Summer 2016

Comparison of a Body Shape Index and Body Mass Index as Predictors of Metabolic Syndrome: NHANES 2007-2012

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COMPARISON OF A BODY SHAPE INDEX AND BODY MASS INDEX AS PREDICTORS OF METABOLIC SYNDROME: NHANES 2007-2012

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 2016

CENTRAL WASHINGTON UNIVERSITY

Graduate Studies

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ABSTRACT

COMPARISON OF A BODY SHAPE INDEX AND BODY MASS INDEX AS PREDICTORS OF METABOLIC SYNDROME:

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August 2016

A newly calculated anthropometric measurement (A Body Shape Index, ABSI) was introduced as a more reliable index of body composition than waist circumference (WC) and body mass index (BMI). ABSI was reported as a stronger predictor for mortality. Thus far, the relationship between ABSI and Metabolic Syndrome (MetS) has not been studied on a large U.S. population. The purpose of this cross-sectional study is to determine whether ABSI is a better predictor of the risk of MetS and its individual risk factors than BMI on a large and diverse sample of the U.S. population using the National Health and Nutrition Examination Survey (NHANES) 2007-2012. The study conducted had a total of 6,921 non-pregnant, non-lactating, fasted adults (≥20 years). Anthropometric measurements (WC, weight, and height) were obtained by qualified personnel. ABSI was defined as WC (m) / [$BMI^{2/3}$ × height (m) $^{1/2}$]. The revised National Cholesterol Education Program Adult Treatment Panel III definition was used to diagnose MetS. Simple and multiple logistic regressions were conducted using SAS 9.2. Simple logistic and multiple regression analysis (adjusted for age, gender, and ethnicity)

showed that all of the odds ratios (OR) for BMI quartiles were higher than ABSI quartiles for MetS and each individual MetS risk factor. Therefore, this study concludes that BMI is a better predictor of MetS and each individual MetS risk factor in the general U.S. population.

ACKNOWLEDGMENTS

I would like to express my deepest gratitude to my committee chair Dr. David Gee for his continuous guidance and assistance on my Masters research.

I am also indebted to the rest of my thesis committee, Dr. Stendell- Hollis and Dr. Casey Mace for their time and constructive critique.

Last but not least, I would like to thank God for blessing me with great parents (Mohammad Radwan and Mai Al-Sarraj) who devote their lives to support me, teach me, encourage me, and love me through it all. To them, I dedicate this thesis.

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CHAPTER I

INTRODUCTION

Metabolic Syndrome (MetS) is a group of inter-related metabolic abnormalities, such as hyperglycemia, hypertension, lipid disorders and abdominal obesity [1]. Together these abnormalities raises an individual's risk of having diabetes and heart-related diseases [2]. The pathophysiology of MetS is still controversial; however, studies have found a strong direct association between MetS and obesity [3].

Currently, body mass index (BMI) is the simplest assessment tool for obesity used worldwide [4]. However, the use of BMI alone to assess for adiposity has limitations, especially among adults with BMI ≤30 kg/m2 [5]. BMI assesses total body weight for height without differentiating between the amount of fat or muscle mass. Most importantly, BMI does not account for fat distribution, this is particularly misleading since abdominal fat deposition is thought to play in an important role in the development of MetS [5]. For those reasons, health organizations recommend measuring waist circumference (WC) along with BMI to better assess for abdominal obesity risk [4]. However, most studies have found a high correlation between WC and BMI to the extent that WC and BMI should not be considered as two independent risk factors in assessing chronic disease risk [6].

To overcome these limitations, Krakauer and Krakauer suggested a new calculated index of body composition called “A Body Shape Index” (ABSI) [7]. The index is based on measuring abdominal obesity without the negative influence of height

and weight: ABSI = WC (m) / [BMI $^{2/3}$ × height (m) $^{1/2}$]. A high ABSI value has been found to correlate with a higher percentage of visceral fat compared to peripheral fat. Due to this characteristic, researchers have assessed the relationship between ABSI and different metabolic risk factors. However, the results were inconsistent. ABSI was found to be a more accurate predictor of resting blood pressure in Portuguese adolescents compared to BMI and WC [8]. It was also a better predictor of hyperinsulinemia, and hypercholesterolemia in a Polish population of sedentary men [9]. However, ABSI was found to be a weaker predictor for MetS among an Iranian population [10].

While the literature on ABSI is increasing, thus far there has not been a large study conducted on a diverse U.S. population. The aim of this cross-sectional study is to determine whether ABSI is a better predictor of the risk of MetS and its individual risk factors than BMI on a large and diverse sample of the U.S. population using National Health and Nutrition Examination Survey (NHANES).

CHAPTER II

LITERATURE REVIEW

Metabolic Syndrome Definition

As early as 1923 a constellation of metabolic abnormalities such as raised blood pressure, glucose, and uric acid, were noticed in a number of patients. At the time, these abnormalities were not defined as a syndrome or disease. However, decades later, Reaven named the collection of metabolic abnormalities as "Syndrome X"[11]. This time it included more specific metabolic abnormalities such as abnormal plasma glucose concentration, elevated blood pressure, increased low-density lipoprotein cholesterol (LDL-Cholesterol), increased triglycerides, and decreased high-density lipoprotein cholesterol (HDL-Cholesterol) [1]. Together, these abnormalities are associated with a significant increased risk of cardiovascular disease (CVD), stroke, type two diabetes mellitus (DMT2), and mortality. The underlying pathophysiology is still controversial. However, many experts believe it may be due to abdominal obesity and/or insulin resistance [12].

Worldwide, MetS does not have one official and standard definition; it is defined differently by several international health organizations. The five leading diagnostic criteria have been established by the World Health Organization (WHO), the European Group for the Study of Insulin Resistance (EGIR), the National Cholesterol Education Program's Adult Treatment Panel III (NCEP: ATP III), the American Association of Clinical Endocrinology and the American College of Endocrinology (AACE-ACE), and by the International Diabetes Federation (IDF).

The WHO published an official clinical definition of MetS in 1999 [1,13]. Insulin resistance was essential to the pathophysiology of MetS, so evidence for insulin resistance or its alternates (DMT2, and impaired glucose tolerance) were a requirement in the WHO MetS definition, along with at least two of the following parameters:

1. Regional Obesity
    - BMI > 30 kg/m^2

      and/or

    - Waist-to-hip ratio (WHR) > 0.9 (males) and > 0.85 (females)
2. Elevated blood pressure
    - High systolic/ diastolic blood pressure ≥ 140/90 mmHg or medical history of antihypertensive medication use
3. Decreased HDL-Cholesterol
    - < 35 mg/dl (males) and < 39 mg/dl (females)
4. High triglyceride concentration
    - ≥ 150 mg/dl
5. Increased urine albumin concentration
    - Albumin: creatine ratio ≥ 30 mg/g

      and/or

    - Rapid excretion of albumin ≥ 20 µg/min

Insulin resistance in this definition could be measured by homeostatic model assessment or even by euglycemic hyperinsulinemic clamp studies [1,13] , but these type of measurements are not commonly performed, which makes this criteria inefficient in clinical settings, and not suitable for epidemiologic studies where quick and simple assessment tools are needed.

