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Anthropometric indices and their cut-off points in relation to type 2 diabetes among Ghanaian migrants and non-migrants: The RODAM study

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ABSTRACT

Aims: To compare body mass index (BMI), waist circumference (WC) and waist-to-hip ratio (WHR) as determinants of type 2 diabetes (T2DM) and determine optimal cut-offs in a sub-Saharan African population.

Methods: Data from the RODAM study including Ghanaians aged 25–70 living in rural Ghana, urban Ghana and Europe were used. Logistic regression was used to assess associations between BMI, WC, WHR and T2DM status, by sex and site. Area under the curve (AUC) were constructed to discriminate between indices and establish performance and cut-off values.

Results: WHR had the strongest association with T2DM in men and women across sites, except for rural men. The highest adjusted odds ratio (aOR) and AUC were in rural women for WHR (aOR = 2.09, 95%CI = 1.47–2.99; AUC = 0.71). Among migrants, WHR had higher

Abbreviations: WC, Waist circumference; HPLC, High performance liquid chromatography; SSA, Sub-Saharan Africa; T2DM, type 2 diabetes mellitus; VAT, visceral adipose tissue

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AUCs compared with BMI ($p < 0.01$) and WC ($p < 0.05$). Cut-offs for BMI and WC in men were lower compared with the WHO reference across sites (WC: 85.4–93.7 vs 102 cm, BMI: 23.1–28.2 vs 30.0 kg/m^2).

Conclusions: WHR outperformed BMI and WC as anthropometric indices in relation to T2DM among Ghanaian migrants. The lower BMI and WC cut-offs for T2DM than WHO established standards, highlights the need for African specific cut-offs to avoid missing high risk populations.

1. Introduction

The global prevalence of diabetes mellitus is estimated at 415 million people and projected to increase two-fold by 2040 [1]. Data from the seven global regions on type 2 diabetes mellitus (T2DM) indicate the largest projected increase to be in Sub-Saharan Africa (SSA). This region is estimated to have a 141% increase in the affected population by 2040 compared with 2015 [1]. Within the SSA region the T2DM prevalence is substantially higher among urban populations (9.5%) compared to rural dwellers (4.8%), with urban populations being at par with SSA migrants in Europe (10.7%) [2]. In addition, the odds for type 2 diabetes among SSA migrants in Europe is about three times higher compared to host European populations [3].

Accumulated data suggest elevation of adiposity in obesity to be a major risk factor for T2DM in addition to others such as family history, education level and lifestyle factors that can act both directly on T2DM or mediated via obesity [4–7]. For example, between 1980 and 2014, there was a corresponding rise in T2DM and obesity with SSA reporting an increase in mean body mass index from 21.0 to 24.0 kg/m^2 in men and 21.9–24.9 kg/m^2 in women [8,9]. Thus, individuals with high adiposity levels are important target groups for prevention of type 2 diabetes onset and clinical guidelines urge case finding for individuals with high adiposity levels [10]. This further enhances early detection of individuals with type 2 diabetes to prevent progression to micro- and macro-vascular complications [11,12].

The World Health Organization (WHO) recommendations for adiposity levels associated with a substantially increased risk for metabolic complications are >30 kg/m^2 for Body Mass Index (BMI), >102 cm (men) and >88 cm (women) for waist circumference, and $\geq$0.90 (men) and $\geq$0.85 (women) for waist-to-hip ratio [13]. These cut-offs have been derived from data on mainly European populations. It has been recognised that these may not be appropriate for other populations. This is evident in Asian populations having a lower BMI cut-off (>27.5 kg/m^2) [14]. Ethnic specific cut-offs for African populations are however still lacking, despite evidence that the general WHO cut-offs are not distinguishing those at high risk for T2DM [15]. In addition, body fat and body fat distribution differ between populations, which may contribute to variations in T2DM prevalence [16,17]. Moreover, there are evidence indicating marked differences in optimal cut-offs in adiposity indices associated with cardio-metabolic risk within SSA populations in different studies conducted in America and Africa [18,19]. It is however, unclear which adiposity index best predicts T2DM in SSA populations.

