Original Article

Anthropometric Indices and Diabetes Disease: Based on the Rafsanjan Cohort Study

Abstract

Background: Various investigations have evaluated the predictive ability of different anthropometric indices for type 2 diabetes mellitus (T2DM) risk and the findings were inconsistent in different populations. This study investigated the relationship between anthropometric indicators and T2DM in the Rafsanjan Cohort Study. **Methods:** The present cross-sectional study included 9895 adults, aged 35–70 years, among them who have completed data, were studied. We obtained the data from the Rafsanjan Cohort Study (RCS), as a part of the prospective epidemiological research studies in Iran (PERSIAN). Fasting blood glucose >126 and use of glucose-lowering drugs were used from cohort data as T2DM. Anthropometric indices were compared for T2DM or prediabetes odds vs. normal group. Demographic characteristics and risk factors were compared in diabetes, prediabetes, and normal groups. **Results:** Of 9895 participants, about 23 (n = 2283) and 35% (n = 3455) of this population had T2DM and prediabetes, respectively. After adjusting for potential confounders, for waist-to-hip ratio (WHR) (OR = 3.25, 95% CI 2.68–3.94) and waist-to-height ratio (WHtR) (OR = 2.90, 95% CI 2.40–3.49), individuals in the highest quartile had a higher probability of developing T2DM than individuals in the lowest quartile. Also, the odds ratio of T2DM increased in participants with overweight, obesity, and abnormal waist circumference (WC) by considering a cutoff point. **Conclusions:** According to our findings, the strongest and weakest anthropometric indexes related to T2DM were WHR and WC, respectively.

Keywords: *Body mass index, prospective epidemiological research studies in Iran (PERSIAN), Rafsanjan Cohort Study (RCS), type 2 diabetes mellitus, waist circumference, waist-to-height ratio, waist-to-hip ratio*

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Introduction

Type 2 diabetes mellitus (T2DM) prevalence has increased dramatically in the last decades and has become a major public health burden worldwide.[1,2] It is estimated that by 2045, the prevalence of diabetes in people aged 20 to 79 will increase from 10.1% to 12.2% and reach 738.2 million people in the world.[3] Age, race, family history, dietary habits, obesity, and insufficient physical activity were well-known and serious risk factors for T2DM, among which obesity was significant.[2]

Although there is a definite relationship between obesity and diabetes, it remains unknown which anthropometric index is suitable to assess obesity and evaluate the risk of T2DM in the population.[4] There are different anthropometric indices to measure body fat accumulation. Body mass index (BMI) as a general obesity indicator and waist-to-hip ratio (WHR), waist circumference (WC), and waist-to-height ratio (WHtR) are indices to assess abdominal obesity.[5]

BMI, which is suggested by the World Health Organization, is the most common index used to measure obesity in people.[6] However, some studies indicated that BMI as a marker to reflect general obesity is not able to show body fat distribution and abdominal obesity.[7,8]

On the other hand, several studies have reported that diabetes was more associated with central obesity than general obesity.[9-11] Hence, other measures of adiposity, such as WHR, WC, and WHtR, have been used in studies to measure abdominal fat.[12] The results were different in various studies. Some had found that indicators of abdominal obesity had better predictive abilities for diabetes risk,[12-14] while others had shown that BMI was better,[6,8] or they had the same predictive powers.[15,16]

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In addition, other studies have shown that the predictive strength of different anthropometric indices for diabetes risk varies in different countries and races.[17-19] Because of the high prevalence and incidence of T2DM in Iran,[20] this study assessed the association between anthropometric indices and T2DM in the Rafsanjan Cohort Study.

Methods

Study population

The Rafsanjan cohort study (RCS)[21] as a branch of the Prospective Epidemiological Research Study in Iran (PERSIAN) cohort[22] is an ongoing population-based longitudinal study of adults, aged 35–70 years, living in urban and rural areas of Rafsanjan, a region in the southeast of Iran. RCS was initiated in August 2015. Participants were selected by multistage random sampling. Detailed protocol of the RCS has been reported previously.[21] In summary, 9991 individuals from both genders participated in RCS. After obtaining their informed written consent, medical history, personal habits, and demographic data of all participants were asked following a standardized interview using validated questionnaires by the PERSIAN.[22] Measurements of blood pressure, physical examinations, and anthropometric parameters were also carried out. Ethical approval was obtained from the Ethics Committee of Rafsanjan University of Medical Sciences (IR.RUMS.REC.1400.055). In the present cross-sectional study, subjects with incomplete data on medical history and fasting blood sugar were excluded, and finally, 9895 subjects were included. The frequency difference between the total number and some of the covariates was related to the missing data.

Anthropometric assessment

Trained healthcare providers measured anthropometric characteristics, including height, waist, hip, and wrist circumferences (cm), and weight (kg) according to the US National Institutes of Health protocols.[21] Since measurement errors were the least in the morning, anthropometric indices were measured while the participants were still fasting. In addition, before examining the anthropometric indicators, participants were asked to remove extra clothes and shoes.