Shortly after the suggested WHO criteria, the EGIR re-defined the syndrome and referred to it as "Insulin Resistance Syndrome" instead of MetS. Similar to the WHO, the EGIR emphasized the significance of insulin resistance to the pathophysiology of MetS [1, 13]. However, the EGIR simplified the diagnosis of insulin resistance by setting the 75^{th} percentile as a cutoff point to reflect abnormal elevated fasting plasma insulin levels, this change made the criteria very applicable in clinical settings. The EGIR also omitted patients with DMT2 from the diagnostic criteria, because insulin resistance is an underlying cause of diabetes, while diabetes is a manifestation of MetS or "Insulin Resistance Syndrome". The EGIR criteria requires two additional factors among the following [3]:

1. Abdominal obesity
    - WC ≥94 cm (males) and ≥80 cm (females)
2. High blood pressure
    - High systolic/ diastolic blood pressure ≥140/90 mm of Hg or the use of anti-hypertensive medications
3. Dyslipidemia

- Decreased HDL-Cholesterol levels <39 mg/dl

and/or

- High triglyceride concentration ≥150 mg/dl

4. High concentration of blood glucose levels manifested in the form of impaired fasting glucose or impaired glucose tolerance

The indicators to assess obesity were simplified to only measuring WC, whereas the WHO definition used WHR or BMI measurements to asses for obesity risk [1, 13]. High levels of urine albumin were omitted from the diagnostic criteria, because there was not enough evidence to support its role in the development of MetS. More emphasis was placed on lipid disorders (high triglycerides, and reduced HDL-Cholesterol) as well as elevated systolic and diastolic blood pressure and their relationship with insulin resistance [3].

In 2001, the NCEP: ATP III adjusted the WHO MetS criteria. The term "Metabolic Syndrome" was reintroduced in preference to "Insulin Resistance Syndrome" because according to NCEP: ATP III, insulin resistance was not a requirement for the pathophysiology of MetS [1,3,13]. The NCEP: ATP III's focus was abdominal obesity measured by WC instead of the general obesity measured by BMI. According to this definition, MetS is present if at least three or more of the following components are met:

1. Central obesity

- WC> 102 cm (males) or > 88 cm (females)

2. Increased triglyceride levels

   - ≥ 150 mg/dl

4. Decreased HDL-Cholesterol concentrations

   - < 40 mg/dl (males) and < 50 mg/dl (females)

5. High blood pressure

   - High systolic/ diastolic blood pressure ≥ 130/85 mmHg

6. Elevated plasma glucose levels

   - Fasting glucose levels > 100 mg/dl

The NCEP: ATP III does take inflammation and its markers into consideration as constituents of MetS but not as necessary components to diagnose MetS. However, the NCEP: ATP III focuses on low HDL-Cholesterol concentrations and high triglyceride levels as individual risk factors in the diagnostic criteria, rather than simply combining them together under the umbrella of dyslipidemia [1,13]. The NCEP:ATP III uses measurements and laboratory equipment commonly used in hospitals making the NCEP:ATP III definition applicable in clinical settings.

In 2003, the AACE-ACE developed a unique criterion to define MetS. The AACE-ACE is a mixture of both the WHO and NCEP: ATP III definitions [1,13]. The AACE-ACE promotes the terminology of "Insulin Resistance Syndrome"; their reasoning is based on pathophysiological mechanisms that drive metabolic consequences such as

atherosclerosis and DMT2. The AACE-ACE is the only definition that heavily depends on the clinician's expert judgement which considers a range of risk factors such as:

1. Below average HDL-Cholesterol plasma levels
    - <40 mg/dL (males) and <50 mg/dL (females)
2. Elevated triglyceride concentrations
    - ≥150 mg/dL
3. Above average systolic and diastolic blood pressure values
    - ≥130/85 mm Hg
4. Above normal fasting glucose levels
    - >140 mg/dL
5. Two- hour post-glucose challenge
    - >140 mg/dL
6. Abnormal fasting plasma glucose levels
    - 110 - 126 mg/dL
7. Inactive lifestyle
8. Focus on ethnic groups at higher risk of metabolic abnormalities
9. Old age
10. Polycystic ovarian syndrome
11. Family history of DMT2, and CVD

The AACE-ACE also emphasizes the role of inflammation and endothelial function. Clinicians are encouraged to investigate the patient as whole [1, 13]. They consider the patient's past, present, and then pinpoint a prognosis. However, because diagnosis is

solely based on the clinicians' judgement, it can be very limiting in terms of consistency and applicability.

In 2005, the IDF released the most recent clinical criteria for MetS. It is very similar to the NCEP: ATP III MetS definition, with the exception of focusing more on ethnic-specific cutoff values for central obesity measured by WC [1, 13]. The rationale behind this prerequisite is to take into consideration ethnic variations in body composition, since certain ethnicities are at greater risk of MetS, even with smaller WC cutoff values. To meet the IDF criteria for MetS, individuals must have at least two of the following risk factors in addition to abdominal obesity:

1. Increased blood pressure levels
    - High systolic/diastolic blood pressure ≥ 130/85 mmHg or medical history of antihypertensive use
2. Increased triglycerides concentration
    - ≥ 150 mg/dl or medical history of lipid-lowering medication use
3. Decreased HDL-C levels
    - < 40mg/dl (males) and <50 mg/dl (females) or history of lipid-lowering medication use
4. Increased fasting blood glucose concentrations
    - ≥ 100 mg/dl or medical record of previous DMT2 diagnosis

The IDF definition is unique because it recognizes the importance of the medical history of different risk factors and does not only focus on recent values of triglycerides, HDL-Cholesterol, blood glucose, and blood pressure [1,13].

Although there is still debate on which of the five definitions is the ideal criteria for clinical application. The NCEP: ATP III definition is the most commonly used criteria of MetS [1,13]. The NCEP: ATP III criteria does not limit the diagnosis of MetS by requiring a specific risk factor to exist. The laboratory equipment that help evaluate specific MetS components in the NCEP: ATP III definition are also readily available in hospital settings. Thus, the NCEP: ATP III criteria is very appropriate to use in both clinical settings and epidemiological studies.

Metabolic Syndrome Prevalence

The prevalence of MetS is increasing alongside the significant progression of obesity. The prevalence of MetS varies between similar studies conducted on the same population, because researchers use their preferred diagnostic criterion of MetS. Prevalence also differs based on the composition (gender, ethnicity, age) of the target population. However, regardless of which criterion was used or the composition of the studied population, the prevalence of MetS is escalating in western civilizations. According to Balkau et al., 20% of adults in the Western world have MetS [14]. However, it is not a problem exclusive to the western region; MetS is also becoming a phenomenon in developing countries. In fact, according to the IDF, 25% of the world's population are suffering from MetS [14, 15]. This occurrence could be due to the popular transition around the word from a customary lifestyle to a more modern one. Populations are now living longer due to better access to healthcare. Developing countries are becoming more urbanized with increasing obesity rates accompanied with an unhealthy diet and a sedentary life style.