This paper assessed which anthropometric measure i.e. BMI, waist circumference, or waist-to-hip ratio, as an adiposity index best predicts T2DM in Ghanaians. Optimal cut-offs associated with T2DM were further determined.

2. Methods

2.1. Study design

The present analyses were part of the Research on Obesity and Diabetes among African Migrants (RODAM) study; a community based, multi-country, cross-sectional study which started from 2012 to 2015. Participants were drawn from three Ghanaian populations; namely rural and urban Ghana, and Europe (Germany, the Netherlands and the United Kingdom). Details of this study's design have been published elsewhere [20]. Briefly, participants enrolled in the study were Ghanaian adults (25–70 years) randomly selected and recruited from 15 locations in urban and 15 villages in rural Ashanti region of Ghana, and European cities; Amsterdam, Berlin and London. The sample size was determined based on power calculations for achieving a power of 0.90 with $\alpha = 0.05$ for detecting 5% difference in T2DM prevalence, as described in Agyemang et al. 2015 [20]. In Ghana, participants were randomly drawn from a list of 30 enumeration areas, based on the 2010 census. Research teams visited the selected communities and organized mini-clinics in the field for 1–2 weeks, to conduct interviews and examine participants. In Amsterdam, the Netherlands, Ghanaians were randomly drawn from the Amsterdam Municipal register, which contains data on country of birth of citizens and their parents. In London, the UK, Ghanaian organisations served as the sampling frame as a population register including ethnicity data was not available. In Berlin, Germany, the registration office of the federal state of Berlin provided a list of Ghanaian individuals, which was supplemented by contact details of members of Ghanaian organisations and churches in Berlin, serving as a sampling frame. For the European sites, Ghanaian origin was defined as one born in Ghana with one or two Ghanaian parents, or being born in any of the European study sites with two Ghanaian parents. Response rates for rural and urban Ghana were 76% and 74% respectively. Amsterdam had 53% of Ghanaians invited taking part in the study with Berlin and

London reporting response rates of 68% and 75% respectively. A total of 5898 participants completed physical examination and blood collection (Supplementary Figure) [21]. Ethical approval was obtained from institutional review boards at the School of Medical Sciences, Kwame Nkrumah University of Science and Technology, University of Amsterdam, Charité-Universitätsmedizin Berlin and London School of Hygiene and Tropical Medicine. Individual informed consents were obtained from the participants prior to sample collection.

2.2. Questionnaire

Demographic data of participants were collected using either face-to-face administration or self-administration of a structured questionnaire [20]. In addition to participants' biodata, other variables included were educational level, alcohol consumption, smoking and physical activity levels. Alcohol consumption was calculated in units/week with 1 unit of alcohol equivalent to a Ghana standard serving size of 500 ml of beer, 250 ml of wine and 80 ml of spirit. Usual serving size options ranged from half a serving size to 3 serving sizes. A positive response to the question 'Do you smoke at all?' was used to categorize a participant as a smoker. For physical activity levels, the WHO Global Physical Activity Questionnaire version 2 was used with levels of activity computed in min/day. Family history of T2DM was determined based on the question: "Has someone in your immediate family (your parents, brothers, sisters and children) been diagnosed with T2DM?". The responses were categorized into "yes", "no" and "I don't know".

2.3. Anthropometric measurements of adiposity

Body weight was measured to the nearest 0.1 kg with a digital scale (SECA 877, UK) after removal of footwear, heavy clothing and pocket contents. Height to the nearest 0.1 cm was measured using a portable stadiometer (SECA 217, UK) with participant's Frankfort plane parallel to the floor. Body Mass Index (BMI) was computed as weight in kg divided by the square of the height in meters (kg/m^2). Waist circumference (WC) was measured midway between the iliac crest and costal margin using a measuring tape in cm. Similarly, hip circumference (HC) was taken over the hip-bone (trochanter major). Subsequently, waist-to-hip ratio (WHR) was computed by dividing WC by HC.

