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Using anthropometric parameters to predict insulin resistance among patients without diabetes mellitus

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Anthropometric parameters are widely used in the clinical assessment of hypertension, type 2 diabetes, and cardiovascular disease. However, few studies have compared the association between different anthropometric parameters and insulin resistance (IR). This study was aimed at investigating the relationship between 6 indicators, including body mass index (BMI), calf circumference (CC), arm circumference (AC), thigh circumference (TC), waist circumference (WC), waist-height ratio (WHtR), and IR. Homeostasis Model Assessment of Insulin Resistance (HOMA-IR) was used to measure IR. Weighted linear regression was used to assess the relationship between different parameters and IR. The receiver operating characteristic curve (ROC) was employed to compare the strength of the relationship between different anthropometric parameters and IR. A total of 8069 participants were enrolled in our study, including 4873 without IR and 3196 with IR. The weighted linear regression results showed that BMI, CC, AC, TC and WC were significantly correlated with IR, except WHtR. After adjusting for multiple confounding factors, we found that BMI, AC and WC were significantly positively correlated with IR, while TC was significantly negatively correlated with IR. Logistic regression results showed that a larger TC was associated with a decreased risk of IR. In addition, BMI and WC had similar areas under the curve (AUC: 0.780, 95% CI 0.770–0.790; AUC: 0.774, 95% CI 0.763–0.784, respectively), which were higher than TC and AC (AUC: 0.698, 95% CI 0.687–0.710, AUC: 0.746, 95% CI 0.735–0.757, respectively). To our knowledge, this is the first study to report a negative correlation between TC and IR among patients without diabetes mellitus. Therefore, TC may be a new tool to guide public health and a clinical predictor of IR in non-diabetic patients.

Keywords Insulin resistance, Anthropometric parameter, Arm circumference, Thigh circumference, Body mass index, Waist circumference, National health and nutrition examination survey (NHANES)

Insulin resistance (IR) is defined as a pathological condition in which the sensitivity of insulin-targeted tissues such as liver, fat and bone to insulin decreases, resulting in hyperinsulinemia[1]. Many potential factors may be associated with the development of IR, such as obesity, stress, age, medications, and genetics[2]. In addition, IR may also contribute to many clinical conditions, such as type 2 diabetes (T2D), metabolic syndrome, fatty liver disease, and cardiovascular disease[3]. IR may be an early predictor of T2D. Studies have shown that impaired β cell function is present more than 10 years before T2D is diagnosed and throughout the disease[3,4]. And the occurrence of IR is earlier than the impairment of β cell function[4]. Therefore, IR may be the earliest clinical manifestation before the onset of T2D. IR is believed to be the key to the pathogenesis of metabolic syndrome, and is also associated with a variety of cardiometabolic risk factors, such as hypertension and dyslipidemia[2]. Therefore, early identification of IR and regular monitoring of changes in data are of great significance for preventing diseases and ensuring people's health.

DeFronzo and his colleagues first systematically proposed the hyperinsulinemic euglycemic clamp, which is considered the gold standard method for assessing IR[5]. However, the complex operation and high cost of this technique limit its routine application in clinics[1]. A number of indicators have been developed to predict IR, the most commonly used being the Homeostasis model assessment of insulin resistance (HOMA-IR), which

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is the product of fasting blood glucose (FBG) and fasting insulin (FI) divided by a constant[6,7]. Compared with laboratory tests, anthropometric parameters are more accessible, less costly, and facilitate long-term monitoring, which maximizes participant engagement. A growing number of studies focus on the correlation between anthropometric parameters and IR. A large observational study involving 2138 patients without diabetes and 193 patients with diabetes showed that the sensitivity and specificity of body mass index (BMI) for diagnosing IR were 78.7% and 79.6%, respectively, compared with the hyperinsulinemic euglycemic clamp[8]. Several cross-sectional studies have reported that IR is positively correlated with waist and hip circumference and negatively correlated with calf circumference[9–12]. However, there is a lack of evidence regarding the relationship between thigh circumference (TC) and IR, and few studies have compared the correlation between different anthropometric parameters and IR.