In the United States, data from the 2003 to 2012 NHANES database indicated that the prevalence of people who met the NCEP: ATP III guidelines for MetS was approximately 33%, suggesting that about 1 in 3 Americans are afflicted with MetS [16]. Based on gender, women (35.6%) were more likely to have Mets than men (30.3%). Based on race, Mexican Americans (36.4%) were more afflicted with MetS than either Caucasian Americans (33.4%) or African Americans (32.7%). Interestingly, the study found MetS prevalence to increase with age [16]. For young adults between the ages of 20 to 39 years old, prevalence of MetS was 18.3%. However, for older adults ages 60 years and older, the prevalence of MetS (46.7%) was almost triple the prevalence of young adults.

From 2003-2004 and 2011-2012 [16], the prevalence of MetS increased by approximately 2%. However, from 2007-2008 to 2011-2012, they found that the prevalence of MetS did not significantly change except for females; MetS prevalence decreased from 39.4% in 2007-2008 to 36.6% in 2011-2012.

MetS significantly raises the possibility of developing CVD and DMT2. People who meet the MetS criteria have double the risk of having a stroke or heart attack, and are five times more likely to develop DMT2 compared with people who do not have MetS [14]. Each additional individual risk factor of MetS leads to an increased risk of CVD; the risk is much greater when MetS itself is present. If DMT2 or CVD are not already present, MetS is a strong predictor for its development. Consequently, even before glucose levels are high enough for someone to be diagnosed with DMT2, MetS can serve as a simple and inexpensive clinical tool that helps clinicians recognize

individuals with abnormalities early on to intervene and prevent further worsening of the condition [2]. MetS criteria is especially useful for identifying patients that normally would have been overlooked because they do not have the more traditional risk factors of developing CVD such as low HDL-Cholesterol concentrations, or high LDL-Cholesterol levels.

Anthropometric measurements are essential clinical tools used to predict morbidity and mortality. They are especially valuable when conducting large-scale studies that require inexpensive and simple measurements. BMI and WC are frequently used as tools to predict metabolic abnormalities, but research is constantly finding limitations in both measurements.

It is of critical importance to have a greater understanding of tools that help predict MetS and its risk factors. Accurate anthropometric assessments will assist with intervention and prevention of disease when abnormality is detected early. Finding the best assessment tools for MetS can help decrease the prevalence of MetS and its consequences worldwide. Lifestyle changes such as diet and exercise play an imperative role in delaying and preventing complications.

Body Mass Index and Metabolic Risks

Obesity is widely assessed in terms of BMI surpassing threshold values. In the mid- nineteenth century, Adolphus Quetelet noticed that there was a proportionate relationship between one's weight and height [17]. Quetelet later defined BMI by

dividing one's total weight by one's squared height [17]. BMI classifies adults according to their appropriate weight status into three categories: underweight, overweight and obese. BMI is widely used in both epidemiologic studies and in clinical settings for assessment and intervention in case weight loss or weight control is needed. One rational behind the use of this index is that studies have found it to be closely related with the percentage of fat in adipose tissues [18]. Another reason is that height is greatly correlated with weight, yet BMI is approximately uncorrelated with height, and with most other obesity indices [18], the independence from height enables comparisons across individuals.

According to the WHO, BMI provides many advantageous qualities; the weight categories provides researchers with a simple tool that can easily compare within and between populations' weight statuses and identify the population's increased risk for metabolic abnormalities. Epidemiological studies have found that a BMI >30 kg/m^2 is correlated with a greater risk for morbidity and mortality [17]. The Prospective Studies Collaboration found a BMI range of 22.5–25 kg/ m^2 to be protective against mortality [19]. The study also interestingly concluded that 5 kg/m^2 above a BMI of 25 kg/ m^2 will significantly increase the risk for mortality by 30%. However, using BMI alone to asses for body fat has several limitations, especially for populations with a BMI $\leq$30 kg/m^2.

BMI represents overall body weight which includes both fat and muscle weight. This limitation causes errors in diagnosing the accurate weight status of many individuals. People with a normal body weight but excess fat mass will often be labeled as healthy. Equally, individuals whose body weight is high due to increased lean muscle

mass will be misdiagnosed as overweight or obese [5]. This is dangerous because muscle and fat have opposite physiological effects on the body [20]. Fat mass increases the risk of mortality and morbidity, while muscle mass helps reduce the risk.

There is wide variation of body fat distribution that BMI cannot accurately detect. BMI does not work the same with different populations, because body composition is different based on gender, age, and ethnicity [21]. Studies have found that at comparable BMI values, women have significantly greater body fat content than do men. Older populations at comparable BMI values with the younger population have significantly higher body fat percentages. Old age is generally accompanied with sarcopenia which could be a potential reason behind this age-related discrepancy of fat content between the young and old.

Asians are a specific ethnic group who are at a significantly greater risk for morbidities at lower BMI values. Generally, Asians are more likely to have metabolic risk factors at a BMI range of 22 kg/m^2 – 25 kg/m^2. The risk increases significantly at a BMI range of 26 kg/m^2 – 31 kg/m^2 [22,23]. Studies have also suggested that since the current BMI cutoff points may underestimate obesity, it may also specifically underestimate cardio-metabolic risks associated with weight gain among non-European populations [24]. Razak et al. found that Chinese, Aboriginal, and South Asian people have plasma lipid and glucose abnormalities at significantly lower BMI cutoff points when compared with Caucasians [24]. Compared to Europeans, the Chinese have a tendency to develop hypertension at a much lower BMI value. Aboriginals have lower blood pressure levels compared to all three ethnicities (Chinese, Aboriginal, and South

Asian) at any BMI category. However, the increase in blood pressure levels with weight gain among South Asians was not greater than in Europeans [24]. Similar findings were discovered in an earlier study that compared blood pressure values between South Asian Canadians and Caucasian Canadians [25].

Razak et al. also found similar BMI cutoff values that detected abnormal lipid profiles (BMI=21.0 kg/m^2) and glucose levels (BMI= 22.0 kg/m^2) among South Asians [24]. For the Chinese and Aboriginals populations, the BMI cutoff values to predict their risk of an abnormal lipid profile were significantly higher compared to the BMI cutoff values that helped predict their abnormal glucose levels. Signs of hypercholesterolemia showed in the Chinese at BMI= 25.9 kg/m^2, and for the Aboriginals at BMI= 26.1 kg/m^2. On the other hand, hyperglycemia signs and symptom appeared for the Chinese at BMI= 20.6 kg/m^2, and for the aboriginals at BMI= 21.81 kg/m^2. Since South Asians in this study had a two times greater risk for abnormal lipid and glucose levels, their risk of developing CVD was much higher compared with other ethnicities. More studies are needed to understand the mechanism that causes South Asians to be more susceptible to metabolic abnormalities at normal BMI values. Understanding findings of studies comparable to this one is very important for clinicians and researchers to evaluate and report accurate data. Studies on multiple ethnic groups help clarify the true relationship between body composition and risk of disease.

The concept of body weight and its association with metabolic abnormalities has been a topic of interest for many years. An earlier study conducted by Denke et al. in 1993 on men [26], and again in 1994 on women [27], investigated the relationship

between body weight and serum lipid abnormalities. In both studies, they found that a high BMI significantly changes an individual's lipid profile negatively. Being overweight according to BMI classifications is associated with elevated levels of total cholesterol, LDL- Cholesterol, decreased levels of HDL- Cholesterol and elevated concentrations of triglycerides.