Weight and height were measured with the participants in a standing position using a digital scale (SECA Digital Scale, Germany) and a stadiometer (SECA Stadiometer, Germany), respectively. WC was determined using a constant tension tape with a precision of 0.1 cm at the level of the umbilicus and hip circumference (HC) was also measured at the widest point over the hips.[21]

The abnormality of WC was evaluated in participants according to three definitions: Adult Treatment Panel III (ATP-III), International Diabetes Federation (IDF), and IDF ethnic-specific cutoff for the Iranian population (Iranian IDF). According to ATP-III, WC $\geq$ 102 cm in men and $\geq$ 88 cm in women were defined as abnormal WC. Based on IDF International, WC $\geq$ 94 cm in men and $\geq$ 80 cm in women was considered abnormal WC. To define abnormal WC based on Iranian IDF, a cutoff point of WC $\geq$ 95 cm in both genders was used (metabolic syndrome criteria).[23]

BMI was calculated as weight (kg) divided by height squared (m2). BMI was divided into four groups (<25, 25–30, 30–35, and $\geq$ 35). Also, WHR and WHtR were determined by dividing the waist to hip and height in cm, respectively. WHR, WHtR, and wrist were categorized into quartiles to assess the dose–response relationship. Also, we used the optimal cutoff points of the three anthropometric indices, including WC, WHR, and WHtR, in a sample of Iranian adults. The proposed optimal cutoffs for WC, WHtR, and WHR were 84 cm, 0.48, and 0.78 for women and 98 cm, 0.56, and 0.87 for men, respectively.[24]

Biochemical measurements

For each participant, samples of fasting blood were collected by trained technicians. Fasting blood sugar (FBS), triglycerides (TG), high-density lipoprotein cholesterol (HDLC), low-density lipoprotein cholesterol (LDLC), and total cholesterol (TC) were measured by a biotechnical analyzer (BT 1500, Italy) at the Central Laboratory in the cohort center.

Assessment of other variables

Socioeconomic status was determined using the wealth score index (WSI). Physical activity was reported as the metabolic equivalent of task (MET) calculated for 24 hours. Personal habits, including cigarette smoking, opium use, and alcohol consumption, were self-reported. Methods regarding the collection of these data had been previously described in detail.[25] Individuals who reported hypertension diagnosed by a physician were considered to have hypertension. T2DM was defined as a fasting blood glucose level equal to or higher than 126 mmol/L, or the use of glucose-lowering drugs.[26] Based on the American Diabetes Association (ADA), a fasting blood glucose level of 100–125 mg/dl in subjects without the use of glucose-lowering drugs was considered prediabetes.[27]

Statistical analyses

Frequency (%) for categorical variables and mean ± standard deviation for the quantitative variables were used and baseline characteristics were compared across the groups of our study using Chi-square (χ^2) for categorical variables and *t*-test for continuous variables.

In addition, crude and two adjusted models were used in the multinomial logistic regression analysis to assess the association, calculated odds ratio, and 95% confidence intervals, between diabetes status and anthropometric indices as dependent and in-depended variables, respectively. Based on subject matter knowledge and epidemiological research, we identified confounder's variables. Potential confounding variables were sequentially entered into models according to their hypothesized strengths of association with anthropometric indices and T2DM or prediabetes. Then, variables with *a P* value < 0.25 were selected as confounders. The baseline model (crude model) has been stratified on anthropometric indices.

Adjusted model 1 included anthropometric indices and basic sociodemographic characteristics (age, gender, education, wealth score index (WSI), cigarette smoking, alcohol consumption, opium consumption, physical activity level, first-degree family history of diabetes, and second-degree family history of diabetes). Adjusted model 2 adjusted including variables in adjusted model 1 and hypertension, LDL, TG, and HDL. Data of the present study were analyzed by STATA 14.0 (STATA Corp, College Station, TX) software. All *P* values are two-sided, and *P* values < 0.05 and 95% confidence intervals were considered statistically significant.

Results

The study population included 4605 males (46.54%) and 5290 females (53.46%), aged 35–70 years, as well as 2283 participants who had T2DM (23.07%), and also 3455 participants who had prediabetes (34.92%). The mean age ± SD of participants was 49.9 ± 9.56 and there was a statistically significant difference in the mean age of T2DM, prediabetes, and normal groups (*P* < 0.001). About 48.5% of the participants had an education level between 6 and 12 years, 41% had BMI between 25 and 29.99, 54% had WC APT III abnormal, 53% had WC Iranian IDF abnormal, and 73% had WC IDF abnormal. Also, there were differences in gender, educational level, physical activity, BMI, wealth score index, cigarette smoking, opium and alcohol consumption, hypertension, HDL, LDL, TG, cholesterol, wrist, WC, WHtR, WHR, and family history of diabetes between diabetes, prediabetes, and normal groups [Table 1].

