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Application of a novel sex independent anthropometric index, termed angle index, in relation to type 2 diabetes: a Trinidadian case–control study

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ABSTRACT

Objective To develop a novel sex independent anthropometric index, termed as angle index, related to type 2 diabetes.

Design Case–control.

Participants The study comprised 121 participants and were divided into two groups. One group had no form of diabetes and served as controls (n=50). The other group had the condition of type 2 diabetes (n=71). 31% (n=37) of the subjects were male and 69% (n=84) were female. 62% (n=75) of the subjects were of East Indian ethnicity, 28% (n=34) were of African ethnicity and 10% (n=12) were of mixed ethnicity.

Setting Participants of the study were from the island of Trinidad, located in the Caribbean. Patients in the study were selected at random from hospital records.

Primary outcome measure It was hypothesised that the mean angle index of patients with type 2 diabetes would be higher than the mean angle index of patients without type 2 diabetes.

Results Patients with type 2 diabetes had a significantly higher angle index value as compared with controls (p<0.001). Angle index was the superior sex independent anthropometric index in relation to type 2 diabetes (area under the curve=0.72; p<0.001) as compared with other sex independent variables. Angle index correlated with glycated haemoglobin (r_s=0.28, p=0.003) and fasting blood glucose (r_s=0.31, p=0.001) levels. Patients with type 2 diabetes were four times more likely to have an angle index greater than 184° (OR 4.2, 95% CI 1.8 to 9.9) as compared with controls.

Conclusion Angle index was a superior sex independent index for discriminating between patients with and without type 2 diabetes, as compared with waist circumference, abdominal volume index, conicity index, blood pressure readings, triglyceride levels and very low-density lipoprotein levels.

Strengths and limitations of this study

► The sample size was sufficient to conclusively demonstrate that angle index was higher in patients with type 2 diabetes as compared with patients without the condition.
► The study demonstrates the importance of characterising central obesity geometrically.
► Although angle index was independent of sex, it was more complicated to calculate by hand as compared with other anthropometric indices.
► Angle index was a good discriminator for patients with and without type 2 diabetes, but due to the case–control design of the study it remains to be seen whether a prospective study will demonstrate that angle index is a good predictor for type 2 diabetes.

in a similar fashion to provide a sex independent anthropometric index that could serve as a predictor or possible diagnostic criteria for type 2 diabetes. This novel anthropometric index could have the possibility of being related to hypertension, cardiovascular disease and even physical attractiveness.[4–7]

Euclidean geometry was applied to derive a possible novel anthropometric index. The geometrical approach led to a derivation of a trigonometric relationship among minimal waist, umbilical waist and hip circumferences. The geometrical approach does not have to be limited to trigonometry, but other aspects of geometry can be applied as demonstrated with a previous study.[8] For the purposes of this study, the possible novel anthropometric index was termed angle index (AI).

Central obesity has greater association with type 2 diabetes as compared with total body fat.[9 10] Computed tomography can be used to accurately determine abdominal visceral fat; however, this computation is expensive and time-consuming as compared with less accurate methods.[11–13] Simpler, inexpensive, less accurate and sometimes debatable

INTRODUCTION

There is currently no known simple predictor for type 2 diabetes; however, one of the most useful sex independent diagnostic parameters for type 2 diabetes is a glycated haemoglobin (HbA1c) reading of ≥6.5% (≥48 mmol/mol).[1–3] This study was motivated
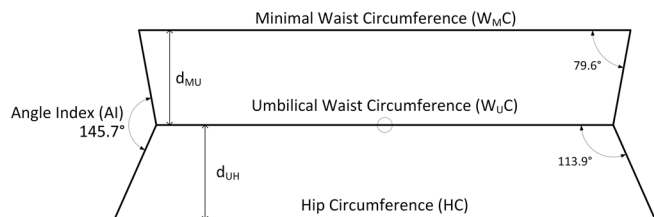
Figure 1 Diagram to conceptualise AI. As an example, $W_MC=104.1\,cm$; $W_UC=96.8\,cm$; $HC=114.5\,cm$; $AI=2.545$ radians or 145.7°; $d_{UH}=d_{MU}=20\,cm$. d_{MU}, perpendicular distance from the traverse section of the minimal waist region to the traverse section of the umbilical waist region; d_{UH}, perpendicular distance from the traverse section of the umbilical waist region to the traverse section of the hip region.

