Review Paper

Obesity risk factors in American Indians and Alaska Natives: a systematic review

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ABSTRACT

Objectives: We systematically reviewed the literature on risk factors for obesity in American Indians (AIs) and Alaska Natives (ANs) of all ages.

Study design: We searched titles and abstracts in PubMed with combinations of the following terms: obesity, body mass index (BMI), American Indian, Alaska Native, and Native American.

Methods: We limited our review to articles that provided an empirically testable claim about a variable associated with obesity, measured obesity as a dependent variable, and provided data specific to AI/ANs.

Results: Our final sample included 31 articles; 20 examined AI/AN youth (<18 years), and 11 examined AI/AN adults (≥18 years). Risk factors for obesity varied by age. In infants, low birth weight, early termination of breastfeeding, and high maternal BMI, and maternal diabetes increased the risk of childhood obesity. In children and adolescents, parental obesity, sedentary behaviors, and limited access to fruits and vegetables were associated with obesity. In adulthood, sedentary behaviors, diets high in fats and carbohydrates, stress, verbal abuse in childhood, and the belief that health cannot be controlled were associated with obesity.

Conclusions: Extant studies have three limitations: they do not apply a life course perspective, they lack nationally representative data and have limited knowledge of the resilience, resistance and resourcefulness of AI/ANs. Future studies that avoid these shortcomings are needed to inform interventions to reduce the prevalence of obesity in AI/ANs across the life course.

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Introduction

In the United States, 41% of American Indians (AIs) and Alaska Natives (ANs) are obese, compared with 39% of non-Hispanic Blacks, 35% of Native Hawaiians/Pacific Islanders, 32% of Hispanics/Latinos, 26% of non-Hispanic Whites, and 8% of Asians.[1] In addition, AI/ANs have high rates of mortality and short life expectancy relative to other racial and ethnic groups.[1] As obesity is a known risk factor for many leading causes of death in AI/ANs, including cardiovascular disease, cancer, type 2 diabetes, stroke, and kidney disease, the population burden of obesity may contribute to the observed disparities in mortality. Obtaining a better understanding of obesity risk among AI/ANs of all ages is thus a public health priority.

Understanding the historical context and concomitant consequences of colonization reveals the many factors that intersect to produce contemporary indigenous health and well-being.[2] Before Western contact, AI/AN had an enviable health status with lifestyles that included vigorous daily activity, wild produce, lean meats, and healthy starches. Native Americans lost land, independence, and political autonomy through conquest, expropriation, theft, and broken treaties. Political and economic subjugation produced tremendous cultural damage and caused historical trauma.[3−6] Forced removal from ancestral homelands to inhospitable areas of the US restricted, or altogether prevented, traditional hunting and agricultural practices. To avoid starvation, many tribes were forced to accept government food relief programs that distributed basic staples high in salt, sugar, and fat. The rapid change in diet, aided more recently by fast food and sedentary lifestyles, has, in part, contributed to the current high prevalence of obesity. Although changes in diet and exercise are among the obvious causes of obesity, other underacknowledged factors exist that converge to produce health inequities. Race, gender, and socioeconomic position interact to determine one's exposure to the causes of obesity and the availability of resources to mitigate the effects of these exposures.[7]

To date, however, no systematic review of the literature on risk factors for obesity across the life course has been conducted for AI/ANs. The present review aims to remedy this omission by characterizing the state of current research and identifying the most pressing issues for future study. In addition to discussing the most important contributions of the literature, as well as its theoretical and methodological limitations, we propose strategies to improve future obesity research in AI/ANs. By using a life course perspective, assembling truly representative population samples, and capitalizing on the resilience, resistance, and resourcefulness of AI/ANs, such research can inform interventions to prevent obesity, reduce its prevalence, and delay the onset of its comorbidities among AI/ANs.

Methods

Search strategy and criteria for inclusion and exclusion

We searched titles and abstracts in PubMed using the following terms: obesity, body mass index (BMI), American Indian, Alaska Native, and Native American. This simple strategy returned 498 peer-reviewed articles published between 1983 and 2016. Next, we applied three inclusion criteria, retaining articles that (1) provided a testable claim about a risk or protective factor for obesity, (2) measured obesity and/or BMI as a dependent variable, and (3) reported findings specific to AI/ANs, which reduced our sample to 74 publications. After reading all 74, we excluded 45, for the following reasons: no AI/AN participants (n = 2), obesity was not the outcome of interest (n = 19), study was purely descriptive (n = 5), study described an intervention (n = 3), and sample was multiracial, but results were not stratified by race (n = 16). Then, we revised the bibliographies and identified two more manuscripts that met our inclusion criteria. Our final sample included 31 publications (Fig. 1). This sample is limited to work published since 1983, because no earlier studies fulfilled our criteria for review. In addition, our criteria removed all commentaries and analyses of indigenous populations outside the United States.