Table 2 shows the odds ratio of prediabetes and T2DM groups by anthropometric indices. The results showed that odds of prediabetes group in crude model increased 1.40 time in participants with BMI 25–29.99 (95% CI 1.26–1.56), 1.78 time in participants with BMI 30–34.99 (95% CI 1.56–2.02), 2.17 time in participant with BMI ≥ 35 (95% CI 1.77–2.66), and 1.06 time in BMI continues (95% CI 1.05–1.07), even after adjusted confounding variables in adjusted model 1 (BMI 25–29.99: OR = 1.52, 95% CI 1.35–1.70; BMI 30–34.99: OR = 2.00, 95% CI 1.74–2.30; BMI ≥ 35: OR = 2.60, 95% CI 2.10–3.22; BMI continues: OR = 1.08, 95% CI 1.07–1.09) the risk of prediabetes group increased significantly and in the adjusted model 2 (BMI 25–29.99: OR = 1.31, 95% CI 1.16–1.47; BMI 30–34.99: OR = 1.65, 95% CI 1.44–1.91; BMI ≥ 35: OR = 2.07, 95% CI 1.66–2.57; BMI continues: OR = 1.06, 95% CI 1.05–1.07), this relationship was still significant.

Also, odds of prediabetes increased in a participant who had abnormal WC (ATP III: OR = 1.76, 95% CI 1.54–2.00; Iranian IDF: OR = 1.62, 95% CI 1.47–1.78; IDF: OR = 1.54, 95% CI 1.35–1.74 and WC Iranian cutoff point: OR = 1.74, 95% CI 1.53–1.98) in adjusted model 1 and adjusted model 2 (ATP III: OR = 1.50, 95% CI 1.31–1.71; Iranian IDF: OR = 1.40, 95% CI 1.26–1.54; IDF: OR = 1.28, 95% CI 1.12–1.46 and WC Iranian cutoff point: OR = 1.48, 95% CI 1.30–1.69), also in the second, third, and fourth quartiles of WHR, WHtR, and wrist after adjusted confounding variables in adjusted models 1 and 2, all of them remain significant. Odds of prediabetes increased in participant who had abnormal WHR Iranian cutoff point (adjusted model 1: OR = 1.78, 95% CI 1.50–2.11, and adjusted model 2: OR = 1.39, 95% CI 1.17–1.66) and abnormal WHtR Iranian cutoff point (adjusted model 1: OR = 1.52, 95% CI 1.32–1.75, and adjusted model 2: OR = 1.29, 95% CI 1.12–1.50) [Table 2].

Results in the crude model indicated that odds of T2DM significantly increased in participants with BMI ≥ 25, BMI continues (OR: 1.11, 95% CI 1.10–1.12), abnormal WC ATP III (OR: 2.21, 95% CI 1.99–2.46), WC Iranian IDF (OR: 2.81, 95% CI 2.53–3.13), WC IDF (OR: 2.32, 95% CI 2.04–2.63), WC Iranian cutoff point (OR: 2.27, 95% CI 2.03–2.55), and all quartiles of WHR, WHtR, wrist, and WHR Iranian cutoff point and WHtR Iranian cutoff point compared reference groups in crud model. After adjusting confounding variables in models 1 and 2, there was a significant relationship between the increased risk of T2DM and all anthropometric indices [Table 2].

Table 3 shows the association between prediabetes and T2DM with anthropometric indices in age groups of both genders. The odds of prediabetes dose–response increased for both age groups and both gender, men and women, in BMI > 30. Also, a dose–response increase in the odds of T2DM was observed in all age and gender groups with increase in BMI. According to Table 3, in other indices, the odds of T2DM and prediabetes increased with increase in anthropometric indices compared to normal levels.

Discussion

In this cross-sectional study, we aimed to assess different anthropometric indices to predict the odds of T2DM among participants of the Rafsanjan Cohort Study. Our study's results indicated that all anthropometric variables were significantly related to T2DM in diabetic patients and prediabetic ones after controlling the potential confounders.

Our findings demonstrated that WHR has the best ability to predict T2DM risk compared to the other indices.

Table 1: Demographic selected medical and laboratory characteristics of study participants

