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Prevalence and Associations of Central Obesity among U.S. Children Ages 6-11: an Analysis of NHANES 2007-2016

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Prevalence and Associations of Central Obesity
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by

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ABSTRACT

Central obesity measures—such as waist circumference (WC) and waist-to-height ratio (WHtR)—were found to have additional predictive power to body mass index (BMI) in assessing cardiometabolic risk. Few studies have assessed how well central obesity measures compared to general obesity as defined by BMI predict vascular health risks among young children. The objective of this dissertation was to estimate the prevalence of central obesity and to assess their associations with dyslipidemia and hypertension among U.S. children ages 6 to 11 years based on the 2007-2016 National Health and Nutrition Examination Survey (NHANES). In 2015-2016, 15.8% of children overall were centrally obese as defined by WC; 29.8% were centrally obese as defined by WHtR; 17.4% were generally obese as defined by BMI. Hispanic American children had a significantly higher prevalence of central and general obesity than non-Hispanic white and black children, and those children living in a high-income family were less centrally obese as defined by WHtR. The study also observed that the prevalence of central obesity as defined by WC was significantly decreased during 2007-2008 through 2015-2016 (from 21.2% to 15.8%). Data suggested that WHtR is a better predictor for dyslipidemia, whereas BMI is a better predictor for hypertension among obesity indexes among U.S. children ages 6 to 11 years. This dissertation provides a foundation for developing childhood obesity-related public health strategies and considerations for pediatric clinicians in screening multi-ethnic groups of children. A more comprehensive investigation of the effectiveness of interventions to reduce WC related to vascular health outcomes can contribute to our understanding of how central fat mass in childhood affects an individual's long-term health.

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Chapter 1: Introduction

Background

Adiposity has been suggested to be an important modifiable risk factor for cardiovascular disease and is strongly associated with atherosclerotic vascular changes (Camhi & Katzmarzyk, 2011; Ciccone et al., 2011; Falaschetti et al., 2010). Body Mass Index (BMI) has been used as a measure of overall obesity, and waist circumference and waist-to-hip ratio have been used as measures of central obesity (where visceral adipose tissue is stored) of both adults and children (Han, Lawlor, & Kimm, 2010). BMI is now routinely applied to estimate body fat not only in epidemiological studies but also in pediatric practice. However, many studies warn that BMI is not an accurate measure of adiposity in individuals, and that BMI is an imperfect measure of body fatness (Crespi, Alfonso, Whaley, & Wang, 2012; Freedman & Sherry, 2009; Metcalf et al., 2011) because it cannot discriminate between lean mass and fat mass among children (Glasser, Zellner, & Kromeyer-Hauschild, 2011; Nevill, Stewart, Olds, & Holder, 2006; Nevill et al., 2010).

BMI generally has a low sensitivity and a high specificity in detecting excess adiposity in children (M. J. Duncan, Mota, Vale, Santos, & Ribeiro, 2012; Freedman & Sherry, 2009; Glasser et al., 2011). BMI is able to correctly identify the fattest children (high specificity, low false positive rate); however, because of its low sensitivity (moderate–high false negative rate), it can misclassify large numbers of children with a high body fat content (Crespi et al., 2012; Freedman & Sherry, 2009). Because BMI varies with age and sex, current growth curve charts consist of age- and sex-specific percentile data for youths. However, the percentiles were derived from different populations, and different cut-offs were used to define overweight and obesity (Beydoun & Wang, 2011; Freedman & Sherry, 2009). BMI explains ~20%-75% of the variability in body fat composition for children (Crespi et al., 2012; Freedman & Sherry, 2009; Glasser et al., 2011), and the error made by BMI in estimating body fat is usually acceptable at the population level but not at the individual level. In addition, there are racial/ethnic differences in body fat composition among children (Sisson et al., 2009), but these differences vary by BMI-for-age (Freedman et al., 2009). Previous analyses of National Health and Nutrition Examination Survey (NHANES) data show some significant differences in adiposity for age by race/ethnicity, particularly for girls (Dugas, Cao, Luke, & Durazo-Arvizu, 2011; Freedman, Khan, Serdula, Ogden, & Dietz, 2006). And, only a few U.S. youth studies on associations between general or central obesity and vascular alteration by ethnicity and socioeconomic status have been conducted (Camhi & Katzmarzyk, 2011; Rodriguez et al., 2010). Therefore, it may be difficult to develop race-specific BMI cut points to identify equivalent levels of body fat.

The clinical significance of central adiposity measures in childhood obesity has been contested, and evidence around the use of central obesity measures as an adiposity index to predict vascular health in childhood obesity is limited. Central obesity indices, including waist circumference (WC) and Waist-based measures, such as waist-to-height ratio (WHtR) and waist-to-hip ratio (WHR), may perform better than BMI as a screening tool (Colin-Ramirez et al., 2009; Hirschler, Molinari, Maccallini, Aranda, & Oestreicher, 2011; Mendoza, Nicklas, Liu, Stuff, & Baranowski, 2012). WC and WHtR may have a key role in the early identification of overweight-related problems in children as young as 5 years of age (Freedman et al., 2007). WHtR has been found to be comparable to BMI for assessing cardiometabolic risk in children and adolescents (Hirschler et al., 2011; Mokha et al., 2010). Only a few U.S. studies have investigated central adiposity and vascular health in obese pre-teen children, and their findings are not consistent (Dhuper, Sakowitz, Daniels, Buddhe, & Cohen, 2009; Mendoza et al., 2012).

In an Australian cohort study, a high WC during childhood and adolescence did predict metabolic syndrome some 20 years later (Schmidt, Dwyer, Magnussen, & Venn, 2011). In a UK prospective cohort, however, WC and WHtR during childhood were no more predictive than BMI in cardiometabolic health during adolescence (Graves et al., 2014; Lawlor et al., 2010). In addition, as evidence linking visceral adiposity and atherosclerosis is growing (Despres et al., 2008), fat distribution may be considered more critical than the degree of adiposity.

Early atherosclerosis is characterized by a long subclinical period with development of pathological changes in arteries of children and adolescents decades before overt clinical manifestations of disease. Associations of known cardiometabolic risk factors with morphologic and functional vascular changes as well as surrogate biomarkers of atherosclerosis are revealed (Botton et al., 2007; Leeson, 2007); however, many pediatric scientists address clinical gaps in caring for high-risk children such as less effectiveness of screening tools designed for adult's coronary heart disease, uncertainty of optimal ages and intervals for general screening of children, and difficulties in evaluating outcomes after therapeutic interventions (Celermajer & Ayer, 2006; Daniels, Greer, & Committee on Nutrition, 2008). Given the strong correlation between central obesity and general obesity, it is uncertain whether the secular trends in WC are independent of those in BMI. In addition, there is no standard definition of vascular health related to severe adiposity or excess body fat in childhood.

The recent studies that examined correlations of central adiposity with early atherosclerosis of children demonstrated that vascular alteration was manifested early, at the age of five (Geerts et al., 2012) and that higher abdominal fat mass was associated with cardiometabolic risk factors (Gishti et al., 2015); however, there was limited evidence about the effect of age, sex, and ethnicity on the associations.

Studies of associations of central obesity in children ages 6 to 11 years with vascular health risk factors (high blood pressure (BP) and dyslipidemia) were also reviewed. In all age ranges, excessive adiposity was associated with several adverse health effects, including hypertension, dyslipidemia, and low grade systemic inflammatory markers. However, the magnitude and nature of associations of general and central adiposity measures with vascular outcomes varied across the studies.

WC was a strong determinant of elevated BP in both healthy and obese children and a major contributing factor to the rising prevalence of high BP in obese children (Barba, Troiano, Russo, Strazzullo, & Siani, 2006; Colin-Ramirez et al., 2009). Systolic and diastolic BP increased significantly with the degree of central obesity without the presence of gender differences (Galcheva, Iotova, Yotov, Bernasconi, & Street, 2011). Also, covariates to include in assessing the associations of adiposity with BP were suggested, including birth weight (Barba et al., 2006), family history of hypertension, puberty status (Colin-Ramirez et al., 2009), salt intake and physical activity of children (Mendoza et al., 2012).

WHtR was developed to correct for the over- and under-estimation of risk among tall and short individuals with similar WC in adults (Browning, Hsieh, & Ashwell, 2010) and its simplicity of cut-off values has a big advantage in studying children from multi-ethnic groups. This central obesity index was strongly correlated with abdominal fat mass measured with advanced imaging techniques (Ashwell & Hsieh, 2005). Several studies (Hirschler et al., 2011; Olza et al., 2014) including the Bogalusa Heart Study (Freedman et al., 2007; Mokha et al., 2010) supported the utility of WHtR to predict vascular health among children. However, its association with high BP was found lower than BMI’s and WC’s (Barba et al., 2006).

Among multi-ethnic studies that were reviewed, race or ethnic differences did not significantly impact associations of adiposity measures with vascular health outcomes. But, a significant racial or ethnic effect has been reported in body fat distribution of younger children (Sisson et al., 2009; Staiano & Katzmarzyk, 2012). A recent U.S. study found that potential racial/ethnic differences in the association between high WC and elevated BP may impact identification of children (ages 9-13 years) at risk for elevated BP, especially among Hispanics (Smith, Gilstad-Hayden, Carroll-Scott, & Ickovics, 2014). Evidence regarding racial/ethnic differences remains limited and inconclusive.

Problem Statement

Excessive fat storage is accompanied by several comorbidities in children. Obesity-induced cardiometabolic risks—such as higher BP, increased insulin resistance, and dyslipidemia before adulthood—are growing concerns globally (Short, Blackett, Gardner, & Copeland, 2009) and monitoring childhood obesity highlights the need to identify high-risk children for targeted interventions. The recent estimate of the obesity prevalence in children and adolescents ages 2 through 19 years in the U.S. is about 17% based on data for 2011-2014 (Ogden et al., 2016). Previous age-specific trend analyses of obesity prevalence between 2003-2004 and 2011-2012 showed no significant change in children and adolescents ages 6 to 19 years, but a decrease in children aged under 5 years (Ogden, Carroll, Kit, & Flegal, 2014). However, a recent report on the trend of obesity prevalence in the US adolescents ages 12 to 19 years shows significantly increased between 1988-1994 and 2013-2014 (Ogden et al., 2016). Moreover, the prevalence of severe obesity, defined by body mass index (BMI) BMI as $\geq 97^{th}$ percentile, has been continuously growing among all age and racial/ethnic categories of US youths ages 6 to19 years (Ogden, Carroll, Curtin, Lamb, & Flegal, 2010); however, these descriptive studies mostly assessed general obesity based on body mass index (BMI) classifications. There is little information about recent time trends in central obesity among US children and adolescents.

Central obesity (aka abdominal obesity) is emerging (Schroder et al., 2014), although it is not yet routinely measured in the pediatric clinical practice. Evidence in youths suggests that visceral fat plays a central role in metabolic derangement and vascular pathology secondary to obesity (Freedman et al., 2007). Centralization of body fat stores rather than overall fat mass has been shown to be associated with increased cardiac risk (Despres & Lemieux, 2006) and central obesity is reported to be more related to cardiometabolic risk factors than BMI in both children and adults (de Jongh et al., 2006; de Koning, Merchant, Pogue, & Anand, 2007).

Since standard BMI is calculated using the height and weight for age, and changes widely during growth, a constant cut-off point cannot be set for children (Freedman & Sherry, 2009). A recent meta-analysis found that children with a normal BMI may still have body adiposity that puts them at risk of obesity-associated morbidities such as diabetes mellitus and hypertension (Javed, Lteif, Kumar, Simmons, & Chang, 2015). Thus, abdominal adiposity measures can be added in clinical practice during childhood for more accurate screening of obesity-induced adverse effects on vascular health (Dencker et al., 2012).

There are several key issues in screening and identifying of children with high risk for obesity-induced vascular disorders, not to mention limited depiction of the pediatric population because of lack of studies and accessibilities (Celermajer & Ayer, 2006; Daniels et al., 2008). For clinical practice and epidemiological studies, child adiposity is usually determined by weight-to-height ratio or BMI percentile, and this overall index may not be the most appropriate in predicting atherosclerotic vascular disorders. Consequently, a better understanding of different screening tool for obesity/overweight in multi-ethnic pediatric populations could guide future health promotion efforts and build effective vascular protective strategies for high-risk children.

While the evidence of adiposity-induced vascular alteration and early atherosclerosis among younger children is accumulating, vascular health outcomes are not consistent with the level of obesity determined by BMI, especially in multi-ethnic children studies (Dai et al., 2009; S. Li et al., 2014; Martin et al., 2015). To explain complex patterns in the association between adiposity and health outcomes and to understand multifactorial nature of childhood obesity, researchers and clinicians have begun to apply social ecological frameworks. It is widely accepted that children from racial/ethnic minority and/or low socioeconomic backgrounds have disproportionately high rates of obesity (Anderson & Whitaker, 2009; Y. Wang & Zhang, 2006). However, recent US youth studies suggest a complex relation between socioeconomic status (SES) and obesity (Fradkin et al., 2015; Weedn, Hale, Thompson, & Darden, 2014). An overall trend of a weakening association between SES and obesity with the patterns differing across ethnic groups was reported among US adolescents between 1971 and 2002 (Q. Zhang & Wang, 2007), but little is known about the recent trend in children.

Significance

Early identification of elevated abdominal fat may be extremely valuable in early prevention of cardiometabolic risk. Detailed estimates for child and adolescent general and central obesity prevalence are important to set up public health programs that focus on reducing or preventing childhood obesity among high-risk groups. Only a few of the published studies included age-, sex-, and ethnicity-specific obesity trends and no analyses of central obesity trends have been analyzed for the NHANES since 1999-2000. Associations of vascular health with central obesity by age, ethnicity, sex, and household income can help clinicians and researchers to identify high-risk groups and to understand adiposity-induced vascular alteration and metabolic disorder induced early atherosclerosis among children. Measuring various vascular biomarkers of children may add important information as subclinical vascular damage reflects the impact of cumulative exposure to cardiometabolic risk factors in preceding years. Moreover, it may help bridge the gap between studies in children before puberty by examining the relationship between central obesity and risk factors because most studies in pre-teen children mainly focused on the association between birth characteristics and vascular health. This investigation provides the most recent national estimates from 2015–2016 on childhood obesity prevalence by sex, age, and race and Hispanic origin, and overall estimates from 2007-2008 through 2015–2016.

Purpose of the Study

The purpose of this dissertation is to assess the impact of adiposity on childhood vascular health. It is important since it may affect the initiation and progression of atherosclerosis and its later cardiovascular alterations. Given the elevated vascular risk factors reported in non-obese children according to BMI and central obesity based on WC, the inclusion of body composition measurements together with vascular health evaluation is desirable for both diagnosis and clinical decision-making.

