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Use of BMI as Marker of Adiposity in a Metabolic Syndrome Severity Score: Derivation and Validation in Predicting Long-term Disease Outcomes

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Abstract

Background—Estimates of adiposity in evaluating the metabolic syndrome (MetS) have traditionally utilized measures of waist circumference (WC), whereas body mass index (BMI) is more commonly used clinically. Our objective was to determine if a MetS severity Z-score employing BMI as its measure of adiposity (MetS-Z-BMI) would perform similarly to a WC-based score (MetS-Z-WC) in predicting future disease.

Methods—To formulate the MetS-Z-BMI, we performed confirmatory factor analysis on a sex- and race/ethnicity-specific basis on MetS-related data for 6,870 adult participants of the National Health and Nutrition Survey 1999–2010. We then validated this score and compared it to MetS-Z-WC in assessing correlations with future coronary heart disease (CHD) and Type 2 diabetes mellitus (T2DM) using Cox proportional hazard analysis of 13,094 participants of the Atherosclerosis Risk in Communities study and Jackson Heart Study.

Results—Loading factors, which represent the relative contribution of each component to the latent MetS factor, were lower for BMI than for WC in formulating the two respective scores (MetS-Z-BMI and MetS-Z-WC). Nevertheless, MetS-Z-BMI and MetS-Z-WC exhibited similar

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AUTHOR CONTRIBUTIONS

Matthew J. Gurka and Mark D. DeBoer designed the study and planned the analysis. Matthew J. Gurka and Stephanie L. Filipp performed the analysis. Mark D. DeBoer and Matthew J. Gurka wrote the manuscript. Solomon K. Musani and Mario Sims provided editing assistance for the manuscript. Matthew J. Gurka is the guarantor of this work and had full access to the data in the study and takes final responsibility for the decision to submit for publication. All authors have read and given final approval of the manuscript.

hazard ratios (HR) toward future disease. For each one standard-deviation-unit increase in MetS-Z-BMI, HR for CHD was 1.76 (95% confidence interval [CI]: 1.65, 1.88) and HR for T2DM was 3.39 (CI 3.16, 3.63) (both p<0.0001). There were no meaningful differences between the MetS-Z-WC and MetS-Z-BMI scores in their associations with future CHD and T2DM.

Conclusions—A MetS severity Z-score utilizing BMI as its measure of adiposity operated similarly to a WC-based score in predicting future CHD and T2DM, suggesting overall similarity in MetS-based risk as estimated by both measures of adiposity. This indicates potential clinical usefulness of MetS-Z-BMI in assessing and following MetS-related risk over time.

Keywords

metabolic syndrome; cardiovascular disease risk; type 2 diabetes; obesity

INTRODUCTION

The metabolic syndrome (MetS) is a constellation of cardiovascular disease (CVD) risk factors that cluster together, likely based on underlying pathology related to cellular dysfunction and pathway-selective insulin resistance.[1–3] These clinical risk factors include central obesity, high blood pressure, high fasting triglycerides, low HDL-cholesterol and high fasting glucose. We used confirmatory factor analysis to study how the usual MetS components correlate with a single MetS “factor”, and how these correlations vary by sex and race/ethnicity. This analysis then directly provides a way to formulate a sex- and race/ethnicity-specific MetS severity Z-score (http://mets.health-outcomes-policy.ufl.edu/) based on how measurements for these MetS components cluster together among population sub-groups.[4, 5] We demonstrated that baseline levels of this MetS severity score correlated with risk of future type 2 diabetes (T2DM)[6–8] and CVD.[7, 9, 10] Moreover, changes in MetS severity score can be tracked over time[11, 12] and confer added risk for future disease,[6, 8, 9] raising the potential for such a score to be used clinically to assess and track MetS-related risk and potentially trigger intervention.

