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Comparing adiposity-related predictors of cardiometabolic disease in two Indigenous Guatemalan municipalities: a cross-sectional receiver operating characteristic analysis

Stephen Alajajian ,[1] Peter Rohloff[1,2]

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[1]Center for Indigenous Health Research, Wuqu' Kawoq | Maya Health Alliance, Tecpán, Guatemala
[2]Division of Global Health Equity, Brigham and Women's Hospital, Boston, Massachusetts, USA

Correspondence to
Stephen Alajajian;
stephen@wuqukawoq.org

ABSTRACT

Objectives (1) To compare the ability of body mass index (BMI), waist-to-height ratio and visceral fat, as measured by bioelectrical impedance analysis (BIA), to predict hypertension and diabetes in men and women and (2) to determine whether the correlation between BMI and visceral fat varies by height quantile.

Design We conducted a cross-sectional analysis of a representative survey that included data on anthropometrics, body composition, glycosylated haemoglobin and blood pressure. We used receiver operating characteristic analysis and DeLong CIs to compare the ability of each adiposity measure to predict diabetes and hypertension in each gender.

Setting Tecpán and San Antonio Suchitepéquez, Guatemala.

Participants 806 non-pregnant adults from 347 households, primarily of Indigenous ethnicity.

Primary outcome measures Diabetes, defined as a haemoglobin A1c of greater than 6.5% or self-reported history and hypertension, defined as a systolic blood pressure over 140 or a diastolic blood pressure over 90.

Results Among the three adiposity measures, visceral fat was the best predictor of diabetes (area under the curve; AUC 0.73 (95% CI 0.66 to 0.81) (men); AUC 0.75 (95% CI 0.7 to 0.8) (women)) and hypertension (AUC 0.7 (95% CI 0.61 to 0.79) (men); AUC 0.76 (95% CI 0.7 to 0.82) (women)), followed by waist-to-height ratio followed by BMI. All three measures better predicted hypertension in women than in men. In sensitivity analysis, visceral fat and waist-to-height ratio better predicted hypertension and diabetes when BMI was below 30 kg/m^2. The correlation between BMI and visceral fat did not vary appreciably by height.

Conclusions Of the three adiposity measures studied, BIA-derived visceral fat best predicted cardiometabolic disease in the population. In clinical practice, alternative techniques beyond BMI need to be considered when assessing adiposity, screening for cardiometabolic disease and diagnosing clinical obesity.

STRENGTHS AND LIMITATIONS OF THIS STUDY

⇒ The study's main methodological strength was the use of receiver operating characteristic analysis with DeLong CIs and the Index of Union method, permitting rigorous, gender-specific comparison of predictive ability and determination of optimal cut-off points across three adiposity measures.
⇒ Additional strengths included a large sample size, the use of data from a representative sampling frame, the inclusion of two cardiometabolic conditions and the use of sensitivity analysis for different body mass index and height thresholds.
⇒ Data are population-specific and generalisability to broader populations is limited.
⇒ Additional limitations include over-representation of women in the sample, unavailability of waist-to-hip ratio and hip circumference data, use of a non-gold standard method of measuring visceral fat, the cross-sectional nature of the study design and the possibility of type II error.

INTRODUCTION

The prevalence of cardiometabolic disease is increasing globally due largely to shifts in dietary and lifestyle patterns.[1 2] Abdominal obesity is a condition of excess visceral fat accumulation and plays an especially important role in cardiometabolic disease development. It is closely linked with a constellation of characteristics that include dyslipidaemia, hypertension, insulin resistance and hyperglycaemia.[1] Visceral fat, as measured by CT scan or MRI, is an independent risk marker for cardiometabolic disease and associated death.[2]

It has been proposed that the accumulation of visceral fat largely explains the connection between obesity and chronic disease.[3] The liver generates fat in the form of triglycerides from excess calories. Fat accumulation in and around the liver leads to abnormalities in liver metabolism that drive insulin resistance and dyslipidaemia.[3] Excess fat deposition into adipocytes leads to an inflammatory state in which proinflammatory cytokines are released into the blood, driving insulin resistance and contributing to the pathogenesis of hypertension and diabetes.[1 3] Given that visceral fat accumulation may not always coincide with body mass index (BMI), it is possible for a person to be categorically obese, as traditionally defined by BMI, and metabolically healthy, or vice versa.[2]

A measure of adiposity is clinically useful in so much as it can predict adverse health outcomes. BMI, which is calculated by dividing the weight of an individual in kilograms by height in metres squared, is widely used in clinical practice as a proxy for metabolic health but has several limitations. First, BMI was developed as a metric to assess the health of populations, not individuals. Therefore, the cut-offs provided to define underweight and overweight in populations may not be appropriate for individuals. Second, optimal BMI cut-offs vary by population given body type differences across populations.[4] Third, BMI does not provide any information about body composition or differentiate among the contributions of muscle mass, subcutaneous fat and visceral fat to body weight.

Alternative measures of adiposity include waist circumference, waist-to-hip ratio, waist-to-height ratio and visceral fat mass, which can be measured or estimated using a variety of direct and indirect techniques including CT scan, MRI, dual energy X-ray absorptiometry (DXA) and ultrasound-derived intra-abdominal thickness. Bioelectrical impedance analysis (BIA) is a practical and cost-effective method of measuring visceral fat, making it a feasible option for clinical practice in lower resource settings, but it may be less accurate than other methods.[5] Waist circumference, waist-to-hip ratio and visceral fat have been shown in various contexts to be superior to BMI in predicting cardiometabolic disease.[1 6 7] However, a recent meta-analysis covering eight world regions found similar predictive ability for hypertension between BMI and waist-to-height ratio using receiver operating characteristic (ROC) analysis.[4] Thus, the optimal adiposity-related predictor of cardiometabolic disease may be population specific.