The aim of this study was to evaluate the correlation between IR and different anthropometric parameters, including BMI, TC, and to obtain quantitative estimates through regression analysis, so as to screen out high-risk groups of IR with the use of anthropometric parameters, and conduct timely risk assessment for IR patients to prevent the occurrence of related diseases.

Methods

Data source

National Health and Nutrition Examination Survey (NHANES) is a large cross-sectional study conducted by the Centers for Disease Control and Prevention to assess the nutritional health status and morbidity of the United States population. The study conducts the survey every two years, using a complex multi-stage sampling to ensure that the survey population is representative. The survey mainly includes five parts: population data, diet data, examination data, laboratory data, and questionnaire data.

Study population

The study used data from the NHANES sample survey from 1999 to 2006. Participants were considered for inclusion if they met the following criteria: (1) Age of enrollment was ≥ 18 years old. (2) With available data about FBG, FI and anthropometric parameters. Participants with unknown diabetes status were omitted. Individuals lacking key covariates, such as age, smoking status, and hypertension status, were excluded. Finally, a total of 8069 participants were included in the study. A detailed flow chart for participant inclusion and exclusion is available in Fig. 1.

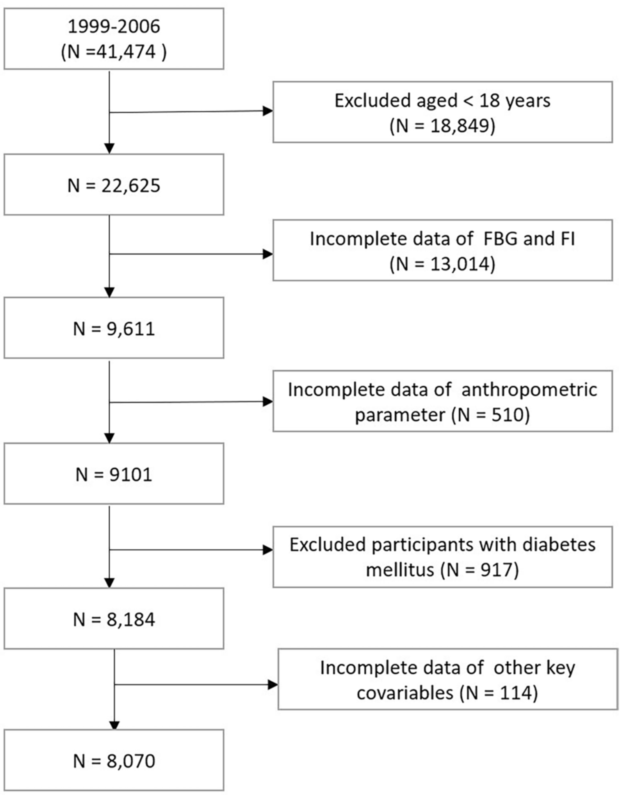

Figure 1. Flow chart of participants selection.

Measurement of anthropometric parameters

When calf circumference (CC) was measured, participants sat with their right calf relaxed. Trained NHANES personnel place the tape measure perpendicular to the long axis of the calf, finding the location of the maximum perimeter, which is CC. During arm circumference (AC) measurement, participants took a standing position with the right arm hanging freely and the elbow relaxed naturally. The operator places the tape measure at the midpoint between the acromial process and the olecranon process behind the upper arm, gently presses it to the skin surface. The length of the tape around the upper arm is AC. Thigh circumference (TC) was measured in a standing position with all weight on the left leg. The operator places the tape measure perpendicular to the long axis of the thigh, and the data recorded around the middle area of the thigh is TC. WC was measured in a standing position with the abdomen relaxed. When the participant is in the stage of minimal breathing, the operator wraps a tape measure around the iliac spine. The participants removed their headdresses, stood up straight and used a stationary altimeter to gain height. CC, AC, TC, WC and height were all obtained by trained professionals, and the value was measured to the nearest 0.1cm. BMI is defined as weight divided by height squared and is expressed in kg/m^2, and waist-height ratio (WHtR) is defined as WC divided by height.

Ascertainment of diabetes mellitus

According to the latest guidelines from the American Diabetes Association, diabetes is considered to be present when: (1) Self-reported diabetes mellitus; (2) Receiving oral hypoglycemic medication or insulin therapy; (3) Fasting blood glucose level ≥ 126mg/ml; (4) Oral glucose tolerance test 2-h blood glucose ≥ 200mg/ml; (5) Glycosylated hemoglobin level ≥ 6.5%.