The adult version of the MetS severity score uses measurement of waist circumference (WC) as an estimate of central obesity.[4] Use of WC is frequently employed as an estimate of visceral adiposity to minimize misclassification of subcutaneous fat and lean body mass as visceral fat, which may occur when measures of body mass index (BMI) are used.[13, 14] However, assessment of WC requires a more rigorous technique and is not as frequently performed in clinical settings, potentially limiting clinical application of such a MetS severity score.[15] Use of height and WC together may provide an even better estimate[16] but faces the same potential difficulties in clinical application. By contrast, BMI is commonly measured clinically.[17] Because it is a measure of body mass and not body fat, BMI has clear potential limitations as an estimate of central adiposity.[15] Nevertheless, among a sample of US adults 20–79, BMI correlated reasonably well with both WC (Pearson’s *r* values 0.88–0.94 based on age groups and sex) and percent body fat (Pearson’s *r* values 0.7–0.86).[18] In formulating the adolescent version of the MetS severity Z-score, we utilized BMI because of a lack of standardized WC values by age; this BMI-based score correlated strongly with additional CVD risk factors (such as insulin,[5, 7] hsCRP,[5] uric acid[5] and adiponectin[7]) and

with long-term risk of T2DM[6, 7] and CVD.[7, 9, 10] This suggested that BMI may serve as a reasonable estimate of central obesity in the context of MetS severity.

The goals of this study were, using NHANES, 1) to perform a confirmatory factor analysis (CFA) in adults for MetS components similarly to what we have done previously,[4] but using BMI as the estimate of central adiposity instead of WC; 2) to compare the CFA using BMI to our prior CFA using WC; and 3) to evaluate the agreement between the two resulting factor (MetS severity) scores (MetS-Z-BMI and MetS-Z-WC, respectively). Then, our fourth and final goal was to use separate existing epidemiologic cohorts to compare MetS-Z-BMI and MetS-Z-WC with respect to their associations with future disease, specifically coronary heart disease (CHD) and T2DM. We hypothesized that when compared to the MetS severity score utilizing WC, a score employing BMI would yield similar correlation with other MetS associated CVD risk factors and with future disease. Such a score would be expected to be more useful clinically given the widespread availability of BMI.

METHODS AND MATERIALS

NHANES

For the initial goals of the study, we used the same analyses on the same dataset used to derive our adult MetS severity score using WC,[4] but substituting BMI for WC. These methods are described in detail elsewhere.[4] Specifically, we used combined two-year cycles from NHANES (1999–2010), a complex, multistage probability sample of the US population[19] conducted by the National Center for Health Statistics (NCHS) of the Centers for Disease Control (CDC). WC, SBP, and laboratory measures of triglycerides, HDL-cholesterol, and fasting glucose were obtained using standardized protocols and calibrated equipment.[19] For SBP, the mean of up to four readings taken on each individual was used. All blood samples used for analyses were obtained following a fast ≥8 hours prior to the blood draw.

Data from non-Hispanic-white, non-Hispanic-black, or Hispanic (Mexican-American/other Hispanic) participants 20–64 years old were analyzed (using race/ethnicity terminology from NHANES). For the initial CFA done previously[4] as well as here, participants were excluded if they were pregnant, had known diabetes or unknown diabetes (fasting plasma glucose >125 mg/dL), or were taking antihyperlipidemic or anti-diabetic medications, as we sought an unbiased setting of metabolic disarray and all of these situations are likely to alter lipid and insulin levels. We did not exclude those on antihypertensives, given that many of these medications are used for indications other than treatment of high blood pressure. Individuals who reported having congestive heart failure (CHF) or CHD, or ever having had a myocardial infarction (MI) or a stroke, were excluded.

Confirmatory factor analysis (CFA) is a statistical approach that analyzes how multiple individual variables correlate together in their contribution to a latent “factor.” This factor can be thought of as operating behind the scenes to influence the levels of its components, with loading factors assigned based on the strength of association between each component and the latent factor. Here, a series of one-factor CFA were performed on the five identified MetS components in adults: BMI, SBP, HDL, triglycerides, and glucose. In our previous