Characteristic	Total (*n*=9895)	Normal (*n*=4157)	Prediabetes (*n*=3455)	T2DM (*n*=2283)	*P*
Age- yr. *n* (%)					<0.001
35–45	3672 (37.11)	2206 (53.07)	1161 (33.60)	305 (13.36)	
46–55	3051 (30.83)	1147 (27.59)	1180 (34.15)	724 (31.71)	
≥56	3172 (32.06)	804 (19.34)	1114 (32.24)	1254 (54.93)	
Mean±SD	49.96±9.56	46.54±8.92	50.35±9.20	55.61±8.35	<0.001
Gender *n* (%)					<0.001
Male	4605 (46.54)	1929 (41.89)	1784 (38.74)	892 (19.37)	
Female	5290 (53.46)	2228 (42.12)	1671 (31.59)	1391 (26.29)	
Education *n* (%)					<0.001
≤5 years	3476 (35.15)	1129 (27.18)	1215 (35.19)	1132 (49.58)	
6–12 years	4795 (48.48)	2229 (53.66)	1663 (48.16)	903 (39.55)	
≥ 13 years	1619 (16.37)	796 (19.16)	575 (19.65)	248 (10.86)	
Mean±SD	8.52±5.05	9.5±4.80	8.50±4.97	6.75±5.14	<0.001
Physical activity *n* (%)					<0.001
Mean±SD	38.79±6.32	39.23±6.53	39.09±6.61	37.56±5.23	
WSI *n* (%)					<0.001
Mean±SD	-0.001±1.00	0.076±0.997	0.005±0.999	-0.150±0.989	
Alcohol consumption *n* (%)					<0.001
No	8889 (90.02)	3674 (88.68)	3081 (89.23)	2134 (93.64)	
Yes	986 (9.98)	469 (11.32)	372 (10.77)	145 (6.36)	
Cigarette smoking *n* (%)					<0.001
No	7342 (74.35)	3068 (74.05)	2484 (71.94)	1790 (78.54)	
Yes	2533 (25.65)	1075 (25.95)	969 (28.06)	489 (21.46)	
Opium consumption *n* (%)					<0.001
No	7546 (76.42)	3206 (77.38)	2560 (74.14)	1780 (78.10)	
Yes	2329 (23.58)	937 (22.62)	893 (25.86)	499 (21.90)	
BMI *n* (%)					<0.001
<25	2847 (28.79)	1501 (36.13)	915 (26.49)	431 (18.90)	
25–29.99	4055 (41.01)	1677 (40.37)	1435 (41.55)	943 (41.36)	
30–34.99	2268 (22.94)	778 (18.73)	842 (24.38)	648 (28.42)	
≥35	718 (7.26)	198 (4.77)	262 (7.59)	258 (11.32)	
Mean±SD	27.84±4.89	26.82±4.69	28.13±4.88	29.23±4.87	<0.001
Wrist					<0.001
Quartile 1	2416 (24.43)	1317 (31.70)	706 (20.44)	393 (17.23)	
Quartile 2	2618 (26.47)	1160 (27.92)	894 (25.88)	564 (24.73)	
Quartile 3	2430 (24.57)	901 (21.69)	910 (26.35)	619 (27.14)	
Quartile 4	2425 (24.52)	776 (18.68)	944 (27.33)	705 (30.91)	
Mean±SD	17.29±1.44	16.98±1.40	17.47±1.41	17.57±1.45	<0.001
WC APT III *n* (%)					<0.001
Normal	4548 (45.99)	2171 (52.26)	1622 (46.96)	755 (33.10)	
Abnormal	5341 (54.01)	1983 (47.74)	1832 (53.04)	1526 (66.90)	
WC Iranian IDF *n* (%)					<0.001
Normal	4623 (46.75)	2358 (56.78)	1539 (44.56)	726 (31.83)	
Abnormal	5265 (53.25)	1795 (43.22)	1915 (55.44)	1555 (68.17)	
WC IDF *n* (%)					<0.001
Normal	2700 (27.30)	1330 (32.02)	985 (28.52)	385 (16.88)	
Abnormal	7189 (72.70)	2824 (67.98)	2469 (71.48)	1896 (83.12)	
WC Iranian cutoff point					<0.001
Normal	3594 (36.34)	1751 (42.15)	1289 (37.32)	554 (24.29)	
Abnormal	6295 (63.66)	2403 (57.85)	2165 (62.68)	1727 (75.71)	
WHtR					<0.001
Quartile 1	2469 (24.97)	1462 (35.19)	736 (21.31)	271 (11.88)	

Contd...

Table 1: Contd...

Characteristic	Total (*n*=9895)	Normal (*n*=4157)	Prediabetes (*n*=3455)	T2DM (*n*=2283)	*P*
Quartile 2	2465 (24.93)	1073 (25.83)	879 (25.45)	513 (22.49)	
Quartile 3	2481 (25.09)	929 (22.36)	937 (27.13)	615 (26.96)	
Quartile 4	2474 (25.02)	690 (16.61)	902 (26.11)	882 (38.67)	
WHtR Iranian cutoff point					<0.001
Normal	3183 (32.19)	1522 (36.64)	1187 (34.37)	474 (20.78)	
Abnormal	6706 (67.81)	2632 (63.36)	2267 (65.63)	1807 (79.22)	
WHR					<0.001
Quartile 1	2495 (25.23)	1455 (35.03)	802 (23.22)	238 (10.43)	
Quartile 2	2447 (24.74)	1105 (26.60)	884 (25.59)	458 (20.08)	
Quartile 3	2464 (24.92)	926 (22.29)	886 (25.65)	652 (28.58)	
Quartile 4	2483 (25.11)	668 (16.08)	882 (25.54)	933 (40.90)	
WHR Iranian cutoff point					<0.001
Normal	815 (8.24)	498 (11.99)	266 (7.70)	51 (2.24)	
Abnormal	9074 (91.76)	3656 (88.01)	3188 (92.30)	2.230 (97.76)	
Hypertension *n* (%)					<0.001
No	7660 (77.41)	3684 (88.62)	2734 (79.13)	1242 (54.40)	
Yes	2235 (22.59)	473 (11.38)	721 (20.87)	1041 (45.60)	
First-degree family history of T2 Diabetes *n* (%)					<0.001
No	5016 (50.69)	2379 (57.23)	1801 (52.13)	836 (36.62)	
Yes	4879 (49.31)	1778 (42.77)	1654 (47.87)	1447 (63.38)	
Second-degree family history of T2 Diabetes *n* (%)					<0.001
No	7465 (75.44)	3050 (73.37)	2692 (77.92)	1723 (75.47)	
Yes	2430 (24.56)	1107 (26.63)	763 (22.08)	560 (24.53)	
TG					<0.001
Mean±SD	169.16±110.74	147.50±77.70	175.43±112.38	199.14±145.78	
HDL *n* (%)					<0.001
Mean±SD	57.75±10.87	58.50±11.04	57.30±10.55	57.07±10.98	
LDL *n* (%)					<0.001
Mean±SD	108.18±30.29	107.59±27.96	111.99±29.87	103.47±34.04	
Cholesterol					<0.001
Mean±SD	198.66±38.04	195.23±35.32	203.16±36.65	198.11±43.80	

