Determining The Best Predictive Anthropometric Assessment Tool for Type-2 Diabetes Mellitus: A case-control Study in Egyptian Adults

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Abstract

Background: The prevalence of type 2 diabetes mellitus (DM) is greatly associated with obesity. This study aimed to determine which anthropometric measure is the most predictive for type 2 diabetes mellitus (T2DM) in Egyptian adults concerning body mass index (BMI), waist circumference (WC), waist-to-height ratio (WHTR) and waist-to-hip ratio (WHR). **Methods:** A case-control study was conducted on 202 randomly selected individuals, 101 of whom were diagnosed T2DM (≥ 20 years old) patients attending the medical units of Minia University hospital and 101 controls who were recruited from the local community and were confirmed negative T2DM diagnosis. **Study Tool:** An interview questionnaire consists two parts: 1) Demographic characteristics, and 2) clinical data including disease history of T2DM, laboratory investigations and anthropometric measurements. The anthropometric measurements were measured according to standard World Health Organization protocols. **Results**: Cases aged 54.68±7.38 with 63.4% were male while controls aged 47.7±11.54 and 35.6% were males. Receiver operating curve analysis showed WC had the highest discriminatory power in men (area- under-the-curve [AUC] = 0.905 at 99.5 cm) and women (AUC=0.801 at 103.5 cm), while AUCs in men and women were (0.885 and 0.784) for WHTR, (0.790 and 0.753) for BMI, and (0.669 and 0.663) for WHR, respectively. After binary logistic regression, age-adjusted odds ratios confirmed the association. **Conclusions:** WC showed the best discriminatory power among other anthropometric measures in predicting T2DM in Egyptian adults at 99.5 cm for men and 103.5 cm for women. **Recommendations:** the study should be replicated on large probability sampling among Egyptians.

Keywords: Anthropometric Measures, Diabetes Mellitus, Prediction, Receiver Operating Characteristics.

Introduction

Diabetes mellitus (DM) is a rapidly growing health problem that the world is facing today. The International Diabetes Federation (IDF) estimated that 463 million are diabetic in 2019 and expected to reach 578 million by 2030, and 700 million by 2045 **(Abouzid, Ali, Elkhawas, & Elshafei, 2022)**.

In Egypt, DM is a fast-expanding dilemma. Egypt is a member of the 21 countries of the Middle East and North Africa (MENA) region. About 55 million people in the MENA region are diabetic and expected to be 108 million by 2045 **(Yousufzai &Barakat, 2022)**. In 2019, IDF estimated that Egypt is the 9th country worldwide with about 8,850,400 cases and a prevalence of 15.2% in adults. Furthermore, Egypt is expected to be the 7th country globally by 2045 **(Azzam, Ibrahim, El-Ghany, & Mohammed, 2021)**.

Obesity is the most common cause of type 2 diabetes mellitus (T2DM). Egypt recorded one of the highest percentages of obesity in the world, especially among women, which harms individual health and costs the county a lot of funds in terms of medication and operations to treat the complications of obesity **(Abouzid et al., 2022)**. After the Kingdom of Saudi Arabia and also the United Arab Emirates, Egypt sited at the third-highest obesity prevalence in the MENA region. Obesity prevalence in Egypt somewhat corresponds to that of Native American and Hispanic populations. According to the Egypt demographic and health census from 2008, around 50% of Egyptian men and 65-80% of Egyptian women are overweight or obese **(Hegazi, El-Gamal, Abdel-Hady, & Hamdy, 2015)**.

The severity of the present situation in the Egyptian context can be judged from the alarming figures wherein, complications of diabetes mellitus started subliminally as atherosclerosis and then eventually manifested as chronic kidney failure, blindness, amputation of the lower extremities, stroke, and acute coronary syndrome **(Arokiasamy, Salvi, & Selvamani, 2021; Nesnawy, Tolba, Roshdy, & Kader, 2020)**. Moreover, the annual cost analysts indicated in 2010 that the economic loss due to type 2 diabetes in Egypt is $1.29 billion per year (regardless of the cost associated with prediabetes and reduced productivity) **(Abouzid et al., 2022)**. Hence, late diagnosis and poor follow-up lead to individual-wise and country-wise harmful consequences, the role of health care providers should be started as early as possible. The work on identifying beneficial convenient non-invasive tools to predict T2DM is of great importance. Importantly nursing category occupies the greatest percentage of the healthcare team, so such work should be more emphasized among them.