MetS severity derivation, we used SBP rather than both SBP and diastolic blood pressure given the two are highly correlated with each other.[20] We chose SBP given it is more strongly associated with insulin resistance[21] and other outcomes.[22] We used SBP here as well given our goal to replicate our previous analysis using BMI instead of WC. Triglycerides were log-transformed, and all variables were standardized (mean=0, SD=1) over the entire sample. The inverse of HDL was used when standardizing, so a higher factor loading score would be similar in interpretation to the other measures in the model. As in our previous study, we performed this CFA both overall and on a sex- and race/ethnicity-specific basis (because of apparent differences in traditional MetS criteria by race/ethnicity[23–29]) using SAS PROC CALIS. The variables were not standardized within groups to allow for potential overall higher standardized scores within the six individual sex- and race/ethnic-specific groups. Chi-square tests of the equality of the factor loadings across the six groups were performed. Models were compared using various fit statistics, both overall and by group. Chi-square and Akaike's Information Criteria (AIC) were used for model comparisons; smaller chi-square and AIC values indicated a better fit. Other goodness of fit indices included the Root Mean Square Error of Approximation (RMSEA; >0.06 indicates a poor fit), the Standardized Root Mean Square Residual (SRMR; >0.08 poor fit), the Goodness of Fit Index (GFI; <0.90 poor fit), and the Bentler-Bonett Normed Fit Index (NFI; <0.90 poor fit).[30] Results from the previous CFA analysis using WC were compared to results from this new CFA analysis on BMI.

The standardized factor coefficients from the BMI CFA (by group) were used to calculate the MetS factor score on each individual. This score can be interpreted as a Z-score (mean 0, SD=1), with higher scores representing an increased risk, or severity, of MetS. As was done with our MetS severity score based on WC (MetS-Z-WC), the linear association between MetS severity score based on BMI (MetS-Z-BMI) and various biomarkers associated with MetS (fasting insulin, adiponectin, hsCRP, and uric acid[4, 7, 31, 32]) was assessed via simple Pearson correlations in the 1999–2010 NHANES dataset.

Using newer NHANES data from 2011–2014, the agreement between the new MetS-Z-BMI score and the established MetS-Z-WC score was assessed via intraclass correlation coefficients (ICC's), with a value of 1 indicating perfect agreement. Bland-Altman figures were also produced, in which differences between the two scores were plotted against MetS-Z-WC.[33]

Validation: Atherosclerosis Risk in Communities (ARIC) Study & the Jackson Heart Study (JHS)

We next set out to validate this score by assessing its correlation with later risk for CHD and T2DM compared to the WC-based score in a combined cohort of the Atherosclerotic Risk in Communities (ARIC) study and Jackson Heart Study (JHS). ARIC is a large community-based epidemiological cohort study beginning in 1987–89 across 4 field centers in the US. Further details regarding study design and objectives are published elsewhere.[34] A total of 15,397 mostly white and African-American participants ages 45–64 years old were enrolled. We utilized data through Visit 5 (2011–2013), with further adjudicated CHD outcomes as described below. JHS began as an extension of African-American participants in the

Jackson, MS site of ARIC and similar methodologies were utilized. Starting in 2000–04, 5,306 participants age 21–95 years were recruited; this included 1,626 participants who had been followed as part of ARIC and for whom data from ARIC and not JHS were utilized for the present analysis.[35] For the remainder of JHS participants, we utilized data through Visit 3 (2009–2013) and further adjudicated CHD outcomes.

After combining the two cohorts (n=19,026), we excluded participants with baseline T2DM (n=2485), CHD (n=973), or stroke (n=393), and participants who were missing baseline data on MetS components (n=792), who had non-fasting labs (n=507), and/or those without follow-up data regarding outcomes (n=2,992).

MetS components were tested using similar approaches for both cohorts as described previously,[35, 36] and MetS severity Z-scores were calculated using both WC and BMI. Incident CHD was ascertained using standard ARIC and JHS protocols[37, 38] and included fatal or nonfatal hospitalized myocardial infarction, fatal CHD, silent myocardial infarction identified by electrocardiography, or coronary revascularization. Follow-up time for incident CHD events was the minimum number of days between the baseline visit and either the first event, death from other causes, last contact, or Dec 31, 2011 (JHS).[37, 38] In ARIC, participants were defined as having T2DM if they reported that a physician had told them they had diabetes, had a fasting glucose ≧126 mg/dL or a non-fasting glucose ≥ 200 mg/dL, or if they reported they were taking insulin or oral hypoglycemic medications.[39, 40] In JHS, participants were defined as having 2DM if they had a fasting glucose ≧ 126 mg/dL or an HbA1c ≥ 6.5% or if they took a diabetic medication within two weeks prior to the clinic visit. This definition of T2DM was used at Visits 1–4 for ARIC participants and at Visits 1–3 each for JHS participants. As primary interest was incident T2DM, for those individuals without T2DM at Visit 1, time to T2DM was defined as the number of years between Visit 1 and the first visit where T2DM was reported, regardless of T2DM status at subsequent visits.