alternatives to characterise obesity include body mass index, waist circumference (WC), waist to hip ratio (W:H), abdominal volume index (AVI) and conicity index (ConI).[13–16] In this study two forms of WC, W:H, AVI and ConI were obtained. These include minimal waist circumference (W_MC), umbilical waist circumference (W_UC), minimal waist to hip ratio (W_M:H), umbilical waist to hip ratio (W_U:H), abdominal volume index for minimal waist (AVI_M), abdominal volume index for umbilical waist (AVI_U), conicity index for minimal waist ($ConI_M$) and conicity index for umbilical waist ($ConI_U$). All the aforementioned anthropometric variables and indices, along with AI, were compared in relation to type 2 diabetes.

AI was defined by the following equation with units in radians.

$$AI = \pi + \tan^{-1}\left[\frac{W_UC-HC}{2(d_{UH})}\right] - \tan^{-1}\left[\frac{W_MC-W_UC}{2(d_{MU})}\right]$$

For further visual simplicity this angle can be converted to degrees. A visual representation of this angle is shown in figure 1 (drawn to scale).

Each circumference is flattened out into a horizontal line which is parallel to the other lines. The dimension, d_{MU}, can be visualised as the perpendicular distance from the traverse section of the minimal waist region to the traverse section of the umbilical waist region. d_{UH} can be visualised as the perpendicular distance from the traverse section of the umbilical waist region to the traverse section of the hip region. d_{MU} and d_{UH} were arbitrarily assigned a value of 20 cm, respectively, since variability of these values was not considered at the onset of the study. The W_MC, W_UC and HC data and calculation for AI can be viewed in online supplementary data S1. To the best of our knowledge, an equation of this nature or derivatives of this equation that incorporate W_MC, W_UC and HC have not been displayed or demonstrated in the literature.

This study hypothesised that AI was a superior sex independent anthropometric index to discriminate between patients with and without type 2 diabetes as compared with other sex independent indices.

METHODS

Patients with type 2 diabetes and patients without diabetes, based on medical records, were selected at random from the Eric Williams Medical Sciences Complex and the San Fernando General Hospital in Trinidad and Tobago. Potential participants were contacted and those who volunteered to participate in the study attended examinations specifically for the study. Smokers, pregnant women and alcoholics were excluded from the study. It was strictly ensured that controls had a fasting blood glucose (FBG) <120 mg/dL and HbA1c <6.5%.

Subjects fasted approximately 8 hours before examination and were instructed to wear light clothing. Initially patients' mass, height and blood pressure readings were obtained on the morning of the blood draw. Patients' W_MC, W_UC and HC were measured with a flexible tape, using modified versions of the WHO and the National Health and Nutrition Examination Survey (NHANES) protocol.[17 18] The W_MC tended to the WHO protocol and the W_UC tended to the NHANES protocol. For simplification and rapid measurement, W_MC was measured at the minimal waist, above the umbilicus, and W_UC directly at the umbilical level. Hip circumference was measured as the largest circumference below the umbilicus passing around the gluteus maximus but not extending beyond the gluteal region.

Venous blood samples were drawn and assayed for FBG, HbA1c, total serum triglyceride (Trig), total serum cholesterol (Chol) and high-density lipoprotein (HDL) using an automated chemistry analyser (cobas 6000, Roche Diagnostics, USA). Low-density lipoprotein (LDL) and very low-density lipoprotein (VLDL) were calculated based on Friedewald's estimation.[19]

Both anthropometric and biochemical data published in the study were not used from the hospital medical records. The data published were obtained from study-specific examination of patients.

Statistics

Software packages G*Power V.3, Minitab V.17 and IBM SPSS V.24 were used for statistical analyses. The χ^2 and Fisher's exact test were used to investigate whether there were associations of age, sex and ethnicity categories with type 2 diabetes in table 1. The χ^2 was also used to determine whether the proportions of cases and controls were similar in table 1. The Anderson Darling test was used to determine whether a particular data set was normally distributed. The independent t-test and Mann-Whitney U test were used in table 2 to test for the difference between means and ranks of parameters. The t-test was used for data that were normally distributed, whereas the U test was used for data that did not follow normal distribution. A general linear model univariate analysis was applied in table 3 to control for age confounder when investigating the difference between the significant sex independent parameters. Adjustment was possibly required since