Simple anthropometric tools have been utilized as surrogate measurements of obesity and have more practical value in both epidemiological studies and clinical practice **(Samajdar et al., 2021)**. Body mass index (BMI) may be an easy methodology that is employed to calculate the prevalence of overweight and obesity in the population. But BMI can be misleading, such as in individuals with a high proportion of lean muscle mass. Waist circumference (WC) is believed to be the best measure of both total fat and intra-abdominal fat mass **(Smith, Christianto, Staynor, & Practice, 2021)**. WC, a more accurate measure of the distribution of body fat, is more strongly associated with morbidity and mortality **(Awasthi, Rao & Hegde, 2017)**. Recently, the waist-to-hip ratio (WHR) and waist-to-height ratio (WHTR) have been proposed as better screening tools than WC and BMI for adult metabolic risk factors. WHTR demonstrated a higher ability than other anthropometric measures in predicting cardiometabolic abnormalities by considering both central fat deposition and intraindividual differences in height **(Zhang et al., 2021)**. A considerable difference still exists as to which measure is mostly accurate to define body fat distribution. Studies from various countries and ethnicities globally showed different predictive powers for anthropometric measures to predict diabetes **(Khader, Batieha, Jaddou, El-Khateeb, & Ajlouni, 2019)**. Therefore, the appropriate cut-off points and predictive power of anthropometric measures should be defined for different ethnicities.

Significance of the study

In Egypt, 40% to 50% of people with diabetes or prediabetes go undiagnosed, even though these numbers may appear to be quite high **(Abouzid et al., 2022)**. Such underdiagnosed cases could be detected utilizing a simple anthropometric measure with an established cut-off value. If all health care providers, especially the nurses, routinely assessed patients and community individuals by such simple tool, many of individual and national ramifications associated with T2DM would be declined.

Aim of the Study

This study aimed to determine which anthropometric measure is the best predictive for type 2 diabetes mellitus in Egyptian adults concerning body mass index, waist circumference, waist-to-height ratio, and waist-to-hip ratio.

Research Question

Which anthropometric measure is the most predictive for type 2 diabetes mellitus in Egyptian adults concerning body mass index, waist circumference, waist-to-height ratio, and waist-to-hip ratio?

Subject and Methods

Research design and study sample

This was a case-control study of 202 participants in a ratio of 1:1, comprising 102 cases (participants with confirmed T2DM) recruited from the hospital and 101 controls (participants without T2DM) also recruited prospectively from the local community.

Sample size

The number of subjects who provides the necessary sample size was 202 as calculated by (fisher et al, 1998) formula: N = (z^2pq/e^2) (N = the required minimum sample size; p = the estimated proportion of T2DM prevalence in the target population 15.6% **(Gabr, Ibraheem, Kasemy, & Soliman, 2020)**; Q = 100 – P (84.4%); e= acceptable error at 0.05; Z = the standard error (1.96) associated with the determined level of confidence 95%).

Sampling method:

Cases and controls were randomly selected by a simple method.

Data collection tool:

Data were collected by personal interviews using a pre-designed questionnaire which contains:

1-Demographic information included gender (male/female), age, marital status, residence (urban/rural), smoking (never smokers and smokers.

2-Clinical data included disease history, laboratory investigations and anthropometric measurements.

a-disease history

T2DM was defined as having a self-reported T2DM history, using insulin or oral hypoglycemic agents, or having Fasting blood sugar ≥126 mg/dl (7.0 mmol/L) which was identified by the patient file record.

b-laboratory investigations

Random blood sugar (RBS) was assessed using an Accu-Chek Active Blood Glucose glucometer. Each blood sample was extracted after 8-12 hours of fasting by the same laboratory team technicians with adherence to the same method over the study period. Samples were centrifuged within one hour at the data collection site and transferred by separate labelled tubes in ice boxes to the central laboratory of the Minia university hospital. Glycated haemoglobin (HbA1c) and total cholesterol were assessed for both cases and controls while 2-hour postprandial blood sugar was conducted for only the controls.

b-Anthropometric measurements

A single measurement was taken for every anthropometric tool by the same tools and the same team of well-trained persons. To measure Weight, subjects were instructed to stand on a digital scale (Seca) with minimal clothes and without shoes. SECA 213 portable stadiometer was used to measure Height. BMI was calculated using its equation [weight (in kilograms)/ height in meters squared]. WC and hip circumference were measured using stretchable tape (Seca 201) in centimeters, over light clothing and without any pressure on the body surface. WC was estimated at the midway between the iliac crest and lower rib margin while WHR was calculated by its equation [WC/ hip circumference] and WHTR by its equation also [WC /height in centimeters].