Wealth score index (WSI); body mass index (BMI); triglyceride (TG); high-density lipoprotein (HDL); low-density lipoprotein (LDL); type 2 diabetes mellitus (T2DM)

This finding is in line with the findings of other studies among different populations. Similar to our results, the Guangzhou Biobank Cohort Study,[28] the RODAM study among Ghanaian migrants and nonmigrants,[29] a study in the Iraqi population,[30] an investigation among the Taiwanese population,[31] and two other studies among Iranian adults[13,32] have shown the superiority of WHR to other indicators. It was also shown that WHtR as another indicator of abdominal obesity is also a better index than BMI. It was consistent with the findings of some investigations,[4,5,12,18] while the superiority of BMI over WHR and WHtR has been mentioned in some other studies that were inconsistent with our results.[6,8] A possible reason for this inconsistency is that indices, like WHR and WHtR, could reflect visceral obesity and body fat distribution better than BMI.[5] It has been revealed by different studies that diabetes is more related to abdominal obesity than general obesity. This might be due to different factors released by adipose tissue and leads to insulin resistance in tissues and increased insulin demands[13,17,33]

In our study, WC appeared to be the weakest predictor of T2DM risk compared to other indicators which was in line with the results of the Jinchang Cohort Study.[34] This finding was not in line with some other investigations. In a study in Malaysia, both WC and BMI had the same but better discriminatory abilities than WHR[8] In three other studies, WC and WHtR were more relative to T2DM than WHR and BMI[17,35], including a study in Iran.[5] This difference in our results could be because WC does not include the participants' height nor the hip circumference; therefore, people with the same WC but taller have a lower risk and people with shorter height have a higher risk for diabetes.[12] In addition, participants with the same WC but a higher WHR have lower hip circumference. The hip area is made up of various components, including bone, fat tissue, and gluteal muscles. The muscle mass in this area is one of the main

Table 2: The odds ratio of prediabetes and type 2 diabetes disease by anthropometric indices