Table 1 Comparison of sex, age and ethnicity between subjects with and without type 2 diabetes

	Total	Non-diabetic patients	Patients with type 2 diabetes	
	n (%)	n (%)	n (%)	P value
Subjects	121 (100)	50 (41.3)	71 (58.7)	0.06*
Sex				
Male	37 (30.6)	20 (16.50)	17 (14.0)	0.06*
Female	84 (69.4)	30 (24.8)	54 (44.6)	
Age				
25–40	3 (2.5)	1 (0.01)	2 (0.02)	0.01†
41–55	43 (35.5)	25 (20.7)	18 (14.9)	
56–65	36 (29.8)	10 (0.08)	26 (21.5)	
66–75	36 (29.8)	11 (0.09)	25 (20.7)	
76–85	3 (2.5)	3 (0.02)	0 (0.0)	
Ethnicity				
East Indian	75 (62.0)	28 (23.1)	47 (38.8)	0.35†
African	34 (28.1)	15 (12.4)	19 (15.7)	
Mixed	12 (12.0)	7 (0.06)	5 (0.04)	

*χ^2 test.
†Fisher's exact test.

there was an association of the age categories with the cases and controls. Receiver operating characteristic (ROC) analysis was used to investigate the performance of a diagnostic test, and the results are displayed in table 4. Spearman's correlation (r_s) was used in table 5 to determine how well the significant sex independent parameters correlated with HbA1c and FBG levels. Binomial logistic regression was used in table 6 to determine both the crude and adjusted odds of AI cut-off categories in relation to type 2 diabetes.

The limit for type I error was set at $\alpha = 0.05$. The effect size (Hedges' g) and power $(1-\beta)$ chosen were 0.53 and 0.80, respectively, for sample size calculation, resulting in an estimation of 114 patients required for the study. The effect size chosen was based on differences in means between groups with and without type 2 diabetes for W_MC and W_UC on preliminary data collected of sample size n=44. The preliminary data set can be accessed in online supplementary data S2. A total of 121 subjects were recruited for the study, which compensated for missing data cells.

Patient and public involvement
There was no patient or public involvement in the design and conduct of the study. Study participants were given their specific results in the study, which included their age, blood pressure readings, height, mass, W_MC, W_UC, HC, W_M:H, W_U:H, AVI_M, AVI_U, $ConI_M$, $ConI_U$, HbA1c, FBG, Trig, Chol, HDL, LDL and VLDL. Any information published from the study would be disseminated to all study participants by the research team.

RESULTS
Table 1 displays the demographics of patients in the study with statistically equivalent distribution of patients between the groups with and without type 2 diabetes (p=0.06). There was no association of sex (p=0.06) or ethnicity (p=0.35) categories in relation to categories with and without type 2 diabetes. There was an association of the age categories to the categories with and without type 2 diabetes (p=0.01).

Table 2 displays the comparison of parameters between sex and subjects with and without type 2 diabetes, using the t-test or U test. The sex independent parameters which were significantly higher in patients with type 2 diabetes were systolic blood pressure (p=0.004), W_MC (p=0.003), W_UC (p<0.001), AVI_M (p=0.003), AVI_U (p<0.001), $ConI_M$ (p=0.003), HbA1c (p<0.001), FBG (p<0.001), Trig (p<0.004), VLDL (p=0.015) and AI (p<0.001; $1-\beta$=0.99). The effect sizes between subjects with and without diabetes, at the end of the study, for W_MC, W_UC and AI were 0.57, 0.68 and 0.76, respectively.

Table 3 summarises the comparison of adjusted means for significant sex independent parameters between patients with and without type 2 diabetes. The means were adjusted for age since table 1 demonstrates that there was a significant association between the age categories and the categories of with and without type 2 diabetes (p=0.01). $ConI_M$ was the only previous significant sex independent parameter from table 2 that was not significantly different between cases and controls when adjustment was made for age (p=0.055).