Validity of the study tool:

- The study tool was developed by the researchers after recent related literature review **(ElKafrawi, Shoaib, and Elghanam, 2017; Borel et al., 2018; Mirzaei & Khajeh, 2018; Quaye, Owiredu, Amidu, Dapare, & Adams, 2019; Chen, Qiu, Guo, Li, & Sun, 2019; Woldegebriel et al., 2020; Fan et al., 2020; Zhang et al., 2021; Luhar et al., 2021; Jayedi et al., 2022**)
- For content validity, the developed tool was further revised by 5 experts in the internal medicine and medical-surgical nursing field to test its comprehensiveness and clarity and the tool was modified accordingly.
- A pilot study was conducted on 10% of the studies' sample (11 cases and 11 controls) of the total sample to assess the tool for its clarity and applicability and to discover any difficulties that may be faced during the actual study. The final form of the tool was modified accordingly, and participants included in the pilot study were not included in the study.

Ethical Considerations

This study was approved by the Research Ethics Committee of the Faculty of Nursing, Minia University, Egypt. The aim and importance of the study were clearly explained to each participant. following that, informed consent was obtained from participants who accepted to be included in the study. The researcher informed each participant that their participation in the study is voluntary and that they can withdraw at any time. all data was coded for confidentiality wise.

Field work

The researchers visited Minia University hospital two days/ a week from 8 am to 2 pm, one day for cases and the controls were in another day. The participants were met individually to explain the aim and procedure of the study before the informed consent. Data were collected within five months and the interview was 20-30 minutes to complete the required data of the study tool.

After that, the fieldwork was conducted according to the operational definition of the participant type as following:

1-Cases: *Participants with confirmed T2DM*

They were patients with type 2 diabetes mellitus - recruited from the medical units of Mina university hospital, Minia city, Egypt. Cases were defined as the patients diagnosed with T2DM attending the hospital. the included cases were those aged ≥ 20 years either male or female, diagnosed with T2DM for ≥ two years, attended the medical units of Mina university hospital, and were willing to participate in the study. to exclude the effect of other cofactors, the study researchers exclude patients of T2DM having severe co-morbidities like chronic renal diseases, chronic lung diseases, and stroke, patients who were referred to the medical units because of other illnesses and pregnant females. the interview and additional workup of anthropometric measures and laboratory investigations were conducted in the hospital.

2-Control: *participants without T2DM*

Community Controls were the individuals not having T2DM, selected from the people coming to the hospital for any reason other than seeking health care (e.g., visiting patients). Controls were defined as individuals aged ≥ 20 years, whether males or females, who were not suffering from type 2 diabetes mellitus and were willing to participate. To rule out diabetes in the control group at the time of enrolment, subjects with RBS < 110 mg/dl, 2 hours postprandial blood sugar <140 mg/dl and HbA1c < 48 mmol/mol (6.5%) **(Chaudhary & Tyagi, 2018)** were eligible to be included as controls.

Figure (1) shows the flowchart that describes the enrollment of diabetic cases and controls.

Statistical analysis:

Data were entered and analyzed using IBM SPSS, version 25. Data were described using percentages and means. Categorical data were compared by either the chi-square test or Fisher exact test (when cell counts < 5) while the independent t-test was used to test the difference between means. As the cutoff values are different according to gender, the performance of anthropometric measures was evaluated using receiver operating characteristics (ROC) analyses for each gender. The Validity of the test was evaluated by calculating the area under the curve (AUC). The AUC values were classified from 0.5 to 1 as 0.9–1.0 Excellent, 0.8–0.9 good, 0.7–0.8 fair, 0.6–0.7 poor, and 0.5–0.6 fail **(Obuchowski & Bullen, 2018)**. The appropriate cut-off value for each AUC was defined after calculating the highest corresponding Youden's J statistic (maximum [sensitivity + specificity - 1]) **(Villarosa-Hurlocker et al., 2020).** Moreover, to further evaluate the discriminatory power of each anthropometric tool to predict T2DM, each anthropometric tool was dichotomized based on the established cut-off value in each gender in this study and tested for their associations by binary logistic regression in the crude model. We further run the logistic regression in an age-adjusted model to exclude the effect of age. As each gender has its cutoff, all regression analyses were also stratified by gender. We did not adjust for multiple comparisons in the analysis because almost all p-values were almost close to zero. A p-value less than 0.05 was considered statistically significant.

