Spring 2017

COMPARISON OF ANTHROPOMETRIC MEASUREMENTS OF ABDOMINAL OBESITY AS PREDICTORS OF CARDIOMETABOLIC RISK FACTORS: NHANES 2011-2014

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A Thesis

Presented to

The Graduate Faculty

Central Washington University

In Partial Fulfillment

of the Requirements for the Degree

Master of Science

Nutrition

by

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June 2017

CENTRAL WASHINGTON UNIVERSITY

Graduate Studies

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ABSTRACT

COMPARISON OF ANTHROPOMETRIC MEASUREMENTS OF ABDOMINAL OBESITY AS PREDICTORS OF CARDIOMETABOLIC RISK FACTORS: NHANES 2011-2014

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Background It has been well established that screening tools for cardiometabolic diseases are less useful among obese populations as risk of these diseases is already high. However, research is lacking in regard to efficient screening tools for cardiometabolic diseases among normal weight and overweight populations.

Objective This study compared the predictive strengths of body mass index (BMI), waist circumference (WC), waist-to-height ratio (WHtR), sagittal abdominal diameter (SAD), and SAD-to-height ratio (SADHtR) with respect to risk of cardiometabolic disorders in normal and overweight U.S. populations.

Design This cross-sectional study utilized data from the 2011-2014 National Health and Nutrition Examination Survey.

Participants/setting The sample included non-pregnant adults with a normal weight or overweight BMI status (≥ 20 years; n = 6482).

Main outcome measures Each anthropometric measure was assessed for predicting risk of the following cardiometabolic disorders: hypertension (HTN), pre-diabetes, diabetes,

high total cholesterol, low high-density lipoprotein cholesterol (HDL-C), high non-HDL-C, and high apolipoprotein B.

Statistical analyses performed Simple and multiple logistic regression analyses compared the odds ratio of each anthropometric measure for each cardiometabolic disorder.

Results When analyzed in separate models, BMI, WC, WHtR, SAD, and SADHtR identified all cardiometabolic risks. In simultaneous models with abdominal obesity measures, BMI no longer identified cardiometabolic risks (ORs <1.0), except low HDL-C. Among normal weight and overweight men, WHtR and SADHtR were stronger measures of cardiometabolic risk except low HDL-C. With normal weight and overweight women, WHtR and SADHtR were stronger measures of risk for hypertension and diabetes, while all of the abdominal obesity measures were similar in assessment of the remaining cardiometabolic risks.

Conclusion In normal weight and overweight adults, anthropometric measures of abdominal obesity, especially those including a factor of height, are better predictors of cardiometabolic risk than BMI and should be a primary screening tool in this population.

ACKNOWLEDGEMENTS

First, I would like to thank my thesis committee chair, Dr. David L. Gee, for all of his guidance and support throughout this whole process. I have learned so much from him and feel so blessed to have worked with such a seasoned researcher. Second, I would like to thank committee member, Dr. Nicole Stendell-Hollis. Her constructive criticism and perspective were very much appreciated. Third, I am very thankful for committee member, Dr. Dominic Klyve. His positive attitude and expertise in statistics were crucial in accomplishing this thesis. Lastly, I would like to thank my sister, Laura Kettel, and my boyfriend, Jayce Reichert, for encouraging me every step of the way.

TABLE OF CONTENTS

LIST OF TABLES

CHAPTER I

INTRODUCTION

While obesity rates in the United States (U.S.) have started to plateau based on body mass index (BMI) measurements, abdominal obesity rates are on the rise according to measures of waist circumference.[1,2] Abdominal obesity, as compared with other distributions of adipose tissue, has specifically been shown to be highly associated with chronic diseases such as diabetes, cardiovascular diseases, and other cardiometabolic diseases.[3–5]

BMI has traditionally been used for the assessment of body weight but has been shown to lack accuracy in terms of body composition. Waist circumference (WC), waist-to-height ratio (WHtR), and sagittal abdominal diameter (SAD) are several measures that are used in assessing abdominal obesity, with SAD being a relatively newer measure. SAD is measured in the supine position using a caliper positioned in the center of the abdomen, midway between the left and right iliac crests, measuring the height of the abdomen, which has been shown to be associated with the amount of visceral fat in the abdomen. Since SAD measurements only require the use of a specialized caliper, this allows for the measurement to be easy, fast, and inexpensive compared to the more precise yet radiation-emitting magnetic resonance imaging and dual-energy x-ray absorptiometry.

To date, a limited number of large-scale studies have been conducted evaluating SAD with various cardiometabolic risks in the U.S. adult population. A study in 2005 by Smith et al. found among men that SAD was a stronger predictor of coronary heart

disease risk when divided by thigh circumference, known as the abdominal diameter index.[6] In 2013, Gletsu-Miller et al. found that SAD was stronger at predicting levels of visceral adipose tissue, and thus the ability to predict risk of dysglycemia, than WC after controlling for confounding variables among a small sample of severely obese women.[7] Similarly, in 2014, Kahn et al. found that SAD was associated with dysglycemia among men and women independently from WC and BMI in a nationally representative sample of the U.S. population.[8] These findings suggest that SAD may be a useful screening tool in the U.S. population among men and women.

Since WHtR has often been shown to be a better measure of abdominal obesity than WC alone, it is logical to expect that SAD may be more effectively used as the SAD-to-height ratio (SADHtR).[9,10] Few studies have investigated the relationship between metabolic risks and SADHtR, with only two studies having been conducted in the U.S. population. One of the studies focused on various abdominal measures and their associations with sex, age, socioeconomic status, and ethnicity, rather than comparing efficacy of abdominal obesity measures.[11] The second study compared several anthropometric measures, including SAD and SADHtR, against cardiometabolic risks in a nationally representative sample of the U.S. population using National Health and Nutrition Examination Survey (NHANES) 2011-2012 data. In that study, Kahn et al. found that SADHtR and WHtR were better at predicting risk of cardiometabolic disorders than BMI[12]; suggesting that SADHtR may be a better screening tool, especially compared to BMI.

Current disease-related research focuses primarily on the whole population, including obese individuals. However, obese populations are already at a high risk of

developing obesity-related diseases making abdominal obesity measures relatively unimportant. When determining a useful screening tool for obesity-related diseases, it is important to find a tool that also works well in normal weight and overweight populations. In some studies, an overweight status has been suggested to be protective, especially among older adults.[13,14] However, recent research suggests that an overweight BMI status based on highest lifetime BMI is associated with increased risk of cardiovascular and all-cause mortality.[15] This implies the need for an abdominal obesity measure among normal weight and overweight populations that may predict disease risk before the development of the disease occurs. Therefore, the objectives of this study include: 1) to compare the predictive strengths of BMI, WC, WHtR, SAD, and SADHtR with respect to risk of cardiometabolic disorders in the normal and overweight U.S. adult population; 2) to compare WC against WHtR, and SAD against SADHtR ratio to determine whether height improves the predictive strengths; and 3) to compare WC against SAD and WHtR and SADHtR to determine which provides the strongest predictive strength of cardiometabolic disorders. It is hypothesized that abdominal obesity measures will be stronger than BMI in cardiometabolic risk prediction and that the inclusion of height with these measures will only strengthen their ability to assess risk.

CHAPTER II

LITERATURE REVIEW

Abdominal Obesity

Abdominal obesity is defined as excess fat in the stomach area and is recognized for its associated risks with cardiovascular disease and insulin resistance, compared to other areas of adiposity in the body.[10,16,17] Abdominal adiposity includes subcutaneous and visceral fat, yet visceral fat has been shown to be more associated with chronic disease than subcutaneous fat.[3–5] Subcutaneous fat may also play a role in abdominal obesity as it consists of two layers of fat, superficial and deep subcutaneous fat. Deep subcutaneous fat is suspected to play a bigger role in the development of chronic disease than superficial subcutaneous fat, specifically with insulin resistance.[18]

Anthropometric Measurements

Body Mass Index

Body mass index (BMI) is the most commonly used screening tool in predicting high body fatness by clinicians. This likely is due to it being an easy and inexpensive measurement requiring only a scale and a stadiometer, both of which are available in all hospitals and clinics. While BMI is used to predict body fatness, it does not measure the body's adiposity, possibly missing individuals at a higher disease risk that have a large waist or high visceral adiposity yet normal BMI. BMI is measured by dividing an

individual's body weight in kilograms by their height in meters squared. The reference ranges for BMI include:

- Underweight: < 18.5 kg/m^2
- Normal weight: 18.5-24.9 kg/m^2
- Overweight: 35-29.9 kg/m^2
- Obese: ≥ 30 kg/m^2

A recent study by Padwal et al. consisting of a cohort of over 49,000 individuals over the age of 40 investigated associations between BMI and body fat percentage with mortality. Adjusted Cox proportional hazards regression models revealed that a low BMI and high body fat percentage are independently associated with increased risk of mortality.[19] However, a low BMI in this case may suggest weight loss related to illness which generally also included a loss of lean body mass. Yu et al. also observed all-cause and cause-specific mortality related to BMI among several cohort studies, but were able to look at a weight history for each participant rather than a single BMI measurement.[15] By using a weight history, Yu et al. were able to distinguish weight loss related to illness versus intentional weight loss. This revealed that individuals with unintentional weight loss were associated with an increased risk of mortality while those with intentional weight loss had a lower risk of mortality. Within their weight history, individuals with a maximum BMI of overweight or higher were associated with increased risk of all-cause mortality and cause-specific mortality, especially cardiovascular disease and coronary heart disease related deaths. Another recent cohort study by Tanamas et al. found that individuals with a normal BMI and an obese waist circumference (≥102 cm in men, ≥88 cm in women), or an obese BMI and obese waist circumference were at increased risk of

all-cause and cardiovascular disease mortality compared to individuals with a normal BMI and waist circumference.[20] With an inability to measure body composition, BMI should be used in combination with other assessments of adiposity to estimate disease risk.