Data extraction

We did not attempt to conduct a meta-analysis, because no study in our final sample used nationally representative data. Following a previous literature review,[8] we used a single age cutoff to classify studies in two groups according to participant age: youth (younger than 18 years; see Table 1) and adults (18 years and older; see Table 2). Our tables summarize the sample characteristics, obesity measures, key variables, and principal findings of each study.
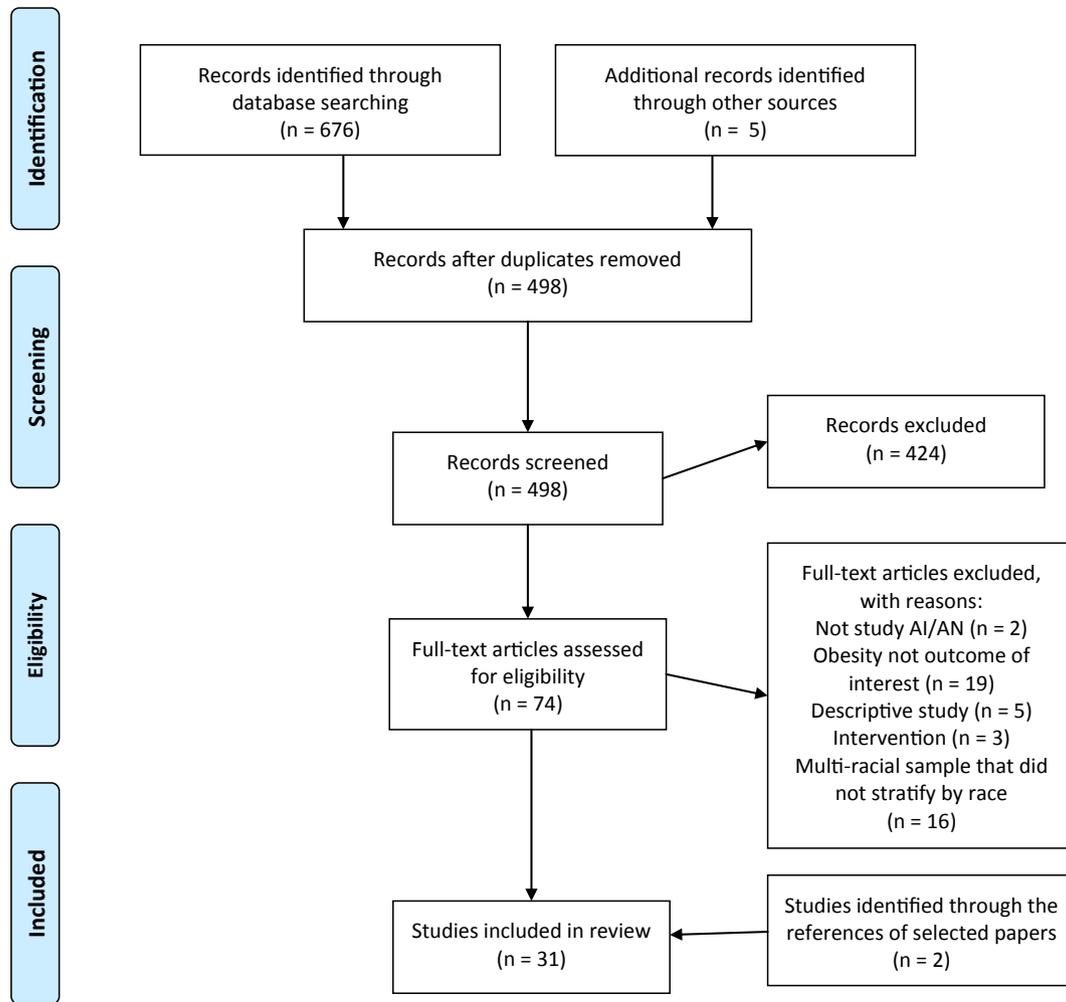
Results

Studies with AI/AN youth

Maternal and child health

A majority of studies (18 of 29) examined AI/AN youth (Table 1). Three articles investigated maternal and child health factors, to determine the principal risk factors for childhood obesity. Lindberg et al.[9] used evidence from three tribes in Wisconsin to determine the extent to which prenatal and postnatal variables explained BMI in childhood. Maternal gestational weight gain, low infant birth weight, and shorter duration of breastfeeding were all associated with children's BMI. Seal and Broome[10] conducted a similar study to examine associations among maternal BMI before pregnancy, infants' birth weight, early incorporation of formula and solid foods, and infants' weight-for-length (WFL) z-score. Although no statistically significant associations were found for WFL z-score, mothers with high pregestational BMI were more likely to have children with higher birth weight and to breastfeed for shorter periods, and they tended to incorporate solid foods earlier than mothers with normal BMI.