Results:

Participants' characteristics

The study included 101 cases and 101 controls. **Table (1)** shows the Demographic characteristics of participants. The age group of 40-59 years represented 68.3% of cases, while controls constituted 53.5% in the same age bracket. 63.4% were male in the cases, while the control population in the community they counted for 35.6%. Most of the cases and controls were married (91.1% and 88.1%, respectively) and from rural areas (65.3% and 77.2%, respectively). Smokers counted for of cases 25.7% of cases and 13.9% of controls.

Table 2 describes the anthropometric characteristics of participants. According to BMI categories, the highest proportion in both cases and controls was to those with BMI ≥ 30 kg/m^2 at 84.2% and 48.5%, respectively with p-value < 0.005. As for abnormal categories of waist circumference, waist-to-hip ratio, and waist-to-height ratio, they were the most represented either in cases (95%, 92%, and 96%, respectively) or in controls (75.2%, 80.2%, and 82.2%, respectively).

Table 3 describes the clinical laboratory characteristics of the participants. Glycated haemoglobin (HbA1c) of ≥ 6.5% was represented only in cases (71.3%) while the highest proportion of control was with HbA1c < 5.7% (88.1%). Total blood cholesterol of > 200 mg/dl took place the highest proportion either in cases (82.2%) or in controls (65.3%).

ROC analysis (Figs. 2, 3 and 4) showed WC was the best predictive tool for diabetes, then WHTR, BMI and finally WHR. Notably, all anthropometric measures had a better predictive ability for diabetes among men than that among women and the cutoff differs according to gender.

Table 4 shows the area under the ROC curve for all participants, men, and women. AUC values in prediction of T2DM for man were 0.905 for WC at 99.5 cm, 0.885 for WHTR at 0.60, 0.790 for BMI at 30.9 kg/m^2, and 0.669 for WHR at cutoff 1. As for women, AUC values in prediction of T2DM were 0.801 for WC at 103.5 cm, 0.784 for WHTR at 0.650, 0.753 for BMI at 33.6 kg/m^2, and r BMI at 30.9 kg/m^2, and 0.663 for WHR at 0.95.

All anthropometric tools were dichotomized according to the established gender-based cut-off values and then tested by binary logistic regression for their associations with the studied outcomes in crude and age-adjusted models **(Table 5).** All dichotomized tools were significantly associated with increased odds ratios for diabetes in both crude and age-adjusted model with WC at the highest OR in both gender and both models. However, ORs in women were nearly one-third of ORs in men in accordance.

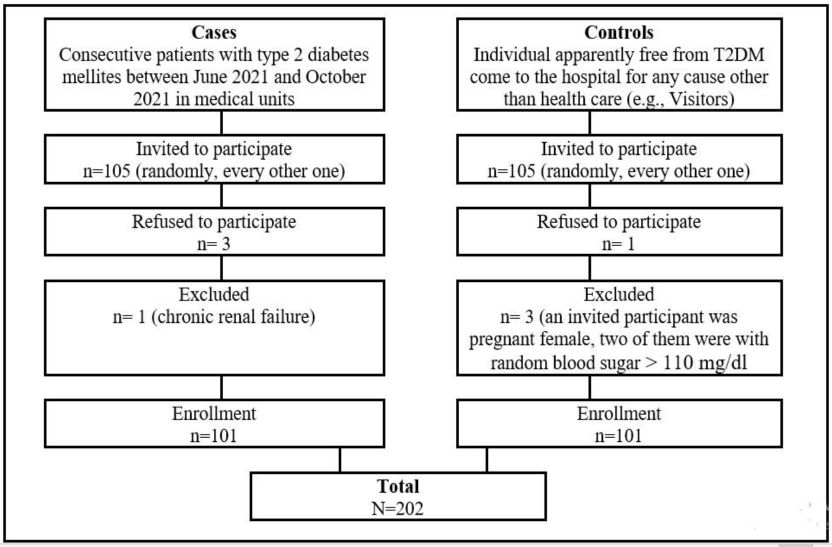

Fig.1 Flowchart describing the enrollment of diabetic cases and controls

Table 1. Demographic characteristics of the study participants (n= 202)

	Cases (n=150) %(n)	**Control (n=150) %(n)**	**Test of Sig.**	***p*-value**
Age (years)				
20 -39	6.9% (7)	29.7% (30)	X^2=17.650*	<0.001
40-59	68.3% (69)	53.5% (54)		
≥ 60	24.8% (25)	16.8% (17)		
mean ± SD	54.68±7.38	47.7±11.54	t=5.120*	<0.001
Gender				
Male	63.4% (64)	35.6% (36)	X^2=15.526*	<0.001
Female	36.6% (37)	64.4% (65)		
Residence				
Urban	34.7% (35)	22.8% (23)	X^2=3.48	0.062
Rural	65.3% (66)	77.2% (78)		
Marital status				
Married	91.1% (92)	88.1% (89)	X^2=0.478	0.489
unmarried	8.9% (9)	11.9% (12)		
Smoking				
Never	74.3% (75)	86.1% (87)	X^2=4.489*	0.034
smoker	25.7% (26)	13.9% (14)		

*P-Value is significant.

