historical trauma, place AIAN adolescents at increased risk for obesity, mental health, and substance abuse disorders as compared to non-AIAN groups [13, 20]. Given that adolescence is a critical developmental stage, biological, cognitive, and psychological changes during this time can affect lifelong health risks and development of healthy lifestyles [39]. In addition, adolescents commonly begin to differentiate from their family and exercise more control over their health during this life stage [40, 41]; thus, they may make decisions that place them at higher risk for obesity. This study extends prior adolescent health research by examining the relationship between SDOH and behavioral health (i.e., mental health and substance use disorders) with obesity risks. Furthermore, though previous work has examined the relationship between the SDOH and obesity among AIAN adolescents [30], to our knowledge, this is the first study to examine the

prevalence of obesity in relationship to mental health and substance use among a large, geographically diverse sample of AIAN adolescents.

Table 2. Adjusted odds ratios for obesity for AIAN adolescents aged 12–19 years old.

	All sample (n = 26,226) OR and 95% CI
Gender	
Male (reference)	
Female	0.76 (0.72, 0.81)***
Age group	
12–14 years (reference)	
15–17 years	0.91 (0.85, 0.96)**
18–19 years	0.84 (0.78, 0.91)***
Health insurance coverage	
Medicaid	1.09 (1.03, 1.15)**
Private	0.99 (0.92, 1.07)
Behavioral health conditions	
Mental health disorder	1.26 (1.16, 1.36)***
Substance use disorder	0.73 (0.64, 0.82)***
AIAN IHS educational attainment: % <high school^a	
Counties above the median (46.0%)	1.17 (1.004, 1.36)*
AIAN IHS Income: % <100% FPL^a	
Counties above the median (27.9%)	1.51 (1.29, 1.78)***
AIAN households with no vehicle access^b	
Counties above the median (12.9%)	0.98 (0.82, 1.16)
AIAN households with incomplete kitchen facilities^b	
Counties above the median (1.8%)	0.98 (0.82, 1.17)
Low access to a grocery store^c	
Counties above the median (25.3%)	0.73 (0.62, 0.87)***
Population AIAN alone or in combination^d	
Counties above the median (14.6%)	0.83 (0.71, 0.98)**
NCHS Rural county	0.997 (0.85, 1.17)

AIAN American Indian/Alaska Native, IHS Indian Health Service, FPL Federal Poverty Level, NCHS National Center for Health Statistics.

*p < 0.05; **p < 0.01; ***p < 0.001.

^aData source: American Community Survey 2010–2015 5-year estimates.

^bData source: US Census Bureau 2000.

^cData source: US Department of Agriculture Food Environment Atlas.

^dData source: US Census Bureau 2010.

SDOH, mental health, substance use and obesity prevalence

Our study augments the existing literature regarding the influence of SDOH on obesity among adolescents. Similar to other studies [1, 2], we found that AIAN adolescents in the United States ages 12–19 years had substantially higher rates of obesity (32.5%) as compared to the general population of U.S. adolescents (20.6%). We further found that several SDOH factors were associated with obesity rates among a national sample of AIAN adolescents.

In terms of the social community context, our study has several implications. Similar to Bullock et al.'s findings [1], AIAN males in our study were more likely to be obese than females, perhaps due to cultural acceptance of “larger” male teens, as found in another study [42]. Sex differences may also be due to some biological (e.g., body composition fat patterning, biological changes, and metabolism differences) and psychosocial/cultural variables (e.g., gender differences in engaging with exercise, parenting and control factors, and societal perceptions) [42]. More research is needed to determine which specific social, cultural, or biological mechanisms influence sex differences in obesity prevalence among AIAN adolescents.

Our study further suggests that AIAN adolescents may have age group differences in obesity. Specifically, AIAN adolescents who were in early, as compared to mid to late, adolescence had higher rates of obesity, which further supports Bullock et al.'s findings [1]. Given that prior research indicates that obesity rates increase with age, and most adolescents do not “grow out of” obesity [43], this study's younger age group may have unique experiences that differed from the older groups. For instance, this finding may reflect an upward trend in obesity among AIAN adolescents. More research is needed around this critical timeframe in development and obesity risks to determine age related trends and related factors.