The final goal of the study is to develop a standardized definition for adiposity (optimal cut-offs) among multi-ethnic samples at different ages. Early signs of vascular alterations in central obesity should also be explored to improve prevention strategies (i.e., algorithms). And, longitudinal studies should be conducted to assess whether a cumulative effect or worsening of BP may occur with increasing age—especially for obese children. Longitudinal studies are also needed to track progression of risk over time in overweight pre-teen children with dyslipidemia compared to overweight children who are metabolically normal by currently available cut-off points.

Obesity-induced vascular alteration in children is a multi-factorial and multi-phases phenomenon. This study was guided by current literature found associated factors with children central obesity related to vascular damage and Social-Ecological Model to address cultural and familial socioeconomic status which contribute to excessive weight and abdominal fat in children. For purposes of population-level obesity prevention research and interventions, improving understanding of the complexity of the shifting environmental and sociocultural influences on child obesity requires a shift from a reliance on mainly behavior change models to a socio-ecological framework. It provides an appropriate primary model for guiding the development, implementation and evaluation of complex school-based obesity prevention interventions. It is vital that public health practitioners and researchers recognize the importance of articulating and applying conceptual frameworks and related models for action to assess central obesity and general obesity in childhood.

Innovation

The study is highly innovative for the following reasons: (1) assessing vascular health in young children before puberty changes occur is important because it shows how body composition is related to single and clustered cardiometabolic factors without any hormonal impact, (2) comparing adiposity measures in children to determine the most sensitive/accurate/ valid measure that is the least invasive for predicting early development of atherosclerosis during childhood, and (3) a less complex measure of central adiposity can then be standardized by age and sex before the onset of puberty and used in future pediatric research.

A descriptive study has fewer burdens to study subjects and researchers, and less possibility of missing cases and data than a longitudinal study. Since previous studies indicated that significant ethnicity (White, African American, and Hispanic) and sex differences exist in distribution of central adiposity among children, it will be useful to examine sex, ethnicity, and socioeconomic status and their impact on associations of obesity-induced vascular alterations.

Research Aims

The objective of the study was to estimate the prevalence of central and general obesity in U.S. children and to investigate associations between central obesity and vascular health among children ages 6 to 11 years. This proposed study includes four specific aims: (1) to estimate prevalence of central and general obesity in U.S. children based on the NHANES 2015-2016 by sex, ethnicity, and family annual income; (2) to assess temporal trends in prevalence of central obesity among U.S. children during 2007 and 2016 by sex, ethnicity, and family annual income; (3) to investigate associations between central obesity and vascular alteration biomarkers (BP and lipids) among children ages 6 to 11 years based on the NAHNES 2007-2016; (4) to explore the impact of age, sex, ethnicity, and family annual income on the association between central obesity and vascular alteration biomarkers (BP and lipids).

Chapter 2: Literature Review and Conceptual Framework

Introduction

BMI has been the most widely recognized surrogate of obesity, but not a valid parameter for the distribution of body fat (Freedman et al., 2005), especially in youth (Eto, Komiya, Nakao, & Kikkawa, 2004), or multi-ethnic children (J. S. Duncan, Duncan, & Schofield, 2009). Other anthropometric indexes such as waist circumference (WC) and waist/height ratio (WHtR), used for defining central obesity, may be better than BMI for predicting risk of hypertension, type 2 diabetes, metabolic syndrome, cardiovascular diseases, and all-cause mortality (Bergman et al., 2007). While the U.S. National Institutes of Health recommends WC screening, especially in overweight or obese adults with a BMI over 25, there is no standard practice for overweight or obese children (Xi et al., 2014). In addition, there is no general consensus defining central obesity of children at the national level. Therefore, U.S. children's results are incomparable with those in other countries. To prevent and control an epidemic of obesity, it is necessary to monitor secular trends both in general and central obesity using U.S. children population-based surveillance. The following literature review discussed gaps in estimating the prevalence and associations of general and central obesity among children.

Prevalence of Obesity among U.S. Children Ages 6-11

The 2011–2012 NHANES data indicate that 17.7% of US children ages 6-11 years were obese as defined by a BMI of ≥ 95th percentile for age and sex, and 16.5% were overweight as defined by a BMI between the 85th and 95th percentiles for age and sex (Ogden & Flegal, 2010; Ogden et al., 2014). Moreover, 34.5% of U. S. adolescents ages 12–19 years were overweight or obese in 2011-2012 (Ogden et al., 2014). Among children and adolescents ages 2 to 19 years, the prevalence of general obesity in 2011-2014 was 17.0% and extreme obesity (BMI of ≥ 97th percentile for age and sex) was 5.8%, while the general obesity prevalence of children ages 6 to 11 years was 17.5 % and extreme obesity was 5.6% in 2011-2014 (Ogden et al., 2016).

The prevalence of central obesity (WC ≥90th percentile for age and sex in NHANES III) was 18.9% among U.S. children and adolescents ages 2 to 18 years in 2011 to 2012, which was similar to the prevalence of general obesity (17%) (Ogden et al., 2014). In addition, the prevalence of central obesity (WHtR ≥0.5) was 33.3% among adolescents ages 6 to 18 years in 2011 to 2012, which was comparable to the prevalence of overweight in the same period (34%) (Ogden et al., 2014).

Although specific techniques have been recommended for measuring WC in clinical settings, there is no uniformly accepted waist-measuring protocol for both children and adults (Rudolf, Walker, & Cole, 2007). The values of WC differed according to measurement site as WC (rib) < WC (middle) < WC (iliac crest) ($p < .001$) in Caucasian pre-pubertal children (mean ages 8.8-9.3 years) (Bosy-Westphal et al., 2010). To date, there is no valid evidence of significantly different validity between WC-measuring sites in estimating visceral fat mass obtained from imaging in pre-teen children. The U.S. National Institutes of Health (NIH) provides a protocol for measuring the horizontal plane of the superior border of the iliac crest (NIH, 2000), while the World Health Organization (WHO) suggests the midpoint between the lowest rib and the iliac crest (WHO, 2008). Due to the discrepancies among definitions of where the waist falls, it is difficult to compare WCs between studies.

Temporal Trend in Prevalence of Central Obesity among U.S. Children

Previous analyses of general obesity trends among children and adolescents showed an increase between 1988-1994 and 1999-2000 (Ogden, Carroll, Kit, & Flegal, 2012), but no change between 2003-2004 and 2013-2014 (Hales, Carroll, Fryar, & Ogden, 2017). Obesity increased among adolescents ages 12 to 19 years between 1988-1994 (10.5% [95% CI, 8.8%-12.5%]) and 2013-2014 (20.6% [95% CI, 16.2%-25.6%]; $p < .001$) as did extreme obesity among children ages 6 to 11 years (3.6% [95% CI, 2.5%-5.0%] in 1988-1994 to 4.3% [95% CI, 3.0%-6.1%] in 2013-2014; $p = .02$) and adolescents ages 12 to 19 years (2.6% [95% CI, 1.7%-3.9%] in 1988-1994 to 9.1% [95% CI, 7.0%-11.5%] in 2013-2014; $p < .001$). No significant trends were observed between 2005-2006 and 2013-2014 (P value range, .09-.87). Among children ages 6 to 11 years, obesity increased from 11.3% (95% CI, 9.4%-13.4%) in 1988-1994 to 19.6% (95% CI, 17.1%-22.4%) ($p < .001$) in 2007-2008, and then did not change (2013-2014: 17.4% [95% CI, 13.8%-21.4%]; $p = .44$) (Ogden et al., 2016).

However, data on the most recent trends in central obesity in U.S. children and adolescents are lacking. A previous NHANES analysis showed that WC and the prevalence of central obesity in U.S. children ages 6 to 11 years significantly increased from 1988 through 1994 and 1999 to 2002 (Okosun, Boltri, Eriksen, & Hepburn, 2006). But, a recent study by Xi et al. (2014) found a decreasing trend in WHtR between 2003 to 2004 and 2011 to 2012 among U.S. children ages 6 to 11 years. The mean WC and WHtR and the prevalence of central obesity remained stable among U.S. children and adolescents between 2003 to 2004 and 2011 to 2012, which is consistent with the trends reported for general obesity (defined by BMI) between 2003 to 2004 and 2011 to 2012. In 2011 to 2012, 18.87% of children and adolescents ages 2 to 18 years were centrally obese (as defined by WC); 33.29% of those ages 6 to 18 years were centrally obese (defined by WHtR). Compared with 2003 to 2004, the prevalence of central obesity in 2011 to 2012, as defined by WC and WHtR, did not change in the total population or by age, sex, and race or ethnic group, except for non-Hispanic White children. Compared with children ages 2 to 5 years, those ages 12 to 18 years (odds ratio [OR] = 1.31; 95% confidence interval [CI], 1.16–1.47) were more likely to be centrally obese as defined by WC. In addition, girls (boys as referent: OR = 1.11; 95% CI, 1.01–1.23) and Mexican American (non-Hispanic White as referent: OR = 1.49; 95% CI, 1.32–1.70) were more likely to be centrally obese. Similar results were found when central obesity was defined as WHtR ≥0.5.

However, use of the 90th percentile cut-off for WC based on data from NHANES III (1988–1994) is controversial (Browning et al., 2010). The average of WC among U.S. children greatly increased between 1988–1994 and 1999–2004, in particular; the relative increase in WC in each age group was varied by sex and racial/ethnic subpopulations (C. Li, Ford, Mokdad, & Cook, 2006). Another central obesity measure, waist-to-height ratio (WHtR), with a 0.5 threshold, is regarded as a simple age- and sex-independent criterion of central obesity and a better predictor than the 90th percentile of WC in both children and adults (Ashwell, Gunn, & Gibson, 2012). Therefore, this study examined the consistency in the prevalence of central obesity as defined by the fixed 0.5 cut-off of WHtR and the 90th percentile of WC and analyze the relationship of WHtR and age- sex-adjusted WC with vascular health biomarkers among U.S. children.

Comparison General versus Central Obesity Measures

BMI has been used as an appropriate first-level screening tool to identify children who should have further evaluation and follow-up. To be a clinically significant measure, it should be diagnostic of high body fat content as well as denote increased risk of adverse health outcome. However, the diagnostic ability of BMI for classifying the degree of adiposity remains questionable among children. Measurement issues related to using BMI in childhood have been raised. BMI fails to distinguish fat and lean mass, and is not appropriate for reflecting fat distribution (which may or may not be associated with age) (Freedman et al., 2005). Finally, it is limited in describing the equal levels of body fat in different populations due to different body composition, and the possible covariates of age, sex, race/ethnicity should be controlled (J. S. Duncan et al., 2009). Estimates of excessive adiposity and prevalence of childhood obesity prevalence rely on the criteria used. Acceptable valid reference values and global classification system should be standardized and utilized among multi-ethnic paediatric populations.

Only high BMI-for-age (above 95th percentile) has moderately high (70-80%) sensitivity and positive predictive values, along with a high specificity of 95% (Freedman et al., 2009). Although BMI-for-age (along with age and race) accounts for much of the variability in body fatness, there are still high possibilities for misclassifications in the prediction of the % body fat of a child. In addition, increases in BMI during childhood growth may imply gaining muscular tissue in several periods rather than fat mass (Cole, Faith, Pietrobelli, & Heo, 2005).

While observing preteens ages 6-11 years, it is critically important to identify children undergoing adiposity rebound, the second rise in BMI that occurs between 3 and 7 years (Cole, 2004). For example, the British 1990 girls chart (Cole, Freeman, & Preece, 1995) showed that an early rebound occurs before 5.5 years, followed by a significantly higher adiposity level than a later rebound (after 7 years). Interestingly, an early age at adiposity rebound is known to be a risk factor for later childhood obesity (Rolland-Cachera, Deheeger, Maillot, & Bellisle, 2006).

The age and sex specific BMI percentiles correspond to a certain segment of the population depending on the distribution of reference population (mainly NHANES data), and the values also depend on the time period during which the data were obtained. The currently used the 2000 Centers for Disease Control and Prevention (CDC) growth charts were constructed over 20 years ago, so they may not statistically represent the current child population. Also, as the prevalence of childhood obesity is increasing, the absolute value of BMI corresponding to reference standard has likely increased.

While the BMI age/sex percentiles are limited to determine the degree of adiposity in children (Freedman et al., 2005), WC and WHtR are used for assessing intra-abdominal fat mass. And, these central obesity measures might more specifically detect excessive adiposity than BMI; in addition, fat distribution may be more important for adverse health outcomes. However, the question as to whether WC is superior to BMI as a valid adiposity measure in children is still unresolved. Previous studies compared each validity mostly from cross-sectional relations between adiposity measures and % body fat mainly in large range of age groups (ages 8-18), whereas the effect of pubertal change on fat distribution remained under studied (Aeberli, Gut-Knabenhans, Kusche-Ammann, Molinari, & Zimmermann, 2013; Barreira, Broyles, Gupta, & Katzmarzyk, 2014). Only a few studies were conducted in pre-teen children and assessed pubertal status of the subjects including data of sex and ethnic differences (Aeberli et al., 2013; Asayama et al., 2000).

Factors Associated with Central Obesity (sex, ethnicity, family income)

Observed total body fat, % body fat, trunk fat, and percentage of trunk fat all increased linearly as a child ages, although different trends emerge and sexual maturation significantly influence on fat centralization (Staiano & Katzmarzyk, 2012). In previous pooled data analyses (Brambilla et al., 2006), factors influencing the correlation between WC and central fat mass were ranked in the order of puberty, age, ethnicity and sex. Significant racial or ethnic effects have been reported in body fat distribution of younger children, but evidence remains limited and inconclusive. In children and adolescents ages 5-18 years, age-adjusted total fat mass was greater in African Americans and girls than in Whites and boys (Staiano, Broyles, Gupta, & Katzmarzyk, 2013). However, White children had greater visceral fat mass (adjusted for age and total fat mass) than African Americans (AA), but the sex difference was not detected until age 10 (Staiano et al., 2013). These findings are comparable with WC patterns observed in other cross-sectional studies.