Table 2. Anthropometric and clinical characteristics of the study participants (n= 202)

	Cases (n=150) %(n)	**Control (n=150) %(n)**	**Test of Sig.**	***p*-value**
Body mass index (Kg/m^2)				
Underweight (< 18.5)	0% (0)	1% (1)	Fisher=32.749*	<0.001
Normal (18.5-24.99)	3% (3)	22.8% (23)		
Overweight (25- <30)	12.9% (13)	27.7% (28)		
Obese (≥ 30)	84.2% (85)	48.5% (49)		
mean ± SD	38.86±7.8	30.59±7.01	t=7.931*	<0.001
Waist circumference				
Normal	5% (5)	24.8% (25)	X^2=15.659*	<0.001
Abnormal (M ≥ 90 cm, F ≥ 80 cm)	95% (96)	75.2% (76)		
mean ± SD	111.63±15.37	92.26±10.47	t=10.469o*	<0.001
Waist-to-hip ratio				
Normal	7.9% (8)	19.8% (20)	X^2=5.970*	0.015
Abnormal (Male ≥ 0.90) (Female ≥ 0.85)	92.1% (93)	80.2% (81)		
mean ± SD	1.13±0.22	1±0.2	t=4.476*	<0.001
Waist-to-height ratio				
Normal	4% (4)	17.8% (18)	X^2=9.998*	0.002
Abnormal (> 0.5)	96% (97)	82.2% (83)		
mean ± SD	0.68±0.09	0.58±0.08	t=9.061*	<0.001

*P-Value is significant.

Table 3. Clinical laboratory characteristics of the study participants (n= 202)

	Cases (n=150) %(n)	Control (n=150) %(n)	Test of Sig.	*p*-value
Glycated Hemoglobin				
<5.7%	15.8% (16)	88.1% (89)	fisher= 122.79*	<0.001
5.7%-<6.5%	12.9% (13)	11.9% (12)		
≥6.5%	71.3% (72)	0.0% (0)		
mean ± SD	7.64±2.01	5.27±0.92	t=10.779*	<0.001
Total cholesterol (mg/dl)				
>200	82.2% (83)	65.3% (66)	X^2=7.392*	0.007
200 or more	17.8% (18)	34.7% (35)		
mean ± SD	194.59±42.08	174.03±32.96	t=3.866*	<0.001

**P*-Value is significant. Abbreviation: (BMI: Body mass index, F: female, M: male).

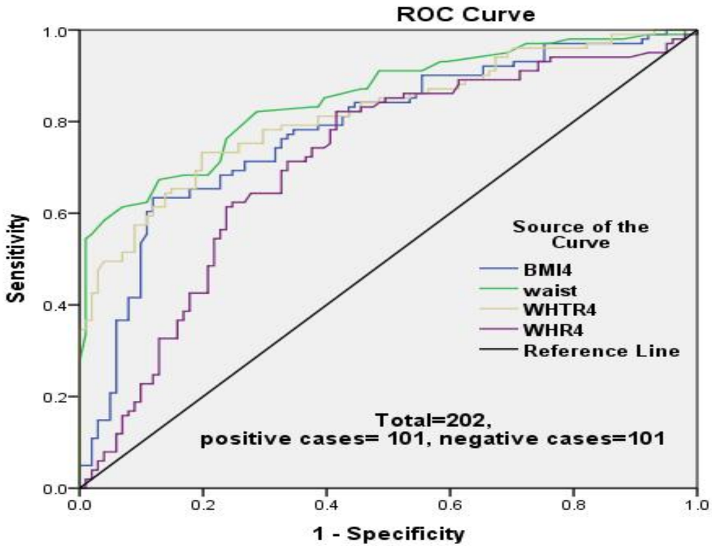

Fig.2. the areas and the receiver operating curve for the anthropometric measures in the prediction of type 2 diabetes Mellitus among all study participants (N=202)