Anthropometric indices	Prediabetes vs. normal			T2DM vs. normal		
	Crude model	Adjusted model 1	Adjusted model 2	Crude model	Adjusted model 1	Adjusted model 2
BMI						
<25	1	1	1	1	1	1
25–29.99	1.40 (1.26–1.56)	1.52 (1.35–1.70)	1.31 (1.16–1.47)	1.96 (1.71–2.24)	2.03 (1.75–2.37)	1.56 (1.33–1.83)
30–34.99	1.78 (1.56–2.02)	2.00 (1.74–2.30)	1.65 (1.44–1.91)	2.90 (2.50–3.37)	2.81 (2.37–3.35)	1.98 (1.65–2.38)
≥35	2.17 (1.77–2.66)	2.60 (2.10–3.22)	2.07 (1.66–2.57)	4.54 (3.66–5.62)	4.37 (3.42–5.60)	2.76 (2.13–3.57)
BMI continues	1.06 (1.05–1.07)	1.08 (1.07–1.09)	1.06 (1.05–1.07)	1.11 (1.10–1.12)	1.11 (1.10–1.13)	1.08 (1.06–1.09)
WC ATP III						
Normal	1	1	1	1	1	1
Abnormal	1.24 (1.13–1.35)	1.76 (1.54–2.00)	1.50 (1.31–1.71)	2.21 (1.99–2.46)	2.41 (2.04–2.84)	1.77 (1.49–2.10)
WC Iranian IDF						
Normal	1	1	1	1	1	1
Abnormal	1.63 (1.49–1.79)	1.62 (1.47–1.78)	1.40 (1.26–1.54)	2.81 (2.53–3.13)	2.29 (2.02–2.58)	1.75 (1.54–1.99)
WC IDF						
Normal	1	1	1	1	1	1
Abnormal	1.18 (1.07–1.30)	1.54 (1.35–1.74)	1.28 (1.12–1.46)	2.32 (2.04–2.63)	2.39 (2.02–2.84)	1.73 (1.45–2.07)
WC Iranian cutoff point						
Normal	1	1	1	1	1	1
Abnormal	1.22 (1.12–1.34)	1.74 (1.53–1.98)	1.48 (1.30–1.69)	2.27 (2.03–2.55)	2.63 (2.23–3.11)	1.95 (1.64–2.32)
WHR						
Quartile 1	1	1	1	1	1	1
Quartile 2	1.45 (1.28–1.64)	1.32 (1.17–1.50)	1.16 (1.02–1.32)	2.53 (2.13–3.02)	2.01 (1.67–2.42)	1.73 (1.42–2.10)
Quartile 3	1.74 (1.53–1.97)	1.47 (1.29–1.68)	1.22 (1.07–1.40)	4.30 (3.63–5.10)	2.85 (2.37–3.42)	2.21 (1.83–2.67)
Quartile 4	2.40 (2.10–2.73)	1.82 (1.59–2.10)	1.46 (1.27–1.69)	8.54 (7.21–10.11)	4.52 (3.76–5.44)	3.25 (2.68–3.94)
WHR Iranian cutoff point						
Normal	1	1	1	1	1	1
Abnormal	1.63 (1.40–1.91)	1.78 (1.50–2.11)	1.39 (1.17–1.66)	5.96 (4.44–7.98)	4.45 (3.22–6.13)	2.94 (2.12–4.06)
WHtR						
Quartile 1	1	1	1	1	1	1
Quartile 2	1.63 (1.44–1.85)	1.50 (1.32–1.71)	1.31 (1.15–1.49)	2.58 (2.18–3.05)	2.15 (1.79–2.58)	1.74 (1.44–2.10)
Quartile 3	2.00 (1.76–2.27)	1.73 (1.52–1.97)	1.42 (1.24–1.63)	3.57 (3.03–4.21)	2.47 (2.06–2.96)	1.80 (1.49–2.17)
Quartile 4	2.60 (2.27–2.97)	2.15 (1.87–2.46)	1.72 (1.49–1.99)	6.90 (5.86–8.12)	4.31 (3.60–5.16)	2.90 (2.40–3.49)
WHtR Iranian cutoff point						
Normal	1	1	1	1	1	1
Abnormal	1.10 (1.00–1.21)	1.52 (1.32–1.75)	1.29 (1.12–1.50)	2.20 (1.96–2.48)	2.33 (1.95–2.79)	1.77 (1.47–2.13)
Wrist						
Quartile 1	1	1	1	1	1	1
Quartile 2	1.44 (1.27–1.63)	1.42 (1.25–1.61)	1.31 (1.15–1.49)	1.63 (1.40–1.90)	1.58 (1.34–1.87)	1.36 (1.14–1.62)
Quartile 3	1.88 (1.65–2.15)	1.83 (1.60–2.09)	1.60 (1.40–1.83)	2.30 (1.98–2.68)	2.21 (1.86–2.62)	1.72 (1.44–2.05)
Quartile 4	2.27 (1.99–2.59)	2.16 (1.89–2.47)	1.82 (1.58–2.09)	3.04 (2.62–3.54)	2.71 (2.28–3.21)	1.95 (1.64–2.33)

The crude model is stratified on the status of anthropometric indices. The adjusted model 1 is adjusted for confounding variables age (continuous variable), gender (male/female), education (continuous variable), WSI (continuous variable), cigarette smoking (yes/no), alcohol consumption (yes/no), opium consumption (yes/no), physical activity level (continuous variable), first-degree family history of diabetes (yes/no), and second-degree family history of diabetes (yes/no). The adjusted model 2 is adjusted for confounding variables in adjusted model 1 and hypertension (yes/no), LDL (continuous variable), TG (continuous variable), and HDL (continuous variable). BMI: Body mass index; WC: waist circumference; WHR: waist-to-hip ratio; WHtR: waist-to-height ratio; WSI: wealth score index; T2DM: type 2 diabetes mellitus

regions of insulin receptors; therefore, low muscle mass in this region may be related to the risk of insulin resistance and diabetes.[4,36] Furthermore, another investigation by Manolopoulos *et al*.[37] suggested that the adipose tissue in this area might have a protective role in T2DM risk by trapping the excess serum fatty acids and secreting adiponectin.

