

# The accuracy of anthropometric measurements of general and central obesity for the prediction of impaired glucose tolerance among the adult population of South India

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## ABSTRACT

**Background:** The distribution of body fat and its variation is of great importance in determining the pathogenesis of insulin resistance. Central obesity has been recognized as an independent risk factor for diabetes. The objective of the study was to evaluate the predictive accuracy of various anthropometric measures of body fat in determining impaired glucose tolerance (IGT) or prediabetes among South Indian population. **Methodology:** This was a community-based comparative cross-sectional study where the anthropometric measures of a representative sample of 171 individuals with glycosylated hemoglobin (HbA1c) in the range for IGT were compared with age- and gender-matched controls with HbA1c in the normal range. The predictive accuracy of the various anthropometric measures of obesity to identify individuals with IGT was estimated using the area under the receiver operating characteristic (ROC) curve. **Results:** Patients with IGT in both genders had significantly higher BMI, waist circumference (WC), neck circumference (NC), and waist-to-height ratio (WHtR). ROC analysis revealed WHtR in females and NC among males to have the largest area under the curve for predicting IGT. In both genders, WC, WHtR, and NC had better predictive accuracy for prediabetes as compared to BMI and waist-to-hip ratio (WHR). **Conclusion:** It is suggested that the WHtR and WC are better screening tools for prediabetes in comparison to BMI and WHR among the South Indian population.

**Keywords:** Impaired glucose tolerance, insulin resistance, South India, waist circumference, waist-to-height ratio

## Background

The prevalence of type 2 diabetes mellitus has reached epidemic proportions in India with an estimated 62.4 million people with diabetes and 77.2 million people with prediabetes.<sup>[1]</sup> Diabetes and obesity are strong risk factors for cardiovascular diseases,

the leading cause of premature death in the world.<sup>[2]</sup> The rising burden of obesity and diabetes poses a direct health risk to India's population by increasing the risk of cardiovascular diseases and escalating health-care expenditures. Aggressive interventions at the population level are needed to identify those individuals at a higher degree of this metabolic risk.

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Adiposity is highly heterogeneous with gender and ethnic differences in body-fat distribution. Epidemiological studies have demonstrated that android pattern obesity often referred to as

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the upper body or central obesity was more frequently associated with insulin resistance syndromes than the gynoid pattern obesity or peripheral obesity.<sup>[3]</sup> Central obesity has been recognized as an independent risk factor for cardiometabolic diseases and a better predictor of cardiometabolic risk than overall obesity. BMI is a nonspecific measure of obesity, which can misclassify individuals with large lean body mass as overweight or obese. The general recommendation is that hip and waist circumferences (WCs) should be considered jointly for inclusion in CVD risk prediction models and in the assessment of obesity-related risk of future death.<sup>[4]</sup> Frayn proposed that the link between visceral adiposity and insulin resistance correlates with subcutaneous abdominal adipose tissue accumulation. Subcutaneous fat probably is significant in determining systemic plasma nonesterified fatty acid concentrations, which plays the major role in the pathogenesis of insulin resistance.<sup>[5]</sup>

McKeigue *et al.* reported the existence of an insulin resistance syndrome, prevalent in South Asian populations which is associated with a pronounced tendency to central obesity compared to the European population.<sup>[6]</sup> The primary-care setting in India lacks an optimal screening strategy for type 2 diabetes and metabolic syndrome to guide primary-care providers with decision-making regarding the need for performing a diagnostic test. Screening tools that include additional anthropometric biomarkers might yield better predictive value. So, there is a need for validation of anthropometric measures for abdominal and generalized obesity across different ethnic groups in India. An uncertainty regarding the degree of correlation between various anthropometric measurements of adiposity and prediabetes in the South Indian population is reflected by a paucity of studies. The objective of the current study is to determine whether anthropometric measurements of upper body obesity significantly predict impaired glucose tolerance (IGT) or prediabetic state.