Cox proportional hazards regression (via SAS PROC PHREG), adjusted for baseline age and stratified by site (4 ARIC sites + JHS), was used to model the relationship between MetS severity, both measured by MetS-Z-WC and MetS-Z-BMI, and time to incident CHD and T2DM. Hazard ratios and 95% CI's were reported, both overall and by sex and race. The ability to discriminate outcomes was quantified by the C-statistic for survival models[41] using programs developed elsewhere (http://ncook.bwh.harvard.edu/sas-macros.html); estimates and 95% Noether confidence intervals are reported. The C statistic is a measure of discrimination, which is a model's ability to distinguish individuals with and without disease. A C-statistic with a value of 1 indicates perfect discrimination. We did not account for the interval censoring associated with incident T2DM; however, given our primary goal of comparing two different MetS severity scores, any bias associated with ignoring the interval censoring would equally impact inferences made on both severity scores. We further examined and compared the ability of the two scores to predict future disease when the two scores disagreed in ARIC/JHS. We calculated the difference between the two scores and categorized the level of disagreement into four categories: 1) Differences less than 1 SD below the mean difference (when MetS-Z-BMI was much lower than MetS-Z-WC); 2) Differences greater than −1 SD but less than the mean difference (when MetS-Z-BMI was marginally lower than its WC counterpart); 3) Differences greater than the mean difference

but less than 1 SD above the mean difference (MetS-Z-BMI marginally greater than MetS-Z-WC); and 4) Differences greater than 1 SD above the mean difference (MetS-Z-BMI much greater than its WC counterpart).

RESULTS

Score Derivation: NHANES

To assess the potential for utilizing BMI as a component of the MetS severity score, we utilized data from 6,870 non-Hispanic-white, non-Hispanic-black and Hispanic adult participants of NHANES. Participant characteristics for this derivation population were published previously.[4] Table 1 displays results from the CFA comparing the MetS severity score using WC (previously published[4]) and BMI, including loading factors for each of the MetS components by sex- and racial/ethnic group. With the exception of Hispanic females, all sex and racial/ethnic subgroups had lower loading factors for the obesity component of the MetS severity score when using BMI compared to WC. These lower loading factors indicate that relative to the other MetS components, BMI had a lower contribution to the latent MetS factor than did WC. This was most striking among non-Hispanic-black males, who exhibited a decrease in loading factor from 0.67 to 0.50. This decreased loading for the obesity component of the MetS severity was likely countered by increased factors related to HDL cholesterol in all groups except non-Hispanic-black females. A sensitivity analysis performing the derivation CFA's excluding individuals on antihypertensive medications yielded similar loading factors for all components (data not shown).

Equations for score generation and internal validation in NHANES

Table 2 provides the equations generated from the CFA for calculating the MetS severity score by sex- and racial/ethnic group using BMI, but including our original WC equations for comparison[4]. Among NHANES 1999–2010 participants, the BMI-based MetS severity score correlated with additional CVD risk factors including insulin, hsCRP, and uric acid (Pearson's R values: 0.61, 0.38, 0.42, respectively; all $p<0.0001$), as had similarly been noted for the WC-based score.[4]

Figure 1 displays Bland-Altman plots from separate subsequent cycles of NHANES (2011–2014; n = 2,211) after calculating the two MetS severity scores using the equations listed in Table 2. These plots, as well as the ICC values, demonstrate a high degree of agreement between the two scores by sex and racial/ethnic group, with ICC values all 0.963–0.996. There appears to be a systematic decrease in agreement between the two scores for non-Hispanic blacks, particularly among females, with the MetS score based on BMI tending to underestimate MetS severity based on WC for larger values of the WC-based score.