Guatemala, a middle-income Latin American country in which nearly half the population is Indigenous, has recently seen rising prevalence of chronic disease, including diabetes and hypertension.[8] Guatemala has one of the lowest average adult statures in the world.[9] Optimal BMI and waist circumference cut-off points for cardiometabolic risk were previously studied in a population of non-Indigenous Guatemalans.[10] Optimal cut-off points for waist circumference, but not for BMI, varied by stature, with shorter individuals being optimally classified as at risk for cardiometabolic disease at lower waist circumference.[10] However, little is known about adiposity-related predictors of cardiometabolic disease in the Indigenous population of Guatemala. Furthermore, optimal cut-off points are lacking in Indigenous populations throughout the Americas.

The prevalence of stunting in Guatemala is significantly higher among the Indigenous population.[11] Lower stature among Indigenous Guatemalans could alter the functionality of adiposity measures, especially those that take height into consideration and especially at the lower extremes of height. For example, in individuals with very low stature, BMI might not correlate as well with visceral fat and therefore might be less able to predict cardiometabolic disease. Furthermore, there is evidence that stunting is associated with alterations in body composition and cardiometabolic health later in life, which could lead to important differences between stunted and non-stunted populations in regard to the relationship between measures of adiposity and cardiometabolic disease.[12]

Given the unique characteristics of the Indigenous population of Guatemala, the lack of previous research in this area, and the need for population-specific approaches to assessing excess adiposity for the detection and prevention of cardiometabolic disease, we set out to compare three measures of adiposity using data from a representative sample taken from two agrarian and predominantly Indigenous Guatemalan municipalities: Tecpán and San Antonio Suchitepéquez. The data were collected as part of a chronic kidney disease (CKD) prevalence study. The three measures of adiposity available from the data were waist-to-height ratio, visceral fat, as measured by BIA and BMI. Our objectives were to (1) compare the ability of BMI, waist-to-height ratio and visceral fat to predict hypertension and diabetes in men and women using ROC analysis and (2) to determine whether the correlation between BMI and visceral fat varies by height quantile.

METHODS

Overview

We conducted a secondary cross-sectional analysis of a previously reported representative survey of two agricultural municipalities, Tecpán and San Antonio Suchitepéquez, which had been undertaken to determine regional CKD prevalence.[13] Ethics approval was given by the institutional review boards of Maya Health Alliance (WK 2018 001), the Institute for Nutrition of Central America and Panama (CIE REV 075/2018) and Partners Healthcare (2017P002476). Original data were collected between June 2018 and October 2019 by field nurses trained in phlebotomy, anthropometry and survey techniques. Non-pregnant adults at least 18 years of age were eligible to participate. Participants were randomly selected from a sampling frame generated by Epicentre's GeoSampler tool (https://epicentre.msf.org/), which identifies human structures by satellite imaging. Additional description of the municipalities and details of the sampling methods and sample size calculation for the original study are available elsewhere.[13] In total, data were available for 806 individuals from 347 households. We did not conduct a power calculation specifically for this analysis given that the sample size was already fixed.

Patient and public involvement

Patients and the public were not involved in the design, conduct, reporting or dissemination plans of the research.

Variables and data collection

Demographic data collected included age, poverty level, gender, education level, preferred language and self-reported ethnicity. Poverty level was assessed using Quick Poverty Score (QPS), which uses asset ownership to predict probability of poverty.[14] Raw QPS scores were grouped into quantiles. Anthropometric data were collected in triplicate and included weight, height and waist circumference. Waist circumference was measured around the narrowest portion of the torso.[15] Waist-to-height ratio was calculated by dividing waist circumference in centimetres by height in centimetres.[16] BMI was calculated by dividing weight in kilograms by height in metres squared.[17]

Additional data collected included visceral fat, glycosylated haemoglobin (Hgb A1c), systolic and diastolic blood pressure and disease history. Visceral fat was measured by BIA using Tanita BC-558 body composition scale,[18] which measures visceral fat on a proprietary scale ranging from 1 through 59 with each integer corresponding roughly to an MRI-based fat area of 10 cm^2.[19] The measurement is taken by having the participant step onto the scale platform while gripping the hand-electrodes and keeping his or her arms perpendicular to the ground.[18] Visceral fat measurement via BIA was chosen for its low cost, ease of use and practicality in low-resource settings though it may produce less accurate estimations of body composition than other measures.[5] Glycosylated haemoglobin was measured from samples of blood serum using the Roche Cobas c111 analyser.[20] Diabetes was defined as a HgbA1c of greater than 6.5%[21] or self-reported history. Hypertension was defined as a systolic blood pressure over 140 or a diastolic blood pressure over 90.[22] In this analysis, diabetes and hypertension were the outcomes of interest, BMI, visceral fat and waist-to-height ratio were the predictor variables of interest, and age and gender were potential confounders. Data were missing for 3% or fewer of observations for all variables of interest, and thus missing data were not imputed.

Statistical analysis

R V.4.4.1 and RStudio 'Chocolate Cosmos' and 'Kousa Dogwood' were used for all analyses, and *ggplot2* was used for all data visualisations. Descriptive reporting of sample characteristics was carried out using the *gt* (grammar of tables) and *gtsummary* packages. Median and IQR were reported for quantitative variables and percentages alongside CIs were reported for qualitative variables. Histograms were generated of BMI, visceral fat and waist-to-height ratio, separated by gender. Scatter plots were generated for BMI against waist-to-height ratio and against visceral fat, separated by gender, and for BMI against visceral fat for eight quantiles of height using the *facet_wrap* function. Pearson's correlation coefficients were calculated for each comparison. An independent two-sample t-test was used for comparisons of normally distributed adiposity measures by gender. Otherwise, Wilcoxon rank-sum test was used. χ^2 test was used to compare prevalence of hypertension and diabetes by gender.

