Anthropometric indices as novel markers of risk in type 2 diabetes mellitus (T2DM) among Nigerian adults in Zamfara State

§1Aguh Ikenna Bruno, 1Sani Zurmi Rabiu, 1Ohaleme Lynda Chinanu and 1Agba Andover Alfred

1Department of Biological Sciences, Federal University Gusau, Zamfara State, Nigeria

§Corresponding author: Aguh, Ikenna Bruno. Email/Phone:mibaguh@yahoo.com, +2348035074624

Abstract

Body mass index (BMI) has traditionally been used as an indicator of body size measure and composition. Although, other measures of adiposity of the abdomen such as waist circumference (WC), waist-hip ratio (WHR), neck circumference (NC) have been suggested as being superior to BMI in predicting disease outcome. This study was designed to compare different anthropometric variables in term of their ability to predict type 2 diabetes mellitus (T2DM). This was a case-control study in 240 participants involving 120 verified T2DM cases and 120 non-diabetics as control. Age, gender and anthropometric data were collected from each participant. Logistic regression models were used with areas under the receiver operating characteristic (AROC) curve to compare the variables predictive statistics. The AROC of WHR to identify T2DM patients was 0.678 (*P*<0.05), with sensitivity 62.5% of and specificity of 60.8%. The AROC for average arm circumference (AAC) model is 0.649 with sensitivity of 55.8% followed by BMI model (AROC 0.635) and WC model (AROC 0.600) (*P*<0.05). Hip circumference (HC) (AROC 0.508) and NC (AROC 0.492) models were not significant predictors of T2DM. Subjects of ≥60 years, AAC value ≥32.6 cm, BMI value ≥ 30 kg/m², and WHR value ≥ 0.93 were at significantly (*P*<0.05) higher odds of developing T2DM than lower subjects with lower values. There were no significant differences (*P*>0.05) in the mean HC and NC values between the diabetic and non-diabetic subjects. The non-diabetic subjects have significantly (*P*>0.05) higher mean height value than the diabetic subjects. Measures of generalized and central obesity were significantly associated with increased risk of developing T2DM. This study revealed that WHR can predict type 2 diabetes mellitus risk more accurately than other anthropometric measures and can thus be helpful in predicting patients with future occurrence of diabetes and providing necessary interventions.

Keywords: Type 2 Diabetes Mellitus, Waist-hip Ratio, AROC, Case control study, Nigeria

INTRODUCTION

Diabetes is a chronic disease that occurs as a result of inability of the pancreatic islet cells to produce sufficient insulin or the failure of the body to effectively utilize secreted insulin. Insulin is a hormone that plays important role in regulating the amount of glucose in the blood stream. Type 2 diabetes results from the body's ineffective use of insulin. Majority of the diabetes cases across the globe have type 2 diabetes accounting for around 90% of all cases, and are largely as result of sedentary lifestyle, obesity and overweight (WHO, 2018). Prediabetes is a condition in which a person has blood glucose level higher than normal but lower than the diagnostic range for diabetes (Tuso, 2014). Lifestyle modifications such as healthy diet and exercise have been proven to delay or prevent the development of diabetes mellitus (Kerrison et al., 2017). The quantification of the body composition by measures such weight, height and waist circumference could serve as estimate of a patient's risk for obesity-related co-morbidities as cardiovascular disease and type 2 diabetes mellitus (Purnell, 2018). Overweight and obesity are defined as accumulation of fat in excess of the body need that it portends trouble to health. Body mass index (BMI) is widely used to quantify obesity in a populace and is a measure of a person's weight (in kilograms) divided by the square of his or her height (in meters). So many observational studies have used BMI to measure general or overall adiposity. BMI is commonly employed as the measure of general or overall adiposity in most observational studies but there is increasing evidence supporting central (abdominal) fat pattern of distribution measured by waist circumference (WC) or waist-to-hip ratio (WHR) as a better estimator of health risk than elevated body weight majorly among older adults (Huxley et al., 2010; Must and McKeown, 2012).

Anthropometry studies human body measurement with regards to proportions of body tissues such muscle, bone and adipose (fat) (NHANES III, 1988). Assessments of subcutaneous fat tissues are very important at identifying individuals at greater risks for cardiovascular disease, hypertension, gallstones, arthritis, diabetes mellitus and other illnesses (NHANES III, 1988).