Although many studies have already established being overweight or obese as a significant risk factor behind many metabolic diseases, there are still studies that challenge this concept. Ärnlöv et al. investigated the association between BMI categories and MetS in 1758 middle-aged men without diabetes [28]. The participants were categorized according to BMI-MetS status. During a 30 years follow-up period, 45% of the subjects died, and 39% developed heart-related diseases. Indeed, the study found an increased risk in overweight and obese men for CVD. However, even men in normal weight BMI categories had a significant increased risk of heart-related diseases. In general, they also found that middle-aged men with MetS had increased risk for CVD and total mortality regardless of their BMI status. Ärnlöv et al. suggested that there's more to MetS than being overweight, and having MetS should not be synonymous with being overweight or obese.

Despite BMI's limitations, it is still a good initial assessment tool of body fatness in clinical settings because it is easily measured (weight, height) and calculated. However, clinicians must be aware of these limitations when using BMI alone as an index of adiposity.

Abdominal Obesity and Metabolic Risks

Studies have recognized that the risk of developing metabolic abnormalities is affected by the individual's body shape [7]. Metabolic abnormalities associated with insulin resistance are commonly present in individuals with abdominal obesity [29]. A high content of visceral fat may be an important underlying cause behind insulin resistance and metabolic abnormalities such as hyperglycemia, hypercholesterolemia, and hypertension. The actual mechanism that links both insulin resistance and abdominal obesity together has not been fully understood. However, excessive fat in adipose tissues result in a flux of free fatty acids and triglycerides in the plasma, which causes physiological changes that leads to a manifestation of metabolic abnormalities; it impairs insulin production, therefore raises blood glucose levels, and eventually leads to DMT2. Excess adipose tissue fat, especially visceral fat also causes insulin resistance by releasing inflammatory cytokines. In addition, excessive visceral fat decreases adiponectin production. Adiponectin is known to help regulate blood glucose levels and improves endothelial function by reducing inflammation, so the lack of adiponectin causes the body to be more susceptible to CVD risk [12].

Because individuals with excessive regional fat have a higher susceptibility for metabolic diseases, the WHO concluded that abdominal obesity should also be measured in conjunction with BMI to better predict disease risk [4,7]. Multiple organizations have recommended that WC measurements be used within BMI categories to classify obesity-related diseases due to the growing evidence of a positive association between regional body fat distribution and MetS risk factors [30,31].

A Canadian study by Brenner et al. examined whether WC or BMI were better predictors of cardio-metabolic health [32]. Through measuring lipid concentrations of healthy, multi-ethnic, group of young adults. Brenner et al. found that WC was a stronger predictor of triglycerides, HDL-Cholesterol, and overall total cholesterol than BMI, especially amongst men in East Asian and Caucasian subgroups. However, there was only a small difference between the two predictors on East Asian women.

Another study conducted by Højgaard et al. looked at the issue from an economical point of view; they compared the relationship between BMI and WC as predictors of future health care costs [33]. They hypothesized that a larger WC at any BMI category indicated a higher future cost, and vice versa, whereas for all levels of WC a higher BMI led to lower future health care expenses. The study further investigated whether measuring both WC and BMI would predict health care costs more accurately than either one alone. Højgaard et al. collected data from a large population of 31,840 adult subjects and analyzed the relationship between future costs of health care and both BMI and WC using categorized and continuous analyses. Based on their categorical analysis, they found measuring WC to be most helpful for individuals with BMI<30 kg/m^2 . It is common for those in the normal weight category to be overlooked, when regional fat is not measured. Nevertheless, when analyzing BMI and WC as continuous variables, the results suggested that for any BMI category, measuring WC does indeed help identify individuals who are at a greater risk of future health care costs regardless of their BMI status. Therefore, the greater the regional fat content at any BMI value, the higher the costs for health care in the future. Conversely, if WC is measured and then

BMI is added for assessment, it will not help in predicting increased future health care costs, except for females with a BMI<30 kg/m2 and WC <88 cm.

On the other hand, other studies suggest that WC may not add much more valuable information about body composition and disease risk than BMI alone. Since WC and BMI are highly correlated, using either one as an individual assessment tool for the prediction of future complications is unhelpful [7]. A recent cross-sectional study conducted by Gierach et al. investigated the correlation between BMI and WC in patients with metabolic abnormalities such as hypertension, diabetes, and lipid disorders [34]. They distinguished the constituents of MetS according to gender and found a significant association between WC and BMI in each group. However, the correlation was lowest in the hypertensive female group, possibly due to the fact that females usually have a smaller WC and lower BMI value compared with males.

In clinical practices, WC measurements are not well implemented despite the simplicity of the method of measurement. There is inconsistency in body measuring sites. In a review of literature, researchers found eight different measurement sites for WC [6]. This is problematic, because different locations will provide different values of WC. An absence of a standardized WC measurement makes it difficult to compare research that studied WC on different populations; the results will always be questioned, unless it's being compared with studies that used the same measurement technique. Another issue is that professional and trained personnel are required to measure WC without any errors. Some sites are more difficult to locate than others are. An example of that is WC measurement at the iliac crest. Although the iliac crest is hard to locate, it is still preferred by the National Institutes of Health and the National Heart, Lung, and Blood Institute

[35]. Weight changes will not affect the iliac crest bone structure, which is good for prospective and longitudinal studies that focus on body composition changes throughout time.

The WHO recommends measuring the center in between the iliac crest and lowest rib. However, the clinician must be able to locate two different structures [35]. Then the clinician will also need to calculate the midpoint of the space between these two sites. Compared to measuring only the iliac crest, this method requires even more skill and time, which is a disadvantage.

In summary, based on the reviewed literature, the determination of which measure of adiposity is better associated with metabolic abnormalities produced inconsistent conclusions. Therefore, there is a need for more research in this area.

A Body Shape Index and Metabolic Risks

In 2012, Krakaur et al. proposed a Body Shape Index (ABSI) that was uncorrelated with BMI, weight, and height in an attempt to better quantify abdominal obesity by further utilizing WC and overcoming the limitations of both BMI, and WC [7]. The researchers suggested that the usage of ABSI along with BMI as an assessment tool eliminated the effect of height and weight (body shape) on an individual's body shape (abdominal obesity). A greater than average ABSI for a given weight and height represented a greater than average WC, and therefore indicated a higher percentage of visceral fat.

In their 5-year follow-up study, Krakauer et al. evaluated the predictive power of ABSI on mortality compared to WC and BMI across BMI categories, race, gender, and

age on a U.S. population sample derived from the NHANES (1999–2004). The study found a nearly exponential increase in mortality in individuals with a greater than average ABSI. In fact, 22% of the mortality rate was due to above average ABSI values; compared to only 15% that was attributed to high WC and BMI values. The researchers suggested that WC and BMI could be confusing predictors because they showed high death rates at both low and high values of BMI. ABSI was successful in predicting the risk of mortality across age, gender and different BMI categories. It was also effective in predicting mortality for Americans of European and African ancestry, but was less effective for those of Mexican origin.

In 2014, Krakauer et al. conducted another study with the same objectives of evaluating ABSI's predictive ability for mortality [36]. However, this time they addressed some of the limitations of their first study and improved it by using longer follow up period data from the British Health and Lifestyle Survey (HALS) on a large British population sample. HALS provided repeated ABSI measurement observations, which enabled them to learn more about changes in ABSI through time. HALS also provided them with the opportunity to compare ABSI with more anthropometric measures such as waist to height ratio, and WHR.