ROC curves were generated by fitting a univariate logistic regression model to each outcome variable of interest using each measure of adiposity as the predictor variable, then extracting and plotting ROC data from the fitted values of the model using the *pROC* package. These plots were generated separately for each gender. The Index of Union method was used to determine the optimal cut-off point for each predictor, along with associated sensitivity and specificity. The Index of Union is defined as the sum of the absolute value of the difference between sensitivity and area under the curve (AUC) and the absolute value of the difference between specificity and AUC, and the Index of Union method identifies the optimal cut-off point as the point at which the Index of Union is least.[23] DeLong CIs, which are statistical estimates of the range in which the true AUC for the population is likely to fall, were calculated for each AUC value. DeLong's test, a statistical test for comparing AUC models,[24] was used to determine whether predictive models that used waist-to-height ratio and visceral fat were statistically different from those that used BMI. Sensitivity analyses were conducted using subsets of the sample that included only individuals with BMI <30 kg/m^2 or BMI <25 kg/m^2 and for tertiles of height for each gender. The decision to conduct these sensitivity analyses was made in light of evidence that BMI or height could influence the predictive ability of adiposity markers in certain populations or subpopulations.[6 10 25]

RESULTS

The sample consisted of 806 observations from 347 households in the agrarian municipalities of San Antonio Suchitepéquez and Tecpán. A flowchart of recruitment and enrolment for the survey along with reasons for non-participation at each stage was previously reported.[13] The sample was predominantly Indigenous and Spanish-speaking and included more women (n=526) than men (n=280), as shown in table 1. Median age was 38 and 36 years old for men and women, respectively. Probability of poverty was greater than 75% for 11% of women and 15% of men. Compared with women, men more commonly smoked (21% vs 1.5%) or had consumed alcohol in the past year (48% vs 19%). Data were missing for age (n=4), poverty (n=10), smoking (n=6), alcohol use (n=5), height (n=8), BMI (n=12), waist circumference (n=15), visceral fat (n=25), diabetes (n=14) and hypertension (n=9).

For both men and women, distributions of BMI and waist-to-height ratio were approximately normal, and the distribution of visceral fat was right skewed as shown in figure 1. Women on average had higher BMI than men (28.0 kg/m^2 vs 25.7 kg/m^2) (p<0.01), whereas men had higher median visceral fat scores than women (8.0 vs 6.0) (p<0.01). Waist-to-height ratio was greater for women

Table 1 Characteristics of a representative sample of two agrarian and Indigenous municipalities in Guatemala

Characteristic	Female N=526*	95% CI	Male N=280*	95% CI	P value†
Age	36 (25, 51)		38 (26, 53)		0.2
Indigenous/Maya ethnicity	395 (75%)	71% to 79%	213 (76%)	71% to 81%	0.8
Prefers Mayan language	84 (16%)	13% to 19%	36 (13%)	9.3% to 17%	0.2
Probability of poverty>75%	57 (11%)	8.5% to 14%	42 (15%)	11% to 20%	0.089
Current smoking	8 (1.5%)	0.71% to 3.1%	58 (21%)	17% to 26%	<0.001
Alcohol intake past year	99 (19%)	16% to 23%	132 (48%)	42% to 54%	<0.001
Height (cm)	146 (142, 150)		158 (154, 163)		<0.001
Body mass index (kg/m^2)	27.4 (24.0, 31.8)		25.7 (22.5, 28.8)		<0.001
Waist circumference (cm)	91 (83, 99)		92 (83, 98)		0.3
Waist-to-height ratio (WHtR)	0.62 (0.57, 0.68)		0.57 (0.53, 0.61)		<0.001
Visceral fat (Tanita, 1–59)	6.0 (3.0, 9.0)		8.0 (4.0, 11.0)		<0.001
Diabetes	82 (16%)	13% to 19%	38 (14%)	10% to 19%	0.5
Hypertension	43 (8.2%)	6.1% to 11%	35 (13%)	9.2% to 17%	0.040

*Median (Q1, Q3); n (%).
†Wilcoxon rank sum test; Pearson's Chi-squared test; Welch two sample t-test.

than for men (0.62 vs 0.57) (p<0.01). Diabetes and hypertension prevalences for men and women are shown in table 1. Diabetes prevalence did not differ significantly between men (14%) and women (16%) (p=0.5), but hypertension prevalence was higher in men than in women (13% vs 8.2%) (p=0.04).

BMI was closely correlated with both waist-to-height ratio (r=0.83) and visceral fat (r=0.64) as shown in figure 2. The strength of the correlation between BMI and visceral fat was stronger for women (r=0.75) than for men (r=0.66), while the slope of the correlation was higher for men (m=0.74) than for women (m=0.55). Consequently, men tended to have more visceral fat than women at the same BMI. There was no obvious difference in the correlation between BMI and visceral fat at the extremes of height as shown in figure 3. The Pearson correlation coefficient (r) remained within the range of 0.65–0.79 for all quantiles of height, with no apparent trend up or down with increasing quantiles of height.