Adams et al.[11] sought to identify maternal and child risk factors for overweight at 36 months and for WFL z-scores at birth and 36 months. At 36 months, 22.2% of the children were overweight and another 18.7% were at risk of overweight. Only maternal smoking at the initial prenatal visit was a significant risk factor for overweight. Pettitt et al.[12] examined the

Fig. 1 – Selection of studies reviewed. AI/AN, American Indian/Alaska Native.

association between maternal BMI and maternal diabetes (either type 2 or gestational diabetes) and offspring BMI. Results showed that maternal diabetes, either type 2 before conception or gestational diabetes during pregnancy, increased the likelihood of obesity among offspring from birth to adolescence. Gallaher et al.[13] analyzed the role of maternal obesity and birth weight in childhood obesity. The prevalence of obesity was 23% among mothers and 20% among children. Both maternal obesity and high birth weight increased the risk of childhood obesity.

Blood quantum
Guidelines to characterize AI identity, ancestry, and tribal membership have been controversial for decades.[14] Previous studies have used the concept of 'blood quantum' to estimate an individual's degree of AI ancestry and its potential association with health outcomes.[15,16] Stern et al.[15] investigated whether gender, age, AI heritage (assessed by blood quantum), or tribal affiliation was associated with the onset of overweight or obesity. For boys, the average BMI was in the overweight range by age 2 years and in the obesity range by age 9 years. For girls, the average BMI was in the overweight category by age 7 years. Male gender was significantly associated with early onset of overweight and obesity, but neither blood

quantum nor tribal affiliation was associated with obesity. Hearst et al.[16] examined the link between obesity risk and AI heritage (assessed by blood quantum). Results showed a positive association between higher blood quantum and risk of overweight and obesity.

Diet and physical activity
Several articles investigated the role of diet and physical activity in overweight and obesity among AI/AN children. Harvey-Berino et al.[17] collected accelerometer data and food diaries, to analyze associations among intake of energy and nutrients, physical activity, and overweight/obesity. Fifty percent of the children were obese, and another 15% were overweight. The authors found that overweight and obese children consumed more fats and carbohydrates than their normal-weight peers. However, no associations appeared between physical activity or macronutrient distribution and overweight or obesity. Stevens et al. examined the contribution of physical activity in second grade to obesity outcomes three years later, in fifth grade. Results showed that physical activity had different effects on participants, based on their baseline BMI. For normal-weight participants, physical activity decreased the percentage of body fat, but for overweight participants, it increased BMI, fat mass, and fat-free mass.[18]

Table 1 – American Indian/Alaska Native (AI/AN) youth (aged <18 years) studies: sample characteristics, obesity measures, key variables, and principal findings.

First author, year	Sample	Obesity measure	Variables	Main findings
Adams 2010[21]	581 children aged 3–8 years in Wisconsin	BMI: Normal <85th percentile Overweight 85th percentile-95th percentile Obese >95th percentile Percentage body fat Waist circumference	Regular participation in sport teams, attendance at physical education programs, time spent playing outdoors, and hours of screen time	Hours of outdoor play and percentage body fat were negatively associated. No significant associations were found with other risk factors.
Adams 2005[11]	252 pairs of mothers and children (0–3 years) in Wisconsin participating in WIC (The Special Supplemental Nutrition Program for Women, Infants and Children)	Overweight and risk of overweight at 36 months and weight-for-length (WFL) (kg/cm) z-scores at birth and at 36 months BMI: risk of overweight ≥85th percentile-<95th percentile overweight ≥95th percentile	Birth weight, prepregnancy BMI, weight change during pregnancy, prenatal smoking, maternal demographics	Maternal smoking at the initial prenatal visit predicted overweight and risk of overweight at 36 months. Children of smokers were also significantly smaller at birth.
De Long 2008[26]	282 adolescents (mean age 14 years) from Minnesota Ojibwe bands	BMI: normal 5th percentile-<85th percentile overweight ≥ 85th percentile	Individual habits, parental attitudes about weight, and socioeconomic factors.	Watching TV, adopting weight-control behaviors, knowledge of nutrition, caring less about fitness, having parents who diet, and low body satisfaction were associated with overweight. Frequent snacking was associated with normal weight.
Fulkerson 2013[22]	422 children on the Pine Ridge Reservation in South Dakota	BMI z-score, based on CDC (The Centers for Disease Control and Prevention) Underweight ≤5th percentile Normal 5th percentile- 84th percentile Overweight/obese ≥85th percentile Percentage body fat Waist circumference	Parents' feeding practices and children's response to food cues and external eating	Higher food responsiveness scores were associated with overweight and obesity only among boys.
Gallaher 1991[13]	261 children aged 1–5 years and their mothers.	Weight for height Obese >95th percentile	Maternal obesity (BMI>95th percentile for women aged 20–29) and birth weight.	Children of obese mothers were more than twice as likely to be obese. Children with high birth weight (>4000 g) were three times as likely to be obese.
Gray 2003[24]	155 urban Native American children and youth aged 5–18 years	BMI: Underweight <5th percentile Normal 5th percentile-<85th percentile At risk of overweight 85 percentile–95 percentile Overweight >95 percentile Skinfold measurements	Energy and macronutrient intake, sedentary activities, activity level, and achievement of Presidential Physical Fitness Award	BMI was associated with age and receipt of Presidential Physical Fitness Awards in all age groups. Screen time and physical activity level were positively associated with BMI among youth aged 9–18 years. Energy and macronutrient intake was not associated with BMI.
Harvey-Berino 2000[17]	20 Mohawk children (18 months–4 years) and their parents on the St. Regis Mohawk Reservation in Hogansburg, New York	BMI: Overweight ≥85th percentile Obese ≥95th percentile Based on National Center for Health Statistics growth charts	Dietary intake and physical activity (measured with TriTrac accelerometer)	Overweight children had a higher intake of energy (402 kcal/day) and of dietary fat and carbohydrate. No differences were found in physical activity or macronutrient distribution between obese and the non-obese participants.