Table 2 Comparison of parameters in study between sex, and between patients with and without type 2 diabetes

Parameter	Total subjects	Male	Female	P value	Subjects without type 2 diabetes	Subjects with type 2 diabetes	P value
Age (years)	58.9±10.5 (n=121)	60.2±9.6 (n=37)	58.4±10.9 (n=84)	0.37	57.2±11.4 (n=50)	60.2±9.7 (n=71)	0.06
SBP (mm Hg)	145.1±21.3 (n=121)	142.0±17.1 (n=37)	146.5±22.8 (n=84)	0.23	138.6±18.0 (n=50)	149.7±22.3 (n=71)	0.004
DBP (mm Hg)	87.2±10.8 (n=121)	87.6±9.5 (n=37)	87.1±11.4 (n=84)	0.64	86.6±9.5 (n=50)	87.7±11.7 (n=71)	0.56
Height (m)	1.64±0.10 (n=121)	1.72±0.08 (n=37)	1.61±0.09 (n=84)	<0.001	1.66±0.10 (n=50)	1.63±0.10 (n=71)	0.16
Mass (kg)	79.4±21.2 (n=120)	85.0±27.7 (n=37)	77.0±17.3 (n=83)	0.08	75.1±12.4 (n=49)	82.4±25.3 (n=71)	0.18
BMI (kg/m^2)	29.4±7.3 (n=120)	28.5±8.5 (n=37)	29.8±6.7 (n=83)	0.04	27.3±4.5 (n=49)	30.9±8.4 (n=71)	0.02
W_MC (cm)	94.0±11.7 (n=121)	94.3±9.4 (n=37)	93.8±12.7 (n=84)	0.81	90.2±10.0 (n=50)	96.7±12.2 (n=71)	0.003
W_UC (cm)	100.5±13.3 (n=121)	97.9±10.9 (n=37)	101.6±14.1 (n=84)	0.15	95.4±10.1 (n=50)	104.0±14.2 (n=71)	<0.001
HC (cm)	106.3±11.8 (n=121)	101.5±8.3 (n=37)	108.4±12.5 (n=84)	0.002	104.2±9.6 (n=50)	107.8±13.0 (n=71)	0.14
W_M:H	0.89±0.07 (n=121)	0.93±0.05 (n=37)	0.87±0.06 (n=84)	<0.001	0.87±0.07 (n=50)	0.90±0.06 (n=71)	0.01
W_U:H	0.94±0.06 (n=121)	0.964±0.057 (n=37)	0.936±0.060 (n=84)	0.02	0.92±0.07 (n=50)	0.96±0.05 (n=71)	<0.001
AVI_M	18.1±4.5 (n=121)	18.0±3.7 (n=37)	18.1±4.8 (n=84)	0.83	16.6±3.5 (n=50)	19.1±4.8 (n=71)	0.003
AVI_U	20.6±5.7 (n=121)	19.4±4.6 (n=37)	21.1±6.1 (n=84)	0.14	18.5±4.0 (n=50)	22.0±6.3 (n=71)	<0.001
$ConI_M$	1.25±0.10 (n=120)	1.25±0.10 (n=37)	1.25±0.10 (n=83)	0.86	1.23±0.08 (n=49)	1.26±0.11 (n=71)	0.003
$ConI_U$	1.34±0.12 (n=120)	1.30±0.11 (n=37)	1.35±0.12 (n=83)	<0.001	1.30±0.09 (n=49)	1.36±0.13 (n=71)	<0.001
AI (°)	180.9±13.0 (n=121)	180.1±11.3 (n=37)	181.3±13.8 (n=84)	0.67	175.5±12.3 (n=50)	184.8±12.3 (n=71)	<0.001
HbA1c (%) (mmol/mol)	6.8%±2.0% 51.2±21.7 mmol/mol (n=118)	6.3%±1.3% 45.4±14.1 mmol/mol (n=36)	7.1%±2.2% 53.8±23.9 mmol/mol (n=82)	0.13	5.4%±0.6% 35.3±6.3 mmol/mol (n=50)	7.9%±2.0% 62.9±21.6 mmol/mol (n=68)	<0.001
FBG (mg/dL)	126.2±56.3 (n=118)	112.5±34.2 (n=36)	132.3±62.9 (n=82)	0.16	89.6±11.3 (n=49)	152.2±61.0 (n=69)	<0.001
Trig (mg/dL)	157.5±102.3 (n=121)	171.9±127.8 (n=37)	151.1±89.0 (n=84)	0.34	129.9±69.6 (n=50)	176.9±116.8 (n=71)	0.004
Chol (mg/dL)	191.1±48.1 (n=121)	175.6±41.7 (n=37)	197.9±49.4 (n=84)	0.02	194.3±47.6 (n=50)	188.8±48.7 (n=71)	0.54
HDL (mg/dL)	47.1±13.0 (n=120)	42.2±10.6 (n=37)	49.3±13.5 (n=83)	0.01	50.9±13.4 (n=50)	44.3±12.1 (n=70)	0.008
LDL (mg/dL)	111.7±43.8 (n=120)	96.6±40.7 (n=37)	118.5±43.7 (n=83)	0.01	115.5±43.2 (n=50)	109.0±44.4 (n=70)	0.43
VLDL (mg/dL)	31.8±20.7 (n=120)	36.0±25.9 (n=37)	30.0±17.8 (n=83)	0.14	27.2±15.1 (n=50)	35.1±23.5 (n=70)	0.02