Epidemiological studies on obesity have utilized measures of body mass index (BMI), waist circumference (WC), waist-to-hip ratio (WHR), hip circumference (HC) and waist-to-stature ratio (WSR). Although, there is contention as to which anthropometric measures more accurately describe obesity and signify the greatest risk for type 2 diabetes and hypertension (Wei et al., 1997; Folsom et al., 2000; Tulloch-Reid et al., 2003; Hayashi et al., 2004; Menke et al., 2007; Zhou et al., 2009).

In a cross-sectional study undertaken in Jinan, China, Wang et al. (2016) reported that among adults aged 50 years and above, the best indicator of the relationship between obesity and type 2 diabetes is waist-to-stature ratio (WSR) for men and BMI for women. Adejumo et al (2018) in their study in southwest Nigeria compared the ability of anthropometric parameters to predict Metabolic Syndrome (MetS) and concluded that the WC was the best at predicting MetS in both men and women. Waist hip ratio (WHR) in both sexes had significant association with essential hypertension and type 2 diabetes mellitus while WC in males correlated strongly with BMI compared to WHR (Asuku et al., 2017).

Overweight and particularly obesity, majorly at younger ages, considerably increases lifetime risk of diagnosed diabetes, while their impact on diabetes risk, life expectancy, and diabetes duration diminishes with age (Narayan et al., 2007). Weight gain and body mass are very important to the formation and increasing type 1 and type 2 diabetes incidences (Al-Goblan et al., 2014). Siddiqui (2018) reported that type 2 diabetes can be prevented to a large extent by increasing physical activities and maintaining a healthy weight. Studies by Fasanmade et al. (2013) did not find routine anthropometric indices as reliable surrogates for atherogenicity measured by abnormalities in total cholesterol, low density lipoprotein and high-density lipoprotein cholesterol in Nigerians with type 2 diabetes and/or hypertension.

The connection between obesity and type 2 diabetes mellitus has been evaluated using several approaches. Imaging techniques such as computed tomography and magnetic resonance directly quantify the abdominal and subcutaneous fat tissues (Pescatori et al., 2019). These procedures are more expensive and intrusive making anthropometric assessments more regularly used. The majority of previous studies were carried out in other part of the world with few reporting available from Africa region most especially Nigeria. This study aims to compare wide ranging anthropometric measures as regards to their ability to predict type 2 diabetes mellitus (T2DM) in Nigerian adults.

MATERIALS AND METHODS

Study design and selection criteria

This was a case control study comprising one hundred and twenty (120) diabetic cases recruited from Federal Medical Centre (FMC), Gusau, Zamfara State, Nigeria. One hundred and twenty (120) non-diabetics recruited from the local community were used as control. Inclusion criteria for cases were those aged ≥ 30 years of either sex diagnosed with T2DM and who consented to participate. Patients of T2DM having other medical conditions like stroke, chronic renal diseases and chronic lung diseases or bedridden at the time of the study recruitment and pregnant females were excluded from the study. Diabetes was ruled out in the non-diabetic control by screening the participants at the time of enrolment into the study by random blood glucose (RBS) estimation using a glucometer (Accu-Chek Active Blood Glucose Monitoring System, Roche Diagnostics Corporation, Mannheim, Germany). Subjects with random blood sugar level (RBS) of less than 7.8 mmol/l were eligible to be included as controls. Institutional ethical committee clearance was obtained from Federal Medical Center, Gusau with approval no IEC 123/2014 before the initiation of the study. Written informed consent was obtained from all the study subjects.

Measurement protocol

The measurement protocol approved by World Health Organization (WHO, 2011) was used for all standardized measurements. Measurements such as neck, waist, and hip circumferences, right and left arm circumferences were made with a stretch-resistant tape that is wrapped snugly around the subject's body part of interest, but not to the point that the tape is constricting. Subjects were asked to stand upright during the measurement, with arms relaxed at the side, feet evenly spread apart and body weight evenly distributed and the reading taken to the nearest 0.1 cm. The height was taken as the perpendicular distance between the top of the head (the vertex) and the bottom of the feet. Readings for subjects' height were taken to the nearest 0.1 cm using a stadiometer and later converted to meter. Weight defined as the force the matter in the body exerts in a standard gravitational field was taken using weighing scales. The subjects were asked to stand on the centre of the scale without support, with their arms loosely by their sides, head facing forward and with their weight distributed evenly on both feet and reading to the nearest 0.1 kg was recorded for each subject. Body mass index (BMI) is defined as a person's weight in kilograms divided by the square of the person's height in metres (kg/m^2). The following indices were computed: WHR: waist circumference (cm)/hip circumference (cm); BMI: weight (kg)/height^2 (m^2); AAC: right arm circumference + left arm circumference/2. The following criteria was used for defining weight status using BMI: BMI <18.5 kg/m^2–Underweight, BMI 18.5- 24.9 kg/m^2Normal weight, BMI 25.0-29.9 kg/m^2Overweight and BMI ≥ 30 kg/m^2 Obese (WHO, 2004).