Hearst 2011[16]	3841 children aged 3—19 years on the Pine Ridge Reservation in South Dakota	BMI z-scores based on CDC: Overweight 85th percentile-95th percentile Obese >95th percentile	Percentage of American Indian heritage (blood quantum), sociodemographic environment, age, sex	Obesity prevalence showed an increasing trend by age. Multilevel modeling found no association between weight and sociodemographic environment. Higher blood quantum increased the risk of overweight and obesity.
Jollie-Trotter 2009[23]	291 children aged 8—12 years in the Northern Plains	BMI: Normal <85th percentile Overweight 85th percentile-95th percentile Obese >95th percentile	Role of individual dietary and physical activity habits, attitudes toward weight, and psychosocial factors	Watching television, intending to eat healthier foods, body dissatisfaction, negative attitudes toward body size, and attempted weight loss were associated with higher BMI.
Jones-Smith 2014[29]	22,863 children aged 7—18 years in California	BMI: Overweight/obese ≥85th percentile BMI z-score	Openings or expansions of American Indian—owned casinos	Opening or expansion of casinos was associated with a reduced risk of childhood overweight and obesity.
Lindberg 2012[9]	471 children aged 5—8 years in Wisconsin	BMI: Normal <85th percentile Overweight 85th percentile-<95th percentile Obese ≥95th percentile	Role of the prenatal environment, birth weight, breastfeeding practices, mother's weight, and father's weight.	Macrosomia, limited breastfeeding duration, and excess gestational weight gain were predictors of overweight at age 1 and at ages 5—8. Gestational diabetes and weight at age 1 were risk factors for overweight at ages 5—8.
Pettitt 1983[12]	629 Pima mothers and their 1935 children, aged 0—19 years	BMI of the mother and obesity status of the offspring	Diabetes status of the mother before or during pregnancy	Maternal diabetes increased the likelihood of obesity among the offspring, from birth to 19 years of age.
Ricci 2012[25]	33 pairs of parents and adolescents (10—14 years) from the Northern Plains	BMI: normal <85th percentile overweight 85th percentile-<95th percentile obese >95th percentile	Parental dietary and exercising habits and attitudes toward diet and physical activity	Parents' support for physical activity and nutritious diets was positively associated with obesity in adolescents. No significant association between parental habits and adolescent BMI.
Salbe 2002[19]	138 Pima Indian children aged 5 years	Body weight Percentage body fat	Energy expenditure, physical activity level, and substrate oxidation	Positive predictors of body weight at 5 and at 10 years were lower levels of participation in sports and more time spent watching television. Physical activity levels were positively associated with body weight at 5 years but negatively associated with body weight at 10 years. Energy expenditure was also positively correlated with body weight at 5 years. Energy expenditure and fat oxidation did not predict obesity. Prospectively, none of the baseline variables predicted body weight or percentage of body fat at 10 years.