Waist Circumference

Waist circumference (WC), another commonly used anthropometric measure, predicts disease risk by measuring central adiposity. This has been shown to be more beneficial for individuals in the normal or overweight BMI reference range, as the predictive power of WC is less effective beyond a BMI of 35 kg/m^2.[21] Central adiposity is more associated with cardiometabolic disease risk related to increased levels of visceral fat,[22] perhaps making it a more ideal screening tool compared to BMI. The reference ranges for a high WC include:

- Males: > 40" (101 cm)
- Females: > 35" (88 cm)

With gender-specific reference ranges, WC can be even more specific in predicting disease risk. In a large prospective study by Schulze et al., WC appeared to be the strongest measure among men and women in predicting risk of diabetes compared to BMI, waist-to-hip ratio (WHR), and waist-to-height ratio. However, once stratified by gender, waist-to-height ratio was a stronger predictor of diabetes risk among men and waist-to-height ratio and WC were deemed equal predictors of diabetes risk among women.[23] A large cross-sectional study including only women residing in Australia, WC along with WHR and waist-to-height ratio were stronger predictors of CVD risk than

BMI. WC and WHR were specifically found to be independent predictors of CVD risk after controlling for BMI.[24] Flegal et al. performed a study using data from NHANES 1999-2004 comparing BMI, WC and waist-to-height ratio compared to body fat percentage. Overall, BMI, WC, and waist-to-height ratio were found to be similar indicators of body fatness, but are more closely associated with each other than with body fat percentage.[13] With many abdominal obesity measures competing similarly or better than WC, a combination of obesity measures may be more beneficial in disease risk assessment.

Waist-to-height Ratio

Many studies support the use of waist-to-height ratio (WHtR) as the ideal screening tool for cardiometabolic disease and mortality.[9,25–28] Unlike other anthropometric measurements, WHtR factors in height to account for larger/smaller statures and their associated waist sizes. An ideal WHtR has been suggested to be less than or equal to 0.5, while a high WHtR would be greater than 0.5. While this is a common used reference value in research, there is technically no standard reference value for WHtR. This has led to discussion of whether 0.5 is an acceptable reference value for whole population, or whether there should be different reference values between gender, age groups, and ethnicities. Bohr et al. found that 0.58 may be a better reference value in younger adults in the prediction of risk of metabolic syndrome.[29] However, with study populations that include a wide range of ages, a WHtR reference value of 0.5 is often used as it appears to be generally accepted in current research.[9]

Sagittal Abdominal Diameter

Sagittal abdominal diameter (SAD) has become an increasingly more common anthropometric measure, as it has been included in the NHANES physiological measurements since 2011. SAD is measured in the supine position using a caliper positioned in the center of the abdomen, midway between the left and right iliac crests. This measures the height of the abdomen, which has been shown to be associated with the amount of visceral fat in the abdomen. While in the supine position, subcutaneous fat is believed to fall to the sides of the body leaving mostly visceral fat exposed, possibly identifying those with higher disease risk. With visceral fat being more correlated with cardiometabolic disease risk, SAD has become a more attractive screening tool. SAD does not currently have cut points to establish risk. Several studies have established their own versions of cut points but no standard has been established. Many studies have examined SAD and its ability to predict visceral adiposity compared to magnetic resonance imaging. While several dated studies found SAD unable to predict visceral adiposity,[30,31] most studies have found an advantage to using SAD over the expensive and radiation-emitting MRI and CT scans.[7,32–36]

Sagittal Abdominal Diameter-to-Height ratio

While SAD has advantages over WC in measuring visceral fat, it still does not account for stature. With improvements in assessing risk by factoring height into WC, it could be assumed that height would improve disease risk assessment with SAD. Only one study has measured SAD-to-height ratio (SADHtR) against the other anthropometric measurements. In this study, Kahn and Bullard found that SADHtR was significantly

better at identifying cardiometabolic risks except for dysglycemia, in which WHtR better identified dysglycemia.[12]

Cardiometabolic Risks

Blood Pressure

Based on data from NHANES 2009-2012, over 32 percent of US adult population has high blood pressure, or hypertension.[37] According to the National Heart, Lung, and Blood Institute, high blood pressure is defined as a systolic blood pressure greater than or equal to 140 mm Hg or a diastolic blood pressure greater than or equal to 90 mm Hg. Self-reported use of anti-hypertensive medications was also used to define hypertension in this study. Left untreated, high blood pressure can lead to heart failure, heart attack, stroke, and many other complications. With such a high prevalence of blood pressure within the U.S., it is important to use measurements of obesity that can identify subjects at risk for hypertension.

Anthropometric Measures and Blood Pressure Risk

Many studies have been conducted observing blood pressure and various measures of general and abdominal obesity, but only several have been conducted on a nationally representative adult population, with only one on the U.S. population. A systematic review by Browning et al. found that WHtR and WC outperformed BMI in identifying risk of hypertension.[9] A meta-analysis by Van Dijk et al. found that WC was moderately correlated with systolic blood pressure (SBP) and both WC and BMI with diastolic blood pressure among men and women. For both genders, WC was overall

significantly more correlated with CVD risk factors, including blood pressure, than BMI. WHtR was determined to be the least correlated with CVD risk factors. However, this sample also only consisted of Caucasians from different regions of the world.[38] There is one meta-analysis by Savva et al. that observed a variety of ethnic groups. This analysis was slightly more comprehensive as its inclusion criteria was for elevated blood pressure, with a systolic blood pressure of 130 mm Hg or greater and/or a diastolic blood pressure of 85 mm Hg or greater. They also included participants that reported diagnosis from a physician or antihypertensive medication use. Based on pooled ratios of relative risk (rRR), neither BMI nor WHtR outperformed the other in regards to elevated blood pressure except among Asians, where WHtR was more favored. However, this finding lost strength once stratified by gender.[39]

In terms of cross-sectional studies, there are two nationally representative study samples, one from Australia by Goh et al. and other from the U.S. by Kahn and Bullard. Goh et al. observed Australian women without a history of heart disease, diabetes or stroke. Their findings included that waist-to-hip ratio and waist-to-stature ratio (WHtR) were more correlated with CVD risk, including systolic blood pressure, than BMI and body adiposity index (BAI: hip circumference divided by height, subtracting 18 from the result).[24] Kahn and Bullard conducted a cross-sectional study that was a nationally representative of the U.S. adult population. Comprising both genders and a variety of ethnicities, Kahn and Bullard were able to establish that odds ratios (ORs) adjusted for age, age-squared, and a quadratic term for each adiposity measure were highest for SADHtR and lowest for BMI in predicting risk of hypertension. When excluding

individuals taking antihypertensive drugs, the prevalence of hypertension dropped among men and women, but remained to be best identified by SADHtR. When competing with BMI, SADHtR was able to identify those with hypertension while BMI could not. However, when competing with BMI, neither WHtR nor BMI were able to identify individuals with hypertension. Of all of the studies mentioned, most found that measures of abdominal obesity including WC, WHtR, WHR, and SADHtR were better at assessing risk of high blood pressure than BMI. However, none of the abdominal obesity measures have been found to be consistently better than one another.[12]

Pre-Diabetes

According to the Centers for Disease Control and Prevention (CDC), over one third of the United States adult population has pre-diabetes, equating to about 86 million adults. Unfortunately, about 90 percent of these individuals are unaware they have pre-diabetes.[40] Along with increased risk of diabetes, pre-diabetes is known to increase risk of cardiovascular disease, stroke, and all-cause mortality.[41] According to the American Diabetes Association, pre-diabetes is defined as a hemoglobin A1C between 5.7 – 6.4%, a fasting plasma glucose of 100-125 mg/dL, and/or a two hour blood glucose level of 140-199 mg/dL following an oral glucose tolerance test. With such a high prevalence of pre-diabetes in the United States, screening methods are needed to identify those at risk for pre-diabetes.

Anthropometric Measures and Pre-Diabetes Risk

Most studies that observe blood glucose or hemoglobin A1c levels focus strictly on diabetes risk rather than pre-diabetes risk. Only two studies comparing abdominal obesity measures analyzed individuals without a diagnosis of diabetes. One study by Kahn et al. from 2014 included individuals with diagnosed diabetes in their NHANES 2011-2012 study sample and also included another group of individuals with a hemoglobin A1c equal to or greater than 5.7%, termed dysglycemia, but without a diabetes diagnosis. While this group may include those with undiagnosed diabetes, the efforts are primarily focused on identifying those with pre-diabetes. In this study, they found that when SAD and BMI quartiles were simultaneously analyzed in the same model, the prevalence of dysglycemia within the third and fourth quartiles for SAD was the greatest. Prevalence of dysglycemia was not significantly associated with the third and fourth quartiles for WC and BMI.[8]

Another study by Kahn and Bullard in 2016 only included individuals without diagnosed diabetes in their NHANES 2011-2012 study sample and compared BMI, WHtR, and SADHtR with risk of dysglycemia, or a hemoglobin A1c of 5.7% or greater. In simultaneous competition with BMI, neither SADHtR nor BMI were able to identify individuals with dysglycemia. However, with WHtR in competition with BMI, WHtR was able to identify dysglycemia while BMI could not. With SADHtR and WHtR in simultaneous competition, neither was significantly different from one another in identifying dysglycemia.[12]

Diabetes

In the United States, 1 in 10 adults have diabetes, with a majority of cases being type 2 diabetes.[37] The American Diabetes Association defines diabetes as a hemoglobin A1C greater than or equal to 6.5%, a fasting blood glucose of 126 mg/dL or greater, and/or a two hour blood glucose level of 200 mg/dL or greater following an oral glucose tolerance test. With many complications including neuropathy, nephropathy, and retinopathy, diabetes can also increase risk of high blood pressure, cardiovascular disease, and stroke.[42]