On the other hand, some other studies have shown that WHR, WHtR, WC, and BMI have the same values to predict T2DM risk.[15] Similarly, an investigation in Mauritius, demonstrated that WHR, BMI, and WC performed similarly in predicting diabetes risk.[16] Another study in Bangladesh showed that WHtR, WHR, and

Table 3: The association between prediabetes and type 2 diabetes disease with anthropometric indices in age groups of both genders

Anthropometric indices	Adjusted OR (95% CI)							
	Male				Female			
	Prediabetes		T2DM		Prediabetes		T2DM	
	35–50 years old	>50 years old	35–50 years old	>50 years old	35–50 years old	>50 years old	35–50 years old	>50 years old
BMI								
<25	1	1	1	1	1	1	1	1
25–29.99	1.12 (0.91–1.37)	1.47 (1.17–1.85)	2.19 (1.50–3.20)	1.66 (1.27–2.17)	1.21 (0.95–1.55)	1.64 (1.20–2.25)	1.12 (0.75–1.68)	1.54 (1.12–2.12)
30–34.99	1.50 (1.13–1.98)	1.60 (1.13–2.26)	2.51 (1.50–3.20)	2.08 (1.42–3.05)	1.50 (1.16–1.96)	1.98 (1.43–2.74)	1.79 (1.19–2.70)	1.68 (1.21–2.35)
≥35	2.08 (1.20–3.59)	1.62 (0.69–3.79)	4.36 (2.03–9.35)	1.44 (0.57–3.66)	1.89 (1.33–2.67)	2.42 (1.56–3.75)	2.33 (1.43–3.79)	2.41 (1.56–3.74)
BMI continues	1.05 (1.02–1.07)	1.07 (1.04–1.10)	1.10 (1.06–1.14)	1.09 (1.06–1.13)	1.05 (1.03–1.07)	1.07 (1.04–1.09)	1.07 (1.05–1.10)	1.06 (1.04–1.09)
WC ATP III								
Normal	1	1	1	1	1	1	1	1
Abnormal	1.51 (1.18–1.93)	1.21 (0.91–1.61)	2.46 (1.73–3.50)	1.34 (0.98–1.82)	1.43 (1.13–1.82)	1.87 (1.32–2.64)	1.39 (0.94–2.06)	2.10 (1.44–3.05)
WC Iranian IDF								
Normal	1	1	1	1	1	1	1	1
Abnormal	1.41 (1.16–1.70)	1.19 (0.95–1.47)	1.87 (1.36–2.55)	1.57 (1.23–2.01)	1.37 (1.14–1.65)	1.56 (1.24–1.97)	1.79 (1.35–2.38)	1.71 (1.35–2.18)
WC IDF								
Normal	1	1	1	1	1	1	1	1
Abnormal	1.25 (1.04–1.52)	1.23 (0.99–1.52)	1.65 (1.21–2.25)	1.76 (1.38–2.25)	1.52 (0.95–2.43)	1.54 (0.75–3.20)	2.20 (0.86–5.62)	1.83 (0.80–4.18)
WC Iranian cutoff point								
Normal	1	1	1	1	1	1	1	1
Abnormal	1.57 (1.28–1.92)	1.20 (0.95–1.52)	2.31 (1.69–3.17)	1.61 (1.25–2.08)	1.54 (1.11–2.14)	1.77 (1.10–2.83)	1.69 (0.95–3.03)	2.57 (1.48–4.46)
WHR								
Quartile 1	1	1	1	1	1	1	1	1
Quartile 2	1.28 (1.01–1.63)	1.23 (0.91–1.66)	1.68 (1.06–2.66)	2.08 (1.38–3.13)	1.01 (0.81–1.26)	1.16 (0.83–1.62)	1.73 (1.18–2.51)	1.37 (0.94–1.99)
Quartile 3	1.29 (1.01–1.67)	1.44 (1.06–1.94)	1.90 (1.18–3.05)	2.94 (1.98–4.36)	1.04 (0.815–1.32)	1.21 (0.87–1.68)	2.28 (1.55–3.34)	1.75 (1.22–2.51)
Quartile 4	1.50 (1.13–2.00)	1.85 (1.37–2.51)	2.78 (1.73–4.47)	4.34 (2.93–6.42)	1.14 (0.86–1.51)	1.48 (1.06–2.07)	3.78 (2.54–5.64)	2.55 (1.77–3.65)
WHR Iranian cutoff point								
Normal	1	1	1	1	1	1	1	1
Abnormal	1.43 (1.12–1.81)	1.50 (1.12–2.00)	2.40 (1.44–4.00)	3.38 (2.18–5.22)	2.17 (0.63–7.43)	0.43 (0.04–4.21)	N	N
WHtR								
Quartile 1	1	1	1	1	1	1	1	1
Quartile 2	1.16 (0.91–1.49)	1.64 (1.21–2.22)	1.89 (1.17–3.06)	2.03 (1.40–2.97)	1.05 (0.82–1.31)	1.76 (1.27–2.45)	1.52 (1.04–2.22)	1.77 (1.25–2.52)
Quartile 3	1.14 (0.87–1.48)	1.77 (1.32–2.39)	1.68 (1.02–2.77)	2.37 (1.65–3.40)	1.40 (1.11–1.78)	1.56 (1.12–2.16)	1.80 (1.23–2.65)	1.47 (1.05–2.07)
Quartile 4	1.56 (1.18–2.06)	2.01 (1.48–2.72)	3.34 (2.05–5.45)	3.05 (2.12–4.40)	1.42 (1.08–1.87)	2.13 (1.53–2.96)	2.90 (1.96–4.29)	2.66 (1.88–2.52)
WHtR Iranian cutoff point								
Normal	1	1	1	1	1	1	1	1
Abnormal	1.38 (1.12–1.69)	1.20 (0.96–1.50)	2.07 (1.51–2.83)	1.66 (1.29–2.12)	1.34 (0.74–2.43)	1.88 (0.63–5.58)	6.26 (0.84–46.56)	1.36 (0.44–4.25)

Contd...