## Materials and Methods

### Study setting and study population

This study was conducted within the framework of the community-based diabetes detection program, a CSR-funded institutional project. This population-based cross-sectional survey was conducted among residents of seven districts of Kerala and Tamil Nadu. A total of 3197 adults aged above 21 years were screened for diabetes mellitus and hypertension. Screening was done during outreach camps by measurement of glycosylated hemoglobin (HbA1c) levels in capillary fingerstick blood sample using a validated HbA1c test which utilizes the boronate affinity method.<sup>[7]</sup>

One hundred and seventy one participants with age from 21 to 60 years with HbA1c values in the range for IGT, that is, 5.7–6.4%,<sup>[8]</sup> and 171 age- and gender-matched individuals with HbA1c in the normal range (<5.7%) were selected for the study from the pool of 3197 volunteers. Participants

with active infection, on steroid medications, pregnancy, liver disease, and comorbid metabolic or endocrine disorders, were excluded.

All the study participants underwent anthropometric assessment. Anthropometric measurements were obtained in duplicate according to standardized procedures. The mean of two measurements was taken to the nearest centimeter. WC was measured midpoint half-way between the right iliac crest and the lower costal region, and hip circumference (HC) was measured at the level of the greater trochanters. Neck circumference (NC) was measured between the mid-cervical spine and mid-anterior neck just below the laryngeal prominence. All measurements were done using nonstretchable plastic tape with subjects standing upright.

### Statistical analysis

The data were described using mean  $\pm$  SD for continuous variables and proportions were used for categorical variables. All quantitative variables except HC and waist-to-hip ratio (WHR) were approximately normally distributed. For normally distributed variables, Pearson's correlation and independent sample's *t*-test were used, and for non-normally distributed variables, nonparametric Spearman's rank correlation and Mann-Whitney *U* tests were used to assess the associations between anthropometric measurements of obesity with HbA1c category. The predictive accuracy of the various anthropometric measures of obesity to identify individuals with IGT was estimated using the area under the receiver operating characteristic (ROC) curve. A *P* value of less than 0.05 was considered to be statistically significant. All statistical analyses were performed with IBM SPSS Statistics V.25.

## Results

The demographic characteristics of the study participants are shown in Table 1. A final sample of 342 study participants comprising 171 cases with IGT and 171 controls with normal blood sugars were included in this study. The case group and control group were comparable with respect to the mean age and gender distribution. A greater proportion of participants in the case group and control group were males. The BMI (body mass index) of the female participants in the study group had significantly greater HC and waist-to-height ratio (WHtR). Male participants were more likely to have higher WHRs and higher WC. Mean NC was significantly higher among males.

**Table 1: Demographic characteristics of the study population**

Demographic characteristic	Cases n (%)	Controls n (%)	<i>P</i>	
Gender	Male	105 (61.4)	112 (65.5)	0.432
	Female	66 (38.6)	59 (34.5)	
Place	Tamil Nadu	90 (52.6)	87 (50.9)	0.644
	Kerala	81 (47.4)	84 (49.1)	
Age	Mean $\pm$ SD	38.22 $\pm$ 13.47	39.84 $\pm$ 11.93	0.242

For comparing the anthropometric measures of obesity, the cases and controls were divided into subgroups based on gender. In both genders, we found a statistically significant difference between the cases and controls in the mean values of BMI, WC, NC, and WHtR. Table 2 shows gender wise distribution of the mean anthropometric measurements of the cases and controls. All circumference measures were larger among the cases (prediabetics), with WC among females showing the largest mean difference (9.6 cm). Although statistically significant, the differences in neck and HCs between the two groups were relatively smaller.

Table 3 describes the gender-specific Pearson's correlation coefficients between adiposity measures and the HbA1c levels. All anthropometric measurements except BMI in men and HC in women showed significant positive correlations. The degree of correlation of adiposity measures with HbA1c levels in females were relatively higher than those observed in male participants. Among women, WHtR, WC, and BMI showed moderate positive correlation with HbA1c levels ( $r = 0.571$ ,  $r = 0.537$ ,  $r = 0.450$ ), whereas in men moderate positive correlation was found with WC and WHtR ( $r = 0.401$ ,  $r = 0.403$ ). A weak positive correlation was observed for both NC and WHR in both genders. However, HC had only a negligible positive correlation.