Anthropometric Measures and Diabetes Risk

In regards to risk for diabetes, most studies have been conducted observing obese individuals rather than individuals of all weight statuses. A systematic review by Browning et al. identified that among prospective and cross-sectional studies, WHtR, WC, and BMI were equally significant predictors of diabetes in men and women.[9] A meta-analysis by Van Dijk et al. showed that when comparing BMI, WC, WHtR, and WHR among men, WC had the strongest correlation with fasting blood glucose levels. WHtR was found to have the weakest correlation with fasting blood glucose. In women, WC and WHR were similarly correlated to fasting blood glucose, and WHtR was again the least correlated.[39] In a meta-analysis by Savva et al. in 2013, diabetes was identified as a fasting blood glucose of 126 mg/dL or greater, a two hour post prandial blood glucose of 200 mg/dL or greater, a physician's diagnosis of diabetes, and/or use of blood glucose lowering medications. In this study, the pooled rRR of WHtR and BMI were

found to be in favor of WHtR in the identification of persons with diabetes in Asians and non-Asians in cross-sectional studies, and just among Asians in prospective studies.[39]

Very few cross-sectional studies exist focusing on the general population versus specific subgroups. A cross-sectional study by Pajunen et al. used Finland's Health 2000 Survey, focused on participants aged 30 years or older. This study did however consist of primarily Northern European Caucasians. Using multivariate models to account for lifestyle factors, it was found that BMI, WC, WHR, and SAD were all significant predictors of incident diabetes. Pairwise comparisons identified that the combination of a high BMI and high SAD was associated with the highest incidence of diabetes.[43] This does not come as a surprise, as individuals with a high weight status and a higher concentration of visceral adipose tissue are already at a high risk for diabetes.

Total Cholesterol

Total cholesterol is a measure of serum LDL cholesterol, HDL cholesterol, and very low-density lipoprotein (VLDL) cholesterol. Based on NHANES 2009-2012 sample data, over 100 million US adults over the age of 20 have high total cholesterol (≥200 mg/dL). Of these adults, nearly 31 million have total cholesterol levels of 240 mg/dL or greater.[37] Total cholesterol is inexpensive to measure and does not require a fasted state, but cannot distinguish between the "good" and "bad" cholesterols. Total cholesterol is generally used in combination with other lipid measures to profile a complete lipid profile. High total cholesterol is defined as greater than or equal to 200 mg/dL or self-reported use of lipid-lowering medications.

Anthropometric Measures and Total Cholesterol Risk

While most studies involving the relationship of anthropometric measures evaluate total cholesterol, the primary outcomes are generally the incidence of CVD, or incidence of all cardiovascular events, rather than incidence of high total cholesterol. In a systematic review by Browning et al., WHtR, WC, and BMI did not differ in their ability to predict high total cholesterol.[9] In a meta-analysis by Van Dijk et al., BMI, WC, and WHR among men were all similarly correlated with risk of high total cholesterol, with WHtR ratio only slightly less correlated. With women, WC and WHR were both found to be significantly better than BMI at predicting risk of high total cholesterol. Again, WHtR was the least correlated with high total cholesterol risk.[38] Savva et al. found through meta-analysis that WHtR and BMI were not statistically significant in identifying dyslipidemia among all ethnic groups. WHtR was found statistically significant over BMI in identifying dyslipidemia among Asian populations, including men and women. It is important to note that dyslipidemia was used as a primary outcome, which does include hypercholesterolemia, but also several other abnormal lipid levels including LDL, HDL, and triglycerides.[39] Given the variety of lipid measurements used in this outcome, it may explain for lack of significance in establishing a superior obesity measure.

HDL Cholesterol

According to CDC statistics from NHANES 2009-2010, about 31 percent of men and 12 percent of women had low HDL cholesterol in the United States.[44] High-density lipoprotein cholesterol, or HDL cholesterol, is generally known as the "good" cholesterol.

HDL cholesterol aids in the removal of cholesterol from the body by delivering unused cholesterol to the liver for removal from the body.[45] Higher levels of HDL cholesterol lower the risk of cardiovascular disease and stroke.[21,46] Low HDL cholesterol has the opposite effect and is defined as less than 40 mg/dL.

Anthropometric Measures and HDL Cholesterol Risk

HDL cholesterol is a very commonly used measurement in current research, most likely related to its measurement not requiring a fasted state. However, it is generally not one of the primary outcomes, grouping it together with other cardiometabolic risk factors in metabolic syndrome or cardiovascular disease research. This has limited the number of research findings related to HDL cholesterol risk alone. In 2010, a systematic review by Browning et al. revealed that BMI, WC, and WHtR were all strongly correlated with risk of low HDL cholesterol.[9] Van Dijk et al. found in a meta-analysis that WC and BMI were almost equally moderately correlated with low HDL risk among men and women, with higher correlations among women.[38]

Non-HDL Cholesterol

Non-HDL cholesterol is calculated as the difference between serum total cholesterol and serum HDL cholesterol. This measurement is thought to be a better representation of "bad" cholesterol compared to serum total cholesterol, as it measures LDL cholesterol, and VLDL cholesterol, a transporter of cholesterol and triglycerides around the body. Based on NHANES 2005-2010 data, the prevalence of high non-HDL cholesterol among US adults is nearly 28 percent.[47] According to the NCEP-III, patients

with triglycerides above 200 mg/dL should also have their serum non-HDL cholesterol levels monitored and kept within 30 mg/dL of their LDL cholesterol goal. Based on this guideline, high non-HDL cholesterol is defined as greater than or equal to 130 mg/dL. Non-HDL can also be measured in a non-fasted state, making it a quick measure to be used in screening risk for CVD.

Anthropometric Measures and Non-HDL Cholesterol Risk

A limited number of studies have been conducted comparing anthropometric measures and their ability to predict high non-HDL risk. A recent study with a similar design by Kahn et al. compared BMI, WHtR, and SADHtR in their ability to predict five cardiometabolic disorders, including "HyperNon-HDLc", or high levels of non-HDL-C. Using data from NHANES 2011-2012, logistic regression models revealed that HyperNon-HDLc was best recognized by SADHtR. Among men and women, BMI was the weakest at predicting HyperNon-HDLc. When analyzed simultaneously, SADHtR and WHtR were comparable in identifying HyperNon-HDLc.[12] These findings support the hypothesis that abdominal measures of obesity may be stronger predictors of risk than BMI alone, especially with identifying high non-HDL cholesterol.

Apolipoprotein B

ApoB is a key structural component of all lipoproteins, including LDL, VLDL, intermediate-density lipoprotein (IDL), chylomicrons, and lipoprotein (a) particles.[48] LDL cholesterol molecules tend to be heterogeneous in terms of cholesterol content. Individuals with a large number of LDL particles with little cholesterol content (or

small/dense LDL particles) may have the same LDL concentration as an individual with fewer LDL particles that are high in cholesterol concentration (large, low density LDL particles). With one ApoB molecule per lipoprotein, ApoB measurements allow clinicians to distinguish LDL concentrations that may have a variable amount of cholesterol content.[49] High Apo B is defined as a serum ApoB level of 80 mg/DL or greater, or self-reported use of lipid-lowering medications. Many studies have concluded that ApoB is a stronger screening tool for CVD than LDL, non-HDL concentrations, or other lipoprotein ratios [50–54], affirming its use as risk factor for research among normal weight and overweight individuals.

Anthropometric Measures and ApoB risk

To our knowledge, only one study has been conducted observing ApoB levels associated with measures of abdominal obesity. In this study by Onat et al.[55], a single scan CT was performed on 157 Turkish participants, aged 34-69 years, in efforts to measure total adipose tissue area, abdominal visceral adipose tissue (VAT) area, and sagittal abdominal diameter in association with cardiovascular risk factors. Among the study population, 34% of participants had metabolic syndrome. Using linear regression analysis, ApoB and HDL-C were found to be independently associated with VAT area among men only. They also observed higher VAT areas in men compared to women for any given waist circumference as well as higher VAT areas in men compared to women for any given body fat mass. This suggests that men may be prone to a higher waist circumference thus a higher VAT area while at a lower BMI. With the measurement of ApoB as a cardiovascular risk factor being a fairly recent concern, more research needs to

be conducted to support its use as a predictive measure. ApoB has been measured by NHANES in both 2 year cycles used in this study and also does not require a fasted state to be measured, making it an ideal measure for use in this study.

Normal Weight/Overweight Risk

Given that obesity status generally has an exponential relationship with cardiometabolic disorders, it can be assumed that obese individuals are at much higher risk of developing cardiometabolic disorders than those that are normal weight or overweight. However, normal weight and overweight individuals may or may not be at as high of risk depending on the amount of visceral adipose tissue, which is more associated with disease risk compared to general obesity. In order to identify risk in these individuals, abdominal obesity measures may need to be compared in order to determine which can be most beneficial in identifying a variety of risk factors. To date, no studies have been performed observing a strictly normal weight or overweight population.

National Health and Nutrition Examination Survey

The National Health and Nutrition Examination Survey (NHANES) is an ongoing nationally representative, cross-sectional survey of the resident civilian, non-institutionalized, United States population. The survey consists of a home interview including demographic, socioeconomic, dietary, and health-related questions. The examination at the mobile examination center (MEC) consists of medical, dental, and physiological measurements, and various laboratory tests. Visiting 15 counties around the country per year, NHANES collects data from about 5,000 people per year to develop a

two-year sample of about 10,000 participants. By oversampling older adults and certain ethnic groups, researchers can establish significant findings among these populations.[56]

Until the 2011-2012 NHANES data cycle, SAD measurements had not previously been collected at the Mobile Examination Center (MEC). However, NHANES has continued to measure SAD since, allowing for two two-year data cycles to be available for research using this anthropometric measure. With only one-third of adult participants being in a fasted state for laboratory measurements, the use of cardiometabolic risk measurements that require a fasted state significantly lowers the study population. The use of laboratory measures that do not require a fasted state allow for the use of all subjects examined and tested at the MEC.