Disease outcomes score validation: ARIC and JHS

As an essential step of validation, we subsequently assessed the validity of the BMI-based MetS severity score by comparing to the WC-based score for prediction of future CHD and T2DM in Cox regression models from a combined cohort of participants of ARIC and JHS (n = 13,094). Further details regarding participant characteristics and disease outcome incidence have been published previously.[8, 10] Table 3 displays HRs for disease incidence

for every 1 standard deviation increment of the BMI- and WC-based MetS severity scores overall and by sex- and racial/ethnic group. The BMI-based score was significantly correlated to both future CHD and T2DM overall, with each increase of 1 standard-deviation unit in the MetS Severity score associated with significantly ($p<0.001$) increased risk (HR, 95%CI) for CHD [1.78, (1.67, 1.90)] and for T2DM [3.37 (3.15, 3.61) The HRs by sex- and racial subgroup for the BMI-based score were similar to those seen for the WC-based score (Table 3). C-statistics confirmed similar discriminatory ability between the two MetS severity scores with respect to both outcomes. For incident CHD, the C-statistic was equal to 0.63 for both versions of the MetS severity score; for incident T2DM, the C-statistic was equal to 0.75 and 0.74 for MetS-Z-WC and MetS-Z-BMI, respectively. We then examined and compared performance of these two scores for various levels of disagreement (Supplementary Table 1). When there was a strong negative disagreement between scores (i.e., the BMI-based score was lower than the WC-based score), the scores remained similar in predicting CVD (overall HR 1.33 and 1.36 for the WC- and BMI-based scores, respectively), while there was a tendency for the BMI-based score to perform better for T2DM prediction (overall HR 3.00 and 3.31 for the WC- and BMI-based scores, respectively). When there was a strong positive disagreement between scores (i.e., the BMI-based score was higher than the WC-based score), the scores were again similar in predicting CVD (overall HR 1.68 and 1.66 for the WC- and BMI-based scores, respectively), while there was a tendency for the WC-based score to perform better for T2DM prediction (overall HR 4.34 and 3.78 for the WC- and BMI-based scores, respectively). When there was only weak disagreement between the scores, the HR's were nearly identical between scores.

DISCUSSION

We demonstrated that a MetS severity scoring system using BMI as an indicator of adiposity provided similar predictive power for future disease as did the score based on WC. Whereas assessment of WC is technically more difficult and time-consuming and is rarely a codified field in electronic health record (EHR) systems, BMI is routinely measured on a clinical basis and is a codified value in the EHR, increasing the opportunity for MetS severity to be automatically calculated by an EHR system.[17] Thus, the availability and comparable performance of the BMI-based score may increase the potential for such a score to be used as a clinical tool that represents a single metric of metabolic disarray and assists in risk assessment—and could be used as an indicator of particularly high risk and need for further intervention. For example, Cefalu at al suggested recommending bariatric surgery on pre-diabetes patients with high BMI.[42] Given difficulties in determining metabolic risk from obesity alone, a MetS severity score above a given cut-off could be used to divide patients in greater need of bariatric surgery in these settings. Because risk exists on a spectrum, such a score could also identify individuals for intervention at earlier degrees of risk, including initiation of metformin or aspirin—though clearly, validation studies would be necessary.

It was perhaps not surprising that the loading weights for BMI were all lower than for WC, leading to a lower relative contribution of the obesity component for the BMI-based MetS severity equations. This may relate to WC being an overall better indicator of visceral obesity, which is considered a key etiologic component of MetS.[13] The widest differences in

loading factors between BMI and WC and the lowest ICC values were among black males, potentially due to a greater misattribution of higher BMI to fat vs. lean mass.[43] Nevertheless, the differences in loading factors between BMI and WC did not appear to be a limitation of the score. Indeed, despite changes in the factor loadings using BMI, the relative order of the obesity measures between racial/ethnic groups remained the same, supporting that both adiposity estimates provided similar information—but that in its contribution to the latent MetS factor, BMI was less dominant among all of the MetS components. Overall, the lower contribution of BMI to the MetS severity score did not significantly affect the association of MetS severity with future disease, emphasizing the importance of the combination of each of the components. The BMI-based score instead had higher factor loadings for HDL for most sex- and racial/ethnic subgroups. This is notable given recent skepticism as to the role of HDL in modifying disease outcomes.[44] Nevertheless, this increased emphasis on HDL in the BMI-based score is consistent with HDL being a component of multiple risk scores for CVD[45, 46] and T2DM[39, 47] and may have contributed to the non-significant elevations in HR's for future CHD and T2DM using the BMI-based score.