Our findings also hold significance regarding population density and its influence on health, especially in terms of its ability to support cultural practices and engaging in rewarding social relationships [7]. Given we found that living in community with a higher concentration of AIAN decreased obesity odds for adolescents, this may be correlated with increased AIAN social cohesion, support, and access to cultural practices, which foster cultural identity. All of which have been previously linked to lower obesity and addiction risks among AIAN adolescents [44–46]. Community context could additionally mitigate exposure to and/or the effects of racial discrimination, which has recently been associated with increased obesity among Native Hawaiian adults [18]. Thus, our findings underscore the potential value of considering community context and correlating social and cultural supports in the prevention of obesity among AIAN adolescents. Our study further reinforces existing literature on health care access and obesity. Although all participants had access to health care through IHS, those with Medicaid had higher obesity rates than those without. Because Medicaid is often associated with low household income [47], our findings may reflect that lower household income correlates with less access to physical activity, school sports, and daily nutritious foods among AIAN adolescents [11]. While we controlled for income at the county level, income at the household level may still be drivers of obesity. Hence, the relationship between Medicaid, individual household income and obesity should be explored further. In terms of education, when examining the aggregate sample and education, at the county level, our results, unsurprisingly,

align with findings that lower education levels and economic stability are associated with higher obesity rates among AIAN adolescents, thus, supporting prior research [11, 43]. However, similar to income, future research should still explore the association between education at the household level.

Regarding the influence of the neighborhood/built environment, our findings deviated from the extant literature. After controlling for other SDOH, lower levels of vehicle access and higher rates of incomplete kitchen facilities were not associated with obesity, as found among an IHS population of older ≥ 50 AIAN adults [48]. Though prior research has indicated neighborhoods that are food deserts, or locations with more limited access to grocery stores, are associated with higher rates of obesity among non-AIAN people [49, 50], we found limited grocery store access to be associated with lower obesity rates. Perhaps limited access to grocery stores results in reduced chance of purchasing junk foods or high sugar content beverages for adolescents. This, in turn, may lead to eating at home and/or what is served by their parent or guardian. Future research is needed to determine how grocery store access influences individual AIAN adolescents and, specifically, affects their eating habits.

In terms of behavioral health and obesity, our findings support existing research suggesting that mental health disorders and odds of obesity are significantly associated among AIAN adolescents [25, 26]. Though early childhood and lifetime stressors have been shown to increase mental health risks, these findings should be understood within the context of historical trauma for AIAN adolescents. "...[Historical] trauma becomes something that not only occurs for the collective... While this does not eliminate the individual from our thinking about trauma, it does add an additional and very important dimension to our understanding of the experience." p. 10 [51]. Hence, the context of historical trauma and its impact on obesity risks cannot be ignored as it may have lasting intergenerational effects. For instance, prior research has found that the offspring of those who experienced communitywide trauma, such as famines, can have significantly higher risks for both obesity and mental health disorders [52]. Given the aforementioned historical and ongoing context for trauma among AIAN adolescents, high obesity rates are not surprising among this population. Meanwhile individual mental health factors may also play a role in behavioral choices obesity risks. In particular, during adolescence, depression and anxiety may increase poor eating habits, such as overeating, and decrease motivation to exercise; both of which can lead to obesity [25]. Although obesity has often been associated with depression, anxiety, and other mental health diagnoses [52–55]; its relationship with obesity among AIAN adolescents has not been thoroughly explored. Thus, our related findings among a large, geographically diverse sample validated the previous proposition that obesity and diabetes prevention programs for adolescents should consider mental health status and functioning for treatment [53].