We further examined the predictive ability of these anthropometric measures to identify individuals with IGT [Table 4]. Among the male participants, NC and WHtR recorded higher area under the ROC curves (0.674, 0.656) than other obesity measures with regards to predicting IGT. The AUC for WC (0.647) was lower than that for NC but higher than that for BMI, HC, and WHR in males. Among all the anthropometric parameters evaluated, WHtR had the highest AUC (0.776) for predicting IGT among females closely followed by WC (0.763). In contrast to the findings among males, female participants had a higher AUC for BMI than NC (0.738 vs. 0.734). WHR was observed to be insignificant in predicting IGT in both genders.

## Discussion

Several lines of evidence suggest that the South Indian population is predisposed to developing insulin resistance marked by a relatively high prevalence of type 2 diabetes and a tendency to truncal obesity.<sup>[9-12]</sup> The current study underscores the importance of body-fat predominance and its association

with insulin resistance among the South Indian population. Furthermore, the results of the study emphasizes the hypothesis that localization of fat in the upper body has an independent effect in decreasing insulin sensitivity.<sup>[13]</sup>

Our data indicated that the measures of central obesity are stronger risk factors for IGT than general obesity measures. We observed moderate positive correlation with HbA1c levels and higher area under ROC curves in predicting IGT for WC and WHtR than BMI in both genders. These observations corroborate the findings by many investigators that central obesity variables proved to be superior to BMI.<sup>[14]</sup> However, the measures for central obesity differ between studies with some using WC and others using WHR and HC. Earlier studies have shown WHR to be a strong predictor for IGT and type 2 diabetes.<sup>[13-16]</sup> In the present study, the authors observed that among the various measures of central obesity, WC was the single most useful predictor of IGT in males and females from South India. This finding is in agreement with many studies showing the relative benefits of WC.<sup>[17,18]</sup> A study by Zhu *et al.* based on the NHANES data reported that WC is a better indicator of diabetes risk than BMI and WHR among different populations.<sup>[19]</sup> Our observations are in accordance with that of meta-analysis by Hollander *et al.*, which reported that adjusted mortality was substantially greater for those with an elevated WC within each of the different BMI categories.<sup>[20]</sup> Interventional studies have also demonstrated that lifestyle-induced reductions in WC are associated with improvements in risk factors for metabolic syndrome.<sup>[21]</sup> In a case-control study done by Mamtani *et al.* in Nagpur,<sup>[22]</sup> the investigators did not observe any additional benefit of WHR over WC. The findings of the present study are directly in line with the most recently published literature. In the year 2019, Neeland *et al.* reported that WC was more strongly associated with the absolute amount of intra-abdominal or visceral fat compared with the WHR.<sup>[23]</sup> The cross-sectional data of 3572 healthy Chinese adults from the Pinggu Metabolic Disease Study, published in the year 2020, conclude that WC is one of the best indicators for hyperglycemic risk. This study utilized computed tomography scan to estimate visceral fat area and subcutaneous fat for comparison.<sup>[24]</sup> A gender similarity in the predictive potential of WC in the current study adds further strength to recommendations to favor use of WC for diabetic risk assessment.

A novel aspect of the present study is the finding that WHtR and NC as better predictors of IGT than BMI. Results from

**Table 2: Comparison of mean anthropometric measurements of the cases and controls as per the gender distribution**

Variables	Males				Females			
	All	Normal	IGT	P	All	Normal	IGT	P
BMI	25.26±3.69	24.24±3.25	26.21±3.83	<0.001	25.76±4.03	24.32±3.56	27.36±3.96	<0.001
WC	91.09±10.28	88.33±9.28	93.68±10.54	<0.001	88.96±10.81	84.57±9.36	94.71±9.91	<0.001
HC	93.36±7.82	91.58±6.91	95.11±8.29	0.004	101.86±5.73	102.45±5.12	101.50±6.19	0.193
NC	38.21±2.94	37.25±2.46	39.10±3.08	<0.001	33.82±2.62	32.87±2.15	34.87±2.71	<0.001
WHR	0.9616±0.0579	0.9521±0.0560	0.9710±0.0585	0.037	0.9132±0.0619	0.9102±0.0593	0.9168±0.0667	0.324
WHtR	54.02±5.86	52.39±5.10	55.55±6.13	<0.001	58.48±16.02	54.14±6.44	64.17±22.08	0.004