Continued

Table 2 Continued

Parameter	Total subjects	Male	Female	P value	Subjects without type 2 diabetes	Subjects with type 2 diabetes	P value

AVI$_M$, abdominal volume index for minimal waist; AVI$_U$, abdominal volume index for umbilical waist; BMI, body mass index; Chol, cholesterol; ConI$_M$, conicity index for minimal waist; ConI$_U$, conicity index for umbilical waist; DBP, diastolic blood pressure; FBG, fasting blood glucose; HbA1c, glycated haemoglobin; HC, hip circumference; HDL, high-density lipoprotein; LDL, low-density lipoprotein; SBP, systolic blood pressure; Trig, triglyceride; VLDL, very low-density lipoprotein; W$_M$C, minimal waist circumference; W$_M$:H, minimal waist to hip ratio; W$_U$C, umbilical waist circumference; W$_U$:H, umbilical waist to hip ratio.

In alignment with the objective of the study, the sex independent parameters that were significantly higher in patients with type 2 diabetes were subjected to ROC analyses. Although both HbA1c and FBG were significant sex independent variables related to type 2 diabetes, they were not included in the ROC analysis since they were already used as exclusion criteria for the controls and would obviously have high area under the curve (AUC). A summary of the AUC is provided in table 4, which reports that the best sex independent discriminator for type 2 diabetes was AI (AUC=0.72, p<0.001). Supplementary data of ROC analysis for both sex dependent and independent parameters can be accessed in online supplementary figure 1 and online supplementary data S3 and S4.

The Spearman's correlation provided in table 5 demonstrated that AI had the highest correlation with HbA1c (r$_s$=0.28, p<0.001) and FBG (r$_s$=0.31, p<0.001) as compared with the other sex independent parameters.

Binomial logistic regression was applied to cut-off categories of AI relative to the categories of patients with and without type 2 diabetes. The results of the applied binomial logistic regression are highlighted in table 6. One significant result was that patients with type 2 diabetes were four times more likely to have an AI >184° (OR 4.2, 95% CI 1.8 to 9.9). An AI cut-off of 184° has lower specificity and higher sensitivity in relation to type 2 diabetes discrimination as compared with 178°, which was graphically represented in the ROC graph of figure 2. The odds were then adjusted for age, which resulted in AI >186° displaying non-significant odds (OR 1.0, 95% CI 1.0 to 1.1), but all other angles in the table displayed significant odds.

The study was repeated for a total sample size of n=72, with equivalent cases and controls. The sample size was calculated based on effect size, g=0.72 for AI and 1−β=0.8, which gave a total of n=64. An additional eight samples were taken, which gave the final sample size of 72 for repeat study, since additional assay reagents for HbA1c and FBG were available. There were no additional reagents for Trig, Chol and HDL assays.

In the repeat study, the means of the different parameters were compared between patients with and without type 2 diabetes, adjusted for age, sex and ethnicity. Only HbA1c, FBG, AI, AVI$_M$ and AVI$_U$ were significant and independent of sex. The repeat study, in online supplementary data S5, S6, S7 and S8), demonstrated that AI (AUC=0.75, p<0.001) was the best sex independent anthropometric discriminator for type 2 diabetes.

DISCUSSION

The study aimed to develop a novel sex independent anthropometric index related to type 2 diabetes which could possibly be used as a predictor for the condition. Application of trigonometry to waist and hip measurements was applied to achieve a novel anthropometric index, termed as angle index (AI). In future clinical practice the angle calculation process could be automated via computing devices. AI is sex independent and more complex in calculation as compared with a singular reading of W$_U$C. Apart from AI being significantly different between patients with and without type 2 diabetes, it was demonstrated that patients with type 2 diabetes were four times more likely to have an AI >184° as compared with controls.