Measurement of IR

Intravenous serum samples were taken after fasting for at least 8 h and then sent to the central laboratory to measure fasting glucose and fasting insulin. Homeostasis Model Assessment of Insulin Resistance (HOMA-IR) is used to assess IR and its value can be calculated according to the formula by Matthews et al.[7]. The formula is defined as the product of FBG (mmol/L) and FI (μU/mL) divided by the constant 22.5.

Measurement of covariates

Covariates include age, sex, education, race/ethnicity, smoking status, drinking status, hypertension status, and hyperlipidemia status. Race/ethnicity is divided into the following five categories: Mexican American, other Hispanic, Non-Hispanic White, Non-Hispanic Black, and other races. Education is divided into three categories: under high school, high school or some college, college graduate or above. Smoking status was classified as current smoker, former smoker, and never smoked. Drinking status was classified as heavy, moderate, mild or never. Hypertension, and hyperlipidemia were classified as present or absent based on self-report at baseline.

Statistical analysis

NHANES is a stratified, multi-stage, and complex sample design survey, so all statistical analyses in our study used appropriate sample weights associated with the NHANES data. Kolmogorov–smirnov test was used to check whether the data conformed to the normal distribution. If $P > 0.05$, the normal distribution was indicated. The continuous data with non-normal distribution should be presented as median (interquartile range), whereas continuous data with normal distribution should be presented as mean and standard error (SE). Baseline characteristics of participants were presented as number and percentage (%) for categorical variables and as mean and SE for continuous variables. Due to differences in race, gender and subjects of study, as well as the lack of standardization of insulin measurement, tangence-point values of HOMA-IR reported in literature vary greatly. According to the latest studies, HOMA-IR > 2.5 is defined as IR[3,13]. Previous studies have shown that HOMA-IR is a biased distribution, and its logarithm can be used to convert the biased distribution into normal distribution data[14]. A weighted multiple linear regression model was used to evaluate the linear relationship between different anthropometric parameters (BMI, CC, AC, TC, WC, and WHtR) and logarithmic HOMA-IR. The receiver operating curve (ROC) was plotted and the intensity of different anthropometric parameters to diagnose IR was assessed according to the area under the curve (AUC). In addition, we divided WC and TC into quartiles (Q1-Q4). A binary logistic regression risk model was used to investigate the association between WC, TC and IR. Model 1 did not adjust covariates. Model 2 adjusted for sex, age, race/ethnicity, education, BMI, and marital status. Model 3 further adjusted the status of smoking status, and alcohol consumption on the basis of Model 2. All statistical analyses were performed using Stata (version 15.1, Stata Corp. LP, College Station, Texas, USA) software, with $P < 0.05$ indicating statistical significance.

Ethical approval

The study was performed according to the guidelines of the Helsinki Declaration. Consent to participate was obtained and the National Center for Health Statistics ethics committee approved the protocol of the NHANES study. The data is publicly available, therefore, the ethical approval statement and the requirement for informed consent were waived for this study.

Results

Study characteristics

A total of 8069 participants (3897 men and 4127 women) were included in the final analysis, with 4873 HOMA-IR ≤ 2.5 (defined as non-insulin resistance) and 3196 HOMA-IR > 2.5 (defined as insulin resistance). Table 1 shows the demographic characteristics and clinical disease status of participants grouped by gender and IR