**Table 3: Correlation between anthropometric indices and HbA1c among males and females**

Anthropometric indices	HbA1c %	
	Males	Females
BMI	0.316	0.450*
Waist circumference (WC)	0.401*	0.537*
Hip circumference (HC)	0.293*	0.077
Neck circumference (NC)	0.332*	0.346*
Waist-to-hip ratio (WHR)	0.306*	0.388
Waist-to-height ratio (WHtR)	0.403*	0.571*

\*Significant at &lt;0.01

**Table 4: Area under the ROC curve for anthropometric variables stratified by gender in predicting impaired glucose tolerance**

Gender	Variables	AUC	P	95% Confidence interval
Male	BMI	0.634	0.001	0.561-0.720
	WC	0.647	<0.001	0.574-0.707
	NC	0.674	<0.001	0.603-0.745
	WHtR	0.656	0.001	0.593-0.737
	HC	0.633	0.004	0.547-0.718
	WHR	0.577	0.090	0.489-0.665
Female	BMI	0.734	<0.001	0.641-0.826
	WC	0.763	<0.001	0.673-0.852
	NC	0.738	<0.001	0.643-0.834
	WHtR	0.776	<0.001	0.690-0.863
	HC	0.367	0.119	0.146-0.594
	WHR	0.593	0.217	0.409-0.778

cross-sectional studies done in China and Sri Lanka have shown WHtR as the best indicator for undiagnosed type 2 diabetes and impaired fasting glucose.<sup>[25,26]</sup> A study carried out in 2018 among young British adults states that the indices directly associated with WC and specifically WHtR had greater diagnostic power in detection of cardiometabolic risk and metabolic syndrome.<sup>[27]</sup> More recently, an observational study done among 558 healthy Qatari adults has shown that anthropometric measures, namely, WC and WHtR, are clinically valuable tools to identify individuals at higher cardiometabolic risk compared to dual-energy X-ray absorptiometry-derived parameters.<sup>[28]</sup> A meta-analysis by Kodama *et al.* showed that WHtR had a statistically greater importance than BMI and WHR in prediction of diabetes.<sup>[29]</sup> A systematic review of 78 prospective and cross-sectional studies indicates that WHtR may be a useful global clinical screening tool for diabetes, with a weighted mean value of 0.5.<sup>[30]</sup> In the same review, the authors support the public health message “keep your WC to less than half your height.”<sup>[30]</sup>

In the present study, NC was strongly predictive of IGT among male participants. Anatomically, upper body subcutaneous fat is a unique fat depot located in a separate compartment compared with visceral adipose tissue. A study by Yang *et al.* concludes that NC surpasses other anthropometric measurements as a powerful marker of both visceral and abdominal subcutaneous fat and significant indicator of insulin resistance.<sup>[31]</sup> Similar conclusions

were reached by many investigators with regard to NC.<sup>[32,33]</sup> The major limitation of our study was its cross-sectional design. Further prospective research is needed to evaluate the validity and diagnostic thresholds of the anthropometric measures.

## Conclusion

The present observational study indicates that WC and WHtR are statistically better obesity indicators for prediction of IGT and future diabetes risk than is BMI or WHR. The authors conclude that the use of general obesity measures like BMI as a measure of obesity is insufficient for assessing the risk of diabetes among the South Indian population. The results of the study establish a clear link between central adiposity and the glycated hemoglobin levels. Based on our comparisons, we recommend that primary-care physicians routinely include WC as a risk assessment tool in the evaluation of patients suspected to have prediabetes. Given the high prevalence of diabetes in Kerala and Tamil Nadu, WC and WHtR can be used as simple screening tools for identifying high-risk individuals in these areas.