The WC values of youths ages 5-18 years in the Bogalusa Heart Study (1992-1994) (n=3,218; 55% White, 49% boy) varied by race (Sisson et al., 2009). After adjusting for BMI and age, only White boys had significantly higher WC than normal (by 2%), overweight (4.3%), and obese Black boys (6%) with no difference in the girls across most age categories (Sisson et al., 2009). The magnitude of the racial effect was greater in overweight and obese boys than in normal-weight boys. However, some biracial studies reported that Black children had significantly larger WC (Griffiths, Dezateux, & Cole, 2011) and greater annual growth of WC among adolescents compared with Whites (Tybor, Lichtenstein, Dallal, Daniels, & Must, 2010), which may be caused by sample differences and factors controlled for analyses. After analyzing the WCs of U.S. children and adolescents using NHANES III, Fernandez, Redden, Pietrobelli, and Allison (2004) found that AA boys (ages 2-18) had lower WCs, and consistently demonstrated a lower rate of increase with age than White or Hispanic boys. These racial effects continue into adulthood, as White adults have more visceral fat mass than AA adults (Camhi et al., 2011; Carroll et al., 2008). Another cross-sectional study (He et al., 2002) demonstrated that Asian children ages 5-12 tended to have more trunk fat mass than Caucasians or AA children. The findings indicate higher risk among Asian children for developing premature vascular damage at lower BMIs. These differences persisted in later adolescence (Novotny, Daida, Grove, Le Marchand, & Vijayadeva, 2006) and adulthood (Lear, James, Ko, & Kumanyika, 2010).

Sex differences in body fat distribution are apparent after puberty. Some studies reported sexual dimorphism in fat patterning, with girls having less waist and more hip fat than boys, after controlling for ethnicity, age, and BMI (L'Abee et al., 2010; Mast, Kortzinger, Konig, & Muller, 1998; Taylor, Grant, Williams, & Goulding, 2010; H. Wang et al., 2007). In addition, these sex differences were detectable at the early age of five (Karlsson et al., 2013). But, few large studies have evaluated the sex difference of visceral fat mass in younger children with appropriate adjustment for cofactors (i.e., age, BMI, total fat mass, puberty status). There is also limited evidence to determine the timing and magnitude of sex differences in regional adiposity in early childhood. It is clear that factors regulating sex-specific total body composition may present already in pre-pubertal period but that those determinants of fat centralization appear during puberty. Therefore, sex difference in central adiposity is closely linked to age- and puberty-related changes in fat distribution. A small sized multi-ethnic pre-pubertal children study (n=172, ages 5-12 years) (He et al., 2002) demonstrated that Asian girls had more trunk subcutaneous fat than Caucasian girls. Also, in a large British cohort study (Griffiths et al., 2011), sexual difference of WC was reported, showing that girls (ages 3-17) had larger WC than boys.

WHtR is considered a relatively constant anthropometric index of central obesity across different age, sex, and ethnicity (Ashwell et al., 2012); thus, a universal WHtR cut-off value of ≥0.5 for determining central adiposity has been proposed for children in different ethnic groups. But, among Chinese children, the value of WHtR for defining obesity was proposed as 0.485 in boys and 0.475 in girls, both having sensitivity and specificity > 0.90 (Weili et al., 2007). These differences across studies may influence variable results. To date, there is scant evidence to support the utility of WHtR in children since previous studies mainly focused on WC among children’s central obesity.

Although socioeconomic status is considered an independent predictor in assessing influence of demographic factors on central obesity among children, family income was rarely investigated both in adults and children. Central obesity prevalence may vary by family income, although patterns might differ depending on sex, race/Hispanic origin, and geographical regions. In terms of general obesity as defined by BMI, a recent U.S. study (Ogden et al., 2017) showed that the obesity prevalence was lower in the highest income women, but this was not the case among the men. The prevalence of obesity among U.S. youths (ages 2-19 years) was 17.0% during 2011-2014, and was lower in the highest income group (10.9%) than in the other groups (19.9% and 18.9%) (Ogden et al., 2018).

Associations between Central Obesity and Vascular Alteration Biomarkers

Vascular alteration is a multifactorial phenomenon with the age of onset determined by genetics, environment, and associated interactive factors (Holtzman, 2008). It has a long subclinical phase with development of pathological changes in arteries of children before overt clinical manifestations of disease (Thubrikar, 2007). Early signs of atherosclerosis, such as impaired endothelial cell function and increased pro-atherogenic biomarkers, have been observed already in pre-teen children (Halcox & Deanfield, 2005; Nagel et al., 2008).

The various studies that examined correlations of general or central adiposity with early atherosclerosis of children demonstrated that vascular alteration was manifested early at the age of five (Geerts et al., 2012) and that higher abdominal fat mass were associated with cardiometabolic risk factors (Gishti et al., 2015). Greater childhood adiposity is associated with adverse cardiometabolic risk factors, but obesity-induced vascular damage during pre-pubertal period (age 6 to 11 years) has rarely been demonstrated. And, there was limited evidence about the effect of age, sex, and ethnicity on the associations.

Association between Central Obesity and Blood Pressure

Elevated blood pressure (BP) at a young age is a predictor of BP elevation later in life.

Hypertension is known as the most common adverse health outcome associated with obesity in men and women (Iacobellis, 2009). The population-based studies conducted in the U.S., the Bogalusa study (Bao, Threefoot, Srinivasan, & Berenson, 1995), and the Muscatine study (Lauer & Clarke, 1989) indicate a carryover effect of childhood high BP into adulthood. However, insufficient evidence was presented regarding the relationship between fat distribution and BP during early childhood, and it is more complicated to assess the net effect size of the degree of adiposity in children than adults.

In children, pre-hypertension and hypertension are commonly defined as systolic and/or diastolic BP ≥ 90th percentile for age, sex, and height and BP ≥ 95th percentile, respectively (Falkner & Daniels, 2004). All previous evidence consistently showed that abdominally obese children are characterized by a central fat distribution pattern and higher BP (Barba et al., 2006; Maffeis, Pietrobelli, Grezzani, Provera, & Tato, 2001; Savva et al., 2000).

Several childhood studies have shown that WC and other central obesity markers are better predictors of BP (Barba et al., 2006; Charakida et al., 2012; Colin-Ramirez et al., 2009); however, other studies have reported similar effects of BMI and WC on changes in systolic BP (Mirzaei, Taylor, Morrell, & Leeder, 2007; C. X. Zhang, Tse, Deng, & Jiang, 2008). Conflicting findings might be due to the different age groups of the study children, the different ethnic mix of the sample, or to differing measurement methods of WC (Genovesi et al., 2008). The magnitude of the correlations with BP were different by children's sex (C. X. Zhang et al., 2008). Limited evidence exists that race or ethnic differences impact the associations of adiposity measures with higher BPs, while a significant racial or ethnic effect has been reported in body fat distribution of younger children (Sisson et al., 2009; Staiano & Katzmarzyk, 2012). A recent U.S. study found that potential racial/ethnic differences in the association between high WC and elevated BP may impact identification of children ages 9-13 years at risk for elevated BP, especially among Hispanics (Smith et al., 2014). Evidence regarding racial/ethnic differences remains limited and inconclusive.

In conclusion, the role of WC in predicting the risk of high BP in children has been controversial. Much of the variation in study findings undoubtedly rests on the BP measurement device, technique, and whether sequential readings were obtained. Most large-scale studies obtain a single BP measurement or several readings on a single examination visit (Barba et al., 2006; Charakida et al., 2012; Falaschetti et al., 2010). The prevalence of hypertension will likely be overestimated unless sequential readings on separate days are obtained. In addition, Karatzi et al. (2009) suggested that the predominance of high systolic BP in children might be related to the measurement setting (office or home). To enable valid comparisons within and across studies, future research should focus on standardized approaches and multiple cross-visit measurements of BP.

Association between Central Obesity and Dyslipidemia

Inadequate levels of low-density lipoprotein cholesterol (LDL), triacylglycerol (TG), and high-density lipoprotein cholesterol (HDL) have been consistently found in childhood obesity. Excessive adiposity and lipid abnormalities in children may increase premature cardiovascular disease risk, but the relationship of dyslipidemia with adiposity among healthy weight children has not been well defined. Adult studies on the distribution of body fat have shown that centralization of fat is strongly associated with pro-atherogenic dyslipidemia (Browning et al., 2010). While adult studies have demonstrated that a central adiposity measure (WC or WHtR) is a better predictor of dyslipidemia than BMI, these findings cannot be assumed to be valid for children. Because ambiguity exists regarding the most appropriate measure of adiposity in predicting children's dyslipidemia, most studies use both general and central adiposity measures for children.

Although WC has proven to be a better anthropometric indicator than BMI Z-score of lipids in children (Rizk & Yousef, 2012; Watts, Bell, Byrne, Jones, & Davis, 2008), U.S. national studies have reported WHtR rather than WC. In the Bogalusa Heart Study, Freedman et al.'s study (2007) concluded that the predictive abilities of the WC and WHtR in identifying children with high LDL and low HDL. However, WHtR was better (.01– .02 higher R^2 values, $p < .05$) in predicting concentrations of total-to-HDL ratio and LDL. Also, a high intercorrelation ($R^2 = 0.78$) between the BMI-for-age z score and WHtR was found (Freedman et al., 2007). The results indicate that dyslipidemia may be more sensitive to central adiposity than other vascular risk factors (fasting insulin, BP). But, the wide age range of the participants, no data of puberty stage, and no reference values of WC should be considered limitations of the study. After analyzing the same nationwide dataset, the higher WHtR was associated with dyslipidemia among normal BMI children and identified those without central obesity and a healthy lipids level among the overweight or obese children, classified by BMI value (Mokha et al., 2010). On multivariate analysis, the normal weight centrally obese children were 1.66 and 2.01 times more likely to have significant adverse levels of LDL and HDL, respectively. In the overweight/obese group, those without central obesity were 0.53 times less likely to have significant adverse levels of HDL ($p < 0.05$) than those with central obesity.

Another multi-ethnic, cross-sectional study in this review found that the associations of adiposity with lipid levels were hardly noticeable in obese pre-teen children (Dhuper et al., 2009). The study participants were children and adolescents with a BMI > 95th percentile for age and who were attending an obesity treatment program (53% female, 81% African American, and

16% Hispanic). More than 50% of the sample had abnormal levels of TG or HDL or both. The prevalence of abnormal HDL levels significantly increased with age, but LDL and TG did not follow this pattern. HDL and TG were significantly associated with WC and WHtR only in obese adolescents; z-BMI was significantly correlated with these and LDL as well (Dhuper et al., 2009).

A multi-ethnic descriptive study (Mendoza et al., 2012) found that the associations of both general versus central adiposity with dyslipidemia were significantly influenced by moderate-to-vigorous physical activity (MVPA). After analyzing data of pediatric participants (n = 2,155) from the NHANES 2003 to 2006, WC was recognized as a main mediator in the relationship between MVPA and HDL ($p < .05$). A strength of the study was the inclusion of covariates such as sex, ethnicity, income, and dietary variables. Their race/ethnicity groups included non-Hispanic, White, non-Hispanic Black, and Mexican-American. Although the dataset was large and population-based, there were many children with missing or incomplete data who were excluded. It was not possible to demonstrate a real lack of difference between children whose data were included and nonparticipants, which may have created a selection bias.

Comparisons of various adiposity measures in predicting risk of premature vascular damage among children have been rarely reported. In Argentina health weight children ages 6-14 years, after controlling cofactors, multiple regression analyses showed that WC (odds ratio (OR) = 6.5) was a better predictor of dyslipidemia, followed by WHtR (OR = 5.4) and BMI (OR = 4.9) in predicting both low HDL and high TG (Hirschler et al., 2011). In adults, growing evidence indicates the superiority of measures of centralized adiposity (such as WC and WHtR) over BMI for detecting dyslipidemia in men and women (de Koning et al., 2007; Despres et al., 2008). A meta-analysis (C. M. Lee, Huxley, Wildman, & Woodward, 2008) involving 10 studies with adults supports the claim that measures of central obesity could be better predictors of dyslipidemia than BMI. However, it remains unclear whether combining BMI with any measure of central obesity will improve upon its discriminatory capability. Also, there is uncertainty about how these adiposity measures perform across diverse ethnic groups. Most of the evidence regarding the relationships between excess weight and risk has been derived chiefly from Caucasian populations (C. M. Lee et al., 2008). It remains unclear whether the relationships are consistent in non-Caucasian populations.

Summary and Conclusion

When studying younger children, there are barriers to recruiting participants, including use of invasive vascular measures. This can affect representativeness of the sample as well as the numbers available for a study. As a result, most pediatric studies with no rigorous limitations in the child's age range have included both pre- and post-pubertal children together. According to Freedman et al. (2007), age is associated with BMI and height but not with BMI-for-age or WHtR among children. In addition, the onset and status of puberty are important factors in assessing associations with adiposity and vascular homeostasis, including lipid metabolism.

Studies also rarely or inconsistently examined ethnic/gender differences. Even in a few multi-ethnic studies using nationwide datasets, the differences among race, sex, and ethnicity were not investigated. This gap in the research is a serious limitation since few data are available to inform our understanding of potential racial/ethnic and gender differences. Also, genetically determined and economically induced vascular risk factors interact with and modulate the progress of arterial alterations from early childhood.

One of the challenges in childhood obesity research is discerning the relative contribution of a child's total body fat to his/her total weight and determining the adiposity-induced adverse health effects. Comparative studies of various adiposity measures in predicting risk of premature vascular damage among children provided varying results. One major reason for these inconsistent findings may be the lack of any standardized classification of adiposity measures, both general and central. Although BMI is the most widely used screening tool, the operational definition of obesity typically varies across studies involving children. Depending on a particular criterion for defining BMI, an early sign of vascular damage may not be detectable in pre-teen children.

BMI is limited to assess body fat distribution and the relation of BMI to fat and fat-free mass among children varies by sex, age, and race/ethnicity in children (Flegal et al., 2010). Obesity-induced the vascular alteration process or risk may vary between different race/ethnicities at the same BMI children. Among some Asian subgroups, risk may begin to increase at a lower BMI than other race/ethnicity groups, although study results have varied in adults (Zheng et al., 2011) and children (Jafar, 2009). Therefore, this multi-racial/ethnic comparison study may contribute to a better understanding of associations between abdominal body fat or various anthropometric indexes and early stages of vascular alteration by different age, sex, and race/ethnicity in youth.

Conceptual Framework of the Study

Central obesity-induced vascular alteration is a multifactorial and multiphase phenomenon. This study aimed to identify the prevalence of central obesity and factors associated with vascular damage in children ages 6 to 12 years (Figure 1). Potential factors investigated in this study include age, sex, ethnicity, family incomes and central obesity. The conceptual framework used to provide guidance is based on a scientific review of current literature. Current research studies have suggested that a family's socioeconomic status may contribute to excessive weight and abdominal fat and increased risk for vascular alteration in children. For example, migration background, parental obesity, and higher educational levels were recognized to be significantly associated with central obesity in schoolchildren (Vorwieger, Kelso, Steinacker, Kesztyus, & URMEL-ICE study group, 2018). Especially, maternal nutritional status such as maternal work outside the home and maternal central obesity may be significantly related to central obesity in younger children (ages 3 to 10) (Melzer, Magrini, Domene, & Martins, 2015). The conceptual framework will increase our understanding of the factors associated with vascular alteration in pre-puberty children.