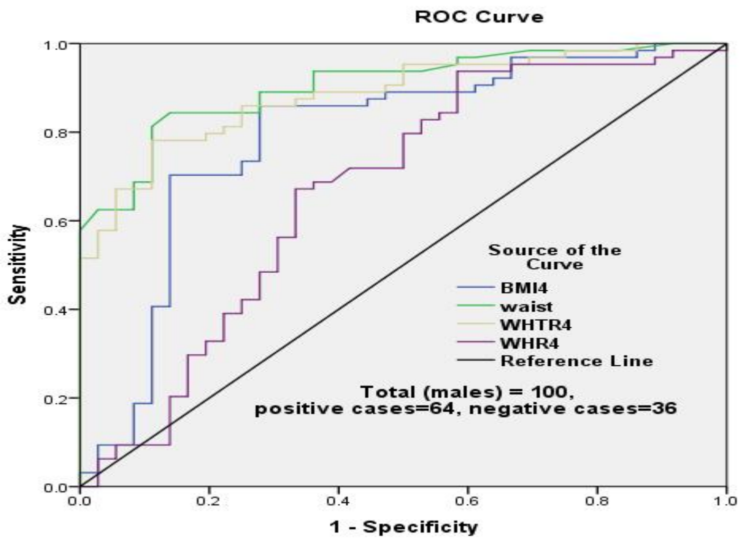

Fig.3. the areas and the receiver operating curve for the anthropometric measures in the prediction of type 2 diabetes Mellitus among men (n=100)

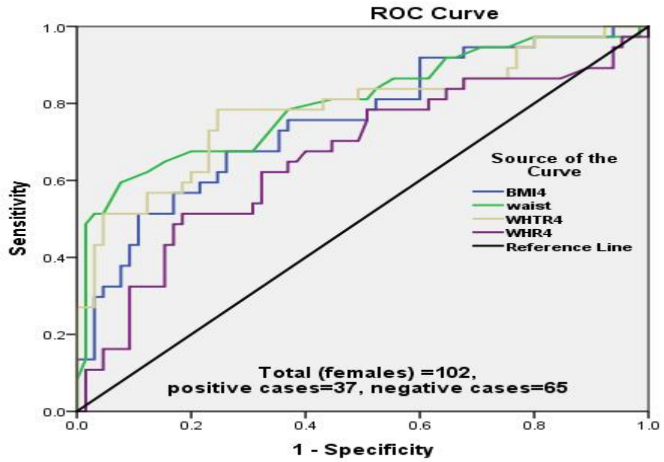

Fig.4. the areas and the receiver operating curve for the anthropometric measures in the prediction of type 2 diabetes Mellitus among Women (n=102)

Table 4: Cut-off values, sensitivity, and specificity for different anthropometric measures (n= 202):

Anthropometric measures	Cutoff	AUC	95% CI	P-value	sensitivity	Specificity
All participants, (n=202)						
BMI	37.6	0.783*	0.719-0.837	<0.001	0.63	0.88
WC	104.5	0.851*	0.798-0.903	<0.001	0.67	0.87
WHR	0.95	0.711*	0.638-0.783	<0.001	0.82	0.58
WHTR	0.65	0.817*	0.759-0.875	<0.001	0.73	0.80
Male participants, (n=100)						
BMI	30.9	0.790*	0.688-0.892	<0.001	0.86	0.72
WC	99.5	0.905*	0.848-0.962	<0.001	0.84	0.86
WHR	1.0	0.669*	0.550-0.788	0.005	0.69	0.64
WHTR	0.60	0.885*	0.822-0.948	<0.001	0.78	0.89
Female participants, (n=102)						
BMI	33.6	0.753*	0.654-0.852	<0.001	0.68	0.74
WC	103.5	0.801*	0.706-0.896	<0.001	0.68	0.80
WHR	0.95	0.663*	0.548-0.777	0.006	0.62	0.68
WHTR	0.65	0.784*	0.685-0.884	<0.001	0.78	0.75

*P-Value is significant. Abbreviations: (BMI: body mass index, WC: waist circumference, WHR: waist-to-hip ratio, WHTR: waist-to-height ratio).