Unfortunately, NHANES investigators only performed a more direct measure of body fat—dual energy X-ray absorptiometry—in a subset of participants, limiting our ability to perform a similar CFA using body fat alone. Nevertheless, studies that have been performed comparing DXA-measured body fat, BMI and WC in the sample population have shown relatively close correlations.[18] Even more specific tests of visceral fat such as CT-based assessment of truncal fat may have provided greater precision regarding central adiposity[48] —but would further limit clinical application.

This set of experiments had several limitations. For the derivation of the MetS severity score we used cross-sectional data and assumed one latent "MetS" factor with all 5 traditional MetS components instead of using a more exploratory approach that allowed for multiple factors. Nevertheless, our assumption of a single factor was supported by a large body of prior research.[21, 49, 50] [[[Remove #48 to stay at 50 REFS]]] For the outcomes-based validation, we utilized cohorts that were followed from 1987 for ARIC and 2000 for JHS; interval advances in CHD prevention may render these results different from current studies of predictive risk. The definitions of incident diabetes in this study could have applied equally to Type 1 diabetes and T2DM. While it was T2DM that we were predominantly interested in, inclusion of Type 1 diabetes may have been expected to biased us against associations between the score and new Type 1 diabetes. While we excluded participants on antidiabetic and antihyperlipidemic medications in deriving these scores, we lacked adequate data regarding treatment with MetS components. This study only included white and black participants, while studies of this score in Hispanics and other racial/ethnic groups remains needed. In particular, assessment of differences in contribution of WC and BMI to such a score would be instructive, given that lipid abnormalities occur at a much lower BMI among South Asian individuals.[28] Finally, future validation will be needed alongside other predictive scores such as the Framingham calculator,[46] the American Heart Association Atherosclerotic Cardiovascular Disease score [45] and the American Diabetes Association prediction score.[47] However, this study had several strengths, including use of separate derivation and validation cohorts and comparison of the new BMI-based MetS severity score to the WC-based score in the prediction of long-term disease outcomes.

In conclusion, we used CFA to generate MetS severity scores that are based not on WC but on BMI—a much more clinically available measure. This score varied by sex and race/ethnicity and strongly correlated with future CHD and T2DM. These data support MetS severity as a tool that could potentially be used in the EHR to follow risk within individuals over time, both as a motivator to change and a way to track response to preventative treatments.

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Highlights

- Waist circumference is often used in classifying metabolic syndrome (MetS), but BMI is more often collected and recorded in clinical settings.
- We developed a measure of MetS severity that uses BMI instead of WC.
- We show that MetS severity using BMI predicts future disease as well as the measure that uses WC.
- MetS severity using BMI has much greater clinical potential than the measure using WC.