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CHAPTER III

JOURNAL ARTICLE

RESEARCH SNAPSHOT

Research Question: Are abdominal obesity measures more strongly associated with cardiometabolic risk than BMI, particularly in normal and overweight adults? And does height improve the ability of abdominal obesity measures to assess cardiometabolic risk?

Key Findings: In this cross-sectional, nationally representative study that included 6482 normal weight and overweight adults from the National Health and Nutrition Examination Survey of 2011-2014, body mass index could only identify risk of low high-density lipoprotein cholesterol, while waist-to-height ratio, sagittal abdominal diameter, and sagittal abdominal diameter-to-height ratio identified six out of seven cardiometabolic risks.

ABSTRACT

Background: It has been well established that screening tools for cardiometabolic diseases are less useful among obese populations as risk of these diseases is already high. However, research is lacking in regard to efficient screening tools for cardiometabolic diseases among normal weight and overweight populations.

Objective: This study compared the predictive strengths of body mass index (BMI), waist circumference (WC), waist-to-height ratio (WHtR), sagittal abdominal diameter (SAD), and SAD-to-height ratio (SADHtR) with respect to risk of cardiometabolic disorders in normal and overweight U.S. populations.

Design: This cross-sectional study utilized data from the 2011-2014 National Health and Nutrition Examination Survey.

Participants/setting: The sample included non-pregnant adults with a normal weight or overweight BMI status (≥ 20 years; n = 6482).

Main outcome measures: Each anthropometric measure was assessed for predicting risk of the following cardiometabolic disorders: hypertension (HTN), pre-diabetes, diabetes, high total cholesterol, low high-density lipoprotein cholesterol (HDL-C), high non-HDL-C, and high apolipoprotein B.

Statistical analyses performed: Simple and multiple logistic regression analyses compared the odds ratio of each anthropometric measure for each cardiometabolic disorder.

Results: When analyzed in separate models, BMI, WC, WHtR, SAD, and SADHtR identified all cardiometabolic risks. In simultaneous models with abdominal obesity measures, BMI no longer identified cardiometabolic risks (ORs <1.0), except low HDL-

C. Among normal weight and overweight men, WHtR and SADHtR were stronger measures of cardiometabolic risk except low HDL-C. With normal weight and overweight women, WHtR and SADHtR were stronger measures of risk for hypertension and diabetes, while all of the abdominal obesity measures were similar in assessment of the remaining cardiometabolic risks.

Conclusion: In normal weight and overweight adults, anthropometric measures of abdominal obesity, especially those including a factor of height, are better predictors of cardiometabolic risk than BMI and should be a primary screening tool in this population.

INTRODUCTION/BACKGROUND

While obesity rates in the United States (U.S.) have started to plateau based on body mass index (BMI) measurements, abdominal obesity rates are on the rise according to measures of waist circumference.[1,2] Abdominal obesity, as compared with other distributions of adipose tissue, has specifically been shown to be highly associated with chronic diseases such as diabetes, cardiovascular diseases, and other cardiometabolic diseases.[3–5]

BMI has traditionally been used for the assessment of body weight but has been shown to lack accuracy in terms of body composition. Waist circumference (WC), waist-to-height ratio (WHtR), and sagittal abdominal diameter (SAD) are several measures that are used in assessing abdominal obesity, with SAD being a relatively newer measure. SAD is measured in the supine position using a caliper positioned in the center of the abdomen, midway between the left and right iliac crests, measuring the height of the abdomen, which has been shown to be associated with the amount of visceral fat in the abdomen. Since SAD measurements only require the use of a specialized caliper, this allows for the measurement to be easy, fast, and inexpensive compared to the more precise yet radiation-emitting magnetic resonance imaging and dual-energy x-ray absorptiometry.

To date, a limited number of large-scale studies have been conducted evaluating SAD with various cardiometabolic risks in the U.S. adult population. A study in 2005 by Smith et al. found among men that SAD was a stronger predictor of coronary heart disease risk when divided by thigh circumference, known as the abdominal diameter index.[6] In 2013, Gletsu-Miller et al. found that SAD was stronger at predicting levels of

visceral adipose tissue, and thus the ability to predict risk of dysglycemia, than WC after controlling for confounding variables among a small sample of severely obese women.[7] Similarly, in 2014, Kahn et al. found that SAD was associated with dysglycemia among men and women independently from WC and BMI in a nationally representative sample of the U.S. population.[8] These findings suggest that SAD may be a useful screening tool in the U.S. population among men and women.

Since WHtR has often been shown to be a better measure of abdominal obesity than WC alone, it is logical to expect that SAD may be more effectively used as the SAD-to-height ratio (SADHtR).[9,10] Few studies have investigated the relationship between metabolic risks and SADHtR, with only two studies having been conducted in the U.S. population. One of the studies focused on various abdominal measures and their associations with sex, age, socioeconomic status, and ethnicity, rather than comparing efficacy of abdominal obesity measures.[11] The second study compared several anthropometric measures, including SAD and SADHtR, against cardiometabolic risks in a nationally representative sample of the U.S. population using National Health and Nutrition Examination Survey (NHANES) 2011-2012 data. In that study, Kahn et al. found that SADHtR and WHtR were better at predicting risk of cardiometabolic disorders than BMI[12]; suggesting that SADHtR may be a better screening tool, especially compared to BMI.

Current disease-related research focuses primarily on the whole population, including obese individuals. However, obese populations are already at a high risk of developing obesity-related diseases making abdominal obesity measures relatively unimportant. When determining a useful screening tool for obesity-related diseases, it is

important to find a tool that also works well in normal weight and overweight populations. In some studies, an overweight status has been suggested to be protective, especially among older adults.[13,14] However, recent research suggests that an overweight BMI status based on highest lifetime BMI is associated with increased risk of cardiovascular and all-cause mortality.[15] This implies the need for an abdominal obesity measure among normal weight and overweight populations that may predict disease risk before the development of the disease occurs. Therefore, the objectives of this study include: 1) to compare the predictive strengths of BMI, WC, WHtR, SAD, and SADHtR with respect to risk of cardiometabolic disorders in the normal and overweight U.S. adult population; 2) to compare WC against WHtR, and SAD against SADHtR ratio to determine whether height improves the predictive strengths; and 3) to compare WC against SAD and WHtR and SADHtR to determine which provides the strongest predictive strength of cardiometabolic disorders. It is hypothesized that abdominal obesity measures will be stronger than BMI in cardiometabolic risk prediction and that the inclusion of height with these measures will only strengthen their ability to assess risk.

METHODS

Study Population and Analytic Sample

The NHANES is an ongoing nationally representative, cross-sectional survey of the resident civilian, non-institutionalized, U.S. population. The survey consists of a home interview including demographic, socioeconomic, dietary, and health-related

questions. The examination at the mobile examination center (MEC) consists of medical, dental, and physiological measurements, as well as various laboratory tests.[16] Several subgroups are oversampled, including Hispanics, non-Hispanic Asians, non-Hispanic blacks, and non-Hispanic whites over 80 years of age. Given this oversampling, sample weights are used to develop a distribution that is representative of the U.S. population.[17]

Data from the NHANES 2011-2012 and 2012-2014 datasets were used to evaluate associations between various measurements of abdominal obesity and cardiometabolic risk factors. Participants consisted of male and female adults of all ethnicities, aged 20+ years who participated in both the home interview and physical examination components of NHANES. Two samples were examined for this study, one consisting of the whole adult population (n = 10,723) stratified by gender and the other consisting of only adult participants with a normal weight or overweight BMI status (n = 6482), also stratified by gender. Females who were pregnant or lactating were excluded from this study as well as participants with missing values for any of the anthropometric and/or laboratory tests.

Anthropometric and Physiologic Measurements

Height, weight, WC, and SAD were measured according to NHANES protocols.[18] WHtR and SADHtR were calculated using the above measurements. Measurements of cardiometabolic risk included blood pressure, hemoglobin A1C, total cholesterol, high-density lipoprotein-cholesterol (HDL-C), non-HDL-C, and Apoliprotein B (ApoB). These measures were chosen in part because they did not required a fasted blood sample and thus allowed for a greater sample size. Descriptions of the examination and

laboratory methods used in this study are described in online NHANES documentation.[19] HTN was defined as having a blood pressure of 140/90 mm Hg or greater[20], or self-reported use of an anti-hypertensive medication. Pre-diabetes was defined as a having a hemoglobin A1C of 5.7-6.4%, while diabetes was defined as a hemoglobin A1C of 6.5% or greater[21], or self-reported use of insulin or a blood glucose lowering medication. High total cholesterol was defined as having a serum total cholesterol level of 200 mg/dL or greater, or self-reported use of a lipid lowering medication. Low HDL-C was defined as having a serum HDL-C level of less than 40 mg/dL.[22] High non-HDL-C risk was defined as having a serum non-HDL-C level of 130 mg/dL or greater, or self-reported use of a lipid lowering medication. Lastly, high ApoB was defined as having a serum ApoB level of 80 mg/dL or greater, or self-reported use of a lipid lowering medication.

Statistical Analysis

Weighted data was used in all statistical analyses using Statistical Analysis Software (SAS System version 9.2, SAS Institute Inc., Cary, North Carolina, USA). Simple logistic regression was performed to estimate the magnitude of the association between each anthropometric measurement with each cardiometabolic risk factor. Subjects were divided into quartiles based on each anthropometric measurement for determination of the odds ratios (ORs) for each cardiometabolic risk factor. The ORs of the first quartile, the reference group, was compared to the ORs of the fourth quartile to determine the strength of each measurement in the prediction of cardiometabolic risk. T-tests were used to establish significant differences between the ORs for BMI and all other abdominal obesity measures for each cardiometabolic risk. Because of the large number

of comparisons being made, a P-value of less than 0.01 was considered to be statistically significant.