According to table 1 there were no associations among the sex and ethnicity categories with cases and control categories; however, there was a significant association between the age categories and categories for with and without type 2 diabetes. This could be expected as patients 45 years and older are at greater risk for type 2 diabetes.[20] In table 3, adjustments were made for age when comparing the means of the significant sex independent parameters.

Both FBG and HbA1c values were significantly higher in patients with type 2 diabetes even though some patients with type 2 diabetes were on glucose-lowering medication and had HbA1c values <6.5%. Sex independent anthropometric indices, W$_M$C, W$_U$C, AVI$_M$, AVI$_U$ and ConI$_M$, were significantly higher in patients with type 2 diabetes, which is in agreement with a number of studies.[8 9] W$_U$C was the second-best discriminator and one of the simplest and rapid measurements to be taken without further need to perform a calculation. In clinical practice, W$_U$C has been recommended over W$_M$C measurement when considering type 2 diabetes.[21]

In table 3, the means of parameters independent of sex were compared between patients with and without diabetes with adjustments for age. No adjustments for sex or ethnicity were made since the analysis displayed in table 1 highlighted that there was no association of sex or ethnicity categories with the categories of patients with and without type 2 diabetes. After adjustments for age, AI was still reported to be significantly different between cases and controls.

Based on the ROC analysis and Spearman's correlations performed, as shown in tables 4 and 5, AI was the best discriminator for type 2 diabetes and had the highest correlation with HbA1c and FBG. This indicates the

Table 3 Comparison of significant sex independent parameters in relation to type 2 diabetes, adjusted for age at 95% CI

Parameter	Total subjects	Subjects without type 2 diabetes	Subjects with type 2 diabetes	P value	η^2	Observed power (%)
HbA1c (%) (mmol/mol)	6.6% (6.4% to 6.9%) 49.0 (45.9 to 52.1) mmol/mol (n=118)	5.3% (4.9% to 5.8%) 34.7 (30.0 to 39.4) mmol/mol (n=50)	7.9% (7.6% to 8.3%) 63.3 (59.3 to 67.3) mmol/mol (n=68)	<0.001	0.42	100.0
FBG (mg/dL)	120.7 (112.2 to 129.2) (n=118)	87.9 (74.9 to 101.0) (n=49)	153.4 (142.5 to 164.4) (n=69)	<0.001	0.33	100.0
AI (°)	180.1 (177.9 to 182.4) (n=121)	175.5 (172.2 to 179.1) (n=50)	184.8 (181.7 to 187.5) (n=71)	<0.001	0.12	97.3
$W_U C$ (cm)	99.7 (97.4 to 102.0) (n=121)	95.1 (91.6 to 98.6) (n=50)	104.2 (101.3 to 107.2) (n=71)	<0.001	0.12	97.2
AVI_U	20.3 (19.3 to21.2) (n=121)	18.4 (16.8 to 19.9) (n=50)	22.2 (20.9 to 23.4) (n=71)	<0.001	0.11	96.3
$W_M C$ (cm)	93.4 (91.3 to 95.4) (n=121)	89.8 (86.6 to 92.9) (n=50)	97.0 (94.3 to 99.6) (n=71)	0.001	0.09	93.0
AVI_M	17.8 (17.1 to 18.6) (n=121)	16.5 (15.3 to 17.7) (n=50)	19.2 (18.2 to 20.2) (n=71)	<0.001	0.09	92.9
Trig (mg/dL)	153.3 (134.9 to 171.7) (n=121)	129.2 (101.0 to 157.5) (n=50)	177.3 (153.6 to 201.0) (n=71)	0.011	0.05	72.2
SBP (mm Hg)	144.3 (140.7 to 147.9) (n=121)	139.7 (134.2 to 145.3) (n=50)	148.9 (144.3 to 153.5) (n=71)	0.013	0.05	70.1
VLDL (mg/dL)	31.1 (27.4 to 34.9) (n=120)	27.1 (21.3 to 32.9) (n=50)	35.2 (30.3 to 40.0) (n=70)	0.038	0.04	55.0
$ConI_M$	1.25 (1.23 to 1.27) (n=120)	1.23 (1.20 to 1.26) (n=49)	1.27 (1.24 to 1.29) (n=71)	0.055	0.03	48.6

η^2, partial eta squared.
AI, angle index; AVI_M, abdominal volume index for minimal waist; AVI_U, abdominal volume index for umbilical waist; $ConI_M$, conicity index for minimal waist; FBG, fasting blood glucose; HbA1c, glycated haemoglobin; SBP, systolic blood pressure; Trig, triglyceride; VLDL, very low-density lipoprotein; $W_M C$, minimal waist circumference; $W_U C$, umbilical waist circumference.