Chapter 3: Research Design and Methods

Study Design

This is a secondary analysis of serial, cross-sectional data from the National Health and Nutrition Examination Survey (NHANES) between 2007 and 2016. The NHANES has run continuously since 1999, with data released in two-year cycles, and conducted by the National Center for Health Statistics (NCHS) of CDC (Department of Health and Human Services., 2015; NCHS, 2015). The NCHS has been offering various downloadable public-use data files, and the NAHNES data files were available for download from the website, https://wwwn.cdc.gov/nchs/nhanes/default.aspx, the CDC FTP file server. The NHANES examined about 5,000 persons each year, and data were released in 2-year cycles.

Study Sample

The NHANES is a nationally representative sample survey of a U.S. civilian non-institutionalized population; the participants were selected using a random sampling method. The survey has been conducted in clusters of counties (or single large counties or metropolitan areas) (NCHS, 2015) based on their characteristics. One county was selected from each large group; together they formed the 15 counties in the NHANES surveys for each year. Within each county, smaller groups (with a large number of households in each group) were formed, and between 20 and 24 of these small groups were selected. All of the houses or apartments within those selected small groups were identified, and a sample of about 30 households were selected within each group.

The participating children and adolescents were categorized into three age groups: Under 1 year to 5 years, 6-11, and 12-19; this present study selected pre-teens children ages 6-11. The age variable was calculated by each respondent’s actual or imputed date of birth (NCHS, 2015);

age-in-months may be more appropriate in younger children. The average of the unweighted response rates for the examined children ages 6–11 years for NHANES between 2005 and 2014 was 80.1% (NCHS, 2015).

Health interviews were conducted in respondents' homes. The physical examination generally occurred within 1 to 2 weeks after the in-home interview. Health measurements were performed in specially designed and equipped mobile centers, which traveled to locations throughout the country. A mobile examination center was a group of trailers set up in a location with easy access for all participants and examinations included BP testing and laboratory testing on blood.

Data Collection Procedure and Ethics Review

The data were collected by interviews with physical examinations and laboratory studies. The study team consisted of a physician, medical and health technicians, as well as dietary and health interviewers. Many of the study staff were bilingual (English/Spanish). In each location, local health and government officials were notified of the upcoming survey. Households in the study area received a letter from the NCHS Director to introduce the survey.

Participants received compensation and a report of medical findings was given to each participant. The survey protocol was approved by the National Center for Health Statistics Research Ethics Review Board; participants 7 to 11 years old provided assent and parental consent, and parents provided informed consent for those <7 years old. All information collected in the survey was kept confidential and privacy was protected by public laws (Department of Health and Human Services., 2015).

In regard to this secondary analysis using NHANES data, the Research Protection Program Institutional Review Board (IRB) of UCSF determined that this research activity did not involve human subjects as defined by the federal regulations summarized in 45 CFR 46.102(f), and hence did not require further IRB oversight.

Study Variables and Definition

General obesity was defined as a BMI at or above the 95th percentile for children of the same age and sex. Overweight is defined as a BMI at or above the 85th percentile and below the 95th percentile for children of the same age and sex. Each child's BMI was converted to an age- and sex-specific z-score based on the CDC's BMI-for-age charts for boys and girls (Kuczmarski et al., 2002). The growth charts were used to identify the corresponding z-scores for overweight (BMI $\geq$ 85th percentile to BMI < 95th percentile) and obesity (BMI $\geq$ 95th percentile) (Kuczmarski et al., 2002). Underweight was defined as having a BMI below the 5th percentile, and normal weight was defined as having a BMI at or above the 5th percentile and below the 85th percentile for age and sex.

Central obesity was defined as waist circumference (WC) equal or above the sex- and age-specific 90th percentile based on data from NHANES III (1988–1994) (C. Li et al., 2006). WC assessed the circumference just above the right iliac crest at the mid-axillary line in a standing position. A retractable steel measuring tape was used to take length and circumference measurements. The value of measurement was taken to the nearest 0.1 cm at the end of the participant's normal expiration (NCHS, 2015). Waist-to-height ratio (WHtR) was calculated as standing height (cm) divided by WC (cm) and central obesity for this dissertation was defined as WHtR $\geq$ 0.5 (Mokha et al., 2010).

Other family and individual factors. Parents or family members of the participants in the household were asked to answer the NHANES screener who visited their house. Children's sex was reported by an interviewee and their age was recorded as calculated from date of birth.

Age was computed from age in months of the participant at the time of physical examination. A family interviewer asked for each household member's birthdate and a computer calculated the age based on the birthdate information. Since age is one of the sampling criteria, the interviewer was required to verify this age with the respondent (NCHS, 2015). Among the NAHNES participants, children from 72 through 132 months of age at the exam were included in the study.

Race/ethnicity was self-reported by two questions: "What race do you consider him/her to be?" and "Do you consider him/her to be Hispanic, Latino, or of Spanish origin?" (NCHS, 2015). Race/ethnicity was categorized as Mexican American, other Hispanic, non-Hispanic White, non-Hispanic-Black, non-Hispanic Asian, and other ethnicity including multi-racial. However, due to the sampling reliability during estimating U.S. children population from the survey data, Mexican American was merged with a Hispanic origin children and non-Asian with other ethnicities including multi-racial children.

Family annual income was asked by an open question: "I'm going to ask about the total income for {names of family members} in {last calendar year}, including income from all sources we have just talked about such as wages, salaries, Social Security or retirement benefits, help from relatives, and so forth. Can you tell me that amount before taxes?" And if a person was not able to provide give us an exact figure for the family income, ask if this income in {last calendar year} was $20,000 or more, or less than $20,000 (NCHS, 2015).

The variable of family annual income was computed as a ratio of family income to poverty guidelines using the federal poverty level guidelines, which were available at (https://aspe.hhs.gov/prior-hhs-poverty-guidelines-and-federal-registerreferences). The poverty index is a ratio measuring the household income to the poverty threshold after accounting for inflation and family size. For example, the poverty threshold for a family of 4 with 2 children younger than 18 years of age in 2010 was $22,113. Therefore, a poverty index of 200% (2.0) for a family of 4 in 2010 was equivalent to ~$44,000 annual household income. For a multiple regression, a ratio of family income to poverty guidelines was categorized as ≤1.30 (low), >1.30 to ≤3.50 (middle), and >3.50 (high) in the study, as previous researchers did (Ogden et al., 2018).

Outcome Variables & Measures

Blood pressure. Blood pressure (BP) was measured on all examinees 8 years and older. After resting quietly in a sitting position for 5 minutes and determining the maximum inflation level, three consecutive BP readings were obtained. If a BP measurement was interrupted or incomplete, a fourth attempt might be made. All BP determinations (systolic and diastolic) were taken in a mobile examination center. Children with any of the following on both arms were excluded from the exam: rashes, gauze dressings, casts, edema, paralysis, tubes, open sores or wounds, withered arms, or arteriovenous shunt (NCHS, 2015). Higher BP was defined as BP (diastolic or systolic) equal or above the 90^{th} percentile of age-, sex-, and height-specific BP derived from the reference population for the 2000 CDC growth charts (National High Blood Pressure Education Program Working Group on High Blood Pressure in Children and Adolescents, 2004).

Lipid panel. Serum HDL and total cholesterol (TC) levels were measured in participants; a total cholesterol-to-HDL ratio were computed from both measurement values. Of the 3,275 children ages 6 to 11 years examined, 917 were exclude due to missing TC or HDL (28%), leaving 2,358 children, representing 72% of the total available sample size.

Blood specimens provided by participants during the physical examination were stored at -20 °C and shipped weekly for laboratory analyses. TC and HDL levels were based on samples taken regardless of fasting state. For the NHANES between 2007 and 2016, the testing was performed at the University of Minnesota; the equipment used was the Roche Modular P chemistry analyzer (Roche Diagnostics). Non-HDL was calculated from TC minus HDL and dyslipidemia was defined as a non-HDL value ≥ 145mg/dL (Dai et al., 2014).

Data Analysis

All analyses were conducted with the svy commands in STATA 15.0 (Stata Corp., College Station, TX) to account for the complex survey design and NHANES probabilistic sampling weights. NHANES data files (five 2-year cycles conducted from 2007-2008 through 2015-2016) were downloaded as SAS transport files and the data file documentation from the website. The sampling weights account for unequal probabilities of selection as a result of planned oversampling, sample design, non-response and missing data; all of the analyses followed NHANES Analytic Guidelines (NCHS, 2015), so that the results were representative of U.S. community-dwelling populations.

Averages, range, and outliers will be checked for data variation. Descriptive statistics, including frequency percentage, mean, median, standard deviation, ranges, and skewness was used to describe the outcome variables. Statistical significance of trends across all outcome variables was determined by using linear and logistic regression for continuous and dichotomous variables, respectively, as a two-sided $p < .05$.

AIM 1. Prevalence of general and central obesity in U.S. children based on NHANES 2015-2016 by sex, race/ethnicity, and family annual income: Prevalence was calculated as the weighted proportion of general obesity or central obesity children ages 6 to 11 years in the estimated population, and subgroup proportions for prevalence were computed by sex, ethnicity, and family annual income. Age-, sex-specific prevalence data were computed as percentages with 95% confidence intervals (CI) using the survey tabulate command in STATA to adjust for the weights and complex survey design of the NHANES. The demographic variables models were sex, race/ethnicity (Hispanic, non-Hispanic White, non-Hispanic Black, and other/multi-racial), and family annual income (low, middle, and high). The ado-command *svylogitgof* was used to evaluate the *F*-adjusted mean residual test, a test specifically developed to assess goodness-of-fit for data from a complex survey design (Archer, Lemeshow, & Hosmer, 2007).

AIM 2. Time trend in prevalence of central obesity among U.S. children between 2007 and 2016 by sex, race/ethnicity, and family annual income: Trends in waist circumference (WC) over 10 years (2007-2008, 2009-2010, 2011-2012, 2013-2014, and 2015-2016) were be estimated for this aim. The trends of WC and BMI over five time periods were compared using the *svy* commands in STATA by generating statistically weighted prevalence and associated 95% CI that adjusted for the complex NHANES survey design. To test differences in prevalence of central obesity across the five time periods, the time periods were entered as an ordinal variable in the multiple regression models while controlling for BMI, sex, racial/ethnic group, and family annual income. STATA's adjusted Wald test were used to compare the computed prevalence of general versus central obesity in each NHANES cycle to the NHANES 2007–2008 estimated prevalence.

AIM 3. Associations between central obesity and vascular alteration biomarkers (BP and lipids) and **AIM 4. Impact of sex, race/ethnicity, and family annual income on the association between central obesity and vascular alteration among children ages 6-11 based on NHANES 2007-2016**: Bivariate analysis was used to test the overall association for participants' characteristics with each continuous outcome variable (systolic, diastolic BP, and non-HDL cholesterol). Then, hierarchical multivariate logistic regression analysis was separately performed with a predictor of central obesity as defined by WC and WHtR, to evaluate the risk of each association with high BP and dyslipidemia. Model 1 did not involve any adjustments, whereas model 2 involved adjustment for BMI to determine an independent association with vascular biomarkers. Variables adjusted in model 3 included the variables adjusted in model 2 as well as age (years), sex, race/ethnicity, and family annual income level. Linear trends were tested separately and quadratic trends will be tested with both linear and quadratic terms included in the models; several general linear model equations were constructed using these groups as predictors and each vascular biomarker (high BP and dyslipidemia) as the outcome.

Chapter 4: Results

The primary goal of this dissertation is to assess the prevalence of central and general obesity and the associations between central obesity and vascular health among U.S. children ages 6 to 11 based on NHANES data. The main findings are summarized in this chapter according to the four specific aims as follows: Aim 1, the most recent national estimates of the prevalence of central and general obesity are presented after adjusting for the weights using the NHANES 2015-2016; Aim 2, trends in estimates of prevalence of central obesity are presented as defined by waist-based measures (WC and WHtR) during for the last 10 years (2007-2008, 2009-2010, 2011-2012, 2013-2014, and 2015-2016); Aims 3 and 4, the associations of obesity with dyslipidemia and high BP, are provided based on analyses of the pooled dataset of these five cycles of NHANES.

Specific Aim 1: To investigate the prevalence of central and general obesity in U.S. children ages 6-11 based on NHANES 2015-2016 by sex, race/ethnicity, and family annual income

Body measurements were obtained in 1,085 children ages 6 to 11 years with a mean (*SD*) age of 8.0 (1.4) years for the NHANES 2015-2016. About half were girls (*n* = 546, 50.3%); 36.1% were Mexican American or other Hispanics. WC was correlated with BMI ($0.94 < r < 0.95$) and height ($r = 0.43$) for both boys and girls ($p < .0001$).

Table 2 presents the estimates of prevalence of general and central obesity in 2015-2016 among 6- through 11-year-old U.S. children by sex, race/ethnicity, and family annual income. In 2015-2016, overall 17.4% (95% CI [14.0, 21.6]) of U.S. children ages 6 to 11 years were generally obese as defined by BMI; 15.8% (95% CI [12.4, 19.9]) were centrally obese as defined by WC; 29.8% (95% CI [24.7, 35.6]) were centrally obese as defined by WHtR. There were no gender differences in the prevalence of general and central obesity among U.S. children ages 6 to

11 years in 2015-2016 (Table 2).

General obesity prevalence of U.S. children ages 6 to 11 varied by race and ethnicity ($p < .0001$). The prevalence of general obesity was the highest in Hispanic children (26.5%) followed by non-Hispanic Black (19.7%), other or multi-racial (18.4%), and non-Hispanic White children (12.6%). Pairwise comparisons revealed that Hispanic children were more likely to be obese (as defined by BMI) than non-Hispanic Whites ($F = 23.25$, $p = .001$) (Figure 2). This ethnic difference was found only in girls ($F = 11.35$, $p = .025$), but not in boys ($F = 6.17$, $p = .152$).

When central obesity was defined by WC, Hispanic children also had the highest prevalence (24.1%) and it was significantly higher than non-Hispanic Whites (F=14.14, p=.011) (Figure 3). This ethnic difference was found between Hispanic boys and non-Hispanic Black boys ($F = 10.12$, $p = .037$) whereas significant difference was found between Hispanic girls and other or multi-racial girls (F = 14.14, $p = .011$).

When central obesity was defined by WHtR, overall 43.0% (95% CI [34.9, 51.5]) of Hispanic American children ages 6 to 11 years were centrally obese in 2015-2016 (39.6% for boys, 46.4% for girls). Hispanic children's central obesity prevalence was significantly higher than non-Hispanic White ($F = 23.35$, $p = .001$) and Black children ($F = 11.29$, p=.026) (Figure 4). Noticeably, non-Hispanics Black boys were less likely to be centrally obese than non-Hispanic White boys ($F = 10.64$, $p = .0316$).