To identify whether abdominal obesity measures were significantly different from one another in their predictive strength, we conducted multiple logistic regression analysis to simultaneously compare BMI with measures of abdominal obesity. Four models were used per cardiometabolic risk: BMI, WC, and WHtR; BMI, SAD, and SADHtR; BMI, WC, and SAD; and BMI, WHtR, and SADHtR. Significant differences were identified for measurements whose 95% confidence intervals (CI) did not overlap. For measurements that only had slight overlap of 95% CI, t-tests were performed to establish significant differences.

RESULTS

The quartile cut-points for each anthropometric measurement for both the entire adult population and for just the normal weight and overweight population can be found in **Table 1**. The ORs of the fourth quartile compared to the first quartile of each cardiometabolic risk based on each anthropometric measurement for the adult male sample and the normal weight or overweight adult male sample are shown in **Table 2**. The ORs for all anthropometric measures were significantly greater in the fourth quartile than the first quartile for BMI and each measure of abdominal obesity for every cardiometabolic risk. While the data are not shown, it is also important to note that ORs consistently increased for with each quartile for each obesity measurement for all of the cardiometabolic risks.

Table 1. Means and quartile cut points based on gender for the NHANES 2011-2014 data sample.

	Quartile Cut Points: All Adults & N/OW Adults											
	Males						Females					
	25p		50p		75p		25p		50p		75p	
	All	NW/OW	All	NW/OW	All	NW/OW	All	NW/OW	All	NW/OW	All	NW/OW
BMI, kg/m^2	24.2	23.3	27.4	25.5	31.3	27.6	23.8	22.4	28.2	24.8	33.7	27.3
WC, cm	89.1	86.0	99.0	93.2	109.2	100.0	84.7	80.5	95.5	87.2	107.4	94.0
WHtR	0.51	0.49	0.56	0.54	0.62	0.57	0.52	0.50	0.59	0.54	0.67	0.59
SAD, cm	19.4	19.1	22.2	21.1	25.5	23.0	20.0	17.6	22.7	19.4	25.8	21.3
SADHtR	0.114	0.110	0.130	0.121	0.147	0.133	0.117	0.110	0.135	0.121	0.157	0.133

N/OW: normal and overweight, BMI: Body mass index, WC: Waist circumference, WHtR: Waist-to-height ratio, SAD: Sagittal abdominal diameter, SADHtR: SAD-to-height ratio.

Among all adult males, BMI was significantly weaker than most measures of abdominal obesity for predicting risk of HTN, diabetes, and high total cholesterol. There were no significant differences between BMI and measures of abdominal obesity for predicting risk of low HDL-C, high non HDL-C, and high ApoB. Similarly, among normal and overweight adult males, most measures of abdominal obesity were statistically stronger than BMI at predicting risk of HTN, pre-diabetes, diabetes, and high total cholesterol.

Table 2. Simple logistic regression analysis of cardiometabolic risks by each anthropometric measurement for all adult males and normal weight or overweight males of the NHANES 2011-2014 sample.

Risk	Measure	All Adult Males		NW/OW Males	
		Odds Ratio	95% CI	Odds Ratio	95% CI
HTN	**BMI**	3.69	2.84 - 4.79	2.31	1.73 - 3.07
	WC	6.93	5.17 - 9.30[a]	7.32	5.51 - 9.71[a]
	WHtR	8.42	6.27 - 11.31[a]	10.57	7.64 - 14.62[a]
	SAD	7.41	5.47 - 10.05[a]	7.04	4.66 - 10.64[a]
	SADHtR	8.06	6.03 - 10.77[a]	9.48	6.35 - 14.18[a]
Pre-DM	**BMI**	1.78	1.30 - 2.42	1.84	1.31 - 2.58
	WC	2.55	1.87 - 3.47	2.95	2.22 - 3.92
	WHtR	2.69	1.98 - 3.65	3.95	2.73 - 5.71[a]

	SAD	3.01	2.29 - 3.96[a]	3.45	2.27 - 5.27
	SADHtR	3.06	2.30 - 4.09[a]	3.96	2.72 - 5.76[a]
DM	**BMI**	6.7	4.35 - 10.33	2.45	1.60 - 3.76
	WC	12.95	8.28 - 20.24	8.35	4.51 - 15.46[a]
	WHtR	19.09	9.97 - 36.57[a]	15.71	7.51 - 32.87[a]
	SAD	15.08	9.31 - 24.41[a]	11.58	5.30 - 25.32[a]
	SADHtR	23.48	11.63 - 47.43[a]	14.29	6.52 - 31.30[a]
High TC	**BMI**	2.43	1.89 - 3.12	2.38	1.80 - 3.16
	WC	3.68	2.72 - 4.96	5.60	3.96 - 7.93[a]
	WHtR	3.98	2.92 - 5.41[a]	6.36	4.41 - 9.16[a]
	SAD	4.02	3.06 - 5.28[a]	4.84	3.62 - 6.48[a]
	SADHtR	3.84	2.94 - 5.01[a]	6.00	4.39 - 8.19[a]
Low HDL	**BMI**	5.17	3.87 - 6.90	4.19	2.88 - 6.08
	WC	5.45	4.26 - 6.98	3.43	2.46 - 4.79
	WHtR	4.49	3.45 - 5.83	3.23	2.32 - 4.51
	SAD	6.28	4.92 - 8.02	4.67	3.16 - 6.89
	SADHtR	5.87	4.45 - 7.74	5.05	3.38 - 7.55
High Non-HDL	**BMI**	4.02	3.18 - 5.08	3.93	2.94 - 5.24
	WC	5.41	4.15 - 7.06	7.00	5.15 - 9.53
	WHtR	5.71	4.35 - 7.51	7.07	5.16 - 9.70
	SAD	5.82	4.56 - 7.41	6.51	4.96 - 8.56
	SADHtR	5.62	4.20 - 7.52	7.48	5.69 - 9.83[a]
High ApoB	**BMI**	4.06	2.84 - 5.81	2.96	1.95 - 4.48
	WC	5.18	3.29 - 8.16	4.60	2.97 - 7.15
	WHtR	5.31	3.47 - 8.12	6.23	3.85 - 10.09
	SAD	5.51	3.79 - 8.02	4.80	3.19 - 7.21
	SADHtR	5.09	3.19 - 8.10	6.97	4.78 - 10.17[a]

NW/OW: normal and overweight, CI: confidence interval, HTN: hypertension, Pre-DM: Pre-diabetes, DM: Diabetes, TC: Total cholesterol, HDL: high-density lipoprotein, Non-HDL: non-high-density lipoprotein; ApoB: apolipoprotein B, BMI: body mass index, WC: waist circumference, WHtR: waist-to-height ratio, SAD: sagittal abdominal diameter, SADHtR: sagittal abdominal diameter-to-height ratio.
Odds ratios represent Quartile 4 compared to Quartile 1.
[a] Denotes significant difference from BMI (≤ 0.0001 $P < 0.01$)

Table 3 reports the ORs of the fourth quartile compared to the first quartile of each cardiometabolic risk based on each anthropometric measurement for the adult female sample and the normal weight or overweight adult female sample by simple logistic regression. Among all adult females, BMI was significantly weaker than most abdominal obesity measures for predicting risk of HTN, diabetes, high non-HDL-C, and high total cholesterol. There were no differences between abdominal obesity measures and BMI with the risk assessment of low HDL-C and high ApoB. Among the normal

weight and overweight female sample, abdominal obesity measures were stronger than BMI when predicting risk for HTN, high, total cholesterol, high non-HDL-C, and high ApoB. There were no differences between abdominal obesity measures and BMI related to risk of pre-diabetes and low HDL-C.

Table 3. Simple logistic regression analysis of cardiometabolic risks by each anthropometric measurement for all adult females and normal weight or overweight females of the NHANES 2011-2014 sample.

Risk	Measure	All Adult Females		NW/OW Females	
		Odds Ratio	95% CI	Odds Ratio	95% CI
HTN	BMI	3.32	2.63 - 4.18	1.92	1.30 - 2.86
	WC	5.07	3.89 - 6.60[a]	4.95	3.27 - 7.48[a]
	WHtR	7.03	5.02 - 9.86[a]	7.46	4.81 - 11.55[a]
	SAD	7.00	5.44 - 8.98[a]	8.90	6.01 - 13.19[a]
	SADHtR	8.00	6.22 - 10.29[a]	11.19	7.15 - 17.52[a]
Pre-DM	BMI	2.72	2.10 - 3.52	2.47	1.63 - 3.74
	WC	2.8	2.08 - 3.77	5.05	3.46 - 7.36
	WHtR	3.73	2.75 - 5.05	5.16	3.17 - 8.40
	SAD	3.04	2.08 - 4.43	4.20	2.62 - 6.75
	SADHtR	3.55	2.49 - 5.06	4.80	3.02 - 7.64
DM	BMI	9.44	6.62 - 13.46	3.90	2.62 - 5.81
	WC	14.93	10.27 - 21.71[b]	14.77	8.45 - 25.83
	WHtR	32.23	20.58 - 50.48[a b]	36.01	13.59 - 95.47
	SAD	21.24	12.66 - 35.64[a]	15.98	8.27 - 30.86
	SADHtR	26.49	15.99 - 43.89[a]	30.61	11.09 - 84.49
High TC	BMI	1.75	1.42 - 2.16	2.04	1.52 - 2.73
	WC	2.36	1.87 - 2.96	3.40	2.62 - 4.42
	WHtR	2.73	2.15 - 3.45[a]	3.93	3.00 - 5.14[a]
	SAD	2.46	1.99 - 3.03	4.46	3.46 - 5.75[a]
	SADHtR	2.53	2.06 - 3.11[a]	4.69	3.56 - 6.17[a]
Low HDL	BMI	7.73	4.72 - 12.67	6.13	3.70 - 10.14
	WC	11.91	7.29 - 19.45	8.32	3.04 - 22.74
	WHtR	12.21	6.62 - 22.53	11.73	4.09 - 33.66
	SAD	10.30	5.49 - 19.33	10.35	5.75 - 18.63
	SADHtR	9.3	5.11 - 16.92	9.00	3.79 - 21.40
High Non-HDL	BMI	3.22	2.68 - 3.87	3.12	2.29 - 4.27
	WC	4.26	3.38 - 5.38	4.90	3.62 - 6.62
	WHtR	4.99	3.96 - 6.29[a]	6.06	4.38 - 8.37[a]
	SAD	4.66	3.82 - 5.69[a]	6.13	4.66 - 8.05[a]
	SADHtR	4.75	3.98 - 5.66[a]	6.97	5.17 - 9.40[a]
High ApoB	BMI	3.25	2.41 - 4.37	2.80	1.97 - 3.99
	WC	4.16	3.08 - 5.62	4.67	3.17 - 6.87