Data analysis

The mean values of anthropometric measures were compared between diabetic and non-diabetic subjects using the *t* test. Relationship between anthropometric variables among diabetic and non-diabetic subjects was determined using chi-square test. Logistic regression analysis was used to evaluate the association between measures of obesity and diabetes and also to compute the odds ratio (OR) and 95% confidence intervals (CI) for diabetes risks associated with the anthropometric measures. The area under the receiver operating characteristic (AROC) curve (c-statistic) for each model was calculated and used as the primary criterion upon which to judge a model's discriminative ability (Pepe *et al.*, 2004). All data analysis was done using the IBM SPSS® V21.0 software for windows (IBM Corporation, Armonk, New York, United States).

RESULTS

The results of this study revealed that subjects who were diabetic had significantly (p<0.05 p=0.000) higher mean age, waist circumference (WC), weight (W), random blood sugar level (RBSL), average arm circumference (AAC), body mass index (BMI) and waist hip ratio (WHR) than the non-diabetic subjects (Table 1). There were no significant differences(p>0.05, p=0.94 and 0.29 respectively) in the mean hip (HC) and neck circumferences (NC) between the diabetic and non-diabetic subjects (Table 1). The non-diabetic subjects were significantly (P<0.05, p=0.04) taller than the diabetic subjects (Table 1). There was increasing prevalence rate of diabetes with increasing BMI values. The prevalence rates were 33.1, 49.3 and 62.9% in the normal, overweight and obese subjects respectively (Table 2). The odds for diabetes in the obese subjects are about 3.143 times higher than in the normal weight subjects (Table 2). The prevalence

of diabetes increases with increasing age. The prevalence rate for subjects between ages 30 and 39 years was 3.0% and increased to as high as 84.8% in diabetic subjects aged 60 years and above. Subjects of ≥60 years old were more likely (OR=178.29) to develop diabetes than the younger subjects of 30–39-year-old (Table 2). Subjects with average arm circumference (AAC) of ≥ 32.6 cm were 3.8 times more likely developing diabetes when compared with subjects with AAC of ≤29.0 cm. (Table 2). The prevalence of diabetes increased with increasing WHR (Table 2). Subjects with WHR of greater than 0.92 were at 3.95 times increased odds of being diabetic when compared to those with WHR of less than or equals 0.88 (Table 2).

Analysis of data revealed that Waist-hip ratio (WHR) was the most significant predicator of diabetes with AROC of 0.678 and OR of 1.27E4 (95% CI = 1.79E4–9.02E5), followed by AAC (AROC= 0.649, OR= 1.12, 95% CI = 1.05–1.19), BMI (AROC= 0.635, OR= 1.09, 95% CI= 1.04-1.44) and WC (AROC= 0.600, OR= 1.03 95% CI= 1.01-1.05) (Table 3). The results of the study also showed that Hip circumference (HC) and NC were not significant predictors of diabetes (Table 3).

Table 1: Mean anthropometric measures in the diabetic and non-diabetic subjects

Anthropometrics	Diabetic	Non-diabetic	*P*-value
Age (year)	55.38±1.01[a]	39.89±0.86[b]	*0.000**
HC	100.3±1.22[a]	100.5±0.97[a]	*0.936ns*
WC (cm)	92.6±1.19[a]	88.3±1.15[b]	*0.009**
W (kg)	74.9±1.38[a]	69.5±1.17[b]	*0.003**
NC (cm)	35.3±0.36[a]	34.8±0.35[a]	*0.288ns*
H (m)	1.60±0.007[b]	1.62±0.008[a]	*0.040**
AAC (cm)	31.9±0.41[a]	29.8±0.38[b]	*0.000**
BMI (kgm^{-2})	29.5±0.58[a]	26.7±0.47	*0.000**
WHR	0.93±0.01[a]	0.88±0.01[b]	*0.000**