Table 5: Crude and Age-adjusted binary logistic regression between anthropometric measures after being dichotomized based on the established cut-off values and type 2 Diabetes mellitus according to gender (n= 202):

	Males n=100		Females n= 102	
	OR (95% CI)	P-value	OR (95% CI)	P-value
Crude model				
BMI	15.9(5.8-43.8) *	<0.001	5.9(2.4-14.2) *	<0.001
WC	33.5(10.5-106.9) *	<0.001	11.7(4.3-31.6) *	<0.001
WHR	8.4(2.7-26) *	<0.001	3.1(1.3-7.1) *	0.009
WHTR	28.6(8.6-94.5) *	<0.001	11.1(4.2-29.1) *	<0.001
Age-adjusted model				
BMI	19.5(6.5-58.4) *	<0.001	6.5(2.5-16.4) *	0.001
WC	38.5(11.5-129.1) *	<0.001	11.5(3.9-33.8) *	0.001
WHR	9.5(2.9-30.6) *	<0.001	2.6(1.1-6.2) *	0.035
WHTR	35.3(10.1-123.2) *	<0.001	10.1(3.8-27.0) *	<0.001

*P- Value is significant. Abbreviations: (BMI: body mass index, OR: odds ratio, WC: waist circumference, WHR: waist-to-hip ratio, WHTR: waist-to-height ratio).

Discussion

To our knowledge, this is the first study in Egypt that compares the predictive ability of different anthropometric tools to T2DM and determines the best one of them.

First, the characteristics of participants in the current study revealed a great alarm for obesity markers among adults in Egypt as abnormal categories of WC, WHR, and WHTR were reported in nearly entire cases and more than two-thirds of the controls. In addition, BMI ≥ 30 kg/m2 and high total serum cholesterol were also recorded at high rates in both cases and controls. Importantly, about two-thirds of participants were rural, aged 40-59 years, most of them were married and nearly one of each five was a smoker. Herein, this situation can lead to multiple ramifications on individual health, family income, national health, and economic burden. These findings are consistent with a recently published study in Mansura governorate conducted by **Azzam et al. (2021)** on "Factors affecting glycemic control among Egyptian people with diabetes" and found that more than two-thirds of participants were rural, aged 40-60 years old, and married, nearly fifth ware smokers, and more than 9 of each ten were overweight or obese. In addition, the Egyptian National Hypertension Survey Program was conducted on 2313 adults older than 25 years of age, in 6 Egyptian governorates, and demonstrated that central obesity was reported in half of the surveyed individuals which is strongly associated with a greater risk of T2DM **(Hegazi et al., 2015)**. Hence, the work of health care for the prevention of T2DM is to be done as early as possible.

Second, the previous studies that compared the predictive ability of anthropometric tools to predict cardiometabolic conditions have contradicting findings. Our case-control study demonstrated a higher ability for WC to predict diabetes followed by WHTR, then BMI and finally WHR among Egyptian adult men and women.

This order of prediction ability comes in agreement with **Zhang et al. (2021)**. Moreover, WC was reported as a better predictor of T2DM compared to other measures among women and men in different populations such as India **(Luhar et al., 2021)**, China **(Fan et al., 2020)**, Singapore **(Lam, Koh, Chen, Wong, & Fallows, 2015)** and Ghana **(Quaye, Owiredu, Amidu, Dapare, & Adams, 2019)**. In addition, a systematic review and dose-response meta-analysis of 78 cohort studies demonstrated that a larger waist circumference, independent of overall adiposity, was strongly and linearly associated with the risk of type 2 diabetes **(Jayedi et al., 2022)**. In Egypt, **ElKafrawi, Shoaib, and Elghanam (2017)** conducted a study to assess waist circumference as a screening tool for type 2 diabetes mellitus in female patients in Menoufia Governorate and shows better association to WC than BMI, but it did not compare to the other anthropometrics.

However, there was plenty of inconsistency concerning the different anthropometric tools in the prediction of T2DM. WHTR was also reported to be a superior predictor compared to other anthropometric tools among women and men of different populations and this was summarized in a systematic review of thirteen studies which demonstrated the superiority of WHTR over other anthropometric tools **(Correa, Thumé, De Oliveira & Tomasi, 2016)**. WHTR was the higher predictive anthropometric measure in Jordan **(Khader et al., 2019)** and Iranian **(Mirzaei & Khajeh, 2018)**, and it has been argued to be superior to a single measure of WC in consideration of intraindividual and ethnic variations in height. Notably, this study shows that WHTR comes after WC with minimal variation in the prediction of T2DM. WHR was also reported to be a better anthropometric predictor for diabetes in some countries **(Borel et al., 2018; Chen, Qiu, Guo, Li, & Sun, 2019; Woldegebriel et al., 2020)**. Concerning BMI, systematic reviews **(Ashwell, Gunn, & Gibson, 2012; Browning, Hsieh, & Ashwell, 2010)** included Caucasian and Asian populations and reported the lesser utility of BMI in detecting undiagnosed T2DM as compared with abdominal indices. On the other hand, other studies revealed that BMI, WC, WHR, and WHTR had to some degree equal predictive performance for the risk of T2DM. WHR, WC, and WHTR had similar predictive power in Bangladeshi women **(Bhowmik et al., 2013)**. Possible justifications for the differences between studies might be related to ethnic and racial variations and variations in fat distribution and body composition from ethnic group to another, food habits, lifestyles, daily life behaviours, national customs and norms, age groups, and gender. Other justifications might be the differences that exist in the study designs, the WC measurement protocols or the definition of cardiometabolic outcomes.