	WHtR	4.39	3.34 - 5.77	8.47	5.43 - 13.22
	SAD	4.88	3.44 - 6.92	6.85	4.85 - 9.66
	SADHtR	4.87	3.69 - 6.43	7.24	5.10 - 10.27

NW/OW: normal and overweight, CI: confidence interval, HTN: hypertension, Pre-DM: Pre-diabetes, DM: Diabetes, TC: Total cholesterol, HDL: high-density lipoprotein, Non-HDL: non-high-density lipoprotein; ApoB: apolipoprotein B, BMI: body mass index, WC: waist circumference, WHtR: waist-to-height ratio, SAD: sagittal abdominal diameter, SADHtR: sagittal abdominal diameter-to-height ratio.
Odds ratios represent Quartile 4 compared to Quartile 1.
[a] Denotes significant difference from BMI (≤0.0001 $P < 0.01$)
[b] Denotes significant difference between WC and WHtR ($P < 0.01$)

Table 4 shows results of multiple logistic regression analysis for all adult males, and separately for normal weight and overweight males, with the OR of quartile four compared to quartile one. When used in simultaneous models with abdominal obesity measures, BMI was no longer able to identify any of the cardiometabolic risks (ORs < 1.0), except low HDL-C (ORs = 1.80 - 3.14), among all male adults, and normal weight and overweight male adults. With all adult males, WHtR outperformed WC in the prediction of risk for four out of seven cardiometabolic risks, while WHtR and WC were equally stronger predictors than BMI for two out of seven cardiometabolic risks. SADHtR only outperformed SAD in predicting risk of diabetes, while SAD and SADHtR were equal predictors of risk for four out of seven cardiometabolic risks. SAD was a stronger predictor than WC in risk for two out of seven cardiometabolic risks, while SAD and WC were similar predictors of risk for five out of seven cardiometabolic risks. WHtR and SADHtR were similar predictors of all cardiometabolic risks except for low HDL-C. In terms of risk of low HDL-C, BMI and WC were equally stronger predictors than WHtR. BMI and SAD were also equally stronger predictors of low-HDL-C than WC. BMI and SADHtR were similar predictors for risk of low-HDL-C compared to WHtR.

With normal weight and overweight adult males, WHtR was stronger than WC in the prediction of risk for five out of seven cardiometabolic risks, while WC and WHtR

were similar predictors of risk for high non-HDL-C. SADHtR was a better predictor than SAD for risk of all cardiometabolic risks except for low HDL-C. SAD was a stronger predictor than WC in the assessment of risk for diabetes, while SAD and WC were similar predictors for all remaining cardiometabolic risks except low HDL-C. SADHtR was stronger than WHtR in the prediction of risk for high ApoB, while SADHtR and WHtR were similar predictors of risk for all other cardiometabolic risks except low HDL-C. For risk of low HDL-C, BMI and SAD outperformed WC, and BMI and SADHtR outperformed WHtR in the assessment of low HDL-C risk.

Table 4. Multiple logistic regression analysis of cardiometabolic risks by each anthropometric measurement for all adult males and normal weight or overweight males of the NHANES 2011-2014 sample.

Risk	Measure	All Adult Males		NW/OW Males	
		Odds Ratio	95% CI	Odds Ratio	95% CI
HTN	**BMI**	0.20	0.12 - 0.33	0.24	0.14 - 0.41
	WC	3.20	1.51 - 6.77[a]	2.00	1.01 - 3.96[ab]
	WHtR	12.19	6.19 - 23.99[a]	17.42	9.29 - 32.67[ab]
	BMI	0.31	0.17 - 0.56	0.35	0.21 - 0.59
	SAD	3.81	1.82 - 7.96[a]	1.56	0.79 - 3.09[ac]
	SADHtR	6.59	3.43 - 12.66[a]	13.57	6.81 - 27.06[ac]
	BMI	0.27	0.14 - 0.50	0.35	0.20 - 0.62
	WC	4.29	2.15 - 8.54[a]	4.48	2.30 - 8.74[a]
	SAD	6.41	3.21 - 12.80[a]	4.66	2.33 - 9.32[a]
	BMI	0.22	0.13 - 0.37	0.21	0.13 - 0.36
	WHtR	7.62	4.53 - 12.82[a]	8.25	4.34 - 15.68[a]
	SADHtR	4.89	2.90 - 8.24[a]	5.39	2.68 - 10.84[a]
Pre-DM	**BMI**	0.30	0.19 - 0.48	0.47	0.30 - 0.75
	WC	1.35	0.74 - 2.46[ab]	1.04	0.52 - 2.07[b]
	WHtR	5.76	3.08 - 10.79[ab]	6.39	2.95 - 13.85[ab]
	BMI	0.30	0.19 - 0.47	0.58	0.40 - 0.85
	SAD	2.09	1.02 - 4.28[a]	1.16	0.51 - 2.65
	SADHtR	4.25	2.16 - 8.37[a]	5.26	2.58 - 10.73[a]
	BMI	0.36	0.22 - 0.57	0.61	0.37 - 0.99
	WC	1.40	0.75 - 2.62[ad]	1.93	1.09 - 3.43[a]
	SAD	5.12	2.70 - 9.70[ad]	2.71	1.38 - 5.34[a]
	BMI	0.24	0.15 - 0.39	0.42	0.28 - 0.64
	WHtR	2.34	1.18 - 4.64[a]	3.39	1.73 - 6.68[a]
	SADHtR	4.27	2.22 - 8.22[a]	2.55	1.43 - 4.55[a]

DM	**BMI**	0.26	0.14 - 0.46	0.23	0.13 - 0.41
	WC	2.14	0.85 - 5.36[ab]	1.13	0.52 - 2.46[ab]
	WHtR	31.88	10.35 - 98.17[ab]	44.85	20.08 - 100.16[ab]
	BMI	0.32	0.17 - 0.59	0.26	0.15 - 0.47
	SAD	2.03	0.74 - 5.61[ac]	1.97	0.54 - 7.11[ac]
	SADHtR	31.43	9.18 - 107.55[ac]	22.44	6.78 - 74.23[ac]
	BMI	0.37	0.21 - 0.67	0.36	0.20 - 0.65
	WC	3.01	1.31 - 6.93[a]	2.30	0.96 - 5.50[ad]
	SAD	13.32	5.61 - 31.59[a]	13.26	4.96 - 35.43[ad]
	BMI	0.21	0.12 - 0.37	0.18	0.10 - 0.32
	WHtR	6.43	3.15 - 13.11[a]	8.54	2.74 - 26.66[a]
	SADHtR	16.12	7.44 - 34.92[a]	9.60	3.19 - 28.90[a]
High TC	**BMI**	0.27	0.19 - 0.39	0.35	0.22 - 0.55
	WC	2.32	1.35 - 4.00[a]	2.84	1.79 - 4.50[ab]
	WHtR	5.77	3.13 - 10.64[a]	5.55	3.02 - 10.20[ab]
	BMI	0.36	0.24 - 0.54	0.5	0.33 - 0.76
	SAD	3.58	1.99 - 6.45[a]	1.47	0.99 - 2.19[ac]
	SADHtR	2.96	1.66 - 5.29[a]	6.747	4.08 - 11.16[ac]
	BMI	0.32	0.23 - 0.45	0.42	0.29 - 0.62
	WC	2.47	1.39 - 4.39[a]	4.67	2.66 - 8.21[a]
	SAD	4.89	2.65 - 9.04[a]	2.55	1.66 - 3.92[a]
	BMI	0.28	0.19 - 0.42	0.35	0.21 - 0.59
	WHtR	4.78	2.70 - 8.47[a]	4.32	2.34 - 7.97[a]
	SADHtR	2.79	1.65 - 4.71[a]	3.79	2.37 - 6.04[a]
Low HDL	**BMI**	3.14	2.21 - 4.45	2.87	1.65 - 5.01
	WC	2.43	1.32 - 4.46	1.42	0.70 - 2.91
	WHtR	0.8	0.40 - 1.58[a]	1.14	0.59 - 2.18
	BMI	1.89	1.31 -2.74	1.80	1.12 - 2.89
	SAD	1.76	1.03 - 3.00	1.87	0.89 - 3.94
	SADHtR	2.16	1.15 - 4.05	1.93	0.88 - 4.22
	BMI	2.35	1.63 - 3.40	2.44	1.38 - 4.31
	WC	0.85	0.54 - 1.33[ad]	0.52	0.25 - 1.07[d]
	SAD	3.61	2.24 - 5.82[d]	4.55	2.48 - 8.33[d]
	BMI	3.03	2.06 - 4.45	2.51	1.53 - 4.13
	WHtR	0.36	0.18 - 0.71[ae]	0.43	0.24 - 0.80[e]
	SADHtR	6.13	3.13 - 11.98[e]	5.44	2.92 - 10.17[e]
High Non-HDL	**BMI**	0.54	0.33 - 0.91	0.73	0.45 - 1.20
	WC	2.13	1.14 - 3.99[a]	2.69	1.58 - 4.57[a]
	WHtR	5.01	2.31 - 10.85[a]	3.71	1.84 - 7.44[a]
	BMI	0.60	0.38 - 0.94	0.91	0.57 - 1.44
	SAD	2.93	1.55 - 5.55[a]	1.55	0.85 - 2.83
	SADHtR	3.50	1.71 - 7.14[a]	5.35	2.62 - 10.93[a]
	BMI	0.57	0.38 - 0.87	0.79	0.53 - 1.19
	WC	2.09	1.18 - 3.73[a]	3.28	1.96 - 5.52[a]
	SAD	5.08	2.86 - 9.04[a]	2.85	1.88 - 4.33[a]
	BMI	0.51	0.29 - 0.88	0.73	0.41 - 1.29
	WHtR	3.29	1.72 - 6.27[a]	2.46	1.41 - 4.31[a]
	SADHtR	3.56	2.08 - 6.08[a]	4.33	2.89 - 6.48[a]
High	**BMI**	0.58	0.26 - 1.29	0.58	0.27 - 1.24