Key: WC=Waist circumference, W=Weight, H=Height, AAC=Average arm circumference, BMI=Body mass index, WHR=Waist-hip ratio, *=Significant, **= Very significant.Values are expressed as mean ± standard error of the mean (SEM). Values with different superscripted alphabets across rows are significantly different at *P*<0.05. N = 120 for diabetic and non-diabetic participants

DISCUSSION

Anthropometric measurements quantitatively assess the composition of the body as regards to the muscle, bone, and adipose tissue and are critical diagnostic criteria for obesity (Casadei and Kiel, 2020). Obesity is linked to raised blood pressure, blood lipids, and blood glucose and those that are obese are significantly at higher risk for disease state such as cardiovascular disease, hypertension, diabetes mellitus, and several other conditions (Din-Dzietham *et al,* 2007). Our results from this case-control study in Nigerian adults showed that mean BMI, WC, WHR and AAC values were significantly elevated in the diabetic as compared to the non-diabetic subjects. These results suggest a stronger association between these markers of adiposity and type 2 diabetes mellitus (T2DM). Studies have shown that visceral and subcutaneous fat cause the release of 'pro-inflammatory' chemicals by fat cells, which makes the body

resistant to insulin action thus disrupting insulin-responsive-cells function through alteration of their response to insulin (Lebovitz and Banerji, 2005; Global Diabetes Community, 2019). Visceral adiposity is also associated with build-up of surplus lipid in liver, resulting in the impairment of cell autonomous which is involved in insulin signaling (Hardy *et al.*, 2012). Our studies reveal that ageing has a significantly larger area under the ROC curve implying a positive association between older age and increasing prevalence of diabetic cases. This is in agreement with the studies carried out by Suastika *et al.* (2011) in some selected villages of Bali in Indonesia which showed that impaired fasting glycemia and type 2 diabetes mellitus were more prevalent in the aged than in the younger persons. The positive association obtained among the older age and the increasing prevalence of diabetic cases may be as a result of aging which causes an increase in insulin resistance and alteration in the beta cell compensatory effects and functions despite decreasing insulin responsiveness (Chang and Halter, 2003; De Tata, 2014). The first- and second-phase insulin secretions usually decrease at the rate of approximately 0.7% per year with aging (Szoke *et al.*, 2008). More so, aging is related with decrease in beta cell proliferation capability and upgraded susceptibility to apoptosis (Maedler *et al.*, 2006).

Table 2: Relationship between anthropometric variables among diabetic and non-diabetic subjects

Anthropometry variable	N	Diabetic subject n (%)	Non-diabetic subject n (%)	*P-Value*	OR	95%CI
Weight status (BMI) (Kgm^{-2})						
Normal[b]	77	27 (35.1)	50 (64.9)	0.002	0.32	0.17-0.60
Overweight	69	34 (49.3)	35 (50.7)		1.80	0.92-3.50
Obesity[c]	89	56 (62.9)	33 (37.1)		3.14	1.66-5.93
Age group (years)						
30-39[b]	66	2 (3.0)	64 (97.0)	0.000	0.006	0.00-0.03
40-49	64	27 (42.2)	37 (57.8)		23.35	5.25-103.85
50-59	59	47 (79.7)	2 (20.3)		125.33	26.77-586.72
≥60[c]	46	39 (84.8)	7 (15.2)		178.29	35.24-901.90
AAC(cm)						
≤29.0[b]	90	33 (36.7)	57 (63.3)	0.000	0.26	0.14-0.50
29.1-32.5	70	32 (45.7)	38 (54.3)		1.46	0.77-2.75
32.6[c] +	80	55 (68.8)	25 (31.2)		3.80	2.01-7.19
WHR						
≤0.88[b]	82	24 (29.3)	58 (70.7)	0.000	0.25	0.13-0.50
0.89-0.92	79	47 (59.5)	32 (40.5)		3.55	1.85-6.83
0.93[c] +	79	49(62.0)	30 (38.0)		3.95	2.05-7.62

Note: For the odds ratios (OR), the "b" labeled tertiles are the baseline for each stated OR, the bold-faced OR were compared the highest tertiles labeled "c"

Table 3: Values for Sensitivity, Specificity, Overall Percentage and area under the receiver operating characteristic (AROC) curve, Odds ratio (OR) and 95% confidence interval (95%CI) for predictor variables using the 0.5 cut off