Table 4 ROC analysis of significant sex independent parameters in relation to type 2 diabetes diagnosis

Parameter	AUC	P value	95% CI	
			Lower bound	Upper bound
AI	0.72	<0.001	0.62	0.81
W_UC	0.70	<0.001	0.61	0.80
AVI_U	0.70	<0.001	0.61	0.79
W_MC	0.67	0.002	0.57	0.77
AVI_M	0.67	0.002	0.57	0.77
$ConI_M$	0.66	0.002	0.57	0.77
Trig	0.64	0.01	0.54	0.75
SBP	0.64	0.01	0.54	0.74
VLDL	0.62	0.02	0.52	0.73

AI, angle index; AUC, area under the curve; AVI_M, abdominal volume index for minimal waist; AVI_U, abdominal volume index for umbilical waist; $ConI_M$, conicity index for minimal waist; ROC, receiver operating characteristic; SBP, systolic blood pressure; Trig, triglyceride; VLDL, very low-density lipoprotein; W_MC, minimal waist circumference; W_UC, umbilical waist circumference.

superiority of AI to the other sex dependent anthropometric variables in relation to type 2 diabetes; however, since AI is reportedly novel, repeat studies are required to qualify its importance or even failure as an obesity characterising index. A single repeat study conducted with >80% power and equal number of cases and controls demonstrated that AI appears to be a good sex independent discriminator when compared with other sex independent anthropometric indices.

When considering an AI cut-off category in relation to type 2 diabetes from table 6 as well as the ROC curve in figure 2, an AI of 184° appears to be a good discriminator between patients with and without type 2 diabetes, whereby patients with an angle of >184° are more likely to have the condition of type 2 diabetes. This could indicate that once an individual does not exceed an AI of 184°, they could possibly decrease the risk of type 2 diabetes;

however, this may be a far-reaching conclusion since the study is of a case–control design and only repeated once.

Accurately quantifying central obesity with current anthropometric variables outlined in this study is challenging; however, the development of AI or a geometrical approach to the abdominopelvic region may be a solution to this problem.[8 22 23] Further studies are required to compare AI with CT assessment of abdominal fat content.[24] Once a high correlation of AI can be found with abdominal fat, this may provide evidence that AI can be used as an obesity measure.[13] Increases in abdominal fat can cause an influx of macrophages into subcutaneous adipose tissue and enlargement of subcutaneous abdominal adipocyte size. Both macrophage influx and adipocyte hypertrophy result in greater secretion of multiple adipokines, which possibly exacerbate insulin resistance resulting in type 2 diabetes.[25 26] The exact interplay of adipokines and the mechanism of action resulting in insulin resistance remains unknown.

Table 5 Spearman's correlation (r_s) of sex independent parameters with HbA1c and FBG

Parameter (n)	HbA1c r_s (p value)	FBG r_s (p value)
AI (°) (n=118)	0.28 (0.003)	0.31 (0.001)
W_UC (n=118)	0.25 (0.01)	0.26 (0.004)
AVI_U (n=118)	0.25 (0.01)	0.26 (0.01)
W_MC (n=118)	0.24 (0.01)	0.23 (0.01)
AVI_M (n=118)	0.23 (0.01)	0.22 (0.02)
$ConI_M$ (n=117)	0.26 (0.01)	0.20 (0.03)
Trig (n=118)	0.17 (0.06)	0.25 (0.25)
SBP (n=118)	0.10 (0.30)	0.13 (0.18)
VLDL (n=117)	0.15 (0.11)	0.20 (0.03)

AI, angle index; AVI_M, abdominal volume index for minimal waist; AVI_U, abdominal volume index for umbilical waist; $ConI_M$, conicity index for minimal waist; FBG, fasting blood glucose; HbA1c, glycated haemoglobin; SBP, systolic blood pressure; Trig, triglyceride; VLDL, very low-density lipoprotein; W_MC, minimal waist circumference; W_UC, umbilical waist circumference.