Characteristics	Total	Male	Female	HOMA-IR ≤ 2.5	HOMA-IR > 2.5
	n = 8069	n = 3897	n = 4172	n = 4873	n = 3196
Age (Mean ± SE)	43.38 ± 0.21	42.73 ± 0.28	44.02 ± 0.30	42.77 ± 0.26	44.45 ± 0.34
Race/ethnicity, n (%)					
Mexican American	597 (7.40)	319 (8.19)	277 (6.64)	303 (6.22)	302 (9.45)
Other Hispanic	395 (4.89)	177 (4.54)	218 (5.22)	196 (4.02)	205 (6.41)
Non-Hispanic White	5842 (72.40)	2837 (72.81)	3004 (72.00)	3667 (75.26)	2155 (67.43)
Non-Hispanic Black	839 (10.40)	375 (9.61)	466 (11.17)	469 (9.62)	376 (11.75)
Other race	396 (4.91)	189 (4.85)	207 (4.97)	238 (4.88)	158 (4.97)
Education, n (%)					
Under high school	1463 (18.13)	743 (19.06)	719 (17.24)	802 (16.45)	672 (21.04)
High school or some college	4573 (56.67)	2158 (55.37)	2416 (57.92)	2700 (55.41)	1881 (58.85)
College graduate or above	2033 (25.20)	996 (25.57)	1037 (24.85)	1371 (28.14)	643 (20.11)
Marital status					
Married	4631 (57.39)	2292 (58.81)	2338 (56.03)	2769 (56.83)	1866 (58.39)
Never married	1602 (19.85)	899 (23.07)	698 (16.73)	992 (20.36)	605 (18.94)
Divorced or other	1836 (22.76)	706 (18.12)	1136 (27.23)	1112 (22.81)	725 (22.67)
Physical activity level, n (%)					
Active	3069 (38.04)	1667 (42.78)	1396 (33.47)	2044 (41.95)	999 (31.25)
Insufficiently active	2311 (28.63)	1015 (26.05)	1299 (31.13)	1332 27.33)	987 (30.90)
Inactive	2689 (33.32)	1215 (31.17)	1477 (35.40)	1497 (30.72)	1210 (37.86)
Smoking, n (%)					
Current	2323 (28.79)	1320 (33.88)	1013 (24.28)	1474 (30.24)	834 (26.09)
Former	393 (4.87)	256 (6.58)	140 (3.36)	249 (5.10)	142 (4.44)
Never	5353 (66.34)	2321 (59.54)	3019 (72.36)	3150 (64.65)	2220 (69.47)
Drinking, n (%)					
Heavy	271 (3.36)	159 (4.08)	108 (2.58)	157 (3.23)	114 (3.57)
Moderate	2843 (35.23)	1463 (37.54)	1366 (32.75)	1798 (36.89)	1030 (32.24)
Mild or never	4955 (61.41)	2275 (58.39)	2697 (64.68)	2918 (59.87)	2052 (64.19)
Hypertension, n (%)					
Yes	1895 (23.49)	889 (22.81)	1007 (24.13)	876 (17.97)	1058 (33.09)
No	6174 (76.51)	3008 (77.19)	3165 (75.87)	3997 (82.03)	2138 (66.91)
Hyperlipidemia, n (%)					
Yes	3019 (37.41)	1552 (39.83)	1472 (35.28)	1585 (32.52)	1449 (45.35)
No	5050 (62.59)	2345 (60.17)	2700 (64.72)	3288 (67.48)	1747 (54.65)
Fasting blood-glucose, mmol/L	5.28 ± 0.01	5.40 ± 0.01	5.17 ± 0.01	5.13 ± 0.01	5.56 ± 0.01
Fasting insulin, μU/mL	10.48 ± 0.13	10.99 ± 0.21	9.99 ± 0.14	6.39 ± 0.04	18.05 ± 0.26
Systolic blood pressure, mm Hg	120.62 ± 0.23	122.19 ± 0.28	119.12 ± 0.35	118.85 ± 0.28	123.88 ± 0.36
Diastolic blood pressure, mm Hg	71.26 ± 0.16	72.61 ± 0.23	69.97 ± 0.22	70.15 ± 0.20	73.32 ± 0.27
Total cholesterol, mg/dL	197.82 ± 0.59	195.81 ± 0.82	199.74 ± 0.84	195.70 ± 0.72	201.76 ± 1.00
Triglyceride, mg/dL	125.83 ± 1.00	132.76 ± 1.52	119.24 ± 1.30	109.40 ± 1.05	156.27 ± 1.83
Low density lipoprotein, mg/dL	119.09 ± 0.53	120.98 ± 0.76	117.29 ± 0.74	116.91 ± 0.65	123.13 ± 0.91
High-density lipoprotein, mg/dL	53.57 ± 0.23	48.28 ± 0.27	58.62 ± 0.34	56.91 ± 0.29	47.39 ± 0.31

Table 1. Characteristics of study participants by gender and insulin resistance in the NHANES 1999–2006. Continuous variables are expressed by means and standard errors (SE), categorical variables are expressed in numbers (percentages).

presence. Most of the participants in the study were non-Hispanic white, and most had more than a high school education. Hypertension and hyperlipidemia were more common among participants with IR. Compared with participants without IR, participants with IR had higher fasting blood glucose, fasting insulin, systolic blood pressure, diastolic blood pressure, total cholesterol, triglycerides, low density lipoprotein levels, and lower high density lipoprotein levels.