Characteristics	Age	WHR	AAC	BMI	WC	NC	HC
Sensitivity	76.5	62.5	55.8	59.2	50.0	40.8	55.8
Specificity	80.8	60.8	62.5	66.7	59.2	62.5	42.5
Overall Percentage	78.7	61.7	59.2	62.9	54.6	51.7	49.2
AROC	0.869	0.678	0.649	0.635	0.600	0.552	0.492
P-value	0.000	0.000	0.000	0.000	0.008	0.172	0.825
OR	1.16	1.27E4	1.12	1.09	1.03	1.04	1.00
Lower 95% CI	1.12	1.79E2	1.05	1.04	1.01	0.97	0.98
Upper 95% CI	1.21	9.02E5	1.19	1.44	1.05	1.11	1.02

Key: Sensitivity=percentage of disease occurrences correctly predicted, Specificity=Percentage of disease non occurrences correctly predicted, AROC =Area under the receiver operating characteristic curve

Our study identified WHR as the best predictor of diabetes when compared to other measures such as AAC, BMI and WC. In another study by Jia *et al.* (2011), WHR with area under curve of 0.63 was the best predictor of diabetes in Chinese men over a 2 years follow-up period. Ta *et al.*, (2010) also reported waist-to-hip ratio (WHR) and systolic blood pressure can identify persons that are more associated with higher risk of type 2 diabetes in Vietnamese population. Study conducted by Asuku *et al.* (2017) on relationships of anthropometric indices of centripetal adiposity with essential hypertension and type 2 diabetes mellitus in Kano metropolis showed WHR had significant association with essential hypertension and type 2 diabetes mellitus in both males and females while WC in males correlated strongly with BMI compared to WHR. However, this contradicts the earlier reports of Khader *et al.* (2019), who reported the higher ability for waist-to-height ratio (WHR) to predict diabetes and hypertension among Jordanian adult men and women compared to other measures of anthropometry. Furthermore, study by Ting *et al.* (2018) suggested neck circumference (NC) as an indicator providing an early prediction of developing type 2 diabetes mellitus. In our study BMI performed better than WC in predicting type 2 diabetes mellitus. This finding is consistent with the findings of Haghighatdoost *et al.*, (2017) that showed BMI being a better predictor compared to other measures among men and women from a population-based cohort study. On the other hand, other studies showed that WC had better predictive powers for the risk of type 2 diabetes than the BMI. Waist circumference gives a better prediction of diabetes risk than does BMI. This is

the conclusion drawn by Feller and her colleagues from the German Institute for Nutritional Research in Potsdam-Rehbrücke in 2010. Our results suggest that excess weight and obesity are major contributing factor to type 2 diabetes mellitus and keeping a healthy body weight may serve as important preventive strategy for type 2 diabetes mellitus onset. Several current weight-loss plans, including diet programs, physical activity and lifestyle modifications have helped in long-term weight reduction and significantly reduced the incidence of diabetes (Tate *et al.*, 2003; Norris *et al.*, 2005; Appel *et al.*, 2011).

CONCLUSION

The findings of this study revealed that high adiposity is associated with a substantially increased risk of type 2 diabetes mellitus. Amongst the measures of adiposity assessed in this study, WHR Waist-to-hip ratio was better identifying diabetes. Keeping a healthy weight, not living a sedentary life with good dieting can help reduce your chances of being type 2 diabetes patient.

Study limitations

We acknowledge the study limitations. Most importantly, the sample size was not large enough and we could not estimate the cut-off points for the anthropometric measures. More so, the duration of the disease in each patient and also the drug used by each of the patient was not taken into account during the period of study.

Conflict of interest

Authors have no conflict of interest to declare.

REFERENCES

Adejumo, E., Adejumo, O., Azenabor, A., Ekun, O., Enitan, S., Adebola, O., Ogundahunsi, O. (2018). Anthropometric parameter that best predict metabolic syndrome in South west Nigeria. *Diabetes and Metabolic Syndrome: Clinical Research and Reviews*, **13**: 48-54.

Al-Goblan, A. S., Al-Alfi, M. A. and Khan, M. Z. (2014). Mechanism linking diabetes mellitus and obesity. *Diabetes, metabolic syndrome and obesity: targets and therapy*, **7**: 587–591.