This study remains innovative in considering substance use disorders as risk factors for obesity among a national representation of AIAN adolescents. Though some authors have previously posited that substance use risks overlap with obesity risks among AIAN youth [56], our study provides support that the presence of a substance use disorders is associated with lower obesity risks. Yet, this differs from previous studies, which indicate that alcohol, cigarette, and

marijuana use are correlated with increased BMI and obesity among adolescents in the U.S. [28, 57–59] and that substance use can predict subsequent increases in BMI [28]. Given the limitations of our data, we were not able to identify the specific mechanisms linking substance use disorders and obesity risks for AIAN adolescents.

Several explanations may explain why AIAN adolescents with a substance use disorder have lower odds of obesity. One may be that AIAN adolescents cope with stress by using substances and may not feel the need, or have opportunities, to overeat. Upon review, several studies have indicated that having a food addiction (i.e., eating behavior characterized by neurological, biological, and behavioral mechanisms as similar to substance use addictions [60]) does not correlate with substance use, and, specifically, may lower alcohol and tobacco use risks. Accordingly, our study’s results imply that some AIAN adolescents may, in fact, use one substance—food, alcohol, tobacco, etc.—as a coping mechanism but not another. This aligns with a previous anecdotal reports of AIAN women feeling compelled to overeat food to cope with stressors, which reportedly rewarded them in ways similar to, and in place of, other potentially addictive substances [60]. Another explanation may be that those with certain substance use disorders may suffer from malnutrition and, or reduction in appetite, consequently reducing risks for obesity. They may further become isolated during substance use and not participate in social contexts with food. Given that we cannot make any specific determinations with our data, future research is needed to explore these associations further among AIAN adolescents.

Study limitations

Despite being the first known investigation of SDOH in combination with mental health and substance use disorders as risk factors for obesity among AIAN adolescents, the study also has several limitations. This sample only included AIAN adolescents who were eligible for IHS services (i.e., are tribally enrolled) and elected to receive care at IHS facilities. Thus, we were not able to include AIAN adolescents who were not members of federally recognized tribes or who were served by other health care facilities. Additionally, some measurement error may be present due to undiagnosed conditions being misclassified. We also only considered data for one fiscal year, and only patients with a valid BMI. Moreover, individual-level education and income level were not available. Longitudinal analyses are needed to clarify how mental health, substance use, and SDOH may interact and influence change in obesity over time among AIAN adolescents.

CONCLUSION

Given the large number of geographically and culturally diverse AIAN adolescents in this sample, the novel findings provide important insight into SDOH and behavioral health factors that influence obesity. It also augments the literature by exploring how mental health and substance use disorders among adolescents may influence rates of obesity. Furthermore, AIAN adolescents are likely influenced by the characteristics of the communities in which they live. All of which have implications for future obesity prevention and intervention programming among

AIAN adolescents and the need to consider mental health and substance use and the influencing social determinants of health.

DATA AVAILABILITY

The data that support the findings of this study are available from the United States Agency Indian Health Services within the Department of Health and Human Services. Restrictions apply to the availability of the data, which are owned by the tribal nations involved and used under approval for this study. Data requests must be submitted to the IHS National Institutional Review Board (irb@ihs.org), and each of the tribal IRBs, tribal councils and tribal authorities involved with the Indian Health Service Data Project.

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MDJJ: conceptualization, original draft preparation, investigation, methodology, investigation, writing—review and editing, project administration; MR: methodology, formal analysis, data curation/management, visualization, writing reviewing and editing; LJ: methodology, visualization, formal analysis, data curation/management, writing reviewing and editing; KRH: conceptualization, methodology, writing—review and editing; AGB: project administration, investigation, supervision, conceptualization, methodology, writing—reviewing and editing; JFS: supervision, conceptualization writing—reviewing and editing, project administration; SMM: conceptualization, supervision, validation, writing—reviewing and editing, funding acquisition, project administration; JC: data curation, writing—reviewing and editing; ALFJ: writing reviewing and editing; CC: writing reviewing and editing; JO: supervision, conceptualization, project administration, data curation, investigation, methodology, writing reviewing and editing.

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COMPETING INTERESTS

The authors declare no competing interests.

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