The research found that ABSI was still the superior predictor for mortality compared to all other anthropometric measurements. However, WHR was equally correlated with mortality. The researchers still preferred ABSI to WHR as a clinical option because it required fewer additional body measurements. Since Krakauer et al. published their study in 2012, the successful ability of ABSI to predict mortality and

assess for a higher fraction of visceral fat, has led to an increased interest to investigate the relationship between ABSI with different health outcomes.

Diabetes

A 15-year follow up study conducted by He et al. assessed whether ABSI could predict DMT2 in a Chinese population [37]. The research found that ABSI significantly and independently predicted DMT2. However, the predictive power of ABSI was not greater than BMI or WC. The study suggested that ethnic differences could be the rationale behind the inconsistency in the predictive ability of ABSI. The Chinese population had lower mean values of BMI, WC and ABSI compared to the U.S. population that included African, European, and Mexican ethnicities only [7]. Asians tend to have smaller body frames along with lower BMI values. The Chinese study also found that ABSI had some correlation with height, weight, and BMI, unlike the original study that only had little correlation [7], possibly due to the different WC measurement protocol used in this Asian study.

Hypertension

Duncan et al. assessed ABSI, BMI, WC and their relationship with blood pressure in 445 Portuguese children and adolescents [8]. The study found ABSI, BMI and WC to be significant, strong predictors for both systolic and diastolic blood pressure for both gender groups. However, ABSI was a significantly stronger predictor of blood pressure because it explained changes in blood pressure much better than the other anthropometric measurements. Interestingly, ABSI predicted changes in systolic blood pressure two times better for boys than it did for girls. Weight for height as well as fat

deposition affects blood pressure values. Boys have more muscle mass, especially in their upper body, which may increase the possibility of altering their WC-for-height ratio. Any changes in WC and BMI will influence the result of ABSI. Therefore, the increase in muscle mass maybe the reason ABSI is a better predictor for boys.

Cheung et al. also assessed the association between ABSI, WC, BMI and hypertension using a large database that nationally represents the Indonesian population, titled: "The Indonesian Family Life Survey Wave 3" [38]. Anthropometric measurements and blood pressure values were obtained from 8255 middle-aged and older adults. The study found that although ABSI significantly predicted hypertension, WC and BMI were the stronger predictors.

Multiple Metabolic Risk Factors

Malara et al. assessed the relationship between ABSI and BMI with multiple metabolic risk factors. Anthropometric measurements (weight, height, WC) were measured from 114 sedentary Polish male university students [9]. Subjects were required to fast overnight, and blood were drawn to determine plasma levels of total cholesterol, HDL-Cholesterol, LDL-Cholesterol, non-HDL-Cholesterol, triglycerides, hyperglycemia and circulating insulin. The research found BMI and ABSI to correlate with different biochemical variables. BMI correlated better with circulating triglycerides. However, ABSI more accurately described the changes in plasma insulin, LDL-Cholesterol and non-HDL-Cholesterol levels. However, neither ABSI nor BMI were significantly better than each other at predicting non-HDL-Cholesterol, and hyperglycemia. The homogeneity of the participants based on age, sex, ethnicity, and socioeconomic status

along with the small sample size weakens the studies' ability to extrapolate the results to a more diverse population.

In a large retrospective cohort study, Fujita et al. assessed whether ABSI could predict diabetes, hypertension, and dyslipidemia on a Japanese population that included 48,593 subjects [39]. The study used yearly health examination data from Chiba City in Japan from 2008 to 2012. Fujita et al. found ABSI, BMI, and WC to significantly predict all three diseases. However, BMI and WC were the more powerful predictors. The study also mentioned that the discrepancy in results could be due to variations of body compositions based on ethnicity. The Japanese study had similar results to the previous Asian studies on Chinese and Indonesian populations.

Metabolic Syndrome

A cross-sectional study on an adult Iranian population compared the predictive ability of ABSI, BMI, WtHR, and Clínica Universidad de Navarra - Body Adiposity Estimator (CUN-BAE) for CVD risk factors using the Isfahan Heart Program, which is a community-based program with the goal of CVD prevention and control in Iran [10]. The program has both physical examinations, and interviews. To assess the relationship between anthropometric measurements and CVD risk factors, they measured plasma total cholesterol, HDL-Cholesterol, LDL-Cholesterol, triglycerides, C-reactive protein, Apolipoprotein A, Apolipoprotein B, and blood pressure. For MetS they used the IDF diagnostic criteria; so in order to be diagnosed with MetS, subjects must have abdominal obesity along with two additional risk factors. Abdominal obesity cutoff values were ethnic-specific. They found all anthropometric measurements to be significantly

correlated with each risk factor; however, the correlation was still considered weak and ABSI was the weakest predictor of both CVD and MetS.

National Health and Nutrition Examination Survey

NHANES is a survey research program run by the National Center for Health Statistics (NCHS) and within the Centers for Disease Control and Prevention (CDC). The survey was developed to assess the health and nutritional status of children and adults in the United States and to observe the health related changes that occur within the nation over time.

NHANES started in the early 1960s; data was continuously collected in 1999. Every year, NHANES studies approximately 5,000 selected subjects to be nationally representative from all age and major ethnic groups. African Americans, Hispanic Americans, and adults 60 year and over are oversampled to produce reliable statistics.

NHANES is unique compared to other surveys because in addition to gathering data through interviews, it also includes extensive physical and laboratory assessments. The subjects are given a health exam interview that includes health-related, dietary recall, demographic, social, and economic questions. Subjects also undergo a medical examination that includes dental, anthropometric, and physiological measurements, in addition to laboratory tests conducted by trained professionals. All age groups except for the very young are given health examinations that include a blood sample [40].

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CHAPTER III

JOURNAL ARTICLE

Abstract

Background and Objective: A newly calculated anthropometric measure "A Body Shape Index" (ABSI) was introduced as more reliable index of body composition than waist circumference (WC) and body mass index (BMI). ABSI was reported as a better predictor for all-cause mortality. However, associations between ABSI and Metabolic Syndrome (MetS) have not been studied in a large U.S population. The aim of this cross-sectional study is to determine whether ABSI is a better predictor of the risk of MetS and its individual risk factors than BMI in a large and diverse sample of the U.S population using National Health and Nutrition Examination Survey (NHANES) 2007-2012 data.

Methods: A U.S. population sample of 6,921 non-pregnant, non-lactating, fasted adults (≥20 years) from NHANES 2007-2012 was used in this study. The revised National Cholesterol Education Program Adult Treatment Panel III definition was used to diagnose MetS. Chi-square test as well as simple and multiple logistic regressions were conducted using SAS 9.2.

Results: Although both ABSI and BMI were associated with risk for MetS, simple and multiple regression analysis (adjusted for age, gender, and ethnicity) showed that all of the odds-ratios (OR) for quartiles of BMI were higher than for quartiles of ABSI for MetS and each individual MetS risk factor. Elevated BMI and ABSI (at the 4^{th} quartile compared to the 1^{st} quartile) increased the risk of MetS [BMI-MetS: OR = 26.6 (95%

confidence interval (95%CI) =20.3-34.8); ABSI-MetS: OR=6.0 (95%CI=4.9-7.3). After adjustment for confounding variables, elevated BMI and ABSI increased the risk of MetS [BMI-MetS: OR = 31.2 (95%CI=23.2-41.9); ABSI-MetS: OR=3.7 (95%CI=2.9-4.5).