Appel, L. J., Clark, J. M., Yeh, H-C., Wang, N-Y., Coughlin, J. W., Daumit, G., Miller, E. R., Dalcin, A., Jerome, G. J., Geller, S. (2011). Comparative effectiveness of weight-loss interventions in clinical practice. *New England Journal of Medicine*, **365**:1959–1968.

Asuku, A.Y., Adamu, L. H., Tela, I. A., Gudaji, A and Datti, S. (2017). relationships of anthropometric indices of centripetal adiposity with essential hypertension and type 2 diabetes mellitus in Kano metropolis. *Nigerian Journal of Basic and Applied Science*, **25**(1): 32-39. DOI:

Casadei, K. and Kiel, J. (2020). Anthropometric Measurement. In: StatPearls [Internet]. Treasure Island (FL): StatPearls Publishing; 2020 Jan-. Available from: https://www.ncbi.nlm.nih.gov/books/NBK537315/

Chang, A. M. and Halter, J. B. (2003). Aging and insulin secretion. *American Journal of Physiology: Endocrinology and Metabolism*, **284**: E7–E12.

Cheng, C. H., Ho, C. C., Yang, C. F., Huang, Y. C., Lai, C. H. and Liaw, Y. P. (2010). Waist-to-hip ratio is a better anthropometric index than body mass index for predicting the risk of type 2 diabetes in Taiwanese population. *Nutrition Research*, **30**(9):585–593.

De Tata, V. (2014). Age-related impairment of pancreatic Beta-cell function: pathophysiological and cellular mechanisms. *Frontiers in Endocrinology*, **5**, 138.

Din-Dzietham, R., Liu, Y., Bielo, M. V. and Shamsa, F. (2007). High blood pressure trends in children and adolescents in national surveys, 1963 to 2002. Circulation, **116** (13):1488-96.

Fasanmade, O. A., Odeniyi, I. A., Amira, C. O. and Okubadejo, N. U. (2013). Association of body mass index and abdominal adiposity with atherogenic lipid profile in Nigerians with type 2 diabetes and/or hypertension. *Nigerian medical journal*, **54**(6), 402–407.

Feller, S., Boeing, H. and Pischon, T. (2010). Body Mass Index, Waist Circumference, and the Risk of Type 2 Diabetes Mellitus: Implications for Routine Clinical Practice. *Deutsches Ärzteblatt International*, **107**(26): 470-6.

Folsom, A. R., Kushi, L. H., Anderson, K. E., Mink, P. J., Olson, J. E., Hong, C. P., Sellers, T. A., Lazovich, D. and Prineas, R. (2000). Associations of general and abdominal obesity with multiple health outcomes in older women: the Iowa Women's Health Study. *Archives of Internal Medicine*, **160**:2117-28.

Ford, E. S., Mokdad, A. H. and Giles, W. H. (2003). Trends in waist circumference among U.S. adults. *Obesity Research*, **11**(10):1223-1231.

Fox, C. S., Massaro, J. M., Hoffmann, U., Pou, K. M., Maurovich-Horvat, P., Liu, C. Y., Vasan, R. S., Murabito, J. M., Meigs, J. B., Cupples, L. A., D'Agostino, R. B. Sr, and O'Donnell, C. J. (2007). Abdominal visceral and subcutaneous adipose tissue compartments: association with metabolic risk factors in the Framingham Heart Study. *Circulation*, **116**:39-48.

Global Diabetes Community, 2019. Available on: *https://www.diabetes.co.uk/diabetes-and-obesity.html*.

Haghighatdoost, F., Amini, M., Feizi, A., and Iraj, B. (2017). Are body mass index and waist circumference significant predictors of diabetes and prediabetes risk: Results from a population-based cohort study. *World Journal of Diabetes*, **8**(7):365–373.

Hajian-Tilaki, K. and Heidari, B. (2015). Is waist circumference a better predictor of diabetes than body mass index or waist-to-height ratio in Iranian adults? *International Journal of Preventive Medicine*, 6:5

Hardy, O. T., Czech, M. P. and Corvera, S. (2012). What causes the insulin resistance underlying obesity? *Current*

Opinion in Endocrinology, Diabetes, and Obesity, **19** (2), 81–87.

Hayashi, T., Boyko, E. J., Leonetti, D. L., McNeely, M. J., Newell-Morris, L., Kahn, S. E. and Fujimoto, W. Y. (2004). Visceral adiposity is an independent predictor of incident hypertension in Japanese Americans. *Annals of Internal Medicine*, **140**:992-1000.