2.4. Laboratory analysis

Participants were asked to undergo a 10-h fast after which blood samples were drawn from the ante cubital vein. Whole blood and plasma were immediately processed and stored at −20 °C before transporting to the local research centers to be checked, registered and stored at −80 °C. All samples were shipped to Charité-Universitätsmedizin Berlin for biochemical analyses. Fasting blood glucose (FBG) was assayed using plasma in an enzymatic colorimetric method (Glucose PAP) with an automated chemistry analyzer (ABX Pentra 400, France). A high-performance liquid chromatography (HPLC) method aligned with Diabetes Control and Complications Trial (DCCT) standards was adapted for quantifying HbA1c using the Tosoh G7 automated HPLC analyzer (USA). Diabetes was classified with respect to WHO guidelines; i.e. fasting glucose $\geq$ 7.0 mmol/L, self-reporting or the use of glucose lowering drugs.

2.5. Data analysis

Study characteristics were expressed as percentages with corresponding 95% confidence intervals for categorical variables. Continuous variables were reported as means with 95% confidence intervals when normally distributed and as median with interquartile range when otherwise. Logistic regression was performed with T2DM as dependent variable and BMI, WC and WHR as independent variables separately. BMI, WC and WHR were z-standardized to enable comparison between these anthropometric measures. Models were subsequently adjusted for age, physical activity education level, family history of T2DM and site of data collection for migrants in Europe. Backward stepwise logistic regression analysis was done using T2DM status as dependent variable with age, sex, site, European site, physical activity, education level, family history of T2DM and one of the adiposity indices (z-standardized BMI, WC or WHR) at a time to determine best models. European site, physical activity and education level had P-values greater than 0.2 and where therefore not retained in the models. Regression fitted values from these models were then plotted in a receiver-operating characteristic (ROC). The generated area under the curve (AUC) was compared for the three indices with the largest area indicating the best predictor at a significance level of $p < 0.05$. Highest sensitivity and specificity values as well as cut-off points were estimated by Liu method which derives a cut-off as the point maximizing the product of sensitivity and specificity [22] using STATA 16.0 (StataCorp, USA). All analyses were stratified by location and sex.

3. Results

3.1. Characteristics of study population

Mean age for men was higher for those with T2DM (54.0 years) compared to those without (46.0 years) (Table 1). Except for HC, men with T2DM recorded higher means for anthropometric indicators of adiposity. Out of the lifestyle characteristics, smoking was more prevalent in men without T2DM (6.8%) compared to those with T2DM (3.5%). On the contrary, physical activity was lower in those with (77.0 min/day) compared to those without T2DM (171.0 min/day). Men with T2DM reported 36.3% positive family history for T2DM. Men without T2DM had similar proportions for no formal education as those with T2DM.

Women with T2DM were on average older (52.7 years) compared to those without T2DM (45.1 years). All the anthropometric indicators as well as the prevalence and alcohol use were higher in women with T2DM as against those without. Physical activity levels were higher in those without T2DM compared to those with the condition (median 102 vs 64 min/-day). Positive family history for T2DM was 45.2% for women

Table 1 – Characteristics of participants included in the analyses, stratified by sex and T2DM status.