In terms of family income, children of higher family income groups had significantly lower prevalence of central obesity as defined by WHtR (18.1%, $p = .022$), indicating that children living in low family income tended to have about 2 times higher prevalence (40.4%) (Table 2). However, when central obesity was defined by WC, these differences were not statistically significant ($p = .068$).

Specific Aim 2: To investigate temporal trends in prevalence of central obesity among U.S. children between 2007 and 2016 by sex, race/ethnicity, and family annual income.

Table 3 shows the characteristics of 5,296 U.S. children ages 6 to 11 years who participated in the NAHNES 2007-2008 through 2015-2016. The distributions of racial/ethnic groups and family annual income were not homogeneous in the five cycles of NHANES due to applying different oversampling methods by a two- ear cycle. There were no significant differences of all body measurements among the five cycles of NHANES participants.

Time trends in prevalence of central obesity from 2007-2008 to 2015-2016 were presented by sex, race/ethnicity, and family income (Table 4). In 2007-2008, 21.2% of U.S. children ages 6 to 11 years were centrally obese as defined by WC and 31.1% were centrally obese as defined by WHtR. The prevalence of central obesity as defined by WC was significantly decreased from 2007-2008 through 2015-2016 ($p = .017$). Based on the unadjusted model, those significant decreases were found among non-Hispanic Whites (p=.002), boys (p = .029), and children living in a middle family annual income ($p = .043$). However, there were no significant linear trends in the prevalence of central obesity as defined by WHtR, by sex, race/ethnic groups, and family annual income (p-values range = .06 to .95) (Table 4). Adjusted overall linear and quadratic trends for central obesity as defined by WC or WHtR among U.S. children ages 6 to 11 years remained non-significant. Figure 5 presents the estimated time trends of central and general obesity prevalence from 2007-2008 through 2015-2016 among U.S. children ages 6 to 11 years.

Specific Aim 3: To assess associations between central obesity and vascular alteration biomarkers (BP and lipids) among children ages 6-11 based on NAHNES 2007-2016.

The serum cholesterol levels of 4,069 U.S. children ages 6 to 11 years were analyzed and the BP of 2,966 of those children ages to 8 to 11 years was assessed during 2007-2016. The estimated prevalence of dyslipidemia (as defined by non-HDL cholesterol ≥ 145 mg/dl) among U.S. children ages 6 to 11 years was 7.7% (95% CI [6.5, 8.7]) during 2007-2016 (Table 5). The estimated prevalence of high BP (as defined by SBP or DBP ≥ 90^{th} for age-, sex-, and height-specific) was 7.2% (95% CI [6.1, 8.5]). Both estimates of prevalence of dyslipidemia and high BP were not different by sex, race/ethnicity, and family annual income (Table 5).

The associations of general and central obesity with dyslipidemia, based on multivariable regression, are presented by each model (Table 6). Compared to children without central obesity, dyslipidemia occurred more frequently among centrally obese children as defined by WC (OR = 3.41, 95% CI 2.68-4.35; model 1). Noticeably, central obesity as defined by WHtR (OR = 4.12, 95% CI 3.22-5.27, model 2) was more strongly associated with the prevalence of dyslipidemia among US children ages 6 to 11 years. Also, children with general obesity as defined by BMI (OR = 3.34, 95% CI 2.63-4.24, model 3) were more likely to have dyslipidemia than non-obese children (Table 6). After adjusting for BMI, the association of central obesity as defined by WC (OR = 2.00, 95% CI 1.34-2.98) and as defined by WHtR (OR = 3.28, 95% CI 2.35-4.58) (data not shown) (all *p*-values < .001) remained significant.

The associations of central obesity with high BP are presented in Table 7. Compared to children without central obesity, centrally obese children as defined by WC (OR = 2.84, 95% CI 2.12-3.80, model 1) and as defined by WHtR (OR = 2.59, 95% CI 1.94-3.46) (all *p*-values < .001, model 2) were more hypertensive. After adjusting for BMI, the association of central obesity as defined by WC (OR = 1.62, 95% CI 1.01-2.69, *p* = .045, model 3) and as defined by WHtR (OR = 1.62, 95% CI 1.06-2.48, *p* = .025) (data not shown) remained significant. Children with general obesity as defined by BMI (OR = 3.00, 95% CI 2.25-4.00) were more likely to be hypertensive than non-obese children (p < .001).

Specific Aim 4: To investigate the impact of age, sex, race/ethnicity, and family annual income on the association between central obesity and vascular alteration biomarkers (BP and lipids).

Adjusted odd ratios were computed from multivariate logistic regressions, as shown by Model 5 in both Table 6 and 7. Among demographic predictors, children's age and sex were identified as significant covariates in the associations of central obesity (as defined both by WC or WHtR) with dyslipidemia (Table 6), which were not significant covariates with high BP (Table 7). Model 5 shows that older girls with general and central obesity were more likely to have dyslipidemia than younger children or boys with general and central obesity (Table 5).

After adjusting for BMI including age, sex, race/ethnicity, and family annual income, the association of central obesity as defined by WC with dyslipidemia remained significant (OR = 1.87, 95% CI 1.24-2.84) with p-values of .002 (Table 6, model 4). Particularly, model 5 shows that central obesity as defined by WHtR (OR = 3.21, 95% CI 2.24-4.56, p < .001) was a significant factor for dyslipidemia after adjusting for BMI including age, sex, race/ethnicity, and family annual income.

Only general obesity (OR = 2.12, 95% CI 1.35-3.35) remained as a significant factor (p = .001 and .002) in the associations with high BP after adjusting for age, sex, race/ethnicity, family annual income, and central obesity (model 4 and 5), as shown in Table 7. U.S. children ages 6 to 11 years who are generally obese are 2.12 times more likely to have high BP compared to non-generally obese children, regardless of central obesity.

Chapter 5: Discussion

This secondary analysis study aimed to assess the prevalence of central and general obesity and to investigate their associations with dyslipidemia and high BP among U.S. children ages 6 to 11 years. The findings indicated that the prevalence of central and general obesity varied by racial/ethnic groups in 2015-2016. The study also observed that the prevalence of central obesity as defined by WC was significantly decreased over the last 10 years (from 21.2% to 15.8%). Among obesity indexes, central obesity as defined by WHtR was significantly associated with dyslipidemia, whereas general obesity as defined by BMI was independently associated with high BP after adjusting for covariates. In addition, the study identified children's age and sex as factors associated with dyslipidemia of U.S. children ages 6 to 11 years. This study provides a foundation for developing childhood obesity-related public health strategies and considerations for pediatric clinicians in screening multi-ethnic groups of children.

Main findings

Specific Aim 1: The observed prevalence of ~15.8% of U.S. children ages 6 to 11 years with central obesity as defined by WC in 2015-2016, was similar to the prevalence of general obesity in the same period (17.7%). In addition, the prevalence of central obesity as defined by WHtR was 29.8%, which was comparable to the prevalence of overweight (34.0%), and was consistent with Xi et al.'s study (2014) that analyzed the NHANES 2011-2012. Because WC ≥90th percentile for sex and age generated in NHANES III was used to define central obesity for this analysis, it is not possible to compare these results with those in other countries.

Moreover, this study found that the estimates of prevalence of general and central obesity varied by racial/ethnic groups among U.S. children ages 6 to 11 years. And, larger WC was observed in Hispanic American children than in non-Hispanic Whites. Hispanic American children had high prevalence of both central and general obesity (24~26%), but significant difference was present only for comparison to the non-Hispanic White children in 2015-2016. A recent study of U.S. children and adolescents (Ogden et al., 2018) also reported a significant racial/ethnic difference of general obesity prevalence ($p<.001$) among the following: Hispanic, 22.0% (95% CI, 19.5%-24.5%); non-Hispanic black, 20.8% (95% CI, 17.8%-23.7%); non-Hispanic White, 15.9% (95% CI, 14.3%-17.5%); and Asian, 12.8% (95%CI, 10.0%-15.6%). These findings are consistent with other U.S. children studies, demonstrating that the prevalence of high BMI-for-age in older children and adolescents was highest among Hispanic children (Hales et al., 2017; Ogden et al., 2010). And, among children ages 2 to 5 years, Hispanic children had a higher prevalence of overweight and obesity as defined by BMI (Lo et al., 2014; Sekhobo, Edmunds, Reynolds, Dalenius, & Sharma, 2010). This dissertation provides additional evidence of a higher prevalence of central obesity defined by waist-based measures among Hispanic American children ages 6 to 11 years.

The high prevalence of central obesity in Hispanic children can contribute to higher levels of body fat mass in this population. Studies suggest that Hispanic youth have more of their body mass stored in the trunk region (Staiano & Katzmarzyk, 2012) and Mexican American adolescents have less lean mass than non-Hispanic White and black adolescents (Borrud et al., 2010). In comparing musculoskeletal muscle mass of older adults with same BMI, the Mexican American men and women had less muscle mass than non-Hispanic Whites and Blacks (Aleman Mateo et al., 2009); these combined body composition differences led to greater % body fat and less fat-free mass among the Mexican Americans than non-Hispanic Whites and Blacks (Heymsfield, Peterson, Thomas, Heo, & Schuna, 2016).

In addition to fat distribution, the contribution of common genetic variants to obesity and obesity-related traits in Hispanic children has been identified in understanding the pathophysiology of childhood obesity (Comuzzie et al., 2012). Studies also observed that Hispanic high school students consume fewer fruits and vegetables than do non-Hispanic Whites (Beech et al., 1999; Pasch et al., 2016). Other than geographical and social factors, additional cultural factors may affect Hispanic American children's obesity. For instance, they consume more cooked or canned beans rather than vegetables than non-Hispanic black and non-Hispanic White or other ethnic groups (Di Noia et al., 2015). And child fatness has been perceived as a sign of good health among Mexican parents (Brewis, 2003; Pasch et al., 2016). Given the high prevalence of childhood obesity and obesity-induced health problems, understanding factors associated with weight-related behaviors and the role of culture in these behaviors in Hispanic children is critical in reducing the high prevalence of obesity.

This dissertation study found that the prevalence of central obesity as defined by WHtR differed by family income. Previous studies constantly reported that the prevalence of general obesity for both boys and girls with lower family income was significantly higher than for those with higher family income among all racial/ethnic groups (Jin & Jones-Smith, 2015; Oddo & Jones-Smith, 2015). A recent analysis of U.S. youth ages 2 to 19 years using the NAHNES 2011-2014 (Ogden et al., 2018) reported that the prevalence of general obesity was associated with household income, showing that high-income groups of children were less obese. The magnitude of the association between family income and childhood obesity was different from race/ethnicity (Gordon-Larsen, Adair, & Popkin, 2003; Wang & Zhang, 2006). However, this dissertation found the impact of family annual income in the prevalence of central obesity as defined by WHtR, but not by WC or general obesity. These conflicting results may be because the sample size was small among some subgroups differences. For example, the unweighted sample size of non-Hispanic Asian girls living in a middle-income family was 9, whereas the estimated prevalence of general obesity was very low (1.3%). Although the study aim was not to investigate obesity prevalence by an interaction between family annual income and race/ethnicity among U.S. children, the data were limited to interpret survey statistical outcomes as reliable findings.

Specific Aim 2: The main findings indicated that changes in mean WC and WHtR remained not significant between 2007-2008 and 2015-2016, or by sex, racial/ethnic groups, and family income groups of U.S. children ages 6 to 11 years. However, using the cut-off values of WC for the 90th percentile for sex and age in NHANES III, the prevalence of central obesity was significantly decreased from 2007 to 2016 (p = .017, 21.2% to 15.8%). These results corresponded with decreases in the prevalence of dyslipidemia and high BP during the same period. But no significant changing trend in central obesity as defined by WHtR was observed in children, which is consistent with the trends reported for general obesity as defined by BMI during 2003-2004 and 2011-2012 in youth ages 2 to 19 years (Ogden et al., 2014). These findings suggest that the observed decrease in WC over the last 10 years may have been slightly larger had there been no significant changes in WHtR or BMI.

The unadjusted models revealed that those significant decreases were found among non-Hispanic White, boys, and children living in a middle-income family. It is well accepted that the consumption of high-calorie foods and sweetened beverages, lack of physical activity, and more time spent in sedentary behaviors (TV or video viewing, computer use) are the main risk factors of central obesity among children. Notably, between 2001 and 2010, TV viewing time and consumption of sweets and sweetened beverages decreased, while the days with ≥1 hour of physical activity, intake of fruits and vegetables, and frequency of eating breakfast significantly increased among U.S. adolescents ages 11 to 16 years (Iannotti & Wang, 2013). Those changes in weight-related behaviors may partially explain why the prevalence of central obesity remained stable 2003-2004 and 2011-2012 (Xi et al., 2014).

Specific Aim 3 and 4: In the study, central obesity as defined by WC or WHtR was found to be positively associated with dyslipidemia, and these associations were independent of general obesity as defined by BMI among U.S. children ages 6 to 11 years. Particularly, the association of central obesity, as defined by WHtR, with dyslipidemia was found to be consistently and independently stronger than general obesity after adjusting for age, sex, race/ethnicity, and family income. This finding is in line with studies by Koba et al. (2013) and Khoury et al. (2013), who reported significant positive associations between WHtR and atherosclerotic dyslipidemia in pre-pubertal children.

Although adult studies have demonstrated that central adiposity measures (WC or WHtR) are better predictors of dyslipidemia than BMI (Browning et al., 2010), the relationship between waist-based measures and dyslipidemia among pre-teen children was not consistently significant in previous studies (Dhuper et al., 2009; Freedman, Dietz, Srinivasan, & Berenson, 2009; Hirschler et al., 2011; Mokha et al., 2010). In addition, several studies reported a gender difference in the ability of waist-based measures to predict dyslipidemia (Sardinha et al., 2016; Wicklow et al., 2015). Also, the additional predictive capacity of waist-based measures was different from types of lipids. For instance, HDL and TG in obese adolescents were significantly associated with WC and WHtR, whereas z-BMI was significantly correlated with LDL (Dhuper et al., 2009).

Variations in the nature and magnitude of central obesity-related dyslipidemia may be explained by differences in children's age, race/ethnicity, or methods used for assessing obesity-related indices. In addition, puberty status is important in determining relationships with adiposity and lipid metabolism in children (Staiano & Katzmarzyk, 2012). This study employed non-HDL serum concentrations as a measure of dyslipidemia. Non-HDL is known to be more indicative of persistent dyslipidemia for children than serum TC, LDL, or HDL concentrations, especially since they are not affected by puberty in either sex (Expert Panel on Integrated Guidelines for Cardiovascular Health and Risk Reduction in Children and Adolescents & National Heart, Lung, and Blood Institute, 2011). And a meta-analysis of adults reported non-HDL was a more specific biomarker of cardiovascular risk than LDL (Sniderman et al., 2011). However, the variances in non-HDL between different population-based studies should be interpreted with caution. Even same racial groups of children studies reported inconsistent patterns for girls' and boys' non-HDL concentrations throughout childhood and adolescence. For example, a Slovakian study found a negative effect of age on non-HDL in both girls and boys with showing higher in the younger (7 to 11 years) than in the older (12 to 17 years) (Alberty, Albertyova, & Ahlers, 2009). But, a Danish/North-European White population-based cohort (Nielsen et al., 2017) found that age affected only boys, not in girls among children and adolescents.