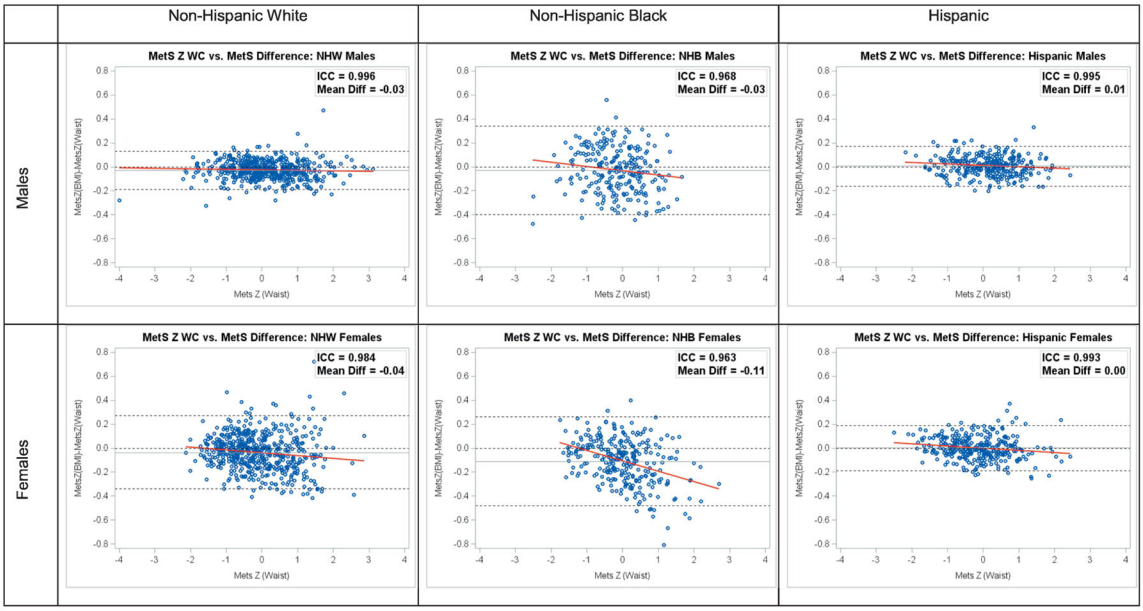

Figure 1.
Bland Altman Plots MetS Difference by Race/Ethnicity and Gender Groups

Table 1

Confirmatory Factor Analysis Results (Adults age 20–64, n = 6,870)*

	Measure of Obesity: Waist Circumference							Measure of Obesity: BMI						
		Males			Females				Males			Females		
Model Fit Indices	**Overall**	**NHW**	**NHB**	**Hisp**	**NHW**	**NHB**	**Hisp**	**Overall**	**NHW**	**NHB**	**Hisp**	**NHW**	**NHB**	**Hisp**
Chi-square (df)	783.0 (30)							764.6 (30)						
Akaike's Information Criteria (AIC)	903.0							884.6						
Root Mean Square Error of Approximation (RMSEA)	0.148							0.146						
Standardized Root Mean Square Residual (SRMR)	0.071	0.075	0.069	0.080	0.065	0.080	0.056	0.070	0.070	0.063	0.076	0.067	0.083	0.059
Goodness of Fit Index (GFI)	0.956	0.952	0.957	0.950	0.958	0.948	0.969	0.958	0.958	0.967	0.954	0.956	0.945	0.965
Bentler-Bonett Normed Fit Index (NFI)	0.817	0.810	0.785	0.792	0.845	0.729	0.862	0.809	0.824	0.809	0.802	0.824	0.654	0.843
Factor Loadings	p-value*							p-value*						
Measure of Obesity	< 0.001	**0.49**	**0.67**	0.36	**0.71**	**0.77**	**0.45**	< 0.001	**0.41**	**0.50**	0.32	**0.69**	**0.73**	**0.48**
SBP	< 0.001	0.17	0.16	0.19	0.33	0.31	0.38	< 0.001	0.15	0.08	0.18	0.34	0.34	0.38
HDL	< 0.001	**0.60**	**0.64**	**0.57**	**0.52**	**0.40**	**0.45**	< 0.001	**0.62**	**0.74**	**0.59**	**0.54**	0.38	**0.46**
Triglycerides	< 0.001	**0.73**	**0.45**	**0.70**	**0.56**	0.37	**0.59**	< 0.001	**0.72**	**0.48**	**0.69**	**0.55**	0.36	**0.58**
Glucose	< 0.001	0.26	0.37	0.27	**0.46**	**0.46**	**0.44**	< 0.001	0.25	0.31	0.27	**0.45**	**0.47**	**0.45**

*Chi-square test (5 df) p-value of the equivalency of the factor loadings across the six groups