	With Type 2 Diabetes	Without Type 2 Diabetes
Men	n = 239	n = 1990
Demographics		
Age, years	54.0 (52.8, 55.1)	46.0 (45.4, 46.5)
Site, %		
Rural Ghana	7.1 (4.5, 11.2)	20.9 (19.2, 22.7)
Urban Ghana	19.2 (14.7, 24.8)	18.7 (17.1, 20.5)
Amsterdam	36.0 (30.1, 42.3)	27.8 (25.9, 29.8)
London	17.6 (13.2, 22.9)	19.4 (17.7, 21.2)
Berlin	20.1 (15.5, 25.7)	13.2 (11.7, 14.7)
Anthropometrics		
BMI, kg/m^2	27.0 (26.4, 27.6)	25.0 (24.8, 25.2)
Waist circumference, cm	95.1 (93.5, 96.7)	86.9 (86.4, 87.4)
Hip circumference, cm	88.7 (74.6, 102.8)	92.5 (89.8, 95.2)
Waist-to-hip ratio	0.96 (0.95, 0.97)	0.91 (0.91, 0.91)
Fasting Glucose, mmol/L	8.7 (8.1, 9.4)	5.1 (5.1, 5.1)
HbA1c, mmol/mol	59.2 (50.8, 57.3)	36.0 (35.7, 36.3)
Lifestyle characteristics		
Smoking, %	3.5 (1.7, 6.8)	6.8 (5.8, 8.1)
Alcohol, units/week[a]	2.2 (1.5, 3.0)	2.5 (2.1, 2.8)
Physical activity, min/day[b]	77 (18, 227)	171 (34, 360)
Positive family history of T2DM, %	36.3 (30.3, 42.8)	16.9 (15.2, 18.7)
No formal education, %	18.1 (13.7, 23.6)	21.4 (19.6, 23.3)
Women	n = 302	n = 3367
Demographics		
Age, years	52.7 (51.5, 53.8)	45.1 (44.7, 45.5)
Site, %		
Rural Ghana	12.9 (9.6, 17.2)	19.0 (17.7, 20.3)
Urban Ghana	29.5 (24.6, 34.9)	28.1 (26.6, 29.7)
Amsterdam	28.8 (24.0, 34.2)	26.9 (25.5, 28.5)
London	20.9 (16.6, 25.8)	18.7 (17.4, 20.1)
Berlin	7.9 (5.4, 11.6)	7.2 (6.4, 8.2)
Anthropometrics		
BMI, kg/m^2	30.2 (29.4, 30.9)	28.1(27.9, 28.3)
Waist circumference, cm	98.6 (97.1, 100.1)	91.3 (90.9, 91.8)
Hip circumference, cm	101.6 (93.5)	99.2 (96.8, 101.5)
Waist-to-hip ratio	0.94 (0.93, 0.95)	0.89 (0.88, 0.89)
Biochemical characteristics		
Fasting Glucose, mmol/L	7.9 (7.4, 8.4)	5.0 (5.0, 5.0)
HbA1c, mmol/mol	61.8 (58.9, 64.7)	36.1 (35.9, 36.4)
Lifestyle characteristics		
Smoking, %	5.6 (2.5, 8.7)	2.9 (2.4, 3.6)
Alcohol, units/week[a]	0.7 (0.3, 1.1)	0.5 (0.4, 0.6)
Physical activity, min/day[b]	64 (8, 231)	102 (17, 283)
Positive family history of T2DM, %	45.2 (39.5, 51.1)	18.4 (17.1, 19.8)
No formal education, %	44.4 (38.7, 50.2)	42.2 (40.5, 44.0)

Numbers are expressed as means with corresponding (95% Confidence Intervals (CI)) or percentages with corresponding (95% CI), BMI = Body mass index, HbA1c = glycated haemoglobin A 1c.

[a] One unit alcohol is 500 ml beer, 250 ml wine or 80 ml liquor.

[b] Physical activity in minutes per day reported as median and (25% percentile, 75% percentile).

with T2DM. The proportion of women with no formal education was similar for those with and without T2DM.

3.2. Association between anthropometric indices and T2DM stratified by site and sex based on z-standardized values

After adjusting for age, physical activity, educational level, family history of T2DM and site for migrants (Table 2), 1 SD increase in BMI was associated with higher odds for T2DM among Ghanaian men in Europe (aOR 1.37, 95%CI 1.08, 1.76), but not among women in Europe nor among men and women in urban or Ghana (Table 2). One SD increase in WC was associated with T2DM in both Ghanaian men (aOR 1.58, 95%CI 1.25, 1.99) and women (aOR 1.38, 95%CI 1.12, 1.71) living in Europe and women living in rural Ghana (aOR 1.78, 95%CI 1.24, 2.56). One SD higher WHR was associated with T2DM among women across sites (aOR ranging from 1.50 in urban women to 2.09 in rural women), and among men living in Europe (aOR 1.67, 95%CI 1.29, 2.16). The adjusted odds per 1 SD higher WHR were consistently