ApoB	**WC**	1.37	0.48 - 3.91	2.36	1.18 - 4.71
	WHtR	6.81	2.74 - 16.91[a]	4.33	1.96 - 9.59[a]
	BMI	0.66	0.33 - 1.30	0.70	0.39 - 1.26
	SAD	2.17	0.87 - 5.41	1.38	0.66 - 2.90[c]
	SADHtR	3.82	1.26 - 11.58	6.89	3.50 - 13.56[ac]
	BMI	0.72	0.36 - 1.45	0.57	0.29 - 1.12
	WC	1.6	0.53 - 4.89	2.92	1.27 - 6.73[a]
	SAD	4.96	1.99 - 12.39[a]	3.01	1.53 - 5.89[a]
	BMI	0.5	0.24 - 1.03	0.55	0.26 - 1.14
	WHtR	3.57	1.35 - 9.43[a]	2.51	0.99 - 6.34
	SADHtR	2.93	1.04 - 8.24[a]	5.60	3.04 - 10.30[a]

NW/OW: normal and overweight, CI: confidence interval, HTN: hypertension, Pre-DM: Pre-diabetes, DM: Diabetes, TC: Total cholesterol, HDL: high-density lipoprotein, Non-HDL: non-high-density lipoprotein; ApoB: apolipoprotein B, BMI: body mass index, WC: waist circumference, WHtR: waist-to-height ratio, SAD: sagittal abdominal diameter, SADHtR: sagittal abdominal diameter-to-height ratio.
Odds ratios represent Quartile 4 compared to Quartile 1.
[a] Denotes significant difference from BMI (≤0.0001 $P < 0.01$), [b] Denotes significant difference between WC and WHtR, [c] Denotes significant difference between SAD and SADHtR, [d] Denotes significant difference between WC and SAD, [e] Denotes significant difference between WHtR and SADHtR.

The results of multiple logistic regression analysis for all adult females, and normal weight and overweight females are reported in **Table 5**. The OR of quartile four was compared to the OR of quartile one. In simultaneous models with abdominal obesity measures, BMI was not able to identify any of the cardiometabolic risks (ORs < 1.0), except low HDL-C (ORs = 0.77-1.92), among all adult females as well as normal weight and overweight females. Among all adult females, WHtR is a stronger predictor than WC for four out of seven cardiometabolic risks, while WHtR and WC are similar predictors for two out of seven cardiometabolic risks. SADHtR is stronger than SAD in the prediction of all cardiometabolic risks except low HDL-C. SAD is a stronger predictor than WC for risk of HTN and pre-diabetes, while SAD and WC are similar predictors for risk of four out of seven cardiometabolic risks. SADHtR is stronger than WHtR in the risk assessment of HTN, while SADHtR and WHtR are similar predictors of risk for all

other cardiometabolic risks except low HDL-C. For risk of low HDL-C, WHtR was stronger than BMI and WHtR was stronger than BMI when in a model with SADHtR.

With normal weight and overweight adult females, WHtR was a stronger predictor than WC for five out seven cardiometabolic risks, while WHtR and WC were similar predictors of risk for pre-diabetes. SADHtR was a stronger predictor of risk than SAD for HTN and diabetes, while SADHtR and SAD were similar predictors of four out of seven cardiometabolic risks. SAD was a better predictor than WC for two out of seven cardiometabolic risks, while SAD and WC were similar predictors of risk for all remaining cardiometabolic risks except low HDL-C. SADHtR and WHtR were similar predictors of risk for all cardiometabolic risks except low HDL-C. With risk of low HDL-C, there were no significant differences between all measures for each comparison model.

Table 5. Multiple logistic regression analysis of cardiometabolic risks by each anthropometric measurement for all adult females and normal weight or overweight females of the NHANES 2011-2014 sample.

Risk	Measure	All Adult Females		NW/OW Females	
		Odds Ratio	95% CI	Odds Ratio	95% CI
HTN	**BMI**	0.19	0.13 - 0.29	0.18	0.09 - 0.35
	WC	1.93	1.01 - 3.68[ab]	1.41	0.65 - 3.09[ab]
	WHtR	17.17	9.23 - 31.93[ab]	21.64	10.23 - 45.80[ab]
	BMI	0.13	0.08 - 0.20	0.16	0.08 - 0.33
	SAD	3.68	2.04 - 6.64[ac]	2.79	1.08 - 7.22[ac]
	SADHtR	13.97	7.54 - 25.89[ac]	17.92	7.56 - 42.45[ac]
	BMI	0.15	0.10 - 0.23	0.19	0.10 - 0.37
	WC	2.13	1.21 - 3.75[ad]	2.11	1.27 - 3.51[ad]
	SAD	18.83	11.50 - 30.84[ad]	16.5	8.76 - 31.07[ad]
	BMI	0.11	0.07 - 0.17	0.12	0.06 - 0.22
	WHtR	4.45	2.71 - 7.30[ae]	4.80	2.22 - 10.38[a]
	SADHtR	15.93	10.09 - 25.15[ae]	14.77	7.48 - 29.15[a]
Pre-DM	**BMI**	0.74	0.46 - 1.20	0.47	0.27 - 0.80
	WC	0.89	0.54 - 1.48[b]	2.81	1.69 - 4.66[a]
	WHtR	5.29	2.98 - 9.38[ab]	4.7	1.97 - 11.23[a]
	BMI	0.61	0.38 - 0.98	0.63	0.39 - 1.02
	SAD	0.90	0.39 - 2.05[c]	2.37	1.08 - 5.21[a]
	SADHtR	5.98	2.84 - 12.58[ac]	3.24	1.49 - 7.04[a]

	BMI	0.8	0.47 - 1.34	0.52	0.32 - 0.85
	WC	1.1	0.67 - 1.83[d]	3.08	1.97 - 4.81[a]
	SAD	3.41	1.86 - 6.26[ad]	3.47	2.03 - 5.93[a]
	BMI	0.49	0.29 - 0.81	0.51	0.29 - 0.88
	WHtR	1.78	0.92 - 3.46[e]	3.67	1.71 - 7.88[a]
	SADHtR	4.26	2.23 - 8.15[e]	3.15	1.89 - 5.25[a]
DM	**BMI**	0.29	0.15 - 0.55	0.2	0.11 - 0.36
	WC	1.14	0.45 - 2.87[b]	1.27	0.51 - 3.15[ab]
	WHtR	88.24	32.92 - 236.52[ab]	107.46	26.58 - 434.49[ab]
	BMI	0.43	0.23 - 0.83	0.39	0.17 - 0.90
	SAD	1.96	0.69 - 5.57[c]	0.91	0.23 - 3.58[c]
	SADHtR	29.93	11.19 - 80.03[ac]	68.24	12.05 - 386.60[ac]
	BMI	0.4	0.21 - 0.79	0.34	0.18 - 0.65
	WC	3.91	1.37 - 11.19[a]	8.69	3.29 - 22.96[a]
	SAD	14.12	4.28 - 46.56[a]	7.01	2.33 - 21.14[a]
	BMI	0.18	0.10 - 0.32	0.17	0.10 - 0.31
	WHtR	22.66	7.98 - 64.34[a]	32.71	5.90 - 181.22[a]
	SADHtR	9.06	3.15 - 26. 04[a]	7.76	1.53 - 39.40[a]
High TC	**BMI**	0.27	0.16 - 0.46	0.43	0.27 - 0.67
	WC	1.78	1.15 - 2.75[ab]	1.54	0.93 - 2.55[ab]
	WHtR	5.06	3.11 - 8.24[ab]	4.99	2.77 - 8.96[ab]
	BMI	0.28	0.18 - 0.45	0.45	0.28 - 0.74
	SAD	1.55	0.89 - 2.68[ac]	2.34	1.44 - 3.79[a]
	SADHtR	5.31	2.96 - 9.54[ac]	3.80	2.10 - 6.90[a]
	BMI	0.27	0.17 - 0.44	0.43	0.27 - 0.68
	WC	2.35	1.46 - 3.78[a]	1.8	1.07 - 3.04[a]
	SAD	3.74	2.56 - 5.46[a]	4.73	2.82 - 7.94[a]
	BMI	0.21	0.12 - 0.37	0.36	0.22 - 0.59
	WHtR	2.78	1.72 - 4.49[a]	2.69	1.46 - 4.95[a]
	SADHtR	4.39	3.10 - 6.22[a]	3.98	2.20 - 7.22[a]
Low HDL	**BMI**	*0.77*	*0.40 - 1.48*	1.30	0.63 - 2.68
	WC	3.32	1.26 - 8.76	1.46	0.44 - 4.86
	WHtR	5.55	1.75 - 17.59[a]	7.29	2.09 - 25.20
	BMI	1.28	0.61 - 2.71	1.92	0.95 - 3.90
	SAD	4.44	1.11 - 17.74	3.02	0.70 - 13.06
	SADHtR	2.06	0.70 - 6.05	2.72	0.60 - 12.28
	BMI	*0.81*	*0.39 - 1.70*	1.53	0.74 - 3.18
	WC	5.03	2.12 - 11.94[a]	2.40	0.92 - 5.90
	SAD	3.76	1.25 - 11.30	3.92	1.30 - 11.82
	BMI	*0.86*	*0.43 - 1.74*	1.28	0.66 - 2.50
	WHtR	8.47	3.42 - 20.98[a]	6.68	1.62 - 27.58
	SADHtR	2.05	1.01 - 4.19	1.9	0.57 - 6.33
High Non-HDL	**BMI**	0.44	0.28 - 0.70	0.61	0.40 - 0.92
	WC	1.79	1.10 - 2.93[ab]	1.33	0.82 - 2.17[b]
	WHtR	6.09	3.56 - 10.41[ab]	6.63	3.76 - 11.69[ab]
	BMI	0.46	0.30 - 0.70	0.64	0.38 - 1.07
	SAD	1.65	0.88 - 3.11[ac]	1.69	1.07 - 2.65[ac]
	SADHtR	6.40	3.63 - 11.29[ac]	5.88	3.51 - 9.85[ac]
	BMI	0.45	0.30 - 0.67	0.65	0.42 - 1.00