Table 1 — (continued)

First author, year	Sample	Obesity measure	Variables	Main findings
Salbe 2002[20]	138 Pima Indian children aged 5 years	BMI: Normal <85th percentile Overweight 85th percentile-≤95th percentile Obese >95th percentile	Body composition, body weight, parental obesity, and fasting plasma concentrations of insulin, glucose, and leptin	Obesity at 5 years was the strongest predictor of obesity at 10 years. Higher maternal BMI, lower fasting insulin levels, and higher fasting leptin levels at age 5 also predicted higher body weight at age 10. In cross-sectional analysis, parental BMI, insulin, and leptin were positively associated with percentage body fat and body weight at 5 and 10 years.
Seal 2013[10]	98 infants aged 16—20 weeks from a small US town	Infants' weight for length z-score, based on CDC	Mother's BMI and breastfeeding practices.	No significant results, but high maternal BMI was associated with high birth weight and early incorporation of solid foods.
Smith 2009[27]	618 children aged 7—14 years from the Wind River Indian reservation in Wyoming	BMI z-score, based on CDC: Normal 5th percentile—<85th percentile At risk of overweight 85 percentile—95 percentile Overweight >95 percentile	Off-school periods	Significant association between off-school periods and higher BMI for fifth-grade girls and for those above the 85th percentile. No association among children with normal BMI.
Stern 2007[15]	100 urban AI children aged 2—12 years	BMI: Overweight ≥85th percentile Obese ≥95th percentile	Gender, age, tribal affiliation, and degree of Indian heritage by blood quantum (25% cutoff)	Male sex was associated with earlier mean onset of overweight and obesity. Blood quantum and tribal affiliation did not predict obesity.
Stevens 2004[18]	454 second grade AI children from the Pathways Study	BMI: overweight ≥95th percentile	Physical activity	Physical activity decreased body fat in normal weight participants, whereas it increased BMI, fat mass and fat-free mass among overweight participants.
Zhang 2011[28]	454 children aged 9—14 years from the Pine Ridge Reservation in South Dakota	BMI z-score, based on CDC: Normal <85th percentile Overweight 85th percentile-<95th percentile Obese ≥95th percentile	Summer vacation	Summer vacation was not significantly associated with BMI z-scores.

BMI, body mass index.

Table 2 – American Indian/Alaska Native (AI/AN) adults (aged ≥18 years) studies: sample characteristics, obesity measures, key variables, and principal findings.

First author, year	Sample	Obesity measure	Variables	Main findings
Bersamin 2014[35]	488 Yup'ik adults from Yukon-Kuskokwim Delta region. Mean age 34 years for women, 38 years for men	BMI. Percentage body fat. Waist circumference	Traditionalism, perceived stress, physical activity	Higher levels of physical activity and lower levels of perceived stress were associated with lower BMI, lower body fat percentage, and smaller waist circumference. Traditionalism was not associated with higher BMI.
Coe 2004[35]	559 women ≥18 years on the Hopi Reservation	BMI in kg/m²: overweight >27.30 obese >32.3	Traditionalism, identified with (a) knowledge of traditional language; (b) participation in cultural activities; and (c) time outside the reservation.	Adults with high scores for traditionalism were 40% less likely to become obese than those with low scores.
Egan 2009[40]	3665 participants aged 15–93 years (mean 39.9) from phase IV of the Strong Heart Study	BMI in kg/m²: underweight <18.5 healthy weight 18.5–24.9; overweight 25–29.9; obese 30–39.9 morbidly obese ≥40 waist-to-hip ratio	Internal health locus of control (HLC) (e.g., 'I have the power to make myself well'), powerful others HLC (e.g., 'Health professionals keep me healthy'), and chance HLC (e.g., 'No matter what I do, if I am going to get sick, I will get sick'	Men with higher waist-to-hip ratios and body fat percentages had higher powerful others HLC. Women with higher waist-to-hip ratios had higher powerful others HLC and higher Chance HLC. BMI was not associated with HLC measures.
Hodge 2009[38]	459 adults ≥18 years on 13 reservations in California	BMI in kg/m²: Morbidly obese >40	Role of sociodemographic, socio-economic, educational attainment, and health status.	Type 2 diabetes and female gender were significantly associated with obesity. Age, dietary habits, physical exercise, and education did not predict of obesity.
Hodge 2014[37]	459 AI/ANs >18 years (mean 41)	BMI in kg/m²: Underweight <18.5 Healthy weight 18.5–24.9; Overweight 25–29.9; Obese 30–39.9 Morbidly obese ≥40	Demographic characteristics, health indicators, preventive and/or risky behaviors, cultural constructs and adverse life events	High blood pressure and history of verbal abuse in childhood were significantly associated with higher BMI.
Huyser 2015[39]	3039 AI/ANs >18 years from 30 sites across the US	BMI	Serious psychological distress	Serious psychological distress did not increase the risk of high BMI after adjusting for demographic and health characteristics.
Murphy 1995[31]	1124 adults ≥20 years (895 Yup'ik, 229 Athabascan)	BMI in kg/m²: overweight: ≥27.8 for men and ≥27.3 for women	Diet, total glucose intolerance, euglycemia, demographics	Women had higher BMI than men, and Yup'ik women had higher BMI than Athabascan women. Overweight increased with age in all groups except Athabascan men. In both tribal groups, overweight was positively associated with total glucose intolerance, as well as with consumption of butter and fried foods in women and of Eskimo potatoes and cereal in men.
Nash 2014[30]	1076 Alaska Natives aged 14–94 years	BMI Waist circumference	Isotopic estimates of sugar intake	BMI and weight circumference were not associated with sugar intake.