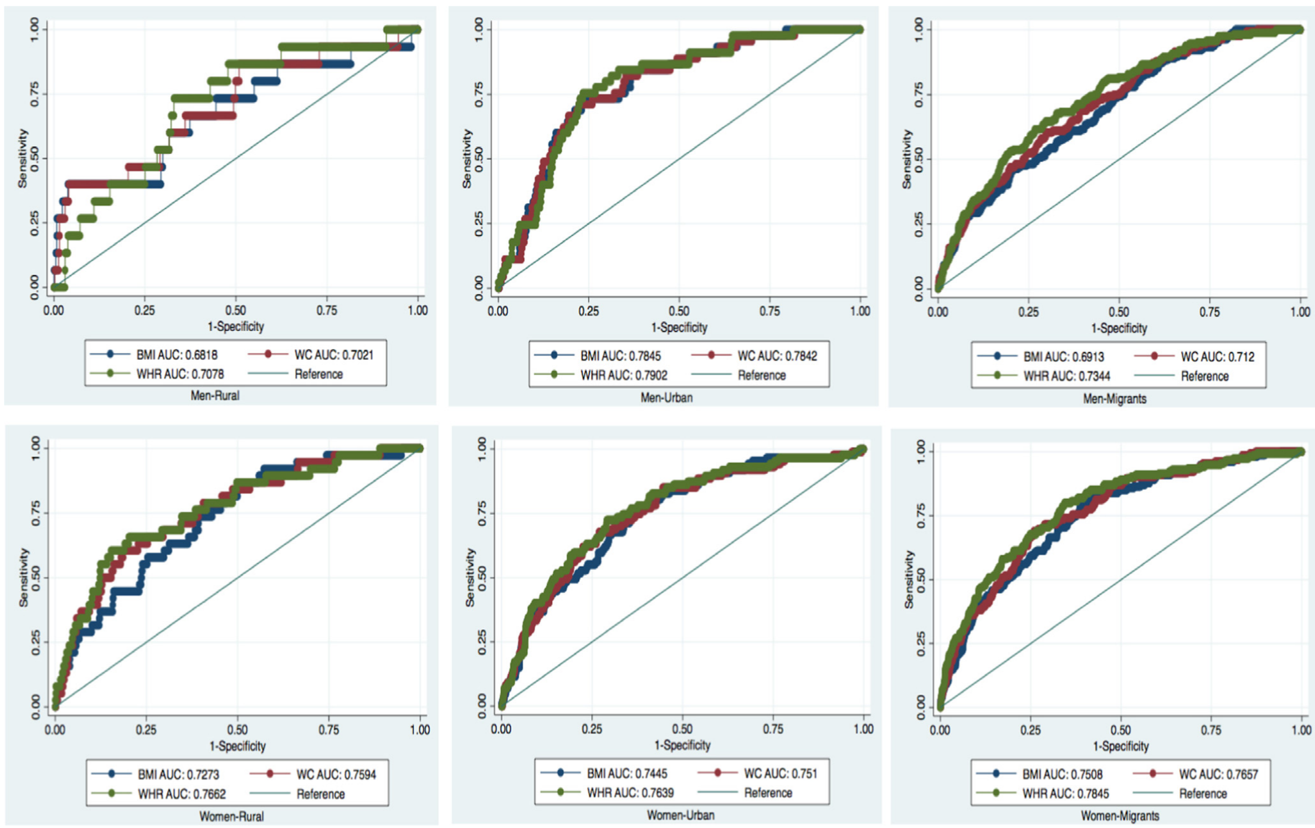

Fig. 1 – Receiver operating characteristic curves for the prediction of type 2 diabetes based on BMI, WC and WHR; stratified by site and sex.

Table 2 – Crude and adjusted odds ratios for T2DM per 1SD increase in BMI, WC and WHR, by site and sex.