	WC	2.43	1.42 - 4.18[a]	1.86	1.06 - 3.25[a]
	SAD	4.60	2.77 - 7.62[a]	4.64	2.73 - 7.88[a]
	BMI	0.32	0.20 - 0.53	0.47	0.29 - 0.77
	WHtR	3.04	1.87 - 4.92[a]	2.86	1.45 - 5.65[a]
	SADHtR	5.34	3.80 - 7.50[a]	4.68	2.48 - 8.85[a]
High ApoB	**BMI**	0.45	0.22 - 0.94	0.54	0.28 - 1.03
	WC	2.00	0.89 - 4.49	0.90	0.37 - 2.17[b]
	WHtR	4.67	1.83 - 11.89[a]	13.41	6.88 - 26.15[ab]
	BMI	0.4	0.19 - 0.82	0.49	0.25 - 0.95
	SAD	1.82	0.48 - 6.84	2.10	0.97 - 4.56[a]
	SADHtR	6.57	2.12 - 20.37[a]	5.97	3.01 - 11.83[a]
	BMI	0.4	0.19 - 0.81	0.58	0.28 - 1.19
	WC	2.01	1.07 - 3.76[ad]	1.20	0.56 - 2.57[d]
	SAD	6.11	2.67 - 13.97[ad]	7.98	3.93 - 16.23[ad]
	BMI	0.32	0.14 - 0.74	0.37	0.19 - 0.70
	WHtR	2.14	0.99 - 4.60[a]	4.32	1.76 - 10.60[a]
	SADHtR	6.87	3.58 - 13.21[a]	4.65	1.99 - 10.87[a]

NW/OW: normal and overweight, CI: confidence interval, HTN: hypertension, Pre-DM: Pre-diabetes, DM: Diabetes, TC: Total cholesterol, HDL: high-density lipoprotein, Non-HDL: non-high-density lipoprotein; ApoB: apolipoprotein B, BMI: body mass index, WC: waist circumference, WHtR: waist-to-height ratio, SAD: sagittal abdominal diameter, SADHtR: sagittal abdominal diameter-to-height ratio.
Odds ratios represent Quartile 4 compared to Quartile 1.
[a] Denotes significant difference from BMI (≤0.0001 $P < 0.01$), [b] Denotes significant difference between WC and WHtR, [c] Denotes significant difference between SAD and SADHtR, [d] Denotes significant difference between WC and SAD, [e] Denotes significant difference between WHtR and SADHtR.

DISCUSSION

In the current study, it is apparent that abdominal measures that include height are able to better predict many cardiometabolic risks among both males and females. Among normal weight and overweight males, WHtR and SADHtR were the strongest predictors of all cardiometabolic risks except low HDL-C. With normal weight and overweight females, WHtR and SADHtR appear to be the best measures of risk for HTN and diabetes, while the remaining cardiometabolic risks are predicted quite similarly between abdominal obesity measures, except for low HDL-C. While WHtR and SADHtR may not be significantly different from each other in disease risk assessment, both are consistently better than abdominal obesity measures that do not include a factor of height and especially superior to BMI. Factoring height into various abdominal measurements may

help better predict risk of cardiometabolic diseases. Height can help to distinguish between individuals with larger midsections related to their small or large stature versus individuals with a high level of visceral adiposity. Many studies have supported this theory, justifying that WHtR is a better measure than waist circumference alone.[9,23–26]

Overall, very few studies have been published using the general population versus specific populations, such as severely obese individuals, gender, ethnicity, or age specific studies. This proves difficult in comparing the current findings to such studies. However, one study[12] by Kahn and Bullard found SADHtR and WHtR tended to have higher ORs than BMI for several cardiometabolic risks, but when compared against each other, found that SADHtR identified better with HTN, hyper-alanine transaminase and hyper-gammaglutamyltransferase than did WHtR. While there are similarities to the study by Kahn and Bullard, the current study included measures of diabetes, high total cholesterol, low HDL-C and high ApoB as cardiometabolic risk factors. ORs for WHtR and SADHtR were the highest among males and females for most cardiometabolic risks congruent with findings by Kahn et al., except that study found SADHtR to be the strongest measure in most cases. Kahn's study also did not include WC or SAD in their comparisons, leaving out an important aspect of this research as SAD tended to have higher ORs for several cardiometabolic risks compared to the other abdominal obesity measures. Also, the inclusion of WC and SAD allowed for the comparisons that included height helping to identify whether the inclusion of height contributed to stronger risk assessment.

Gletsu-Miller et al. published a study[7] involving 60 clinically severely obese women in efforts to predict visceral adiposity in association with dysglycemia. When comparing to BMI and WC, they found SAD to be a better estimate of visceral adiposity

and most associated with dysglycemia related to decreased beta-cell function. The current study demonstrated similar findings, as SAD was a stronger predictor of pre-diabetes than WC among all adult females. With these results showing the fourth quartile compared to the first quartile, this also coincides with that study, as the fourth quartile among all adult females likely consists of mostly obese females. However, in the current study, WHtR and SADHtR, while not significantly different from one another, were stronger predictors than WC and SAD. While notable, this finding expands on Gletsu-Miller et al.'s findings, as measures of height were not used in that study.

Smith et al. published a study[6] observing a cohort of 466 male participants in regards to various anthropometric measures of obesity and their relation to known coronary heart disease risk factors. When comparing BMI, WC, WHR, waist-thigh ratio, SAD, and abdominal diameter index, Smith et al. found that abdominal diameter index was the strongest at predicting risk of coronary heart disease after adjusting for 10-year Framingham CHD risk. Abdominal diameter index is a ratio of SAD and thigh circumference, emphasizing the increased importance of the use of SAD. One important difference in that study was the absence of height in the anthropometric measurements. Overall, the ORs for each of the anthropometric measures were very comparable and quite possibly not significantly different than one another, as tests of significance between each anthropometric measure were not conducted. With the absence of height, obesity measures tended to be very similar predictors of coronary heart disease among men, accentuating the need for an enhanced measure of obesity for disease risk prediction. With the current study's findings, it is clear that including measures of height increase the ability to predict cardiometabolic risk, including heart disease risk factors.

While the current study has many strengths, including a large nationally representative sample consisting of four years of data, the use of ratios of abdominal obesity to height in predicting metabolic risks, gender stratification, and a focus on the normal weight and overweight adult population, it also has some limitations. One limitation of this study was the use of only non-fasted laboratory measurements. While there are many fasted laboratory measures that could assist with defining each cardiometabolic risk and also allow for the use other cardiometabolic risks, only a third of the participants at the MEC could be utilized, as only the morning group of participants was required to be fasted. This significantly lowered the sample size, making it more difficult to stratify based on normal weight or overweight status and gender. As NHANES continues to measure SAD, future studies may be able to use more sample years that could allow for the use of fasted laboratory measures. However, the laboratory measures used in this research are adequate in defining cardiometabolic diseases.

Additionally, several measures of abdominal obesity were not included in this research. Abdominal index, which is defined as waist circumference to thigh circumference to height ratio, was not included among the anthropometric measures as thigh circumference is not included in the NHANES physiological measurements. Hip circumference is also not included among NHANES measurements, eliminating the possible use of waist-hip-height ratio, a fairly new measurement. Several studies[6,27,28] have included abdominal index and waist-hip-height ratio, making them intriguing measures for future research.

CONCLUSIONS

Abdominal measures of obesity were better predictors of risk for all cardiometabolic disorders except low HDL-C in the normal weight and overweight populations. Factoring height into the abdominal obesity measurements improved the assessment of cardiometabolic disease risk. WHtR and SADHtR tended to be the best measures for risk assessment among men and women. While some of the abdominal measures of obesity were not significantly different than one another for some cardiometabolic risks, all were better predictors of disease risk than BMI. Abdominal measures of obesity, particularly those that include height, should be considered for use in clinical practice to strengthen the ability to predict risk of cardiometabolic diseases among normal weight and overweight populations.

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