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Table 2 – (continued)

First author, year	Sample	Obesity measure	Variables	Main findings
Redwood 2009[34]	10,372 AI/ANs >18 years	BMI Waist circumference Waist-to-hip ratio	Physical activity	Participants with higher levels of physical activity had significantly lower BMI, smaller waist-to-hip ratio, and smaller waist circumference.
Teufel 1990[33]	14 obese and 14 non-obese women aged 18−35 years from the Hualapai Tribe in Arizona	Obese = triceps plus subscapular skinfold measurement >90th percentile	Patterns of food use and nutrient intake	Obese women were more likely to have higher energy intake than their non-obese counterparts because of consumption of sweetened and/or alcoholic beverages.
Trude 2015[32]	424 American Indians aged 18−75 years	BMI	Consumption of healthy foods, high-fat foods, animal flesh, and unhealthy snacks	Consuming unhealthy snacks was associated with higher BMI.

BMI, body mass index.

A two-part study by Salbe et al.[19,20] explored energy expenditure, physical activity, sedentary behaviors, and substrate oxidation as risk factors for elevated BMI and body fat percentage. The prevalence of obesity at age 5 years was 28%; at age 10 years, it was 53%. Higher body weight and body fat percentages at age 5 years as well as at age 10 years were associated with less frequent participation in sports and more time spent watching television. Surprisingly, more frequent physical activity was associated with higher body weight at age 5 years but negatively associated with body weight at age 10 years.[19] The second part of the study examined height, weight, body composition, parental obesity, birth weight, and fasting insulin, glucose, and leptin concentrations as possible risk factors for obesity. Parental BMI, fasting insulin, and fasting leptin were positively associated with body weight and percentage of body fat at ages 5 and 10 years. In a prospective analysis, obesity at age 5 years was the strongest risk factor for obesity at age 10 years.[20]

Adams and Prince[21] examined associations between physical activity, BMI, body fat percentage, and waist circumference. Based on BMI, 25% of the sample was obese and 20% were overweight. Body fat percentage was negatively associated with time spent playing outdoors, but no associations were found between BMI and time playing outdoors, weekly hours of sport participation, or frequency of physical education classes. In a similar study, Fulkerson et al.[22] examined whether overweight or obesity was associated with children's responsiveness to food (defined as interest in food and pace of eating) or parents' strategies to regulate such responsiveness. A statistically significant relationship appeared between food responsiveness and overweight/obesity in boys, but not in girls.

Jollie-Trottier et al.[23] studied associations of BMI with diet, physical activity, attitudes toward weight, emotional eating, self-esteem, and cultural identification. High BMI was associated with body dissatisfaction, negative perceptions of body size, more time spent watching television, and more attempts to lose weight. However, no associations were found between BMI and emotional eating, self-esteem, or cultural identification. Gray and Smith[24] investigated correlations between BMI and physical fitness, dietary intake, and activity levels. Sixty-three percent were either overweight or at risk of overweight. BMI was positively associated with age and negatively associated with achievement on the Presidential Physical Fitness Test. Among participants aged 9−18 years, obesity was positively associated with lower activity levels and more time spent watching television.

Two studies examined obesity risk in AI/AN adolescents.[25,26] De Long et al.[26] aimed to determine the extent to which individual habits, parental attitudes toward nutrition, and socioeconomic variables could explain BMI. They found statistically significant associations between higher BMI and greater frequency of watching television, efforts to control weight, snacking, body dissatisfaction, and parental attitudes toward diet and health. In a similar study, Ricci et al.[25] measured the role of parental determinants of BMI with data from the Northern Plains. The results were counterintuitive: parents with the most positive attitudes about exercise and healthy diet were the most likely to have overweight children. However, no

statistically significant associations linked parental physical activity or dietary behaviors with adolescent BMI.

Environmental factors

Two studies examined the extent to which the school calendar year affected childhood BMI. Smith and colleagues reported that compared with BMI during the academic year, BMI during school vacations typically increased among fifth-grade girls but not among girls in other grades or among boys in any grade.[27] Zhang and colleagues conducted a similar analysis, but they found no association between vacations and changes in BMI.[28] Finally, Jones-Smith et al.[29] examined the effect of openings or expansions of tribally owned casinos on overweight and obesity in 117 school districts encompassing tribal lands in California. Openings or expansions of casinos were associated with increases in per capita income, reductions in BMI, and reductions in the risk of overweight and obesity.