Table 3: Contd...

Anthropometric indices	Adjusted OR (95% CI)							
	Male				Female			
	Prediabetes		T2DM		Prediabetes		T2DM	
	35–50 years old	>50 years old	35–50 years old	>50 years old	35–50 years old	>50 years old	35–50 years old	>50 years old
Wrist								
Quartile 1	1	1	1	1	1	1	1	1
Quartile 2	0.99 (0.77–1.27)	1.83 (1.38–2.43)	1.23 (0.76–1.97)	1.48 (1.06–2.06)	1.32 (1.03–1.67)	1.24 (0.92–1.68)	1.26 (0.86–1.83)	1.45 (1.06–1.98)
Quartile 3	1.40 (1.09–1.81)	1.76 (1.31–2.36)	2.14 (1.36–3.37)	1.62 (1.16–2.26)	1.49 (1.16–1.92)	1.79 (1.30–2.46)	1.23 (0.83–1.82)	2.03 (1.46–2.81)
Quartile 4	1.44 (1.11–1.87)	1.82 (1.35–2.45)	2.21 (1.40–3.49)	1.61 (1.15–2.27)	1.97 (1.52–2.56)	1.99 (1.45–2.73)	2.05 (1.41–3.00)	1.98 (1.43–2.75)

The adjusted model is adjusted for confounding variables age (continuous variable), gender (male/female), education (continuous variable), WSI (continuous variable), cigarette smoking (yes/no), alcohol consumption (yes/no), opium consumption (yes/no), physical activity level (continuous variable), first-degree family history of diabetes (yes/no), second-degree family history of diabetes (yes/no), Hypertension (yes/no), LDL (continuous variable), TG (continuous variable), and HDL (continuous variable). BMI: Body mass index; WC: waist circumference; WHR: waist-to-hip ratio; WHtR: waist-to-height ratio; WSI: wealth score index; T2DM: type 2 diabetes mellitus

WC have the same predictive abilities in women.[38] The possible explanation for the difference in the results of the studies can be due to the difference in race, age, and gender. Another possible reason can be the difference in the study design or different methods.[18]

We also found that all anthropometric indices were positively associated with the presence of prediabetes. BMI showed the strongest association with prediabetic state among others; however, this finding was consistent with the results of the Jinchang Cohort Study,[34] while some other studies have shown the superiority of abdominal obesity indicators.[39,40] It should also be mentioned that some prediabetic participants may have received positive suggestions on weight loss and lifestyle changes, which could have affected the results, so more research is required on this issue.[40] Furthermore, wrist circumference was shown to be associated with T2DM risk and prediabetic state in our results. Similarly, it was shown by some other studies that wrist circumference is associated with T2DM among men and women[4,41]

The main strength of our study is the large sample size and detailed information about variable anthropometric indicators. However, there were some limitations in the present investigation. First, the present study is a cross-sectional study, and therefore, the causal relationship cannot be determined in this investigation. Second, each of the anthropometric indicators was measured only once in this cross-sectional study for each participant, and these indicators, which were our independent variables, may change over time due to the disease process. Third, it is possible that the results were influenced by treatments that were not adjusted, such as oral antidiabetic drugs and corticosteroids, or medical recommendations for weight loss.

Conclusion

In summary, the findings of our study showed that all anthropometric indices were associated with T2DM odds. Among these indices, WHR had the highest correlation with diabetes. In addition, WHtR also had a higher association with T2DM than BMI as an indicator of general obesity, and WC had the weakest association among them.

Ethics approval and consent to participate

The Ethics Committee of Rafsanjan University of Medical Sciences approved this study (Code of Ethics: IR.RUMS.REC.1400.055). Written informed consent was obtained from the participants. The data of participants were kept confidential and were only accessible to the study investigators. All methods were performed by the relevant guidelines and regulations.

Consent for publication

Not applicable.

Availability of data and materials

The datasets used during the current study are available on the Persian Adult Cohort Study Center, Rafsanjan University of Medical Sciences, Iran. The data are not available publicly. However, upon a reasonable request, the data can be obtained from the corresponding author.

Authors' contributions

FA and AV designed the study and supervised the project. FR and SMP collected the data. FA prepared Tables 1, 2, 3. PK and ZK performed the statistical analysis. FA, ZJ, PK, MK, and AV wrote the main manuscript text. AV revised the paper. All the authors have read and approved the final manuscript.

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Conflicts of interest

There are no conflicts of interest.

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