	BMI		WC		WHR	
	OR (95%CI)	aOR (95%CI)	OR (95%CI)	aOR (95%CI)	OR (95%CI)	aOR (95%CI)
Migrants						
Men	1.59 (1.30, 1.96)*	1.37 (1.08, 1.76)*	2.02 (1.68, 2.42)*	1.58 (1.25, 1.99)*	2.30 (1.91, 2.76)*	1.67 (1.29, 2.16)*
Women	1.42 (1.21, 1.65)*	1.15 (0.93, 1.41)	1.83 (1.57, 2.14)*	1.38 (1.12, 1.71)*	1.90 (1.62, 2.23)*	1.54 (1.24, 1.93)*
Urban Ghana						
Men	1.17 (0.77, 1.79)	1.07 (0.63, 1.79)	1.39 (0.99, 1.96)	1.15 (0.75, 1.76)	1.73 (1.24, 2.42)*	1.46 (0.91, 2.34)
Women	1.09 (0.88, 1.35)	1.03 (0.82, 1.30)	1.40 (1.12, 1.74)*	1.24 (0.96, 1.58)	1.71 (1.35, 2.16)*	1.50 (1.14, 1.96)*
Rural Ghana						
Men	2.00 (0.94, 4.24)	2.11 (0.93, 4.76)	2.25 (1.26, 4.03)*	1.90 (0.97, 3.72)	1.49 (0.95, 2.35)	1.17 (0.69, 1.99)
Women	1.41 (0.99, 1.98)	1.42 (0.97, 2.09)	1.91 (1.37, 2.65)*	1.78 (1.24, 2.56)*	2.30 (1.69, 3.11)*	2.09 (1.47, 2.99)*

BMI = Body mass index, WC = Waist circumference, WHR = Waist-to-hip ratio, OR = Odds ratio, CI = Confidence Interval, aOR = adjusted odds ratio, models are adjusted for age, physical activity, education level, family history of T2DM and sites for migrants.
Anthropometric indices were z-standardized.
* Statistically significant at $p < 0.05$.

higher than the adjusted odds for BMI and WC across sites in both men and women, except for rural Ghanaian men in whom the adjusted odds for T2DM were highest per 1 SD increase in BMI (aOR 2.11, 95%CI 0.93, 4.76).

3.3. *ROC analysis of WC, BMI and WHR for predicting T2DM*

WHR consistently showed the highest AUCs stratified by sex and site and adjusted for age and family history of T2DM (education, physical activity and site were not retained in the model) (Fig. 1). AUCs reported for WC (Table 3) were significantly higher than for BMI in both migrant men ($p = 0.002$) and women ($p = 0.021$). Similarly, AUCs for WHR were higher than for BMI in both migrant men ($p = 0.002$) and women ($p = 0.003$). Additionally, AUCs for WHR were also higher compared to WC in migrant men ($p = 0.013$) and women ($p = 0.035$). In rural women, reported AUC for WC was higher compared to that for BMI ($p = 0.031$).

Table 3 – Comparison of area under the curve for anthropometric indices among populations.

	Population					
	Migrants		Urban Ghana		Rural Ghana	
Anthropometric indices	Men	Women	Men	Women	Men	Women
BMI vs WC	0.69 vs 0.71	0.75 vs 0.77	0.78 vs 0.78	0.74 vs 0.75	0.68 vs 0.70	0.73 vs 0.76
p	*0.002**	*0.021**	*0.919*	*0.254*	*0.334*	*0.031**
BMI vs WHR	0.69 vs 0.73	0.75 vs 0.78	0.78 vs 0.79	0.74 vs 0.76	0.68 vs 0.71	0.73 vs 0.76
p	*0.002**	*0.003**	*0.460*	*0.058*	*0.508*	*0.189*
WC vs WHR	0.71 vs 0.73	0.77 vs 0.78	0.78 vs 0.78	0.75 vs 0.76	0.70 vs 0.71	0.76 vs 0.76
p	*0.013**	*0.035**	*0.405*	*0.123*	*0.836*	*0.760*

Adjusted for age and family history of T2DM.
* Statistically significant at $p < 0.05$.