Among the three adiposity measures, visceral fat was the best predictor of diabetes and hypertension among men and women, followed by waist-to-height ratio, followed by BMI (figure 4). Visceral fat, but not waist-to-height ratio, showed a statistically significant improvement in performance over BMI in its ability to predict diabetes in men (AUC=0.73 (95% CI 0.66 to 0.81) vs 0.64 (95% CI 0.56 to 0.73), p=0.01) and women (AUC=0.75 (95% CI 0.7 to 0.8) vs 0.6 (95% CI 0.53 to 0.67), p<0.01), and in its ability to predict hypertension in women (AUC=0.76 (95% CI 0.7 to 0.82) vs 0.63 (95% CI 0.54 to 0.71), p=0.01) (table 2). All three measures of adiposity were better predictors of hypertension in women than in men (AUC of 0.63 (95% CI 0.54 to 0.71) vs 0.59 (95% CI 0.49 to 0.69) for BMI; 0.67 (95% CI 0.6 to 0.75) vs 0.64 (95% CI 0.55 to 0.74) for waist-to-height ratio; and 0.76 (95% CI 0.7 to 0.82) vs 0.7 (95% CI 0.61 to 0.79) for visceral fat), while ability to predict diabetes was similar in men and women (figure 4).

Optimal cut-off values for BMI were higher for women than for men in the ROC curves for both diabetes and hypertension, as shown in table 2. The optimal cut-off value for BMI was 28 kg/m^2 for women versus 25.6 kg/m^2 for men for prediction of diabetes, and 28 kg/m^2 for women versus 26.5 kg/m^2 for men for prediction of hypertension, though sensitivity and specificity for BMI were generally poor. However, the optimal cut-off value for visceral fat was markedly higher for men than for women (9.5 for men vs 6.5 for women on the Tanita scale for both diabetes and hypertension). Visceral fat and waist-to-height ratio performed better than BMI in the ROC curves but still yielded sensitivities and specificities that were below 0.8 for both men and women for both hypertension and diabetes in the main analysis.

In sensitivity analyses that included only non-obese individuals (BMI<30 kg/m^2), visceral fat and waist-to-height ratio were better predictors of diabetes and hypertension than in the main analysis (online supplemental figure 1). AUC for diabetes with visceral fat as the predictor increased from 0.75 to 0.8 in women and from 0.73 to 0.75 in men. AUC for hypertension with visceral fat as the predictor increased from 0.76 to 0.82 in women and from 0.7 to 0.72 in men. When only individuals with BMI <25 kg/m^2 were included, visceral fat was an even better predictor of diabetes and hypertension in women, with AUC increasing to 0.85 for diabetes and 0.9 for hypertension, but the same improvement in AUC was not observed in men (online supplemental figure 2). No clear trend was found in the sensitivity analysis by height

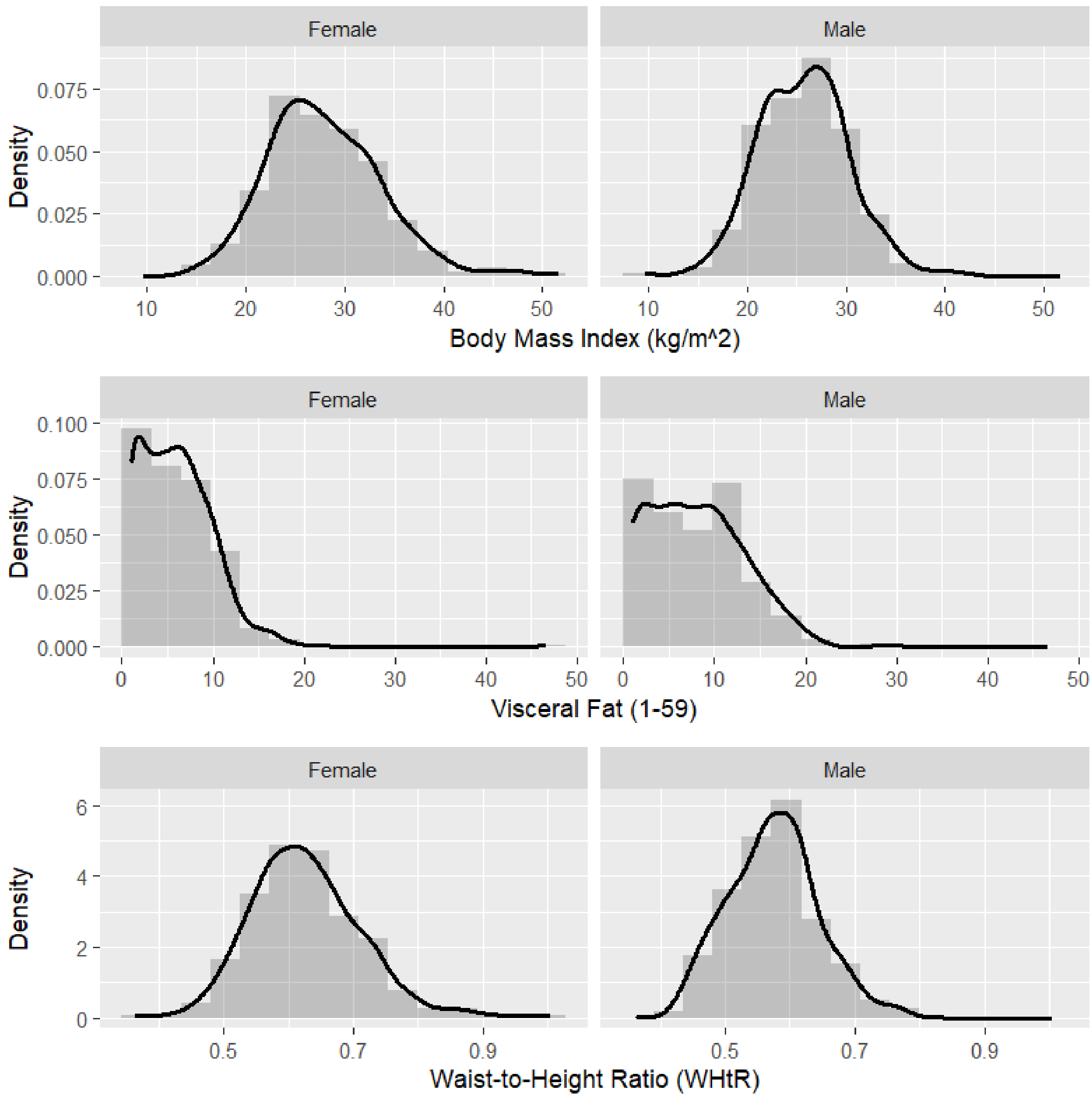

Figure 1 Histograms of body mass index, visceral fat and waist-to-height ratio in men and women from a representative sample of two agrarian and Indigenous municipalities in Guatemala.