The results also suggested that WHtR was a useful index in identifying centrally obese children with dyslipidemia, even better than WC. Given the fact that WC was highly correlated with children's height in the study, tall children might fall into a higher WC percentile than children at the same age, which were falsely defined as centrally obese. On the other hand, central obesity in children with delayed statue growth might be underestimated by using age-specific WC cut-offs. However, in children younger than 6 years (Sijtsma et al., 2014) and adolescents (Agredo-Zuniga, Aguilar-de Plata, & Suarez-Ortegon, 2015), WC was found to have stronger associations with high-LDL than WHtR. But, in terms of the correlation with HDL-cholesterol, WHtR was better than WC or BMI (Sijtsma et al., 2014). The study findings support the evidence that WHtR has an additional predictive value for dyslipidemia among children before puberty.

This study observed that older children or girls were more likely to have dyslipidemia than younger children or boys, given the same degree of central and general obesity. The mechanism to explain why some obese children still maintain normal lipid metabolisms remains unclear. Also, little is known about the prevalence and the different types of lipid abnormalities among obese children who are metabolically healthy. In fact, the estimates of standard errors and ranges of WC, WHtR, and BMI were wider in overweight or centrally obese children, which suggests a higher chance of finding an association with other covariates that were not included in this analyses.

The positive association between obesity and hypertension has been demonstrated in children. In the analyses, general obesity—but not central obesity—was significantly and independently associated with high BP among U.S. children. The findings are consistent with previous studies (Genovesi et al., 2008; Maximova et al., 2011) which suggested that BMI was a better predictor of BP; however, other studies do not support this finding by showing superiority of waist-based measures (Barba et al., 2006). Conflicting findings might be due to the different age groups of children, the sample's homogeneity, the various ethnic mix of the sample, and different measurements of WC (Genovesi et al., 2008).

The findings do not support the use of waist-based measures in addition to BMI to identify children with high BP. The high correlation between WC and BMI ($r > 0.9$) was found, which may explain why waist-based measures do not have additional predictive power to BMI in predicting high BP. Maximova et al. (2011) observed that WHtR and BMI were highly correlated ($r \geq 0.93$) in Canadian children ages 8 to 10 years, and that WHtR and BMI also had a relatively weak ability to identify children with elevated BP. In the Bogalusa study, in 2,498 children ages 5–17 years old, the magnitudes of associations with high BP were similar for BMI z-score and WHtR, and both indices were highly correlated ($r = 0.88$) (Freedman et al., 2009). As all values were dichotomized and entered into regression models, the magnitude of true associations may be weaker than when continuous values of WC, WHtR, and BMI would be used. And the optimal waist-based measures may vary by different racial/ethnic groups of children. For example, Asian American children tend to be shorter than non-Hispanic White or Black children for the same age and sex; therefore, a lower WHtR cut-off has been applied (Nawarycz et al., 2010).

Considering these findings, the role of WC or WHtR in predicting the risk of high BP in children has been controversial. Variations among BP study's findings were undoubtedly enlarged by the BP measurement device, technique, and whether sequential readings were obtained. Most population-based large scale children studies that obtained a single BP measurement or several readings on a single visit (Barba et al., 2006; Charakida et al., 2012; Falaschetti et al., 2010). Karatzi et al. (2009) suggested that the predominance of high systolic BP in children might be impacted by the measurement setting (office or home). Also, the NAHNES participants' BP at initially high levels decreased with more frequent measurements due to an accommodation effect (CDC, 2009). Thus, prevalence of hypertension will likely be overestimated unless sequential readings are obtained on separate days. Therefore, the U.S. National Institutes of Health recommended that hypertension should be defined as elevated BP that is measured on three separate occasions (CDC, 2009).

Limitations

Sampling; In this study, the ethnicity of a child is a significant factor for predicting central and general obesity; however, from 2011 through 2014, non-Hispanic black, non-Hispanic Asian, and Hispanic children among subgroups were oversampled for the NHANES (NCHS, 2015). Any non-Hispanic child reporting more than one race was included in an “other” category and included in analyses for the total estimates but not reported separately. Additional years of NAHNES might provide more reliable information about obesity prevalence by income, especially among non-Hispanic Asian children. American Indian/Native Alaskans and Asians were not analyzed separately in this study. According to a comparison of obesity prevalence in U.S. preschool children across major racial/ethnic groups (Anderson & Whitaker, 2009), racial/ethnic disparities in obesity were found at the highest prevalence among American Indian/Native Alaskan children, the lowest prevalence among non-Hispanic White and Asian children, and an intermediate prevalence among Hispanic and non-Hispanic black children.

Due to the exclusion of areas with younger children, there is a potential non-coverage bias in the NHANES sample that should be considered when interpreting results. Therefore, appropriate statistical methods were applied to minimize confounding and bias. For estimates with greater statistical reliability for demographic sub-domains such as younger children with multi-ethnicity, combining two or more two-year cycles of the continuous NHANES laboratory data is encouraged and strongly recommended (Lamb, Ogden, Carroll, Lacher, & Flegal, 2011). When pooling two or more datasets, new sample weights may be needed to calculate before beginning any analysis of the data because NCHS does not calculate and include all possible combinations. Furthermore, methodological developments are occurring to deal with the problems of missing data and various forms of bias. For example, pubertal status (i.e., Tanner pubertal stages) was not assessed in NHANES, which may confound relationships with adiposity and metabolic risk.

Missing information; This is the population for which clinically simple and reliable anthropometric measures such as BMI and WC are needed. In addition, data were available for a variety of confounders including proxy measures for socioeconomic status, which is known to influence metabolic risk, especially for family annual income—missing data= 7~8%, including refused to answer. Although the dataset was large and population-based, there were many children with missing or incomplete data who were excluded. It was not possible to demonstrate a real lack of difference between children whose data were included and nonparticipants, which may have created a selection bias.

Other covariates of WC such as maternal information, parents' education, and parents' weight status were not included in the analyses. Increases in energy intake, portion sizes, and sweetened beverage intake and declines in sufficient vigorous physical activity, despite declines in sedentary behaviors (e.g., hours of TV viewing) (Taveras, Gillman, Kleinman, Rich-Edwards, & Rifas-Shiman, 2010) likely contributed to the secular trends in mean WC and WHtR. In addition, growing evidence indicates a potentially causal relationship between stress and central obesity in adults (Singh & Shen, 2013). However, it is unknown whether emotional stress activated by psychosocial and socioeconomic difficulties, depression, and anxiety may also contribute to the increasing trends of WC and WHtR among children.

The NHANES variables related to vascular risk factors are narrow in children less than 12 years of age. Serum total cholesterol and HDL levels of children ages 6 to 11 years are available in the NHANES since 2005, but LDL levels are no longer available in this age group after 2005 (NCHS, 2015). As described in previous children's studies (Kwon, Burns, & Janz, 2010; Lamb et al., 2011), blood pressure was measured in children under 8 years of age and thus are not available for analysis; yet it is an important component of metabolic syndrome and vascular risk factors. However, when properly used, the NHANES database constitutes a valuable and unique resource for studying children's health across multi-ethnic groups in the U.S.

Possible cofounders were the family history of dyslipidemia and hypertension, status of puberty, and birth weight. Particularly, the timing of an adolescent growth spurt may influence cholesterol levels because the increase in body fat may be accelerated. Since the Mexican children had a high prevalence of being overweight/obesity (35.9%), it could result in a more physiologically mature group than would be typical for this pre-teen period. Regarding data management, dichotomized lipids and BP values, also, may have limited the findings.

Other factors possibly influencing the association between adiposity and BP may exist besides sex, age, birth weight, practice of regular physical activity, parental overweight/obesity, and educational levels that were controlled for while analyzing the data. Furthermore, there was no explanation regarding how covariates were selected and the correlations between these factors and BP were not presented. BP and WC were only measured on a single occasion, which could affect estimates of the prevalence of high BP and fat distribution of children. Weight gain since birth and birth weight should be considered as significant factors in assessing the impact of adiposity on BP in future studies. The study used children's home postcode as an indicator of child SES, which has been validated in previous studies. Ethnic background was based on either the mother's, father's or child's country of birth, and was used to adjust for unmeasured confounders associated with this variable.

The design of the current study does not allow for the establishment of a causal association between increased WC and elevated BP, but this is a limitation of all cross-sectional studies. An additional limitation in the current study was the absence of an imaging method to assess intra-abdominal fat. Moreover, factors such as dietary and lifestyle habits that may affect trends in central obesity were not included in the study.

Relevance to Nursing and Healthcare Providers

Given the study observations of a decrease in the prevalence of general and central obesity among U.S. children for the last decade, continued progress is needed to reduce disparities, a goal of *Healthy People 2020*, with a target of childhood obesity prevalence <14.5% (U.S. Department of Health and Human Services, 2018). Particularly, the study findings identified Hispanic children as a high-risk group, which is clinically important in developing obesity-related prevention and treatment strategies for this subpopulation.

Waist measures should be included in the screening and assessment of overweight and obese children. Assessing central obesity in screening children is recommended to classify a child at high risk for early vascular alteration. This study observed that waist-based measures were independently associated with dyslipidemia among children ages 6 to 11 years. This finding is consistent with previous youth studies that suggested that WC is a robust predictor of cardio-metabolic biomarkers such as insulin resistance, high LDL, and BP independent of BMI (Khoury et al., 2012; S. Lee, Bacha, Gungor, & Arslanian, 2006; Tybor, Lichtenstein, Dallal, Daniels, & Must, 2011). Currently, there is need for a unified WC measurement protocol in pediatric care settings. The method used in the NHANES assessed the circumference just above the right iliac crest at the mid-axillary line, which is the largest circumference among other anatomical sites used in screening children (Bosy-Westphal et al., 2010). However, in a study of Brazilian children ages 6 to 9 years, the WC measured at midpoint between the last rib and the iliac crest was correlated the most strongly with body fat percentage (Sant'Anna Mde et al., 2009).

Also, this study observed WHtR as a stronger measure of vascular health risk than other anthropometric indices (BMI, WC) in multi-ethnic children ages 6 to 11 years. The finding proposes the clinical use of WHR as a fast and effective screening tool, considering that it requires no adjustment for age and sex. Moreover, WHtR is easier to measure and calculate than BMI with indicating a universal value of 0.5 can be appropriate for assessing an increased vascular risk among multi-ethnic groups.

Future Study for Assessing Central Obesity and Vascular Health in Children

Future studies should investigate the distribution and effect of obesity on other vascular specific biomarkers such as insulin resistance, C-reactive protein, and the possible effects—individually and combined—of multiple risk factors present concomitantly in children for detecting early stage of vascular damage. In addition, following studies investigating the effectiveness of interventions to reduce central fat mass and effect outcomes such as early vascular alteration will be an important next step to determine how WC in childhood affects an individual’s long-term health. WHtR has been suggested as a useful parameter to assess fat distribution in children, but some issues are worth investigating, such as a residual correlation with height during growth (Tybor, Lichtenstein, Dallal, & Must, 2008). As neck circumference (NC) is emerging recently (Androutsos et al., 2012), future comparison studies can be conducted to evaluate the association of NC with central obesity among U.S. children.

The differentiated cut-offs for the different studied parameters may be due to ethnic differences, as well as the lack of standardization of the anatomical point used in the assessment of waist-based measures. Therefore, new studies are necessary to further investigate the usefulness of these parameters in determining central obesity in childhood, including the standardization of the place where measures are to be taken and the determination of cut-offs that are comparable between different populations. Further studies evaluating the long-term predictability of general and central obesity measures for their associations with early vascular alteration or atherosclerosis will provide more information to establish preventive vascular health strategies for high-risk children.

Conclusion

Greater childhood adiposity is associated with adverse cardiometabolic risk factors, but obesity-induced vascular damage during pre-pubertal period has rarely been demonstrated. In this cross-sectional study in a representative sample of U.S. children ages 6 to 11 years based on NHANES 2007–2016, positive associations of general and central obesity with vascular alterations were observed. This study adds to the current growing body of knowledge regarding a childhood clinical assessment tool for early vascular alteration by using central obesity (waist circumference (WC) and waist-to-height ratio (WHtR)). It can be concluded that WHtR has shown good performance in the assessment of central obesity among U.S. children aged 6 to 11 years. These findings can provide future standard clinical practice guidelines and education to families and future research in childhood obesity. A central obesity index may be a more sensitive assessment in children to assess future adiposity-induced vascular health risk.

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Table 1. Study Variables and Definition

Variables	Definition	Variable Name in Data file	Participants
Central obesity	Waist circumference (WC) ≥ age- and sex-specific 90^{th} percentile based on data from NHANES III (1988-1994)	BMXWAIST (cm)	All age
	Waist-to-height (WHtR) ≥0.5	BMXHT (Standing Height (cm))	
General obesity	Age- sex- BMI as ≥ 95^{th} percentile	BMXBMI (Body Mass Index (kg/m^2))	All age
Demographic factors		DEMO_H Data	All age
	Age at exam	RIDEXAGM	
	Sex	RIAGENDR	
	Race/Ethnicity	RIDRETH3 (including Asian)	
	Family annual income	INDFMPIR (ratio to poverty)	
Blood pressure	Mean value of 3 times measurements both diastolic and systolic pressure (mmHg)	BPXDI1-3 (Diastolic: Blood pressure (1^{st}- 3^{rd} measurements) (mm Hg) BPXSY1-3 (Systolic: Blood pressure (1^{st}-3^{rd} measurements) (mm Hg))	8 years and over
Lipid panel	Total cholesterol High-density lipoproteins (HDL)	LBDTCSI (Total Cholesterol (mmol/L) LBDHDD (Direct HDL-Cholesterol [mg/dL])	All age

Table 2. Estimated Prevalence of Obesity of U.S. Children Ages 6-11 Years in 2015–2016

	General Obesity BMI ≥ 95th percentile				Central obesity WC ≥ 90th percentile				Central obesity WHtR ≥ 0.5			
		95% CI				95% CI				95% CI		
	Percent	Lower limit	Upper limit	p^a	Percent	Lower limit	Upper limit	p^a	Percent	Lower limit	Upper limit	p^a
sex				*.172*				*.547*				*.217*
Boy	19.2	15.1	24.0		15.3	11.0	20.9		28.2	22.7	34.6	
Girl	16.2	13.0	20.0		16.3	13.5	19.7		31.5	25.5	38.1	
Race and Ethnicity				***.000***				***.003***				***.000***
Non-Hispanic White	12.6	9.5	16.7		12.0	7.9	17.9		25.7	19.3	33.3	
Non-Hispanic Black	19.7	14.2	26.6		15.5	11.7	20.4		21.1	17.2	25.6	
Other, multi-racial	18.4	11.9	27.3		14.2	9.5	20.7		29.5	22.3	38.0	
Hispanic	26.5	21.8	31.8		24.1	19.4	29.6		43.0	34.9	51.5	
Family income				*.053*				*.068*				***.022***
Low	22.6	17.6	28.5		20.7	15.8	26.6		40.4	33.3	47.9	
Middle	17.5	13.4	22.5		16.4	12.7	20.9		29.6	24.9	34.7	
High	12.0	7.0	19.9		9.6	4.5	19.3		18.1	9.0	32.9	

Data from the NAHNES 2015-2016, estimates are weighted according to the analytic guidelines

BMI, body mass index; WC, waist circumference; WHtR, waist to height ratio.