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## Conflicts of interest

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**Abbreviations:** ROC: Receiver operating characteristic curve; WHtR: waist-to-height ratio; NC: neck circumference; BMI: body mass index; WHR: waist-to-hip ratio; WC: waist circumference; CVD: cardio vascular disease; CSR: corporate social responsibility; IGT: impaired glucose tolerance; HC: hip circumference; SD: standard deviation; NHANES: National Health and Nutrition Examination Survey; VFA: visceral fat area; DXA: dual-energy X-ray absorptiometry

## References

1. Anjana RM, Pradeepa R, Deepa M, Datta M, Sudha V, Unnikrishnan R, *et al.* Prevalence of diabetes and prediabetes (impaired fasting glucose and/or impaired glucose tolerance) in urban and rural India: Phase I results of the Indian council of medical research-IndiaDIABetes (ICMR-INDIAB) study. *Diabetologia* 2011;54:3022-7.
2. Yusuf S, Hawken S, Ôunpuu S, Dans T, Avezum A, Lanus F, *et al.* Effect of potentially modifiable risk factors associated with myocardial infarction in 52 countries (the INTERHEART study): Case-control study. *Lancet* 2004;364:937-52.
3. Garg A. Regional adiposity and insulin resistance. *J Clin Endocrinol Metab* 2004;89:4206-10.
4. Cameron AJ, Magliano DJ, Shaw JE, Zimmet PZ, Carstensen B,