Relationship between anthropometric parameters and IR

The weighted linear regression results showed that BMI, AC and WC were significantly positively correlated with IR, while CC and TC were significantly negatively correlated with IR. After adjusting for confounding factors, the relationship between CC and IR becomes insignificant. Furthermore, we observed that the association between WHtR and IR was not significant in either the coarse model or the model after adjusting for confounders. Detailed results can be obtained in Table 2.

BMI and WC are ideal parameters to predict IR

Figure 2 and Table 3 show the AUC values and the corresponding 95% CI of IR predicted by different anthropometric parameters in American adults. Among the 4 anthropometric parameters, BMI and WC had similar AUCs (AUC: 0.780, 95% CI 0.770–0.790; AUC: 0.774, 95% CI 0.763–0.784, respectively), higher than TC and AC (AUC: 0.698, 95% CI 0.687–0.710, AUC: 0.746, 95% CI 0.735–0.757, respectively). This relationship persisted after gender stratification.

Relationship between IR and anthropometric parameters as four categorical variables

After conducting a stratified analysis of the anthropometric parameter values, we found that IR showed an upward trend with the increase of WC. Compared with group Q1, groups Q2, Q3 and Q4 all significantly increased the risk of IR (OR: 1.57, 95% CI 1.22–2.03; OR: 3.23, 95% CI 2.43–4.28; OR: 5.67, 95% CI 3.94–8.17, respectively). In addition, we observed that a larger TC was associated with a lower IR risk. Compared with group Q1, groups Q2, Q3 and Q4 all decreased the risk of IR (OR: 0.66, 95% CI 0.54–0.82; OR: 0.75, 95% CI

	Model 1		Model 2		Model 3	
	β (95% CI)	*P*	β (95% CI)	*P*	β (95% CI)	*P*
BMI	0.051 (0.037, 0.065)	< 0.001	0.047 (0.033, 0.060)	< 0.001	0.048 (0.034, 0.061)	< 0.001
CC	−0.015 (−0.024, −0.006)	0.001	−0.007 (−0.016, 0.003)	0.153	−0.007 (−0.016, 0.002)	0.147
AC	0.013 (0.005, 0.022)	0.002	0.013 (0.004, 0.022)	< 0.001	0.013 (0.004, 0.022)	0.003
TC	−0.012 (−0.018, −0.006)	< 0.001	−0.021 (−0.028, −0.015)	< 0.001	−0.022 (−0.029, −0.016)	< 0.001
WC	0.015 (0.012, 0.019)	< 0.001	0.020 (0.015, 0.025)	< 0.001	0.021 (0.016, 0.026)	< 0.001
WHtR	−0.469 (−1.286, 0.348)	0.260	−0.557 (−1.551, 0.437)	0.272	−0.739 (−1.728, 0.251)	0.144

Table 2. Association between different anthropometric parameters and insulin resistance.* *The association between anthropometric parameters and insulin resistance was evaluated by weighted inear regression. BMI: body mass index; CC: calf circumference; AC: arm circumference; TC: thigh circumference; WC: waist circumference; WHtR: waist-to-height ratio; β: regression coefficient; CI: confidence interval. Model 1: no covariates were adjusted. Model 2 adjusted: age, sex, race/ethnicity, education, BMI, and marital status. Model 3 adjusted: Model 2 + drinking state, smoking status.