Conclusions: BMI is a better predictor of MetS and every individual MetS risk factors in the general U.S adult population.

Introduction

Metabolic Syndrome (MetS) is a group of inter-related metabolic abnormalities such as hyperglycemia, hypertension, lipid disorders and abdominal obesity [1]. Together these abnormalities raises the risk of developing cardiovascular disease and type 2 diabetes [2]. The pathophysiology of MetS is still controversial; however, studies have found a strong direct association between MetS and obesity as well as with abdominal obesity [3].

Currently, Body Mass Index (BMI) is the simplest, practical and most used assessment tool for obesity [4]. However, the use of BMI alone to assess for adiposity has limitations, especially among adults with BMI $\leq$30 kg/m^2 [5]. BMI assesses total body weight for height without differentiating between the amount of fat and muscle mass. Most importantly, BMI does not account for the variation in fat distribution, particularly since abdominal fat deposition is thought to play an important role in the development of MetS [5]. For those reasons, the World Health Organization recommends measuring waist circumference (WC) along with BMI to better assess for abdominal obesity risk [4]. However, most studies have found a high correlation between WC and BMI to the extent that WC and BMI should not be considered as two independent risk factors in assessing chronic disease risk [6].

To overcome these limitations, Krakauer and Krakauer presented a new calculated index of body composition called “A Body Shape Index” (ABSI) [7]. The index is based on measuring abdominal obesity without being influenced by height and

weight: $ABSI = \frac{wc\ (m)}{BMI^{\frac{2}{3}}\ X\ Height\ (m)^{\frac{1}{3}}}$ [7]. A high ABSI value has been positively correlated to a higher percentage of visceral fat, compared to peripheral fat [7]. Due to this characteristic, researchers have assessed the relationship between ABSI and different metabolic risk factors, however the results have been inconsistent. ABSI was found to be more strongly associated with blood pressure in Portuguese adolescents compared to BMI and WC [8]. It was also a better predictor of circulating insulin, low density lipoprotein cholesterol (LDL-Cholesterol) and non-high density lipoprotein cholesterol (Non-HDL-Cholesterol) in a Polish population of sedentary men [9]. However, ABSI was found to be a weaker predictor for CVD risks and MetS among an Iranian population [10]. The variation in results could be due to different ethnic backgrounds, as well as different ABSI cut off points between populations.

While the literature on ABSI is increasing, there has not been a large study conducted on a diverse U.S. population. The aim of this cross-sectional study was to determine whether ABSI is a better predictor of the risk of MetS and its individual risk factors than BMI on a large and diverse sample of the U.S. population using the National Health and Nutrition Examination Survey (NHANES) 2007-2012.

Methods and Materials

NHANES

NHANES is a series of cross- sectional surveys that uses a stratified, multistage probability cluster-sampling program to select its subjects [11] . It is run by the Centers for Disease Control and Prevention to evaluate the health and nutritional status of the

civilian, non-institutionalized U.S. population. NHANES releases datasets every two years with about 5,000 individuals examined each year. Mexican-Americans and African-Americans, pregnant women, low-income Caucasians, older adults, children and adolescents were oversampled to produce more reliable and accurate statistics. The NHANES survey is unique because it included both home interviews and physical examinations. The household questionnaires include dietary-recall, medical history, health-related, socioeconomic, and demographic questions. The medical examinations includes anthropometric, physiological, and laboratory measurements, as well as dental, auditory, and retinal tests conducted by trained professionals [11]. The information collected from NHANES has been widely used to assess for disease risk and prevalence.

Participants

This study considered adults (≥20 years) with WC, height, and weight measurements, who provided a fasted blood sample, and excluded women who were breastfeeding and/or pregnant. Data were taken from three sets of NHANES cycle years between 2007-2012. The total sample size was 6921 subjects that included 3412 males and 3509 females.

Metabolic Syndrome

MetS was defined using the National Cholesterol Education Program Adult Treatment Panel III as having three or more of the following risk factors [1]: Serum level of triglycerides of 150 mg/dL or greater; HDL-Cholesterol level of less than 40 mg/dL in males or less than 50 mg/dL in females; WC greater than 102 cm in males or greater than

88 cm in females, fasting plasma glucose level of 100 mg/dL or greater or taking anti-diabetic agents; blood pressure of 130/85 mm Hg or greater or the use of anti-hypertensive agents.

Anthropometric Measurements

WC was measured horizontally with a steel tape to the nearest 0.1 cm after a normal exhalation at the iliac crest. Weight was measured with a digital scale. Height was measured using a vertical stadiometer with subjects standing erect, and distributing their weight equally on both heels. All measurements were conducted by trained personnel following NHANES protocols. BMI was calculated as $BMI = \frac{Weight\ (Kg)}{Height\ (m^2)}$, and ABSI was calculated according to Krakauer and Krakauer's formula $ABSI = \frac{wc\ (m)}{BMI^{\frac{2}{3}}\ X\ Height\ (m)^{\frac{1}{3}}}$.

Blood Tests and Blood Pressure

Serum triglyceride concentrations were measured using an enzymatic assay that involved the hydrolysis of the triglycerides, the phosphorylation and oxidation of glycerol, and the photometric analysis of the oxidation products. HDL-Cholesterol concentration was measured after other lipoproteins precipitate in a mixture of heparin–manganese, the enzymatic oxidation of cholesterol and the photometric analysis of the oxidation products. Both serum triglyceride and HDL-Cholesterol were measured using Roche Modular P chemistry analyzer [12]. Plasma glucose levels were measured through the reaction of hexokinase and glucose-6-phosphate dehydrogenase with the NADPH photometrically analyzed. Details of the analytical methods used in the NHANES study

can be found on their webpage [11]. Only blood from fasted participants were included in this study. The average of three readings was used to determine blood pressure level.

Statistical Analysis

Statistical analysis software (SAS 9.2) was used for descriptive and inferential statistics. The general characteristics data are presented as the mean ± SD. The alpha (p) level was set at $p < 0.05$ for statistical significance tests. ORs using simple logistic and multiple regression analysis (PROC SURVEYLOGISTIC) were determined to establish how strong the relationship is between ABSI, and BMI with MetS and its individual risk factors. Subjects were divided into quartiles based on either BMI or ABSI for analysis of the ORs. The lowest quartile of BMI or ABSI was established as the reference group and the ORs for MetS or each of the individual MetS risk factors were calculated to determine the strength of association of BMI or ABSI on MetS or each of the individual MetS risk factors. Establishing the quartile cut points for BMI and ABSI were done using the entire adult population (both fasted and unfasted) to have a larger sample size that would provide better estimates of BMI and ABSI values for the U.S population.