Studies with AI/AN adults

Diet and physical activity

Eleven studies examined risk factors for obesity in AI/AN adults (Table 2). Four of them focused on the role of diet. Nash and colleagues recruited a sample of adolescent and adult Yup'ik people aged 14–94 years from southwest Alaska[30] (68% obese) to investigate the relationship between sugar intake and obesity. However, no significant associations appeared. Murphy et al.[31] investigated the association of glucose intolerance with BMI and the frequency of consuming various food groups in a sample of AN adults aged 20 years and older from 15 villages along the Yukon and Kuskokwim rivers. Participants included Yup'ik and Athabascan tribal members. Notably, the prevalence of obesity was higher in women than in men, with variation by tribe: 27% of Yup'ik men and 51% of Yup'ik women versus 25% of Athabascan men and 39% of Athabascan women. Participants with glucose intolerance were also more likely to be overweight than those with normal glucose levels. Women with higher BMI were more likely to consume butter and fried foods, whereas men with higher BMI were more likely to consume Eskimo potatoes (an indigenous tuber) and cereal. Trude et al.[32] used food frequency questionnaires to develop factors based on intake of food in several categories: healthy foods, high-fat foods, animal flesh, and unhealthy snacks. Surprisingly, consumption of unhealthy snacks was associated with lower BMI. Finally, Teufel and colleagues investigated dietary patterns in a sample from the Hualapai Tribe in northwest Arizona. Obese women had higher energy intake than their non-obese counterparts because they consumed more beverages, both alcoholic and non-alcoholic. No association appeared between obesity and intake of fat or fiber.[33]

Two studies examined the association between physical activity and obesity in Native adults. Redwood et al.[34] found that participants with higher levels of physical activity had lower BMI, smaller waist-to-hip ratios, and smaller waist circumferences than those who exercised less. Bersamin et al. studied BMI, physical activity, traditionalism, and perceived stress in adolescents and adults. Average BMI was 26.2 kg/m^2 among men and 29.1 kg/m^2 among women. Risk of obesity was negatively associated with physical activity and positively associated with perceived stress, but not associated in either direction with traditionalism.[35]

Blood quantum and traditionalism

Coe and colleagues also evaluated potential associations between traditionalism and obesity.[36] Three indicators were used to measure traditionalism: language use, participation in Native cultural activities, and time spent off reservation. Study participants with the highest scores for traditionalism were 40% less likely to be obese than those with the lowest scores. Hodge et al.[37,38] conducted two studies with data from 13 tribal communities in California (25% overweight, 36% obese, 11% morbidly obese). In the first study, they examined the association of morbid obesity with demographic, socioeconomic, and health status variables. They found a statistically significant association with female sex but not with marital status, education, employment, tribal enrollment, percentage of AI/AN ancestry (assessed by blood quantum), or knowledge of a traditional tribal language.[38] In the second study, they evaluated demographic characteristics, health indicators, preventive and risky behaviors, cultural constructs, and adverse life events as predictors of obesity.[37] Verbal abuse in childhood and hypertension were the only factors significantly associated with higher BMI.

Psychological distress and self-control

Huyser et al.[39] investigated the association between obesity and experiencing serious psychological distress among participants enrolled in the Special Diabetes Project for Indians—Healthy Heart Project. No significant associations were found. Finally, a study conducted by Egan et al.[40] centered on the concept of the health locus of control (HLC), which refers to the degree to which people believe they can control their own health. The study assessed associations among HLC, waist-to-hip ratio, body fat percentage, and BMI. All were originally recruited for an earlier project, the Strong Heart Study. Three types of HLC were assessed: internal (e.g., 'I have the power to make myself well'), powerful others (e.g., 'Health professionals keep me healthy'), and chance (e.g., 'No matter what I do, if I am going to get sick, I will get sick'). Men with higher waist-to-hip ratios and body fat percentages were more likely to report powerful others HLC, whereas women with higher waist-to-hip ratios were more likely to report powerful others HLC and chance HLC. However, BMI was not associated with any HLC measures.

Discussion

The most consistent finding of our review is that risk factors for obesity in AI/ANs vary by age. In infants, low birth weight, early termination of breastfeeding, and high maternal BMI increase the risk of childhood obesity. In children and adolescents, parental obesity, sedentary behavior, and limited access to fruits and vegetables are associated with obesity. In adulthood, the associations shift to sedentary behavior, high intake of carbohydrates and fats, stress, verbal abuse in childhood, and the belief that one cannot control one's health. Although the results of this study cannot be generalized to the

US population, per se, obesity risk factors for AI/ANs might offer hints to examine other racial minorities.