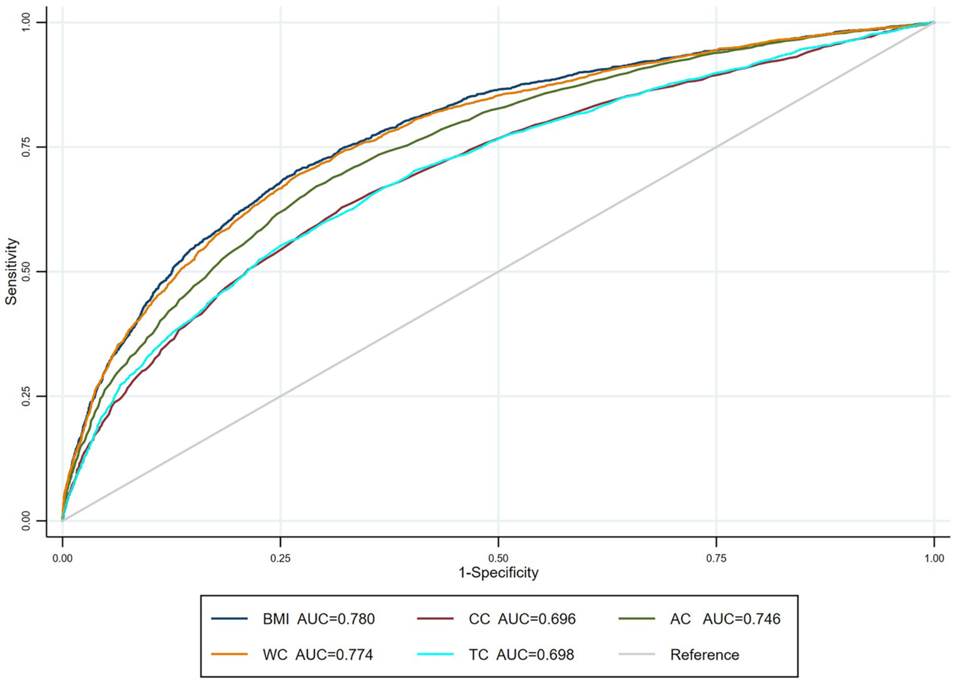

Figure 2. Receiver operating characteristics for body mass index, calf circumference, arm circumference, thigh circumference, waist circumference, waist-height ratio and elevated homeostatic model assessment of insulin resistance.

	Total (n = 8069)	P	Male (n = 3897)	P	Female (n = 4172)	P
BMI	0.780 (0.770, 0.790)	< 0.001	0.781 (0.766, 0.796)	< 0.001	0.783 (0.768, 0.797)	< 0.001
CC	0.696 (0.684, 0.708)	< 0.001	0.695 (0.678, 0.711)	< 0.001	0.695 (0.679, 0.711)	< 0.001
AC	0.746 (0.735, 0.757)	< 0.001	0.723 (0.707, 0.739)	< 0.001	0.767 (0.755, 0.783)	< 0.001
TC	0.698 (0.687, 0.710)	< 0.001	0.689 (0.672, 0.705)	< 0.001	0.706 (0.690, 0.721)	< 0.001
WC	0.774 (0.763, 0.784)	< 0.001	0.776 (0.762, 0.790)	< 0.001	0.772 (0.758, 0.786)	< 0.001

Table 3. The area under the curve of different anthropometric parameters in the prediction of insulin resistance. BMI: body mass index; CC: calf circumference; AC: arm circumference; TC: thigh circumference; WC: waist circumference; β: regression coefficient; CI: confidence interval.

0.60–0.94; OR: 0.47, 95% CI 0.35–0.62, respectively). This association persisted in models 2 and 3 after adjusting for covariables. Detailed information is available in Table 4.

Discussion

This cross-sectional study included 8069 participants and compared 6 different anthropometric parameters. The most prominent finding of this study is that TC is significantly negatively correlated with IR, while WC is significantly positively correlated with IR. Therefore, we speculated that individuals with higher TC may have a lower risk of IR, and individuals with higher WC may have a higher risk of IR. In addition, we observed that WC may be an ideal predictor of IR among the 6 parameters.