Table 6 The odds of patients having type 2 diabetes when considering specific angle index (AI) cut-off values

AI cut-off categories (°) (n=121)	Crude odds (95% CI)	Adjusted odds* (95% CI)
>178	3.3 (1.5 to 7.0), p=0.002	3.1 (1.4 to 6.6), p=0.004
>180	2.8 (1.3 to 6.0), p=0.007	2.6 (1.2 to 5.6), p=0.015
>182	3 (1.4 to 6.4), p=0.006	2.7 (1.2 to 6.0), p=0.014
>184	4.2 (1.8 to 9.9), p=0.001	3.9 (1.6 to 9.4), p=0.002
>186	3.5 (1.4 to 9.0), p=0.008	1.0 (1.0 to 1.1), p=0.308

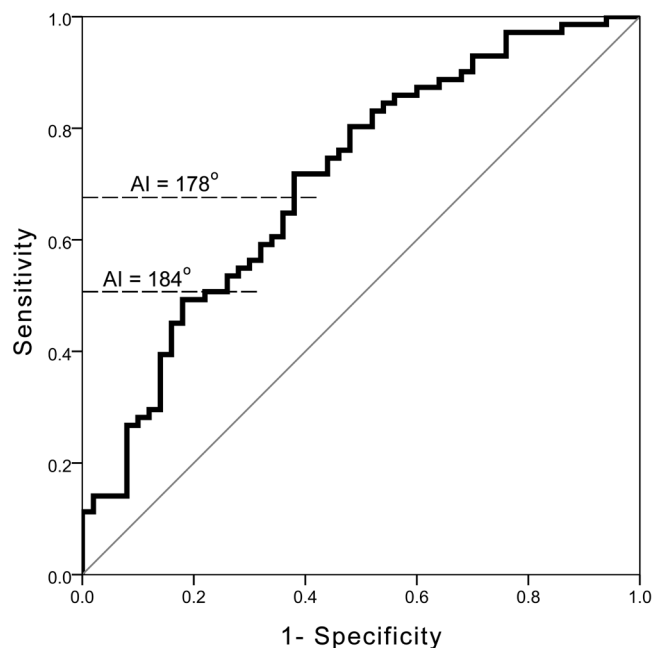*Odds of patients having type 2 diabetes, adjusted for age.

Figure 2 Receiver operating characteristic analysis of angle index (AI) as test variable in relation to type 2 diabetes diagnosis as state variable.

In retrospect, it was conceptualised that instead of arbitrarily assigning a value to the sum of d_{MU} and d_{UH}, these distances could be measured. In a routine clinical setting d_{MU} could be modified by measuring the distance from the minimal waist to the umbilical waist along the posterior body trunk. Likewise, a similar measurement approach could be done for d_{UH} from the umbilical waist to the hip along the posterior body trunk. This study does not provide data or analysis for modified measurements of d_{MU} and d_{UH}, but it may be worthwhile to determine if such could alter AI sufficiently to have greater association with type 2 diabetes.

It is strongly recommended that WC should be part of a patient's medical history, even if standardised WHO and NHANES protocols are not followed. Obesity characterisation is important for patient care and disease risk assessment. Further development of AI or geometrical approaches to the abdominopelvic region may have the potential to serve as a valuable predictor for type 2 diabetes. Additionally, it may be worthwhile to extend the concept of AI to cardiovascular disease, metabolic syndrome, perioperative risk and human attractiveness.

Strengths and limitations
The study was sufficiently powered (>80%) when considering the difference between the AI of patients with and without type 2 diabetes. The computation of AI is more complex as compared with calculation of other anthropometric indices, which may limit the use of AI. The design of the study was not prospective and thereby cannot conclusively demonstrate that AI would be the best predictor for type 2 diabetes or pre-diabetes.

CONCLUSION
The development of a novel sex independent anthropometric index, termed as angle index (AI), was accomplished. AI in its initial stage of development appears to be a relevant discriminator for type 2 diabetes when compared with other sex independent anthropometric indices. Repeat studies in different populations are required to fully assess AI as an obesity measure; however, the geometrical approach to the abdominopelvic region may have future relevance in metabolic diagnostics.

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