Data expression as estimated proportion with 95% CI, confidence interval

[a] Weighted Chi-square tests p-values *<.05*

Table 3. Unweighted Sample Characteristics of Children Ages 6-11 Years, Participated in NHANES 2007–2016 (N=5,296)

	2007–2008	2009–2010	2011–2012	2013–2014	2015–2016	p^a
All, *n*	1,011	1,019	1,075	1,106	1,085	
Age	8.05 ± 1.42	8.04 ± 1.45	7.96 ± 1.43	7.97 ± 1.46	8.02 ± 1.42	*.921*
Sex, %						*.442*
Boys	49.7	52.9	52.6	52.5	49.7	
Girls	50.3	48.2	47.4	47.5	50.3	
Race or ethnicity, %						***<.0001****
Non-Hispanic white	28.9	32.7	23.3	25.6	22.2	
Non-Hispanic black	26.5	18.4	28.1	27.7	13.9	
Other including multi-racial	4.7	7.2	16.8	14.7	15.0	
Hispanic	39.9	41.8	31.8	32.0	36.1	
Family income, %						***.0001****
Low	45.9	46.1	49.5	51.3	41.5	
Middle	36.8	34.8	31.1	29.4	38.3	
High	17.3	19.1	19.4	19.4	20.2	
Height (cm)	131.4 ± 10.8	131.6 ± 10.9	131.5 ± 10.6	131.3 ± 10.9	130.8 ± 10.5	*.436*
Weight (kg)	32.6 ± 11.4	32.4 ± 11.0	32.5 ± 11.3	32.2 ± 11.4	32.1 ± 10.6	*.845*
BMI, (kg/m^2)	18.4 ± 4.05	18.3 ± 3.94	18.4 ± 4.28	18.3 ± 4.00	18.4 ± 3.94	*.830*
WC (cm)	63.9 ± 11.8	63.3 ± 11.1	63.5 ± 11.6	63.3 ± 11.1	63.5 ± 11.1	*.817*
WHtR	0.485 ± 0.069	0.480 ± 0.067	0.482 ± 0.071	0.481 ± 0.065	0.485 ± 0.068	*.437*

Note. Sample sizes for each variable vary due to missing data. Percentages may not add up to 100 due to rounding.

Data expression as estimated mean ± standard deviation

BMI, body mass index; WC, waist circumference; WHtR, waist to height ratio.

[a] *p*-values for comparing 5 datasets of NHANES from 2007-2008 through 2015–2016, $p < .05$

Table 4. Time Trends in Prevalence of Central Obesity of U.S. Children Ages 6-11 Years during 2007-2008 and 2015–2016

	2007–2008		2009–2010		2011–2012		2013–2014		2015–2016		Absolute Increase	*p* for Trend
	%	SE	%	SE	%	SE	%	SE	%	SE		
WC ≥ 90th percentile												
All	21.17	1.05	21.72	1.63	19.01	1.70	20.16	2.12	15.80	1.74	-5.37	***.017***
Sex												
Boy	20.02	1.42	20.79	2.26	14.21	1.87	16.49	1.58	15.29	2.30	-4.73	***.029***
Girl	22.33	1.98	22.73	1.86	24.35	1.78	24.31	3.40	16.33	1.46	-6.00	*.104*
Race or ethnicity												
Non-Hispanic white	22.56	1.55	20.27	2.65	16.07	3.38	18.11	3.07	12.00	2.31	-10.56	***.002***
Non-Hispanic black	16.84	2.21	23.30	3.74	20.63	2.43	17.38	2.10	15.54	2.04	-1.30	*.263*
Other, multi-racial	8.75	3.90[a]	23.60	7.09[a]	12.50	2.50	20.23	5.08	14.20	2.61	5.45	*.801*
Hispanic	24.42	2.32	23.73	2.04	27.02	2.21	25.76	2.74	24.13	2.41	-0.29	*.870*
Family income												
Low	22.41	2.31	20.56	2.25	24.20	1.97	23.00	3.29	20.70	2.52	-1.71	*.952*
Middle	23.34	1.85	20.39	3.55	16.25	2.49	20.18	3.02	16.41	1.93	-6.93	***.043***
High	13.55	2.31	23.10	5.48	14.90	4.55[a]	14.82	2.54	9.62	3.31[a]	-3.93	*.110*
WHtR ≥ 0.5												
All	31.05	1.45	28.13	1.47	27.97	1.92	30.13	2.66	29.83	2.57	-1.22	*.962*
Sex												
Boy	29.96	2.44	27.88	1.60	23.23	2.76	27.81	2.73	28.24	2.80	-1.72	*.695*
Girl	32.16	2.59	28.40	2.78	33.27	2.02	32.83	3.80	31.49	2.98	-0.67	*.749*
Race or ethnicity												
Non-Hispanic white	32.26	2.12	23.02	2.22	22.36	3.73	25.56	3.36	25.66	3.31	-6.60	*.227*
Non-Hispanic black	22.72	2.62	29.85	3.73	24.05	2.75	24.17	2.02	21.06	1.98	-1.66	*.302*
Other, multi-racial	11.63	4.23[a]	28.70	7.57	22.09	3.78	26.57	4.95	29.52	3.70	17.89	*.055*

Hispanic	39.81	2.24	39.08	2.12	45.03	3.72	43.93	3.47	43.00	3.92	3.19	*.272*
Family income												
Low	33.87	2.85	33.80	2.52	35.13	2.42	33.99	3.73	40.36	3.45	6.49	*.244*
Middle	34.35	3.30	24.65	2.89	25.05	3.00	34.22	4.20	29.56	2.29	-4.79	*.950*
High	21.37	3.49	24.26	5.32	21.74	4.59	20.29	3.94	18.08	5.55[a]	-3.29	*.479*

Data from the five cycles of NAHNES from 2007-2008 through 2015-2016, estimates are weighted according to the analytic guidelines

Data expression as estimated proportion with SE (relative standard error)

[a] Estimate might be unreliable because relative standard error is >30%

Table 5. Estimated Prevalence of Dyslipidemia and Hypertension among U.S. Children Ages 6 to 11 Years during 2007 and 2016

	Dyslipidemia Non-HDL ≥ 145mg/dl				Hypertension[a] SBP or DBP ≥ 90th percentile for age- sex- height-			
		95% CI				95% CI		
	Percent	Lower limit	Upper limit	*p*	Percent	Lower limit	Upper limit	*p*
sex				*.589*				*.291*
Boy	7.21	5.63	9.20		6.53	4.99	8.51	
Girl	7.93	6.46	9.70		7.97	6.28	10.0	
Race or Ethnicity				*.576*				*.213*
Non-Hispanic White	7.94	6.37	9.85		6.84	5.23	8.91	
Non-Hispanic Black	6.27	4.83	8.11		7.20	5.38	9.57	
Other, multi-racial	7.62	5.25	10.9		10.56	6.97	15.7	
Hispanic	7.44	6.18	8.93		6.84	5.34	8.73	
Family income				*.302*				*.299*
Low	8.45	7.11	10.0		8.54	6.53	11.1	
Middle	7.44	5.98	9.22		6.66	4.80	9.17	
High	6.27	4.15	9.37		6.34	4.55	8.75	

Data from pooled NAHNES 2007-2016, estimates are weighted according to the analytic guidelines
Data expression as an estimated proportion with 95% CI, Confidence Interval
HDL, high-density lipoproteins; SBP, systolic pressure; DBP, diastolic pressure
[a] Analyzed means of blood pressure among children aged 8 to 11 years

Table 6. Factors Associated with Dyslipidemia[a] among U.S. Children Ages 6-11 Years: Multivariable Regressions[b]

	Model 1	Model 2	Model 3	Model 4	Model 5
Variable	OR (95% CI)	OR (95% CI)	OR (95% CI)	OR (95% CI)	OR (95% CI)
Central obesity (WC ≥ 90^{th})	**3.41 (2.68-4.35)*****			**1.87 (1.24-2.84)****	
Central obesity (WHtR ≥ 0.5)		**4.12 (3.22-5.27)*****			**3.21 (2.24-4.59)*****
General Obesity (BMI ≥ 95^{th})			**3.34 (2.63-4.24)*****	**2.23 (1.47-3.37)*****	**1.54 (1.09-2.18)***
Age (years)				**1.17 (1.07-1.28)****	**1.14 (1.04-1.25)****
Sex (Girls)				**1.36 (1.06-1.75)***	**1.26 (0.98-1.63)***
Race or ethnicity					
Non-Hispanic white				1.15 (0.75-1.78)	1.17 (0.75-1.83)
Non-Hispanic black				0.68 (0.43-1.09)	0.76 (0.47-1.22)
Other, multi-racial				0.77 (0.50-1.19)	0.74 (0.48-1.15)
Hispanic				reference	reference
Family income					
Low				1.23 (0.84-1.79)	1.16 (0.80-1.70)
Middle				1.20 (0.81-1.76)	1.17 (0.79-1.72)
High				reference	reference

[a] Defined by non-HDL≥145mg/dl

[b] All variables (age, sex, race/ethnicity, and family annual income) included in the model.

Data expression as an OR, odds ratio with 95% CI, Confidence Interval

****p* value <*.001*, ***p* value <*.01*, **p* value <*.05*

Table 7. Factors Associated with Hypertension[a] among U.S. Children ages 8-11 Years: Multivariable Regressions[b]

	Model 1	Model 2	Model 3	Model 4	Model 5
Variable	OR (95% CI)	OR (95% CI)	OR (95% CI)	OR (95% CI)	OR (95% CI)
Central obesity (WC ≥ 90^{th})	**2.84 (2.12-3.80)*****			1.55 (0.95-2.52)	
Central obesity (WHtR ≥ 0.5)		**2.59 (1.94-3.46)*****			1.54 (0.98-2.41)
General Obesity (BMI ≥ 95^{th})			**3.00 (2.25-4.00)*****	**2.15 (1.33-3.47)****	**2.12 (1.35-3.35)****
Age (years)				1.06 (0.89-1.26)	1.04 (0.88-1.24)
Sex (Girls)				1.00 (0.75-1.35)	1.01 (0.75-1.36)
Race or ethnicity					
Non-Hispanic white				0.61 (0.38-0.98)	0.60 (0.37-0.96)
Non-Hispanic black				0.59 (0.36-0.97)	0.57 (0.35-0.94)
Other, multi-racial				0.53 (0.33-0.84)	0.50 (0.31-0.81)
Hispanic				reference	reference
Family income					
Low				1.23 (0.84-1.79)	1.38 (0.89-2.14)
Middle				1.20 (0.81-1.76)	1.02 (0.64-1.62)
High				reference	reference

[a] Defined by SBP or DBP≥90^{th} percentile for sex-, age-, and height-specific

[b] All variables (age, sex, race/ethnicity, and family annual income) included in the model