Previous studies have shown that anthropometric parameters may be employed to predict IR. A small observational study involving 79 obese adolescents showed that BMI and WC are important predictors of IR, and WC prediction may be more effective[15]. However, the small sample size and the fact that all participants were obese adolescents may limit the general applicability of the conclusion. Another Korean study including 4427 patients with T2D showed that calf circumferences were significantly related to IR, which may be a new anthropometric index to predict IR. Larger CC were associated with a lower risk of IR in both men and women[16]. A systematic review and meta-analysis of 31 observational studies involving more than 300,000 people suggests that WHtR is a better tool for screening cardio-metabolic risk factors than WC and BMI[17]. However, primary outcomes were defined as hypertension, hyperlipidemia, and metabolic syndrome, and IR was not included. Recent studies have used anthropometric parameters in combination with laboratory indicators to assess IR. A cross-sectional study including 2255 participants with IR and 7629 participants with non-IR showed that the ratio of triglyceride-glucose to WHtR (TyG-WHtR) is a stable indicator for identifying IR and can be effectively used in clinical practice[18]. Another study conducted in China showed that among all 12 indicators related to blood lipids and obesity, the ratio of triglycerides- glucose to BMI (TyG-BMI) is the best predictor of male metabolic syndrome[19]. In addition, anthropometric parameters combined with triglycerides-glucose were better predictors of metabolic syndrome than anthropometric parameters alone. However, compared with HOMA-IR, anthropometric parameters combined with laboratory results were not a better predictor of IR. Moreover, obtaining these indicators still requires laboratory equipment, so this may limit the ability to quickly and easily assess IR in clinics. Currently, there is insufficient evidence about the association between TC and IR. A cross-sectional study involving 5719 participants showed no significant correlation between TC and IR. However, participants included in the study included both diabetics and non-diabetics. To the best of our knowledge, our study is the first to report the relationship between TC and IR among patients without diabetes mellitus.

Characteristic	Participants No	Model 1 OR (95% CI)	Model 2 OR (95% CI)	Model 3 OR (95% CI)
WC, (range),cm				
Q1 (58.6–83.8)	2027	1 (ref)	1 (ref)	1 (ref)
Q2 (83.9–94.1)	2007	1.50 (1.18, 1.90)	1.57 (1.22, 2.03)	1.56 (1.21, 2.00)
Q3 (94.2–104.4)	2011	2.97 (2.30, 3.84)	3.23 (2.43, 4.28)	3.21 (2.42, 4.27)
Q4 (104.5–169.7)	2024	4.98 (3.60, 6.88)	5.67 (3.94, 8.17)	5.69 (3.94, 8.22)
TC, (range), cm				
Q1 (34.0–48.1)	1998	1 (ref)	1 (ref)	1 (ref)
Q2 (48.2–52.2)	2040	0.66 (0.54, 0.82)	0.65 (0.52, 0.82)	0.65 (0.51, 0.81)
Q3 (52.3–56.8)	2023	0.75 (0.60, 0.94)	0.77 (0.59, 1.01)	0.76 (0.58, 1.00)
Q4 (56.9–94.8)	2008	0.47 (0.35, 0.62)	0.49 (0.34, 0.70)	0.48 (0.33, 0.69)

Table 4. The association between insulin resistance and anthropometric parameters as four categorical variables* * The association between anthropometric parameters and insulin resistance was evaluated by weighted binary logistic regression. WC: waist circumference, TC: thigh circumference; OR: odds ratio; CI: confidence interval; ref: reference. Model 1: no covariates were adjusted. Model 2 adjusted: age, sex, race/ethnicity, education, BMI, and marital status. Model 3 adjusted: Model 2 + smoking status, drinking status.

BMI, a measure based on weight and height, is the standard way to define obesity in public health and clinical guidelines. BMI, which represents overall obesity, has the inherent limitation of not distinguishing between body shape and the distribution of fat tissue[20]. Central obesity, also known as abdominal obesity, is clinically characterized by a greater distribution of fat in the abdomen than in the limbs. Our results of regression analysis showed that the correlation between BMI and WC was not strong (correlation coefficient: 0.347), so BMI and WC may express different information[21]. Published evidence shows that compared with normal-weight people without central obesity, normal-weight people with central obesity have an increased risk of diabetes (OR: 1.35, 95% CI 1.25–1.46), while overweight people without central obesity have a slightly reduced risk (OR: 0.83, 95% CI 0.66–1.03)[22]. In addition, studies have reported that central obesity is associated with a significantly increased risk of death, exceeding the risk of obesity (HR: 1.48, 95% CI 1.35–1.62; HR: 1.12, 95% CI 0.99–1.27, respectively)[21]. These findings suggest that the use of BMI in the diagnosis of obesity may not be ideal in people with normal-weight and central obesity. With increasing age, there are corresponding changes in body fat distribution, mainly manifested by an increase in total fat and abdominal fat, which can be independent of weight gain[23]. BMI was unable to monitor fat gain associated with increasing age, nor was it able to identify significant increases in abdominal fat. WC was sensitive indicators to assess central obesity, and increasing evidence suggests that central obesity may be the key to the development of IR[24].