tertiles for either gender (online supplemental figures 3 and 4).

DISCUSSION

In a representative sample of 806 individuals from two agrarian and Indigenous Guatemalan municipalities, BMI was closely correlated with both waist-to-height ratio and visceral fat, as measured by BIA. The correlation between BMI and visceral fat did not vary appreciably over increasing quantiles of height. ROC curves demonstrated that of the three measures, visceral fat best predicted diabetes and hypertension in both men and women, followed by waist-to-height ratio, followed by BMI. In three out of four scenarios, visceral fat was a statistically better predictor of cardiometabolic disease than BMI. All three measures better predicted hypertension in women than in men. In sensitivity analysis, waist-to-height ratio and visceral fat better predicted hypertension and diabetes when BMI was below 30 kg/m^2.

A major strength of our study is that it addresses the need for population-specific approaches to assessing excess adiposity that extend beyond the limitations of BMI.[26] To our knowledge, it is the first study to investigate visceral fat as a cardiometabolic disease predictor and

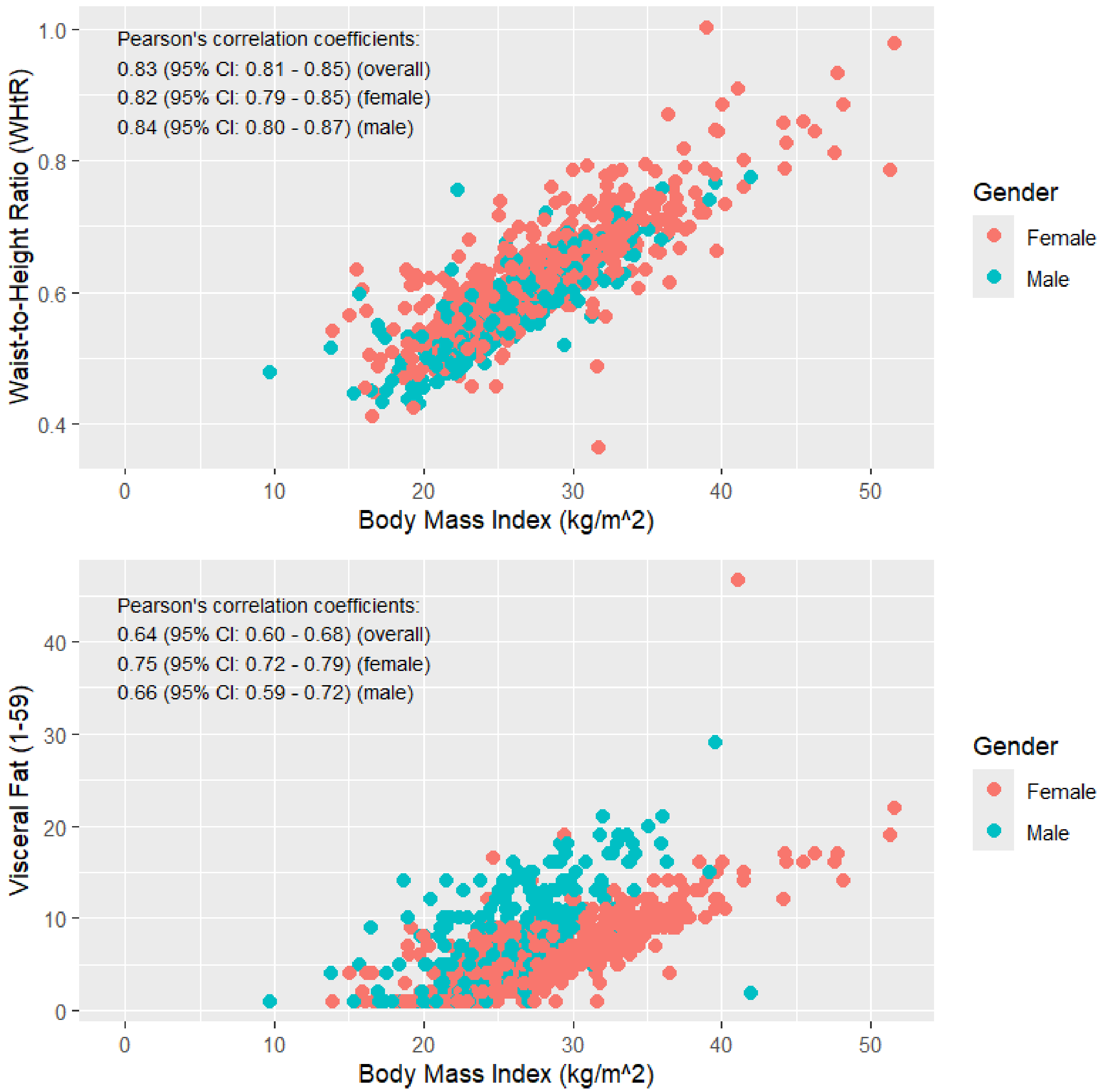

Figure 2 Correlations between body mass index and waist-to-height ratio and between body mass index and visceral fat in men and women from a representative sample of two agrarian and Indigenous municipalities in Guatemala.

to report gender-segregated cut-off values for multiple adiposity-related predictors of cardiometabolic disease in an Indigenous population in Guatemala. Other strengths of this study include a large sample size, the use of data taken from a representative sampling frame in both municipalities surveyed and availability of data on two cardiometabolic conditions: hypertension and diabetes. Another strength is the use of sensitivity analysis to determine the predictive ability of visceral fat and waist-to-height ratio for different BMI and height thresholds.