Huxley, R., Mendis, S., Zheleznyakov, E., Reddy, S. and Chan, J. (2010). Body mass index, waist circumference and waist:hip ratio as predictors of cardiovascular risk--a review of the literature. *European Journal of Clinical Nutrition*, **64**:16-22.

Jia, Z., Zhou, Y., Liu, X., Wang, Y., Zhao, X., Wang, Y., Liang, W. and Wu, S. (2011). Comparison of different anthropometric measures as predictors of diabetes incidence in a Chinese population. *Diabetes Research and Clinical Practice*, **92**(2):265-271.

Kerrison, G., Gillis, R. B., Jiwani, S. I., Alzahrani, Q., Kok, S., Harding, S. E., Shaw, I. and Adams, G. G. (2017). The Effectiveness of Lifestyle Adaptation for the Prevention of Prediabetes in Adults: A Systematic Review. *Journal of Diabetes Research*, vol. 2017, Article ID 8493145.

Khader, Y., Batieha, A., Jaddou, H., El-Khateeb, M. and Ajlouni, K. (2019). The performance of anthropometric measures to predict diabetes mellitus and hypertension among adults in Jordan. *BMC Public Health*, 19:1416.

Lebovitz, H. E. and Banerji, M. A. (2005). Visceral Adiposity Is Causally Related to Insulin Resistance. *Diabetes Care*, **28** (9): 2322-2325.

Maedler, K., Schumann, D. M., Schulthess, F., Oberholzer, J., Bosco, D., Berney, T. and Donath, M. Y. (2006). Aging correlates with decreased beta-cell proliferative capacity and enhanced sensitivity to apoptosis: a potential role for Fas and pancreatic duodenal homeobox-1. *Diabetes*, **55**:2455–2462.

Menke, A., Muntner, P., Wildman, R. P., Reynolds, K. and He, J. (2007). Measures of adiposity and cardiovascular disease risk factors. *Obesity,* **15**:785-95.

Must, A. and McKeown, N. M. (2012). The Disease Burden Associated with Overweight and Obesity. In: Feingold, K. R., Anawalt, B., Boyce, A., *et al.*, editors.

Endotext. South Dartmouth (MA): MDText.com, Inc.; 2000-. Available from: https://www.ncbi.nlm.nih.gov/books/NBK279095/

Narayan, K. M. V., Boyle, J. P., Thompson, T. J., Gregg, E. W. and Williamson, D. F. (2007). Effect of BMI on Lifetime Risk for Diabetes in the U.S. *Diabetes Care*, **30** (6) 1562-1566; DOI: 10.2337/dc06-2544.

NHANES III (1988). Westat, Inc. 1650 Research Boulevard Rockville, MD 20850 (301) 251-1500.

Norris, S., Zhang, X., Avenell, A., Gregg, E., Brown, T., Schmid, C. and Lau J. (2005). Long-term non-pharmacological weight loss interventions for adults with type 2 diabetes mellitus. *Cochrane Database of Systematic Reviews*, 2005 Apr **18**;(2):CD004095.

Peng, L. N., Lin, M. H., Lai, H. Y., Hwang, S. J., Chen, L. K. and Chiou, S. T. (2010). Risk factors of new onset diabetes mellitus among elderly Chinese in rural Taiwan. *Age and Ageing*, **39**: 125-128.

Pepe, M. S., Janes, H., Longton, G., Leisenring, W. and Newcomb, P. (2004). Limitations of the Odds Ratio in gauging the performance of a diagnostic, prognostic, or screening marker. *American Journal of Epidemiology*, **159:**882– 890.

Pescatori, L. C., Savarino, E., Mauri, G., Silvestri, E., Cariati, M., Sardanelli, F. and Sconfienza, L. M. (2019). Quantification of visceral adipose tissue by computed tomography and magnetic resonance imaging: reproducibility and accuracy. *Radiologia Brasileira*, **52**(1), 1–6.

Purnell, J. Q. (2018). Definitions, Classification, and Epidemiology of Obesity. In: Feingold, K. R., Anawalt, B., Boyce, A., et al., editors. Endotext [Internet]. South Dartmouth (MA): MDText.com, Inc.; 2000-. Available from: https://www.ncbi.nlm.nih.gov/books/NBK279167/

Qiao, Q. and Nyamdorj, R. (2010). The optimal cutoff values and their performance of waist circumference and waist-to-hip ratio for diagnosing type II diabetes. *European Journal of Clinical Nutrition*, **64**(1):23-29.