3.4. *Performance and cut-offs of anthropometric indices*

The cut-off for BMI was highest for Ghanaian migrant women (30.2 kg/m^2) with sensitivity and specificity of 63% and 56% respectively, and lowest for men in urban Ghana (23.1 kg/m^2) with 65% and 47% sensitivity and specificity, respectively (Table 4). Optimal cut-offs for BMI were lower compared with the WHO established cut-offs for all sites except migrant women. A trend for lower optimal WC cut-offs was observed in men across sites compared with women. Optimal WC cut-offs were lower compared with the WHO cut-offs among men across sites. WHR cut-offs were similar between women and men in urban Ghana (0.92 and 0.91) and rural Ghana (0.94 and 0.93) and higher in men (0.95) compared to women (0.89) among migrants. WHR showed the overall the highest AUC at cut-off-points for men and women across all three sites.

4. Discussion

Our findings suggest that while WC, BMI and WHR all perform well as anthropometric measurements for classifying odds for T2DM among Ghanaians, WHR performs better than WC and both WHR and WC outperform BMI among Ghanaian migrants. We found that optimal cut-offs for BMI, WC and WHR in relation to T2DM deviate in the Ghanaian population from the WHO established reference cut-offs. Our data suggest that the optimal anthropometric cut-offs for assessing T2DM risk differ between men and women and levels of urbanization.

Although prevailing standard cut-offs for anthropometric indices derived from Europeans have long been used to categorize populations on their risk of cardiovascular diseases and T2DM, results from this current study adds to building evidence suggesting the need for ethnic specific cut-offs for these indices to minimize misclassification.

In agreement with previous studies among other populations [23,24], our findings show WHR as a better anthropometric measurement associated with T2DM particularly among migrant Ghanaians. WC also showed good AUCs for predicting risk of T2DM at determined cut-offs based on sex and population classified by level of urbanization. Nonetheless, the ROC curve analysis showed that all three anthropometric indices performed well irrespective of sex and location (Fig. 1). It can therefore be inferred that WC, BMI and WHR can be used as a proxy of adiposity for both clinical and epidemiological purposes in the Ghanaian population. However, WHR and WC were better determinants of T2DM compared to BMI.

The observed variation in cut-offs for these anthropometric indices between rural Ghanaians, urban Ghanaians and Ghanaian migrants residing in Europe suggests that even within the same ethnicity, there are differential optimal cut-offs with based on level of urbanization. Previous analyses using RODAM study data showed that at the same BMI or WC, the prevalence of T2DM was highest in Europe, followed by Urban Ghana, and lowest in rural Ghana [2]. Environmental exposures, such as unhealthy diet and physical inactivity, differing between these locations are likely driving this differential association between anthropometrics and T2DM. The level of urbanization may therefore be important to take into account when assessing T2DM risk in a population.

Contrasting established WHO cut-offs for WC that are higher for men (102 cm) than for women (88 cm), we found that optimal cut-offs for Ghanaian women were higher than for men in more urbanized locations. Similar observations were made among populations from Benin and Haitians with African ancestry [25]and South Africans [26], where WC cut-offs were reported higher in women than in men. Consistent with the European based WHO cut-offs, studies among Europeans, Chinese [2] and Tunisians [26] showed optimal WC cut-offs to be higher for men than for women. Notably, BMI cut-offs among Indians, Mauritians [27], Swedes and Iraqis [28] men in relation to T2DM were higher compared to what is reported for both sexes in this study. The explanation for the differences in cut-offs across populations and sexes may be related to differences in fat deposition. It has been suggested that the capacity to store energy as subcutaneous fat differs between populations and sexes, with a lower capacity to store energy as subcutaneous fat in South Asians [29], particularly in men. Energy that cannot be stored as subcutaneous fat, is stored as visceral fat or in muscle and liver, increasing T2DM risk. Studies in Europeans showed differences in visceral adipose tissue (VAT) deposition for a given WC between men than in women [30]. There is further evidence showing that VAT is lower and subcutaneous adipose tissue is higher in African Americans than in European Americans with T2DM, indicating differences between populations in the effects of VAT on insulin resistance [31]. Studies in SSA are lacking and are needed to unravel the reasons for the dif-

Table 4 – Optimal cut-offs for the anthropometric indices body mass index (BMI), waist circumference (WC) and waist-to-hip ratio (WHR) in predicting T2DM.