Data expression as an OR, odds ratio with 95% CI, Confidence

$^{***}p$- value <.001, $^{**}p$-value <.01, $^{*}p$-value <.05

Figure 1. Framework of the Study with Specific Aims

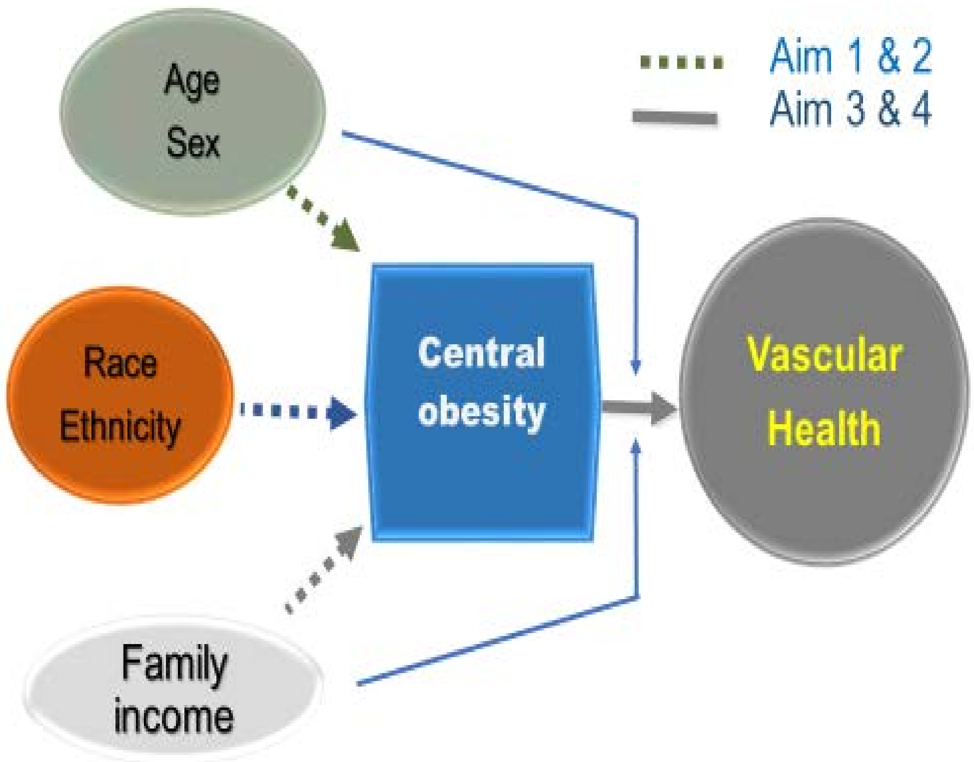
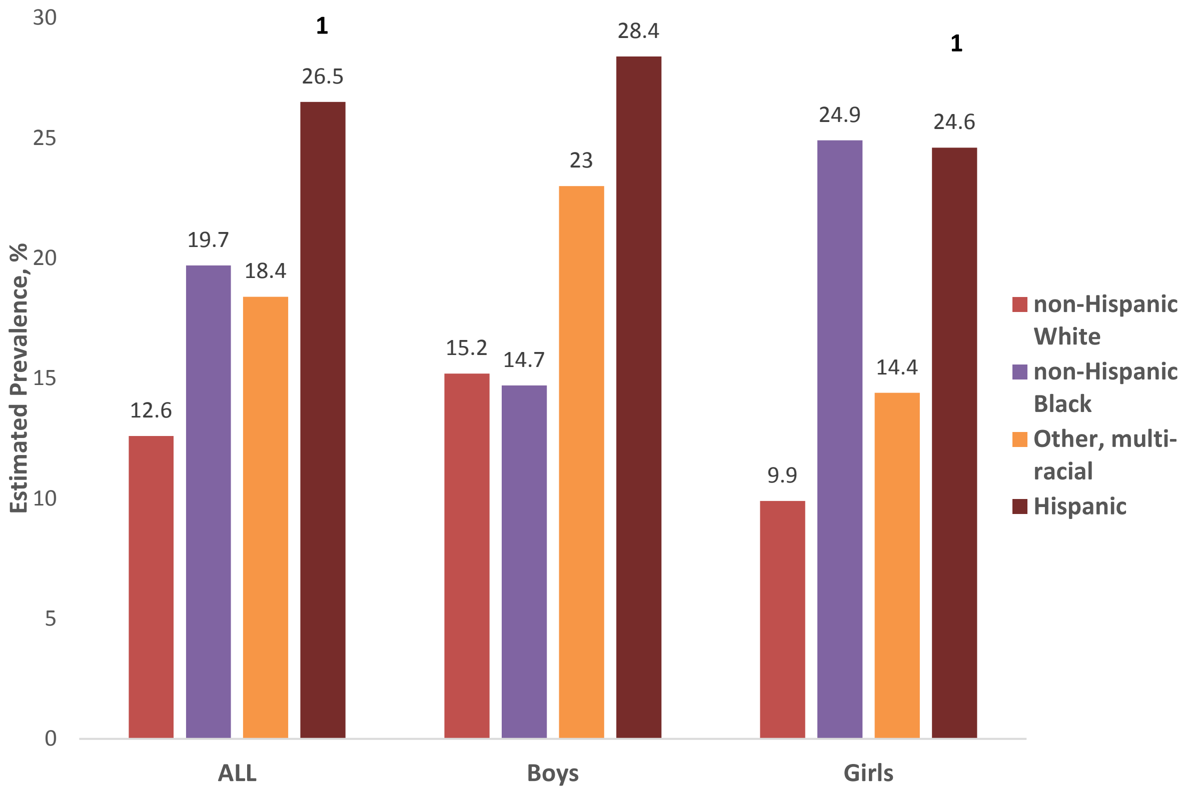


Figure 2. Prevalence of General Obesity among U.S. Children Ages 6-11 years by Race/Ethnicity and Sex



Data from the NAHNES 2015-2016, estimates are weighted according to the analytic guidelines

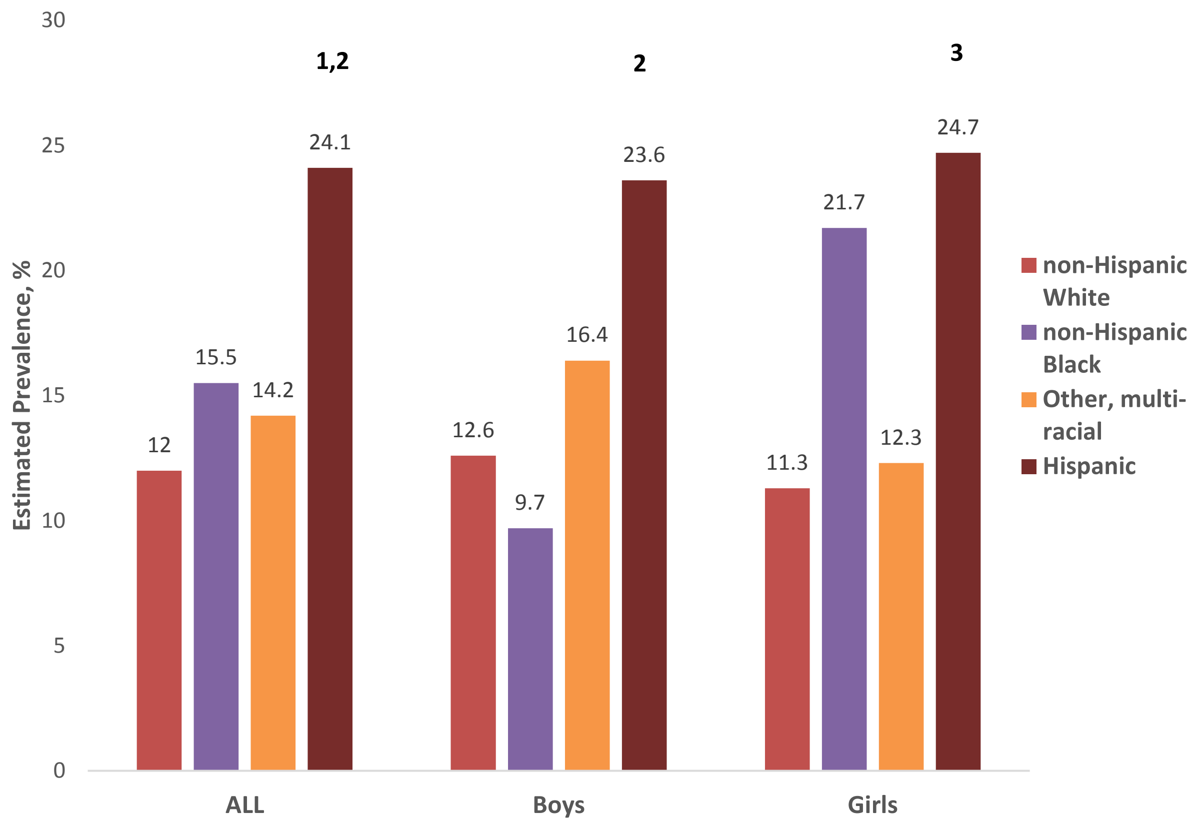
[1]Significantly different from non-Hispanic White

[2]Significantly different from non-Hispanic Black

[3]Significantly different from other, multi-racial

Bonferroni-adjusted *p-value<.05*

Figure 3. Prevalence of Central Obesity defined by WC among U.S. Children Ages 6–11 Years by Race/Ethnicity and Sex



Data from the NAHNES 2015-2016, estimates are weighted according to the analytic guidelines

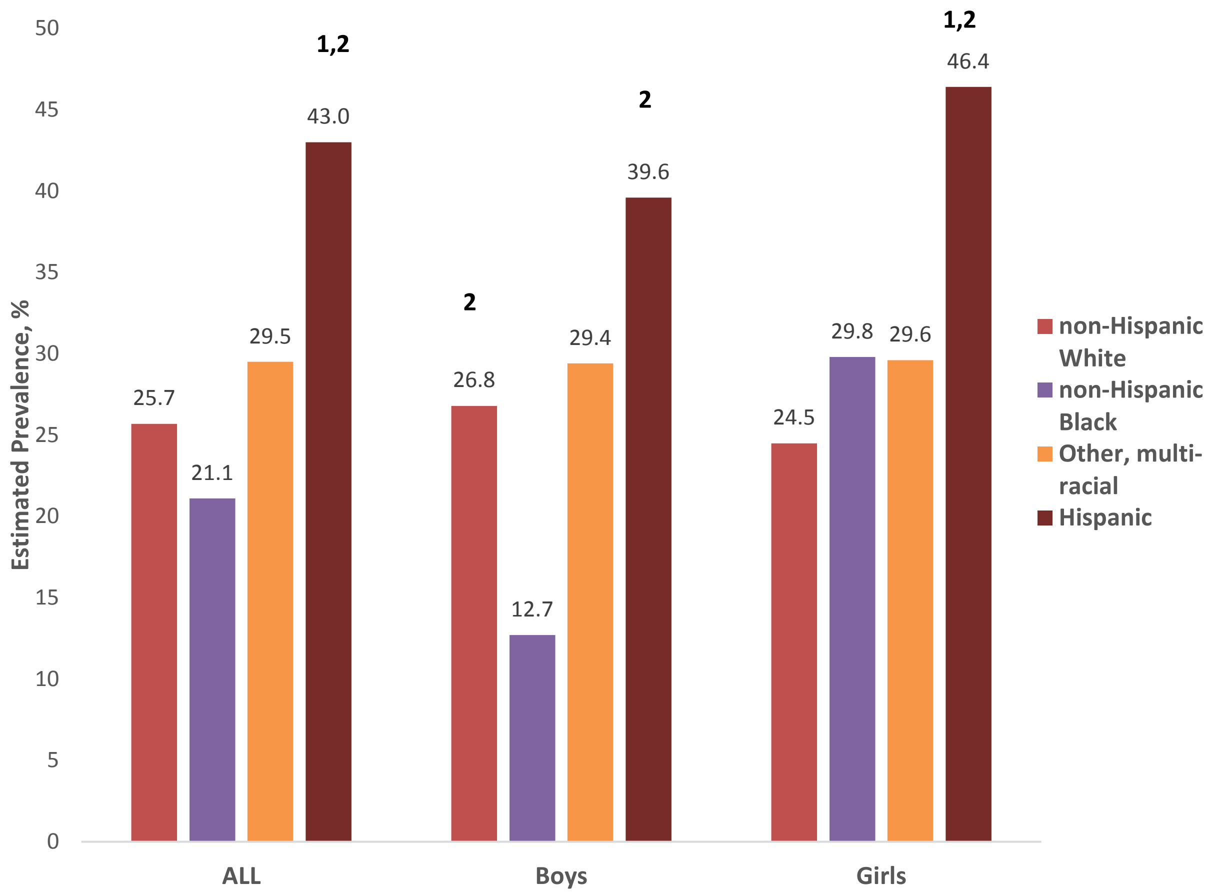
[1]Significantly different from non-Hispanic White

[2]Significantly different from non-Hispanic Black

[3]Significantly different from other, multi-racial

Bonferroni-adjusted *p-value<.05*

Figure 4. Prevalence of Central Obesity defined by WHtR among U.S. Children Ages 6–11 Years by Race/Ethnicity and Sex



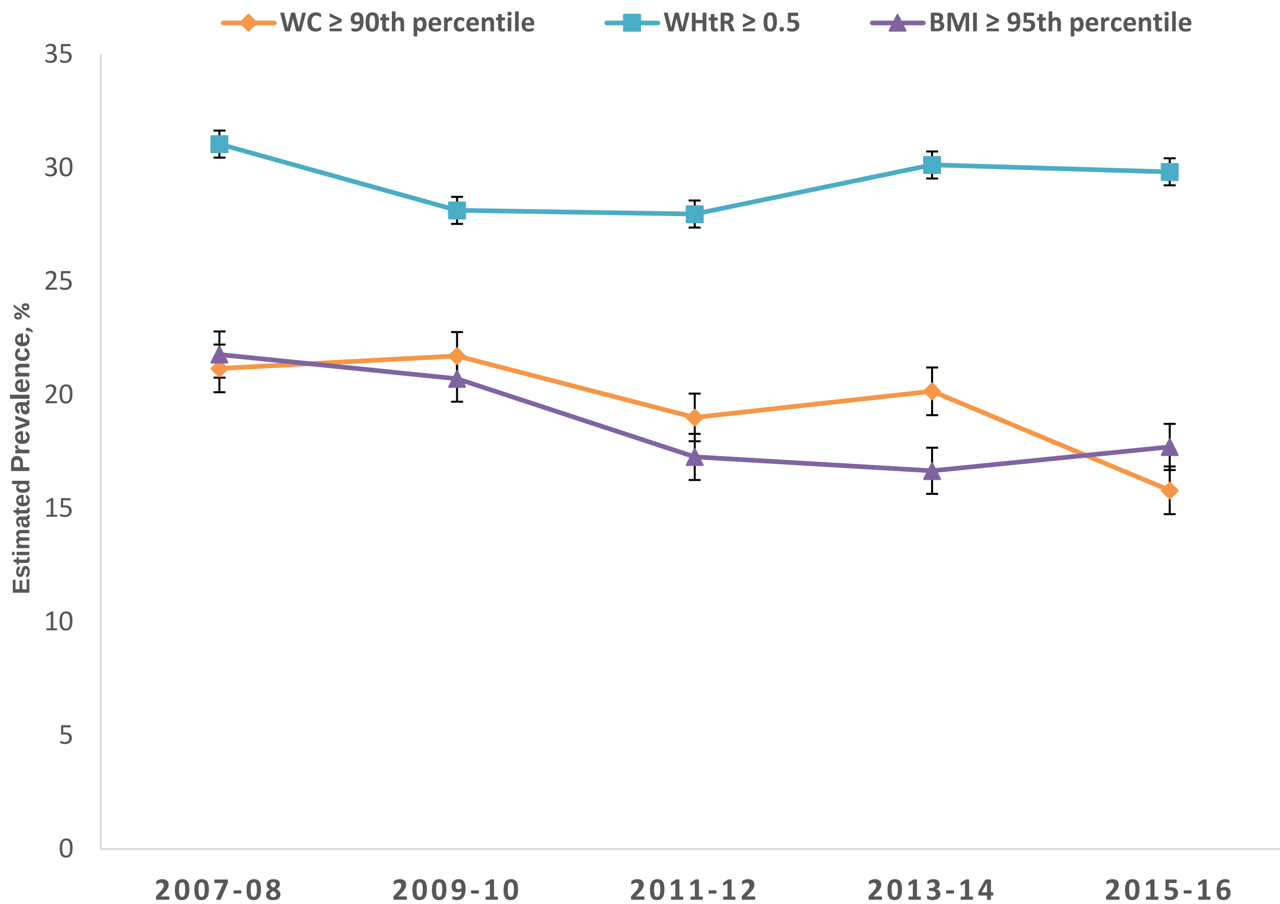
Data from the NAHNES 2015-2016, estimates are weighted according to the analytic guidelines

[1]Significantly different from non-Hispanic White

[2]Significantly different from non-Hispanic Black

Bonferroni-adjusted *p-value<.05*

Figure 5. Time Trends in Prevalence of Central and General Obesity of U.S. Children Ages 6-11 Years between 2007 and 2016



Data from the five cycles of NAHNES from 2007-2008 through 2015-2016

Estimates are weighted according to the analytic guidelines

Data expression as estimated proportion with SE (relative standard error)

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Author Signature *Jong Hee Lee* Date 06/10/2018