Siddiqui, S. (2018). Obesity and diabetes: interrelationship. *Advances in Obesity, Weight Management and Control*, **8**(2):155-158.

Snijder, M. B., van Dam, R. M., Visser, M. and Seidell, J. C. (2006). What aspects of body fat are particularly hazardous and how do we measure them? *International Journal of Epidemiology*, **35**(1):83-92.

Suastika, K., Saraswati, M., Gotera, W., Budhiarta, A., Sutanegara, I., Gunadi, I., Nadha, K., Wita, W., Rina, K., Santoso, A., Matsumoto, K., Kajiwara, N. and Taniguchi, H. (2011). Prevalence of Obesity, Metabolic Syndrome, Impaired Fasting Glycemia, and Diabetes in Selected Villages of Bali, Indonesia. *Journal of the ASEAN Federation of Endocrine Societies*, **26**: 159-162.

Szoke, E., Shrayyef, M., Messing, S., Woerle, H., van Haeften, T., Meyer, C., Mitrakou, A., Pimenta, W. and Gerich, J. (2008). Effect of Aging on Glucose Homeostasis: Accelerated deterioration of -cell function in individuals with impaired glucose tolerance. *Diabetes care*, **31**(3): 539-543.

Ta, M. T., Nguyen, K. T., Nguyen, N. D., Campbell, L. V. and Nguyen, T. V. (2010). Identification of undiagnosed type 2 diabetes by systolic blood pressure and waist-to-hip ratio. *Diabetologia*, **53** (10):2139–46.

Tate, D. F., Jackvony, E. H. and Wing, R. R. (2003). Effects of internet behavioral counseling on weight loss in adults at risk for type 2 diabetes. *Journal of the American Medical Association*, **289**:1833–1836.

Taylor, A. E., Ebrahim, S., Ben-Shlomo, Y., Martin, R. M., Whincup, P. H., Yarnell, J. W., Wannamethee, S. G. and Lawlor, D. A. (2010). Comparison of the associations of body mass index and measures of central adiposity and fat mass with coronary heart disease, diabetes, and all-cause mortality: a study using data from 4 UK cohorts. *American Journal of Clinical Nutrition*, **91**(3):547-556.

Ting, M., Liao, P., Wu, I., Chen, S., Yang, N., Lin, T. and Hsu, K. (2018). predicting type 2 diabetes mellitus occurrence using three-dimensional anthropometric body surface scanning measurements: A prospective cohort study. *Journal of Diabetes Research*, vol. 2018, Article ID 6742384, 10 pp

Tulloch-Reid, M. K., Williams, D. E., Looker, H. C., Hanson, R. L. and Knowler, W. C. (2003). Do measures of body fat distribution provide information on the risk of type 2 diabetes in addition to measures of general obesity? Comparison of anthropometric predictors of type 2 diabetes in Pima Indians. *Diabetes Care,* **26**:2556-2561.

Tuso, P. (2014). Prediabetes and lifestyle modification: time to prevent a preventable disease. *The Permanente Journal,* **18**(3): 88–93.

Wang, S, Ma, W, Yuan, Z, Wang, S., Yi, Z., Jia, H. and Xue, F. (2016). Association between obesity indices and type 2 diabetes mellitus among middle-aged and elderly people in Jinan, China: a cross-sectional study. *British Medical Journal*, 6:e012742.

Wei, M., Gaskill, S. P., Haffner, S. M. and Stern, M. P. (1997). Waist circumference as the best predictor of noninsulin dependent diabetes mellitus (NIDDM) compared to body mass index, waist/hip ratio and other anthropometric measurements in Mexican Americans--a 7-year prospective study. *Obesity Research*, **5:**16-23.

WHO (2018).Obesity. Available on: https://www.who.int/topics/obesity/en

WHO expert consultation (2004). Appropriate body-mass index for Asian populations and its implications for policy and intervention strategies. Lancet, **363**:157–163.

World Health Organization (2011). Waist Circumference and Waist–Hip Ratio: Report of a WHO Expert Consultation. Available from: http://apps.who.int/iris/bitstream/handle.

Zhou, Z., Hu, D. and Chen, J. (2009). Association between obesity indices and blood pressure or hypertension: which index is the best? *Public Health Nutrition*, **12**:1061-1071.