Our study also has some important limitations. First, the data are population-specific and therefore generalisability to larger populations in Guatemala, Latin America and the world is limited. Second, differential refusal rates among men and women led to over-representation by women in the sample. This limitation was largely mitigated by the fact that our analysis was gender segregated. Third, no measures of hip circumference or waist-to-hip ratio were available in the dataset, limiting comparisons with studies that used those measures. However, the availability of waist-to-height ratio provided an alternative anthropometric measurement that reflects body composition. Fourth, we measured visceral fat by BIA, which is not the gold standard. However, our use of BIA does provide results that may be more applicable to real world situations. Fifth, we acknowledge that the cross-sectional nature of the analysis precludes conclusions about the direction of causality. Finally, we acknowledge

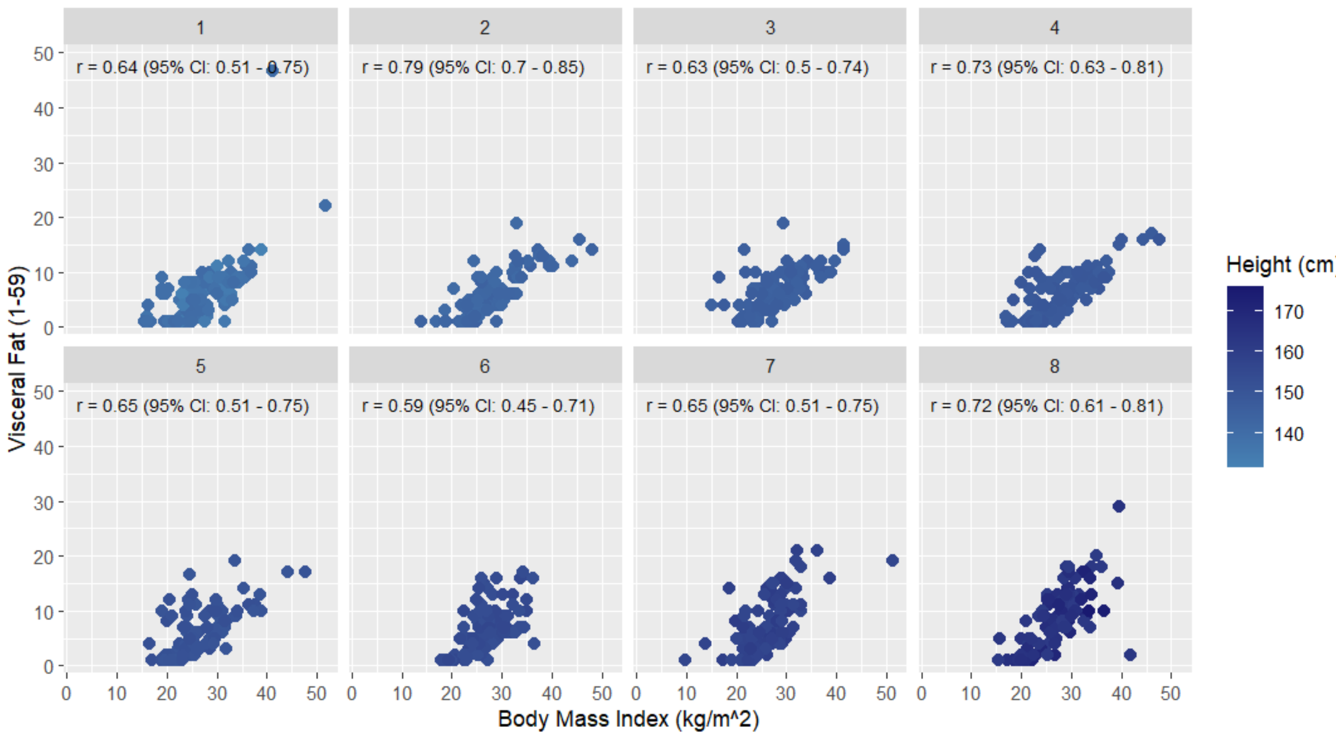

Figure 3 Correlations between body mass index and visceral fat by ascending quantiles of height using data from a representative sample of two agrarian and Indigenous municipalities in Guatemala using Pearson correlation coefficient (r).

the possibility of type II error if sample size was insufficient to detect true differences between adiposity-related predictors of cardiometabolic disease.