NHW = Non-Hispanic White; NHB = Non-Hispanic Black; Hisp = Hispanic

Table 2

Equations for Sex and Race/Ethnic-Specific Metabolic Syndrome Risk Z-Score

Using WC
Males
Non-Hispanic White = −5.4559 + 0.0125 * WC − 0.0251 * HDL + 0.0047 * SBP + 0.8244 * ln(Tri) + 0.0106 * Glu
Non-Hispanic Black = −6.3767 + 0.0232 * WC − 0.0175 * HDL + 0.0040 * SBP + 0.5400 * ln(Tri) + 0.0203 * Glu
Hispanic = −5.5541 + 0.0135 * WC − 0.0278 * HDL + 0.0054 * SBP + 0.8340 * ln(Tri) + 0.0105 * Glu
Females
Non-Hispanic White = −7.2591 + 0.0254 * WC − 0.0120 * HDL + 0.0075 * SBP + 0.5800 * ln(Tri) + 0.0203 * Glu
Non-Hispanic Black = −7.1913 + 0.0304 * WC − 0.0095 * HDL + 0.0054 * SBP + 0.4455 * ln(Tri) + 0.0225 * Glu
Hispanic = −7.7641 + 0.0162 * WC − 0.0157 * HDL + 0.0084 * SBP + 0.8872 * ln(Tri) + 0.0206 * Glu
Using BMI
Males
Non-Hispanic White = −4.8316 + 0.0315 * BMI − 0.0272 * HDL + 0.0044 * SBP + 0.8018 * ln(Tri) + 0.0101 * Glu
Non-Hispanic Black = −4.8134 + 0.0460 * BMI − 0.0233 * HDL + 0.0020 * SBP + 0.5983 * ln(Tri) + 0.0166 * Glu
Hispanic = −4.8198 + 0.0355 * BMI − 0.0303 * HDL + 0.0051 * SBP + 0.7835 * ln(Tri) + 0.0104 * Glu
Females
Non-Hispanic White = −6.5231 + 0.0523 * BMI − 0.0138 * HDL + 0.0081 * SBP + 0.6125 * ln(Tri) + 0.0208 * Glu
Non-Hispanic Black = −6.7982 + 0.0484 * BMI − 0.0108 * HDL + 0.0073 * SBP + 0.5278 * ln(Tri) + 0.0281 * Glu
Hispanic = −7.1844 + 0.0333 * BMI − 0.0166 * HDL + 0.0085 * SBP + 0.8625 * ln(Tri) + 0.0221 * Glu

Table 3

MetS-WC vs. MetS-BMI: Predicting Incident CHD and T2DM in ARIC and JHS

	MetS Z-score (Waist Circumference)		MetS Z-Score (BMI)	
	Hazard Ratio (95% CI)*	**C-Statistic (95% CI)****	**Hazard Ratio (95% CI)***	**C-Statistic (95% CI)****
Incident CVD				
Overall	1.72 (1.61, 1.83)	0.63 (0.62, 0.64)	1.78 (1.67, 1.90)	0.63 (0.62, 0.64)
Non-Hispanic White Males	1.50 (1.37, 1.64)	0.58 (0.57, 0.60)	1.52 (1.39, 1.66)	0.58 (0.57, 0.60)
Non-Hispanic White Females	1.73 (1.54, 1.95)	0.64 (0.61, 0.66)	1.81 (1.60, 2.05)	0.64 (0.61, 0.66)
Non-Hispanic Black Males	1.65 (1.33, 2.04)	0.60 (0.56, 0.65)	1.60 (1.29, 1.99)	0.59 (0.55, 0.64)
Non-Hispanic Black Females	1.55 (1.26, 1.90)	0.62 (0.57, 0.67)	1.63 (1.29, 2.05)	0.61 (0.56, 0.66)
Incident T2DM				
Overall	3.27 (3.06, 3.50)	0.75 (0.73, 0.76)	3.37 (3.15, 3.61)	0.74 (0.73, 0.76)
Non-Hispanic White Males	2.71 (2.37, 3.10)	0.70 (0.68, 0.73)	2.68 (2.35, 3.06)	0.70 (0.67, 0.72)
Non-Hispanic White Females	4.61 (4.04, 5.27)	0.81 (0.79, 0.84)	4.86 (4.24, 5.57)	0.82 (0.80, 0.84)
Non-Hispanic Black Males	2.89 (2.48, 3.38)	0.72 (0.69, 0.75)	2.74 (2.30, 3.25)	0.69 (0.66, 0.72)
Non-Hispanic Black Females	3.14 (2.78, 3.56)	0.76 (0.74, 0.78)	3.50 (3.08, 3.98)	0.76 (0.74, 0.78)

*Adjusted for baseline age and stratified by center

**10-Year Risk; Noether Confidence Intervals (unadjusted)