Results

General characteristics of the participants are presented in Table 1. In this study, the mean age for both males and female was approximately 50 years with broad representation in all age categories. The mean BMI of the sample population reflected the current high prevalence of overweight and obesity in the U.S population. The mean fasting plasma glucose concentration fell within the pre-diabetic category. The mean WC

in women was above the cutoff point for abdominal obesity, while it was below the cutoff point in men. The mean systolic blood pressure fell in the pre-hypertensive range while the mean diastolic blood pressure fell within the normal range. In addition, the population had normal values for HDL-Cholesterol and triglycerides concentrations. The ABSI mean was 0.082±0.0047 $m^{11/6}/kg^{-2/3}$ for males and 0.081±0.0049 $m^{11/6}/kg^{-2/3}$ for females, which was similar to the study by Krakauer and Krakauer [7] that used NHANES data from 1999-2004 and reported a total population average ABSI of 0.0808±0.0053 $m^{11/6}/kg^{-2/3}$.

Table 1.Physical characteristics and Metabolic Syndrome risk factors of fasted, non-pregnant, non-lactating adults from the National Health and Nutrition Examination Survey, 2007-2012.

Characteristics	Males (n=3412)	Females (n=3509)
Age (y)	49.8 ± 17.6	50.3 ± 17.5
Standing height (cm)	174.5±7.7	160.8+7.3
Weight (kg)	87.3±19.8	75.8+20.5
Waist circumference (cm)	101.1+15.3	96.8+16.2
Body Mass Index (Kg/m^2)	28.9±5.8	29.3+7.4
A Body Shape Index ($m^{11/6}/kg^{-2/3}$)	0.082±0.0047	0.081+0.0049
Systolic Blood Pressure	124.7±16.7	121.1+19.5
Diastolic Blood Pressure	70.9±12.7	67.4+12.6
HDL-Cholesterol (mg/dL)	48.5±14	57.9+15.7
Triglyceride (mg/dL)	142.6±120.2	122.8+94.6
Fasting Glucose (mg/dL)	111.8±35.5	106.1+33.8

*Values expressed as means ± SD using Proc Means in SAS 9.2.

As shown in Table 2, the lower prevalence of MetS in the lowest quartile of BMI compared to ABSI and the higher prevalence in the highest quartile compared to ABSI

indicates the greater sensitivity of BMI over ABSI in predicting MetS. Similarly, this greater difference in prevalence for low HDL-Cholesterol between the lowest and highest quartile of BMI compared to ABSI also reflects the greater sensitivity of BMI over ABSI in predicting low HDL-Cholesterol. In contrast, the differences in prevalence for hyperglycemia, hypertension, and hypertriglyceridemia between the lowest and highest quartiles were similar for both BMI and ABSI. The much smaller differences in prevalence of abdominal obesity between the lowest and highest quartiles of ABSI can be attributed to the inclusion of WC in the calculation of ABSI.

Table 3 reports the prevalence of MetS within BMI and ABSI quartiles stratified by ethnicity. The difference in the prevalence of MetS in the lowest quartile and highest quartiles of BMI compared to ABSI indicates the greater sensitivity of BMI over ABSI in predicting MetS within all three ethnic subgroups (non-Hispanic whites, non-Hispanic blacks, and Mexican-American). The prevalence of MetS within the lowest ABSI quartile is approximately double that found in the lowest BMI quartile, which represents the less selective nature of ABSI in each ethnic subgroup.

Table 4 shows the prevalence of MetS by BMI and ABSI quartiles stratified by gender. The prevalence of MetS in the lowest ABSI quartiles was approximately twice that in the lowest BMI quartiles for males, and 3.5 times greater for females. As with the overall U.S. population. Again, this shows that ABSI is a weaker predictor of MetS compared to BMI in either gender.

Table 2.Prevalence of Metabolic Syndrome and risk factors by BMI, and ABSI quartiles.

BMI Qs (2)	**MetS**	**MetGLU**	**MetBP**	**MetHDL**	**MetTG**	**MetWC**
First	7.5 ± 1.3	30.6 ± 1.3	23.7 ± 1.7	14.7 ± 1.4	11.5 ± 0.9	6.9 ± 0.9
Second	23.9 ± 1.4	47.9 ± 1.8	35.1 ± 1.5	22.2 ± 1.6	25.2 ± 1.2	41.5 ± 1.8
Third	46.3 ± 1.9	54.9 ± 1.9	44.8 ± 1.7	31.6 ± 1.6	32.9 ± 1.5	77.5 ± 1.3
Fourth	68.5 ± 1.8	68.9 ± 1.6	55.1 ± 1.5	45.9 ± 1.5	39.3 ± 2.2	99.6 ± 0.2
P-value (1)	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001
ABSI Qs (2)	**MetS**	**MetGLU**	**MetBP**	**MetHDL**	**MetTG**	**MetWC**
First	18.6 ± 1.2	34.9 ± 1.6	22.4 ± 1.2	24.3 ± 1.4	15.9 ± 1.4	34.1 ± 1.5
Second	33.4 ± 1.5	47.1 ± 1.7	35.4 ± 1.6	30.3 ± 1.3	27.5 ± 1.2	49.1 ± 1.7
Third	37.9 ± 1.8	52.8 ± 1.8	40.4 ± 1.8	27.5 ± 1.6	28.5 ± 1.4	63.4 ± 1.6
Fourth	57.5 ± 1.9	68.3 ± 1.9	60.6 ± 2.1	30.6 ± 1.7	37.2 ± 2.1	77.9 ± 1.3
P-value (1)	<.0001	<.0001	<.0001	0.0020	<.0001	<.0001

(1)Chi-square test comparing prevalence across BMI or ABSI quartiles

(2) Values of population's BMI and ABSI quartiles. BMI: (1st Q=< 24.24, 2nd Q=≥ 24.24 and < 27.98, 3rd Q=≥ 27.98 and < 32.35, 4th Q= ≥ 32.35) ABSI: (1st Q=< 0.0782705, 2nd Q=≥ 0.0782705 and < 0.0814802, 3rd Q=≥ 0.0814802 and < 0.0847535, 4th Q=≥ 0.0847535)

Table 3.Prevalence of Metabolic Syndrome in different ethnicities according to BMI, and ABSI quartiles.

BMI Quartiles	**NH-Whites (%)**	**NH-Blacks (%)**	**Mexican-American (%)**
First	7.7	7.2	5.2
Second	25.5	19.8	19.8
Third	48.8	33.2	42.12
Fourth	71.3	59.7	65.8
P-value (1)	<.0001	<.0001	<.0001
ABSI Quartiles	**NH-Whites (%)**	**NH-Blacks (%)**	**Mexican-American (%)**
First	18.4	18.9	21.6
Second	34	36.8	31.2
Third	36.3	48.9	43.8
Fourth	57	61.9	55.5
P-value (1)	<.0001	<.0001	<.0001

(1)Chi-square test comparing prevalence of MetS across quartiles of BMI or ABSI

Table 4.Prevalence of Metabolic Syndrome in different genders according to BMI and ABSI quartiles.

BMI Quartiles	**Males (%)**	**Females (%)**	**ABSI Quartiles**	**Males (%)**	**Females (%)**
First	7.2	6.4	First	13.1	21.6
Second	20.9	17.9	Second	32.1	33.9
Third	43.7	28.3	Third	37.7	37.3
Fourth	72.9	47.3	Fourth	56.9	57.4
P-value (1)	**<.0001**	**<.0001**	**P-value (1)**	**<.0001**	**<.0001**

(1)Chi-square test comparing prevalence of MetS across quartiles of BMI or ABSI.