Variable	AUC at cut point	At optimal cut-off			WHO cut-off
		Sensitivity	Specificity	Cut-off	
BMI (kg/m^2)					
Migrants					
Men	0.59	49%	69%	28.2	30.0
Women	0.59	63%	56%	30.2	30.0
Urban Ghana					
Men	0.56	65%	47%	23.1	30.0
Women	0.52	56%	47%	27.2	30.0
Rural Ghana					
Men	0.63	41%	85%	23.3	30.0
Women	0.60	56%	64%	24.5	30.0
WC (cm)					
Migrants					
Men	0.65	70%	60%	93.7	102
Women	0.64	62%	65%	98.5	88
Urban Ghana					
Men	0.59	52%	65%	87.0	102
Women	0.55	61%	50%	90.2	88
Rural Ghana					
Men	0.65	41%	89%	85.4	102
Women	0.68	74%	62%	85.1	88
WHR					
Migrants					
Men	0.67	66%	69%	0.95	>0.90
Women	0.65	71%	58%	0.89	>0.85
Urban Ghana					
Men	0.65	72%	58%	0.91	>0.90
Women	0.64	65%	62%	0.92	>0.85
Rural Ghana					
Men	0.66	53%	79%	0.93	>0.90
Women	0.71	64%	78%	0.94	>0.85

AUC = Area under curve.

ferential cut-offs for anthropometrics in relation to T2DM in Ghanaian men and women compared with European-ancestry men and women.

It is interesting to note that BMI and WC cut-offs in Ghanaian men across all three geographical regions were lower than WHO cut-offs (≥30 kg/m^2 and >102 cm respectively). This adds to the evidence of Ghanaian men being at risk of T2DM at lower deposits of body fat and is in agreement with earlier findings from this same population [2] and in Asian and African studies conducted among minorities living in North America and the United Kingdom [32,33]. It is therefore indicative that Ghanaian men at risk of T2DM could be missed using higher WHO cut-offs for BMI and WC as determinants. Similarly, lower optimal cut-offs reported for Ghanaian women living in rural and urban Ghana for BMI, and for WC in rural Ghana suggests that WHO cut-offs may not be appropriate for screening for increased T2DM risk in this group.

Notwithstanding these findings, inferences from this study should be drawn bearing in mind limitations. The odds for T2DM using WC, BMI and WHR were assessed with a cross-sectional design, which has an inherent limitation of not being able to infer causality. Longitudinal study designs in multiple SSA populations are needed to validate the cut-offs established for the assessed anthropometric indices and generate cut-offs that can be implemented across different SSA populations.

5. Conclusion

Our findings suggest that WHR performs better than BMI and WC as anthropometric indices for assessing the burden of T2DM among migrant Ghanaians and that optimal cut-offs for assessing T2DM burden among SSA differ from the established WHO cut-offs. This highlights the need for SSA specific cut-offs for anthropometric indices in classifying risk for T2DM. Moreover, the lower optimal cut-offs for BMI and WC observed among Ghanaian men across sites, and for BMI among women living in Ghana and WC for rural women, could lead to missing high risk T2DM populations when the WHO cut-offs are used for screening.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Data availability

The datasets generated during and/or analysed during the current study are available from the corresponding author on reasonable request.

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Contribution statement

SND, KACM, WKBAO, EFL, CA, JA, AA, SB, LS, KKG and EOD conceived and designed the study. CA, EB, KM, JA, FM, JS, PA and EOD carried out recruitment of participants and data collection. SND, KACM and DB conducted the statistical analysis and drafted the manuscript under supervision of CA and EOD. All authors contributed to the data interpretation, read and approved the final manuscript.

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