We note several limitations of the studies in our review. Foremost is their conception of obesity as a fixed health outcome, instead of a trajectory over time. Only four studies, all limited to children, examined obesity longitudinally. Two studied changes between the ages of 5 and 10 years,[19,20] and two others studied changes between the school year and subsequent vacation periods.[27,28] A second limitation concerns the composition of study samples. Most studies examined children or adolescents, and among the minority that recruited adults, most were limited to women. Given the refractory nature of obesity in adults, youth is a prime age to study. Although studies of children and youth present useful findings on risk and protective factors, further evidence is needed to determine whether the direction and size of the reported effects persist in other age groups. A third limitation is the prevailing focus on diet and physical activity as the principal risk factors for obesity. Recent studies with non-Native samples associate obesity with phenomena as diverse as the composition of the gut microbiome[41] and the incarceration of family members,[42] but we do not know whether these variables influence obesity outcomes in AI/ANs.

A fourth limitation involves methodology, insofar as most studies used local and regional samples assessed at a single point in time. The results of such research cannot be generalized to the total AI/AN population and do not lend themselves to meta-analysis. The preponderance of samples from highly circumscribed geographical areas and the scarcity of longitudinal data underscore the absence of any national efforts to collect population-representative data that would be suitable for testing specific research hypotheses pertinent to AI/ANs. Cross-sectional models by themselves have limited power to assess causal relationships between specific variables and obesity, and they have been unable to tease out some of the most important factors involved. Moreover, the general sparseness of data is a critical limitation for studies of obesity pathogenesis in AI/ANs. For decades, public health researchers have debated the best strategies for sampling underrepresented minorities[43,44] and retaining them as participants in research studies.[45] We recommend oversampling of AI/ANs, as well as continuing research into the best strategies for aggregating data on small tribal populations to increase the robustness of findings.[46]

The absence of longitudinal data on weight, body composition, and related variables in AI/ANs has hindered efforts to evaluate risk factors for obesity over the life course. Such research is essential to reliably assess the impact of variables commonly associated with obesity, such as female sex, and their differential effects over time. Previous studies have examined the longitudinal effects of certain key variables in the general population,[47–50] but we do not know the extent to which AI/ANs conform to the patterns established by this work. Longitudinal data will enable identification of the most critical time frames for intervening on overweight and obesity in this population.

Finally, extant research has not analyzed resilience as a protective factor against obesity. Previous studies have shown the extent to which resilience prevents undesirable health outcomes, especially in the context of mental health and substance abuse.[51,52] However, no study to date has characterized the potential contribution of resilience to obesity prevention efforts. This research, along with efforts to recognize the resistance and resourcefulness of AI/AN communities, is expected to generate insights for future partnerships and interventions.

Limitations of this review

We relied on the terms American Indian, Alaska Native, and Native American to identify publications on our population of interest. Although we included many studies that identified the names of specific tribal communities, such as the Pima and the Mohawk, we did not conduct independent searches for each of the 567 federally recognized tribes. Therefore, we might have missed some relevant articles. In addition, we selected publications that included the terms 'obesity' or 'body mass index' in the title or abstract, but perhaps using alternative terms such as 'overweight' or 'waist circumference' would have led us to other pertinent papers. We also limited our search to the PubMed database, which comprehensively indexes journals in public health and medicine but does not include all journals in other disciplines, such as sociology and anthropology.

Another important limitation is our omission of studies that examined obesogenic processes without directly measuring their effect on individual BMI. Here, we refer to a broad body of scholarship, tangential to obesity outcomes, whose focus ranges from weight loss patterns[53,54] to disparities in access to healthy foods.[55–57] Although these studies offer valuable insights on obesity and its disparities, we excluded them because they did not provide evidence of specific risk or protective factors in our population of interest. Nevertheless, we recognize that this work offers potential hypotheses that could inform future health research with AI/ANs.

Conclusion

We conducted a systematic review of the literature on risk factors for obesity in AI/ANs. Most studies emphasized that risk factors vary by age. Given the manifest theoretical and methodologic limitations of extant work, we advocate for major improvements in future research. Theoretically, we recommend a life course approach that can trace the trajectory of obesity and provide explanations that go beyond unidirectional contrasts between normal weight and overweight or obesity. Methodologically, we highlight the importance of culturally sensitive aggregation of regional samples to enable statistically valid assessments of obesity and related variables at the national level. We encourage researchers to examine the extent to which the resilience, resistance, and resourcefulness of AI/ANs could prevent undesirable cardiometabolic outcomes, and to the extent possible, we encourage investigators to use both regional and national data to increase the generalizability of findings. We also suggest new data collection efforts that sample AI/AN longitudinally across the United States and collect pertinent measured and self-reported health and social data to better establish the determinants of obesity in

this population. We anticipate that such research will provide compelling explanations for obesity and its comorbidities, while inspiring future interventions.

Author statements

Ethical approval

This study was deemed exempt by the Institutional Review Board at our university.

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Competing interests

All authors declare that they have no conflict of interest.

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