Few studies of Indigenous populations in Guatemala or elsewhere in Latin America are available for comparison with our findings. The BMI cut-off values we obtained for hypertension and diabetes were similar to those obtained by Gregory *et al* in four Guatemalan villages, but the population under study by Gregory *et al* was not Indigenous.[10] In that study, the BMI cut-off for men was 25.9 kg/m^2 for hypertension and 25.2 kg/m^2 for pre-diabetes compared with 26.5 kg/m^2 for hypertension and 25.6 kg/m^2 for diabetes in our analysis. The BMI cut-offs for women were 27.6 kg/m^2 and 27.3 kg/m^2 for hypertension and pre-diabetes, respectively, versus 28 kg/m^2 for both hypertension and diabetes in our analysis. A study of Guarani and Terena Indigenous women in Midwest Brazil found, after adjusting for confounding factors in regression analysis, that waist circumference but not BMI was associated with greater hypertension prevalence. However, the 80 cm waist circumference threshold reported was a reference threshold and not specific to the local population.[27] Additional research is needed on adiposity-related cardiometabolic disease predictors in Indigenous populations in Latin America. The Lancet Diabetes and Endocrinology Commission, in a recent report proposing a revised definition of clinical obesity, advocated for the use of at least one anthropometric or body fat measurement in addition to BMI to confirm excess adiposity, emphasising the need for validated cut-off points appropriate to age, gender and ethnicity.[26]

Our finding that BIA-derived visceral fat was a better predictor of diabetes, compared with other adiposity measures, including BMI, is compelling and coincides with research from other populations. Jung *et al* analysed baseline data from a cardiometabolic health study that included 1603 Korean adults and found that visceral fat mass, as measured by whole-body DXA scan, was the best predictor of diabetes and pre-diabetes among several anthropometric measures, including BMI and waist-to-hip ratio, in both men and women.[7] AUC for diabetes or pre-diabetes using BMI or visceral fat mass as a predictor variable were similar to those found in our analysis for both men and women. Zhang *et al* found, in a cross-sectional analysis of 3572 adults from villages in outer Beijing, that visceral fat area, measured by CT scan, was more closely associated with fasting and postprandial hyperglycaemia than BMI, but not as closely associated as waist-to-hip ratio and waist circumference.[6] The larger gap in performance between visceral fat area and BMI was seen for postprandial hyperglycaemia (OR 1.80 vs 1.67).

Zhang *et al* had suggested, noting that the population from which their sample was taken was leaner than that studied by Jung, that visceral fat mass may be a better predictor of cardiometabolic disease in more obese populations.[6] They also referenced a 1992 study that found visceral-to-subcutaneous fat ratio to be a better predictor of metabolic health than waist-to-hip ratio in 63 obese women.[25] However, we found in sensitivity analyses that visceral fat was a better predictor of both diabetes and hypertension in Tecpán and San Antonio Suchitepéquez for individuals with BMI <30 kg/m^2. Additionally, visceral

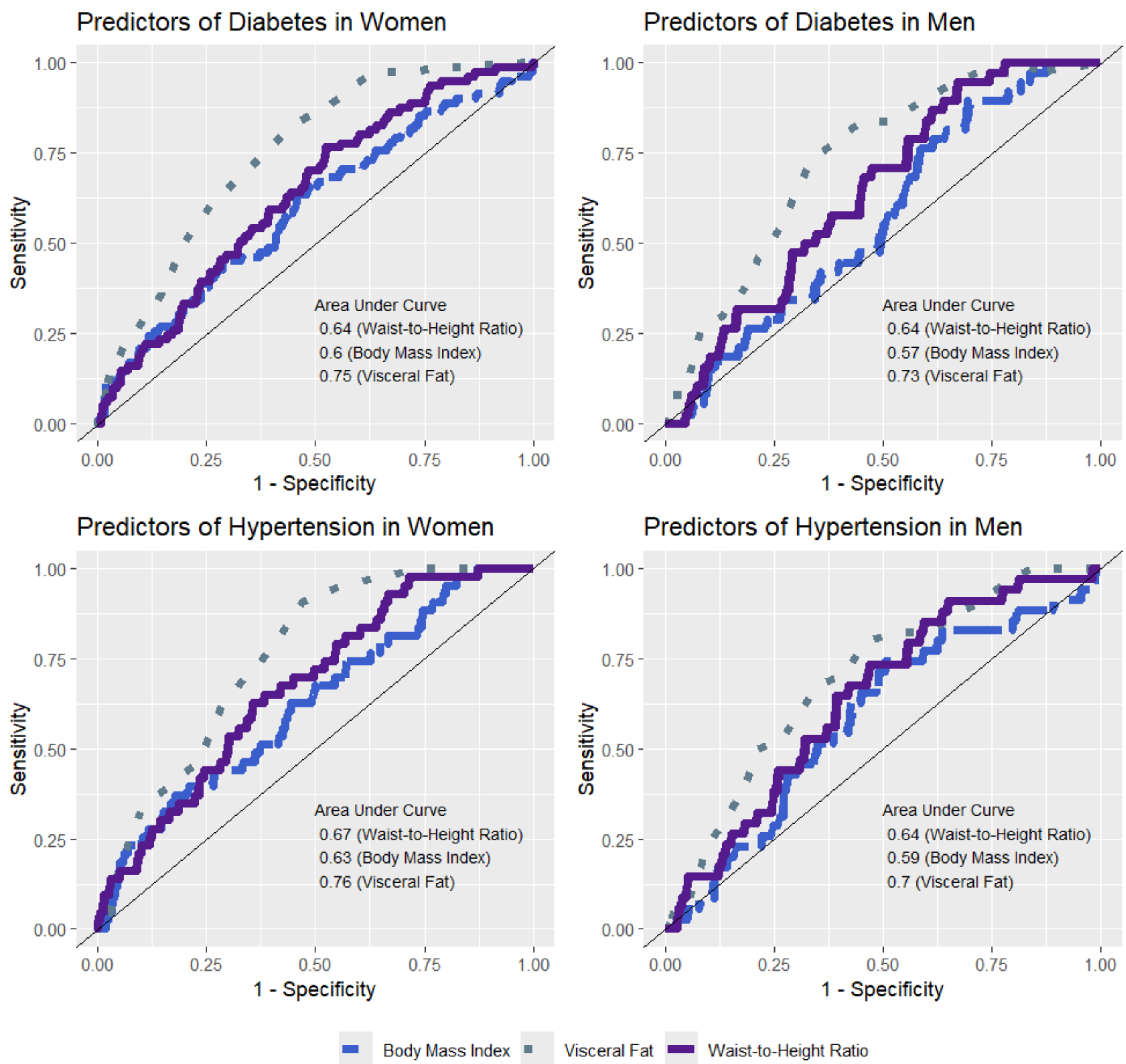

Figure 4 Receiver operating characteristic curves for adiposity-related predictors of diabetes and hypertension by gender using data from a representative sample of two agrarian and Indigenous municipalities in Guatemala.