The following reasons may explain why IR is positively correlated with WC and negatively correlated with TC: First, visceral fat accumulation may be one reason. The risk of obesity largely depends on the amount of visceral fat[25]. Previous studies have reported that excessive visceral fat content is strongly associated with hyperinsulinemia and insulin resistance[26,27]. The accumulation of visceral fat is often manifested as central obesity, which is an essential feature of metabolic disease. Therefore, larger WC may be associated with an increased risk of IR. Second, in individuals with a certain BMI, a larger TC may be associated with a smaller WC, which may be associated with a lower risk of IR. Third, a larger TC reflected an increase in subcutaneous femur fat. Femoral fat reservoirs have a relatively high activity of lipoprotein lipase and a relatively low rate of stimulated lipolysis, and these reservoirs protect the liver and muscles from high exposure to free fatty acids[28]. Studies have shown that compared with the abdominal fat pool, the femoral fat pool is more passive and can store fatty acids for a long time to play its protective properties. Femoral fat also captures excess fatty acids, thereby preventing the adverse effects associated with ectopic fat precipitation. In addition, femoral fat was positively correlated with beneficial adipokines such as adiponectin and leptin, and negatively correlated with inflammatory cytokines[29].

Our results may have important public health and clinical value. First, there is increasing evidence that IR is associated with the occurrence of a variety of diseases, such as type 2 diabetes, metabolic syndrome and cardiovascular disease[3]. Therefore, early identification and close monitoring of IR are of great significance in preventing related diseases. Our results show that anthropometric parameters are closely related to the occurrence and development of IR. Compared with laboratory tests, anthropometric parameters are easy to measure and obtain, so they can be used to predict the occurrence of IR and detect the dynamic changes of IR. Second, our study reported that IR was positively correlated with WC and negatively correlated with TC. Therefore, when developing strategies to reduce IR risk, more attention can be paid to changes in abdominal and thigh fat.

Strengths and limitations

Anthropometric parameters were measured by trained professionals, not self-reported, and are easy to measure, so our results may have general applicability. However, our study also has the following limitations: First, the cross-sectional design used in this study makes it impossible to infer a causal relationship between anthropometric parameters and IR. Second, the tangential points of HOMA-IR reported in the literature differ greatly[30], and the measurement of insulin has not been standardized, which may confuse the real relationship between anthropometric parameters and IR. According to WHO recommendations, IR can be defined as above the highest quartile (75th) of the HOMA-IR index[31]. HOMA-IR = 2.5 was selected as the cut-off value for diagnosing IR, according to the latest literature. Third, we included only the US population, which may limit the general applicability of our results.

Conclusions

Our study evaluated the association between 6 different anthropometric parameters and IR among patients without diabetes mellitus. The results showed a significant positive correlation between BMI, AC, and WC with IR, which is consistent with previous conclusions. In addition, we also observed a significant negative correlation between TC and IR. The hypothesized mechanism may be that femoral fat has a protective effect on metabolism and thus reduces the risk of IR. This is the first study to show a negative correlation between TC and IR in a non-diabetic population. Due to cross-sectional study design, the association between anthropometric parameters and IR may be exaggerated or underestimated to some extent. Therefore, large sample, multi-center cohort studies can be designed in the future to determine the exact relationship between the two.

Data availability

The study examined publicly accessible datasets. This information is available at https://www.cdc.gov/nchs/nhanes/.

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Author contributions

J.J.L and X.S.J designed the study, analyzed the feasibility of the study, and wrote the manuscript of the paper. Z.Y.F collated and merged the data. J.J.L conducted the statistical analysis, draw figures and tables. J.M.H reviewed the manuscript, provided critical scientific input, and checked the whole process of the study.

Competing interests

The authors declare no competing interests.

Additional information

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