Data in table 5 reports the results of the ORs for MetS using simple logistic regression analysis with the lowest quartiles of BMI or ABSI as the reference group. All of the ORs for corresponding quartiles of BMI were higher than for quartiles of ABSI.

Table 5.Simple Logistic regression Analysis by BMI and ABSI Quartiles.

Quartile	**Odds Ratio (95%CI)**	
	BMI	**ABSI**
1 (Lowest, reference)	1	1
2	3.9(3.1-4.9)	2.2(1.9-2.7)
3	10.7(8.4-13.7)	2.7(2.2-3.4)
4	26.6(20.3-34.8)	6(4.9-7.3)

Results of a multiple logistic regression analysis that adjusted for gender, age group, and ethnicity is shown in Table 6. These results show that compared with the first (lowest quartile) of BMI, the adjusted ORs for MetS in the second, third, and fourth BMI quartiles were 3.6, 10.9, and 31.2 times greater, respectively than the reference group (first quartile) ($p<0.05$). In contrast, the adjusted ORs for MetS in the second, third, and fourth ABSI quartiles were only 2.0, 2.1, and 3.7 times greater, respectively ($p<0.05$). The substantially lower adjusted ORs for ABSI than those for BMI indicate that BMI is

more predictive of risk for MetS than ABSI. Similarly, for the rest of the MetS risk factors (hyperglycemia, hypertriglyceridemia, hypertension, and low HDL-cholesterol), the adjusted ORs for ABSI were below those for BMI. Not surprisingly, the adjusted ORs for abdominal obesity were far greater with quartiles of BMI than for ABSI because of the high correlation between BMI and WC as well as the inclusion of WC in the calculation of ABSI. These results indicate that BMI is more predictive of each MetS risk factor than ABSI.

Table 6. Multiple logistic regression analysis of Metabolic Syndrome and risk factors by BMI and ABSI Quartiles.

Quartile		**Odds Ratio (95%CI)**				
BMI	**MetS**	**MetGLU**	**MetBP**	**MetHDL**	**MetTG**	**MetWC**
1	1	1	1	1	1	1
2	3.6(2.9-4.5)	1.8(1.4-2.2)	1.4(1.2-1.8)	1.8(1.4-2.3)	2.3(1.9-2.9)	22.5(16.4-30.7)
3	10.9(8.4-14.11)	2.3(1.9-2.9)	2.3(1.8-2.9)	3(2.3-4)	3.4(2.7-4.2)	262.4(179.9-382.9)
4	31.2(23.2-41.9)	5.1(4-6.5)	4.1(3.1-5.4)	1.8(1.4-2.3)	4.9(3.8-6.2)	>999.9(>999.9->999.9)
ABSI						
1	1	1	1	1	1	1
2	2(1.6-2.3)	1.3(1.1-1.6)	1.6(1.3-1.9)	1.5(1.2-1.8)	1.74(1.4-2.2)	2.2(1.8-2.7)
3	2.1(1.6-2.6)	1.4(1.1-1.7)	1.4(1.1-1.7)	1.4(1.1-1.7)	1.8(1.4-2.3)	4.1(3.4-5.052)
4	3.7(2.9-4.5)	2(1.7-2.5)	2(1.7-2.4)	1.9(1.5-2.3)	2.5(1.9-3.3)	8.5(6.6-10.9)

Discussion

This NHANES 2007-2012 cross-sectional study of 6,921 adults revealed that BMI could predict the risk of MetS and its individual risk factors better than ABSI in a U.S diverse population. The multiple logistic regression analysis demonstrated that the ORs for ABSI were below those for BMI after adjustment for gender, age, and ethnicity. Although all ABSI quartiles were significantly associated with prevalence of each MetS risk factor, it was not a better predictor than BMI.

To the best of our knowledge, this is the first study of a nationally representative sample of subjects in the U.S. to compare the relationship between ABSI, and BMI with risk for MetS and its individual risk factors. The only other study that studied MetS was conducted on a large adult Iranian population which also concluded that ABSI was a weaker predictor of MetS risk compared to BMI [10]. Most of the previous studies also supported the superiority of BMI over ABSI in predicting comorbidities. ABSI was weaker than BMI as a predictor of diabetes in a Chinese population [13] and hypertension in an Indonesian population [14]. ABSI was also the weaker predictor of diabetes, hypertension, and dyslipidemia in an adult Japanese population [15]. In contrast, there are studies that support the superiority of ABSI over BMI. ABSI was found to be better correlated to changes in circulating total cholesterol and insulin than BMI, yet BMI was better correlated only with circulating TGs in a study of young Polish sedentary men [9]. However, this study was limited with a small number of participants, with the same gender, ethnicity, and social status and whose mean BMI fell within the normal weight classification. In addition, waist circumference was measured at the center between the lower edge of the ribs and the iliac crest [9]. In contrast, this study and the original

Krakauer study [7] used the NHANES database where waist circumference was measured just above the uppermost lateral border of the ilium. Thus, the difference in measurement site may have contributed to the differences in the results of these studies.

A study conducted on Portuguese adolescents aged 10–17 years found ABSI, BMI and WC to be significant predictors of BP. However, ABSI was a better predictor for both systolic and diastolic blood pressure [8]. However, these results are exclusive to adolescents and therefore may not be comparable with adults. It is also worth noting that 74.2% of the Portuguese population were classified as normal weight and that blood pressure was only measured once for each participant (in contrast to the three measurements typically recorded in NHANES) which could potentially provide a less accurate assessment of blood pressure. WC was also measured at the level of the umbilicus [8]. Different WC measurements makes it difficult to compare ABSI results between study populations.

In contrast to many of the studies cited here [8–10,13–15], our study included a very diverse population. NHANES oversamples and selectively chooses participants of different ethnicities, age groups, and socio-economic statuses to provide more reliable data that could be compared in different subpopulations. This study also offers high quality data that includes both home-interviews and physical examinations collected by trained personnel, also providing the most accurate assessment of certain risks factors and diseases [11].

In Krakauer et al. [7] study introducing ABSI, they reported a stronger relationship between ABSI and mortality than with BMI. In fact, they reported that 22% of the

mortality rate was due to high ABSI values, compared to only 15% that was attributed to a high BMI value [7]. This finding is in contrast to our study which demonstrated the stronger association between increasing BMI and risk for MetS than for ABSI. These different findings may be the result of using different outcomes: mortality versus MetS. There is a J-shaped or a U-shaped relationship between BMI and mortality [16]; however the association between BMI and different metabolic risk factors found in our studies and others were linear [17]. These contrasting results are consistent with the "obesity paradox" where overweight and obese subjects with established heart disease have a lower mortality risk than normal-weight subjects. Perhaps BMI can be a stronger predictor of cardio-metabolic risk while ABSI can be more strongly associated with mortality from coronary heart disease.

Conclusion

ABSI in this U.S. population was a weaker predictor of MetS and its individual risk factors than BMI. Simple logistic and multiple regression analysis (adjusted for age, gender, and ethnicity) showed that all of the odds-ratios for ABSI were all far below those for BMI for MetS, and its risk factors.

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