fat was an even better predictor of diabetes (AUC=0.85) and hypertension (AUC=0.90) in women when BMI was less than 25 kg/m^2. This finding suggests that the presence of high visceral fat in individuals with lower BMIs, especially women, would have high prognostic value for the detection of cardiometabolic disease, at least in the population we studied.

A recent analysis by Zhou *et al* from eight world regions compared ROC curves for hypertension using BMI and waist-to-height ratio as predictors, finding the two measures to have similar predictive ability.[4] Like Zhou, we found that waist-to-height ratio was not a statistically better predictor of cardiometabolic disease than BMI for either gender. However, in our analysis, both BMI and waist-to-height ratio had lower predictive ability for hypertension than the global study reported for Latin America. These differences may reflect population-specific characteristics that impact the relationship between BMI and body composition, or between adiposity and hypertension. Both the global study and ours found BMI and waist-to-height ratio to be better predictors of hypertension in women than in men. This gender discrepancy may be partly explained by the higher rates of smoking and alcohol use among men, as these behaviours tend to raise blood pressure, making adiposity a less significant factor in relative terms.

We did not find any studies comparing ROC curves between visceral fat and BMI as predictors of hypertension.

Table 2 Receiver operating characteristic data for adiposity measures as predictors of diabetes and hypertension in two agrarian and Indigenous municipalities in Guatemala

		Diabetes						
		AUC*	CI (L)†	CI (U)‡	P value	Optimal cut-off	Sensitivity	Specificity
Men	BMI (kg/m^2)	0.57	0.48	0.66	–	25.6	0.58	0.50
	Waist-to-height ratio (WHtR)	0.64	0.56	0.73	0.23	0.59	0.58	0.62
	Visceral fat (Tanita units 1–59)	0.73	0.66	0.81	0.01	9.5	0.73	0.67
Women	BMI (kg/m^2)	0.6	0.53	0.67	–	28	0.59	0.56
	WHtR	0.64	0.57	0.7	0.4	0.63	0.59	0.61
	Visceral fat (Tanita units 1–59)	0.75	0.7	0.8	< 0.01	6.5	0.73	0.63
		Hypertension						
		AUC*	CI (L)†	CI (U)‡	P value	Optimal cut-off	Sensitivity	Specificity
Men	BMI (kg/m^2)	0.59	0.49	0.69	–	26.5	0.57	0.58
	WHtR	0.64	0.55	0.74	0.41	0.59	0.65	0.61
	Visceral fat (Tanita units 1–59)	0.7	0.61	0.79	0.1	9.5	0.68	0.65
Women	BMI (kg/m^2)	0.63	0.54	0.71	–	28	0.63	0.56
	WHtR	0.67	0.6	0.75	0.42	0.65	0.63	0.64
	Visceral fat (Tanita units 1–59)	0.76	0.7	0.82	0.01	6.5	0.77	0.61

*Area under the curve.
†Confidence interval (lower).
‡Confidence interval (upper).
BMI, body mass index.

However, Karlsson *et al* conducted a genome-wide association study to identify visceral adiposity loci and found that predicted visceral fat mass was associated with hypertension. The effect was considerably stronger in women than in men (OR of 7.34, 95% CI 4.48 to 12.0 in women vs OR of 2.50, 95% CI 1.98 to 3.14 in men), which is consistent with our findings.[28]

CONCLUSIONS

In two agrarian and Indigenous Guatemalan municipalities, BIA-derived visceral fat was a significantly better predictor of hypertension and diabetes in both men and women than BMI. Visceral fat was a better predictor of cardiometabolic disease in individuals with lower BMIs. Waist-to-height ratio also performed better than BMI in predicting hypertension and diabetes in both genders, but the difference was not statistically significant. The correlation between BMI and visceral fat did not vary appreciably across quantiles of height as might have been expected given the high prevalence of stunting in the population. Further research is needed to determine the extent to which these findings are generalisable to broader populations. In addition, there are important implications for clinical practice. At a minimum, clinicians need to consider using alternative techniques beyond BMI when assessing adiposity in Guatemalan Indigenous populations and in other diverse global populations. More work is needed to determine population-specific cut-off values for adiposity-related predictors of cardiometabolic disease for use in screening protocols. More effort is also needed to explore the utility of simple point-of-care BIA devices and to validate their incorporation into regular clinical practice.

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Competing interests PR has received funding for research from the National Institutes of Health. SA has no competing interests to declare.

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Ethics approval This is a secondary analysis of an existing deidentified dataset and therefore ethical approval for the analysis was not required. The original study from which the dataset was derived was approved by the institutional review boards of Maya Health Alliance (WK 2018 001), the Institute for Nutrition of Central America and Panama (CIE REV 075/2018) and Partners Healthcare (2017P002476).

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Data availability statement Data are available in a public, open access repository. Statistical code and dataset are available from the Harvard Dataverse (https://doi.org/10.7910/DVN/IA5ELX)[29]

ORCID iD
Stephen Alajajian https://orcid.org/0000-0001-9203-8994

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