The appropriate cut-off points for predicting diabetes among Egyptian men were 99.5 cm for WC, 0.6 WHTR, 30.9 Kg/m2 for BMI, and 1.0 for WHR. For women, the appropriate cut-off points were 103.5 cm for WC, 0.65 for WHTR, 33.6 Kg/m2 for BMI, and 0.95 for WHR. The order trend of dissimilatory power for the anthropometric measures was confirmed by crude and age-adjusted binary logistic regression after dichotomizing anthropometric measures based on the established cutoff values. Notably, odds ratios tend to be exaggerated and this could be due to the small sample size **(Fuyama, Hagiwara, & Matsuyama, 2021)**, however, the odds ratios served the study as a support analysis for ROC findings in the prediction ability.

Different cut-off values were reported for other populations. As for the current study, some of the proposed reasons could add some interpretation for why WC performed the best in the prediction of T2DM in Egyptian adults:

First, T2DM is linked to obesity and in particular abdominal obesity. Visceral fat acts hormonally to induce T2DM by secreting a group of hormones called adipokines which cause impaired glucose tolerance (**ElKafrawi, Shoaib, and Elghanam, 2017)**. Therefore, measures like WC, which reveal abdominal obesity would be a superior predictor of T2DM than BMI which is a measure of general obesity.

Second, some of the previous studies used self-reported diabetes of lesser than two years and many early T2DM patients are more likely to be obese than normal weight during the study conduction regardless of their WC. This could cause an overestimation of the BMI effect. Besides, it may underestimate the effect of WC due to the greater relative risk of WC in “normal weight” subjects than in "overweight subjects".

Third, the height of Egyptian adult height tends to be gender matched. In other words, males tend to be 170s cm in height and females at 150s **(Hassan, El-Masry, El-Banna & El Hussieny, 2014).** Thus, WHTR comes closely as the second tool after WC in the prediction of T2DM in this study.

Fourth, in Egypt, unhealthy lifestyle factors were greatly reported, and hip circumference is greatly affected by lifestyle risk factors with a different figure. For example, narrow hips are correlated with a heightened risk of diabetes **(Nilsson, Hedberg, Leppert & Ohrvik, 2018)**, however, large hip is correlated with sedentary life **(Naghizadeh, Saghafi-Asl, Amiri & Karamzad, 2019)**. Hence, the anticipated discrepancy in hip would decrease the accuracy of WHR in the prediction of T2DM.

In addition, Ethnic and racial differences might have a role in this discrepancy.

Conclusions

This study was an effort to compare the discriminatory power of different anthropometric measures to predict T2DM, using hospital cases and community controls. WC has the highest predictive ability for T2DM diabetes among the adult population in Egypt. Accordingly, the study researchers suggest WC as a tool of choice among the anthropometric measures with a cut-off value of 99.5 cm for men and 103.5 cm for women to predict T2DM among Egyptian adults.

Limitations of the study

Although the study determined which anthropometric measure could be the most predictive for T2DM in Egyptian adults, the generalizability of the results is a limitation of the study due to the smaller sample size.

Recommendations

Based on the study results, the health system can utilize WC as one of the indicators for the risk assessment of diabetes. Herein, the study researchers recommend WC be utilized in assessment sheets of health check-ups, admission, and follow-up in hospitals and outpatient clinics. For individuals at risk for diabetes, anthropometric measures can help them to early identify the occurrence of disease. For diabetics, WC can be routinely measured for follow-up of disease control.

Further studies of a large cohort type are required to confirm the study outcomes, especially the cut-off values.

Declaration of competing interests:

None.

Author contributions:

SN and LG: Conceptualization, Methodology, data analysis, all authors: contributed to data collection and Writing-Reviewing, Editing, they seriously revised the final version of the manuscript.

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