- Alberti KG, *et al.* The influence of hip circumference on the relationship between abdominal obesity and mortality. *Int J Epidemiol* 2012;41:484-94.
5. Frayn KN. Visceral fat and insulin resistance—causative or correlative? *Br J Nutr* 2000;83(S1):S71-7.
  6. McKeigue PM, Shah B, Marmot MG. Relation of central obesity and insulin resistance with high diabetes prevalence and cardiovascular risk in South Asians. *Lancet* 1991;337:382-6.
  7. Biomedical measuring devices, systems, and methods for measuring analyte concentration. Available from: <https://patents.google.com/patent/US20190232287A1/en>. [Last accessed on 2019 Nov 3].
  8. Inzucchi S, Bergenstal R, Fonseca V, Gregg E, Mayer-Davis B, Spollett G, *et al.* Diagnosis and classification of diabetes mellitus. *Diabetes Care* 2010;33:S62-9.
  9. Zhu S, Heymsfield SB, Toyoshima H, Wang Z, Pietrobelli A, Heshka S. Race-ethnicity-specific waist circumference cutoffs for identifying cardiovascular disease risk factors. *Am J Clin Nutr* 2005;81:409-15.
  10. Ramachandran A, Jali MV, Mohan V, Snehalatha C, Viswanathan M. High prevalence of diabetes in an urban population in south India. *BMJ* 1988;297:587-90.
  11. National Family Health Survey (NFHS-4), 2015-16: India. Mumbai: IIPS.
  12. Chandalia M, Abate N, Garg A, Stray-Gundersen J, Grundy SM. Relationship between generalized and upper body obesity to insulin resistance in Asian Indian men. *J Clin Endocrinol Metab* 1999;84:2329-35.
  13. Evans DJ, Hoffman RG, Kalkhoff RK, Kissebah AH. Relationship of body fat topography to insulin sensitivity and metabolic profiles in premenopausal women. *Metabolism* 1984;33:68-75.
  14. Rosenthal AD, Jin F, Shu XO, Yang G, Elasy TA, Chow WH, *et al.* Body fat distribution and risk of diabetes among Chinese women. *Int J Obes Relat Metab Disord* 2004;28:594-9.
  15. Haffner SM, Stern MP, Hazuda HP, Pugh J, Patterson JK. Do upper-body and centralized adiposity measure different aspects of regional body-fat distribution? Relationship to non-insulin-dependent diabetes mellitus, lipids, and lipoproteins. *Diabetes* 1987;36:43-51.
  16. Ohlson LO, Larsson B, Björntorp P, Eriksson H, Svärdsudd K, Welin L, *et al.* Risk factors for type 2 (non-insulin-dependent) diabetes mellitus. Thirteen and one-half years of follow-up of the participants in a study of Swedish men born in 1913. *Diabetologia* 1988;31:798-805.
  17. Jia WP, Lu JX, Xiang KS, Bao YQ, Lu HJ, Chen L. Prediction of abdominal visceral obesity from body mass index, waist circumference and waist-hip ratio in Chinese adults: Receiver operating characteristic curves analysis. *Biomed Environ Sci* 2003;16:206-11.
  18. Hadaegh F, Zabetian A, Harati H, Azizi F. Waist/height ratio as a better predictor of type 2 diabetes compared to body mass index in Tehranian adult men—a 3.6-year prospective study. *Exp Clin Endocrinol Diabetes* 2006;114:310-5.
  19. Zhu S, Heymsfield SB, Toyoshima H, Wang Z, Pietrobelli A, Heshka S. Race-ethnicity-specific waist circumference cutoffs for identifying cardiovascular disease risk factors. *Am J Clin Nutr* 2005;81:409-15.
  20. de Hollander EL, Bemelmans WJ, Boshuizen HC, Friedrich N, Wallaschofski H, Guallar-Castillón P, *et al.* The association between waist circumference and risk of mortality considering body mass index in 65-to 74-year-olds: A meta-analysis of 29 cohorts involving more than 58 000 elderly persons. *Int J Epidemiol* 2012;41:805-17.
  21. Ross R, Hudson R, Stotz PJ, Lam M. Effects of exercise amount and intensity on abdominal obesity and glucose tolerance in obese adults: A randomized trial. *Ann Intern Med* 2015;162:325-34.
  22. Mamtani MR, Kulkarni HR. Predictive performance of anthropometric indexes of central obesity for the risk of type 2 diabetes. *Arch Med Res* 2005;36:581-9.
  23. Neeland IJ, Ross R, Després JP, Matsuzawa Y, Yamashita S, Shai I, *et al.* Visceral and ectopic fat, atherosclerosis, and cardiometabolic disease: A position statement. *Lancet Diabetes Endocrinol* 2019;7:715-25.
  24. Zhang F, Li Y, Zhao Y, Zhou X, Ji L. Is visceral abdominal fat area a better indicator for hyperglycemic risk? Results from the Pinggu metabolic disease study. *J Diabetes Investig* 2020. doi: 10.1111/jdi.13217. [Epub ahead of print]
  25. Xu Z, Qi X, Dahl AK, Xu W. Waist-to-height ratio is the best indicator for undiagnosed type 2 diabetes. *Diabet Med* 2013;30:e201-7.
  26. Jayawardana R, Ranasinghe P, Sheriff MH, Matthews DR, Katulanda P. Waist to height ratio: A better anthropometric marker of diabetes and cardio-metabolic risks in South Asian adults. *Diabetes Res Clin Pract* 2013;99:292-9.
  27. Amirabdollahian F, Haghghatdoost F. Anthropometric indicators of adiposity related to body weight and body shape as cardiometabolic risk predictors in British young adults: Superiority of waist-to-height ratio. *J Obes* 2018;2018:8370304.
  28. Kerkadi A, Suleman D, Salah LA, Lotfy C, Attieh G, Bawadi H, *et al.* Adiposity indicators as cardio-metabolic risk predictors in adults from country with high burden of obesity. *Diabetes Metab Syndr Obes* 2020;13:175-83.
  29. Kodama S, Horikawa C, Fujihara K, Heianza Y, Hirasawa R, Yachi Y, *et al.* Comparisons of the strength of associations with future type 2 diabetes risk among anthropometric obesity indicators, including waist-to-height ratio: A meta-analysis. *Am J Epidemiol* 2012;176:959-69.
  30. Browning LM, Hsieh SD, Ashwell M. A systematic review of waist-to-height ratio as a screening tool for the prediction of cardiovascular disease and diabetes: 0.5 could be a suitable global boundary value. *Nutr Res Rev* 2010;23:247-69.
  31. Yang L, Samarasinghe YP, Kane P, Amiel SA, Aylwin SJ. Visceral adiposity is closely correlated with neck circumference and represents a significant indicator of insulin resistance in WHO grade III obesity. *Clin Endocrinol (Oxf)* 2010;73:197-200.
  32. Laakso M, Matilainen V, Keinänen-Kiukaanniemi S. Association of neck circumference with insulin resistance-related factors. *Int J Obes Relat Metab Disord* 2002;26:873-5.
  33. Ben-Noun L, Laor A. Relationship of neck circumference to cardiovascular risk factors. *Obes Res* 2003;11:226-31.