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Stronger associations of waist circumference and waist-to-height ratio with diabetes than BMI in Chinese adults

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ABSTRACT

Aims: To compare the magnitude of associations of the obesity indicators with the risk of prediabetes and diabetes.

Methods: We performed an individually region-, sex-, and age-matched case and control analysis involving 42 918 Chinese adults aged 20–88 years (6876 matched prediabetes and normal glucose regulation [NGR] groups and 2873 matched newly diagnosed diabetes mellitus [NDM] and NGR groups).

Results: Compared with their respective NGR controls, the participants with prediabetes or NDM had significantly higher mean levels of obesity indices as follows: waist circumference (cm), 85.3 vs. 81.8 and 87.9 vs. 82.9; waist-to-height ratio (WHtR), 0.531 vs. 0.509 and 0.546 vs. 0.514; and body mass index (BMI) (kg/m^2), 25.4 vs. 24.1 and 25.9 vs. 24.2 (all $P < 0.001$). The odds ratios (95% confidence intervals) of NDM with waist circumference, WHtR, and BMI per standard deviation (SD) increase were 1.88 (1.80–1.97), 1.88 (1.80–1.97), and 1.69 (1.62–1.76) in the total population.

Conclusions: Mean differences in the three obesity indices were around 0.3 SD between matched prediabetes cases and NGR controls, and around 0.5 SD between matched NDM cases and NGR controls. Waist circumference and WHtR were more strongly associated with diabetes than BMI among Chinese adults.

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1. Introduction

The prevalence of diabetes is rapidly increasing worldwide [1], and obesity is one of the underlying risk factors for type 2 diabetes [2,3]. As the most practical indicators for identifying obesity, waist circumference, waist-to-height ratio (WHtR), and body mass index (BMI) have been demonstrated as valid predictors of incident diabetes mellitus (DM) [4–6]. However, in view of significant differences in obesity characteristics, glycemic metabolism, and significant heterogeneities in the impact of obesity on the development of diabetes among different ethnicities [7–10], it is of practical value to investigate which indicators are more strongly associated with the risk of DM in the Chinese population. Additionally, differences in these anthropometric indicators between participants with prediabetes or newly diagnosed diabetes mellitus (NDM) and their controls with normal glucose regulation (NGR) have not yet been investigated at a population level. Addressing these issues will significantly help in developing diabetes intervention strategies for Chinese adults.

A matched case and control analysis may increase the validity of comparisons between cases and controls due to comparable matching factors [11]. Additionally, because selecting a fixed number of controls to match cases tends to result in systematic biases, a 1:1-M matched analysis is a better alternative. Moreover, the statistical analysis for a 1:1-M matched analysis is as easy as that for an unmatched analysis or matched analysis with a fixed number of controls per case [12].

Using the China National Diabetes and Metabolic Disorders Study dataset [9], we designed a national population-based matched case and control analysis to investigate the differences in waist circumference, WHtR, and BMI between participants with prediabetes or NDM and their matched NGR controls. We also compared the magnitude of associations of these obesity indicators with the risk of prediabetes and diabetes with the same increase in standard deviation (SD).

2. Materials and methods

2.1. *Study design and population*

This analysis was based on the China National Diabetes and Metabolic Disorders Study dataset, a 2007–2008 representative prevalence survey of diabetes in Chinese adults involving a multi-stage sampling process [9]. This survey took geographic region, population size, and economic status into consideration and involved 14 provincial centers (11 provinces, 2 municipalities, and 1 autonomous region) [9]. The study procedure was as previously described [9].

The study population was selected from 46 239 participants aged ≥20 years with complete fasting plasma glucose (FPG) and 2-hour plasma glucose (2-h PG) data [9]. First, 43 915 adults with waist circumference, WHtR, and BMI between the 0.05 and 99.95 percentiles (54.0 cm ≤ waist circumference ≤ 126.0 cm, 0.34 ≤ WHtR ≤ 0.78, and 14.7 kg/m^2 ≤ BMI ≤ 41.7 kg/m^2), and without any previous diagnosis of diabetes were selected for matching. Second, a 1:1-M matched case and control (varied numbers of controls) design was constructed, where those with NGR (N = 34 088) were matched to those with prediabetes (N = 6939) or NDM (N = 2888) based on region (provincial center, urban/rural), sex, and age (± 2 years, in the same age group). Finally, we selected 42 918 participants (men: 17 000, women: 25 918) aged 20–88 years [mean age: 44.7 years (men), 44.7 years (women); 6876 (1:1–106) matched prediabetes and NGR groups and 2873 (1:1–113) matched NDM and NGR groups] (Fig. 1). The 1-M matching program was conducted using Structured Query Scripting Language in Microsoft SQL Server 2005 (Appendix A).

A detailed description of the collection of demographic information and laboratory testing of blood samples (plasma glucose and lipid levels) has been previously reported [9]. The participants were classified as current smokers or non-current smokers, current drinkers or non-current drinkers, those having regular leisure-time physical activity or those not having regular leisure-time physical activity, those with less than a high school education, those with a high school education, or those with a college or higher level education, those with family history of disease in their first-degree relatives or those without family history of disease in their first-degree relatives, and northern or southern Chinese populations. Current smokers were those who had smoked ≥ 1 cigarette/day for at least 1 year. Current drinkers were those who had consumed ≥ 30 g of alcohol/week on average for at least 1 year. Participants were considered to engage in regular leisure-time physical activity if they engaged in moderate or vigorous activity for 30 min or more per day at least 3 days a week. Participants were classified as part of the northern or southern Chinese population based on where they resided for at least 5 years before the survey (northern Chinese: Beijing, Liaoning, Shanxi, Shaanxi, Xinjiang, Shandong, Henan, and Heilongjiang; southern Chinese: Shanghai, Guangdong, Sichuan, Jiangsu, Fujian, and Hunan). Blood pressure, body weight, and height were measured according to a standard protocol [13]. Height and weight were measured in standing position while the participants were barefoot and in light clothing using the Height & Weight Scale to the nearest 0.1 cm and 0.1 kg, respectively. Waist circumference was measured at the horizontal plane between the inferior costal margin and the iliac crest on the mid-axillary line. BMI and WHtR were respectively calculated as weight divided by height squared and waist circumference divided by height.

The study program was reviewed and approved by the Clinical Research Ethics Committee of the China-Japan Friendship Hospital (No. 2007–026). Written informed consent was obtained from each participant before data collection.

2.2. *Study-outcome definitions*

Prediabetes, i.e. impaired glucose regulation, was defined as FPG ≥ 6.1 mmol/L and < 7.0 mmol/L, or 2-h PG ≥ 7.8 mmol/L and < 11.1 mmol/L but with no previous diagnosis of diabetes; NDM was FPG ≥ 7.0 mmol/L or 2-h PG ≥ 11.1 mmol/L but with no previous diagnosis of diabetes. NGR was defined as FPG < 6.1 mmol/L and 2-h PG < 7.8 mmol/L but with no previous diagnosis of diabetes [14].

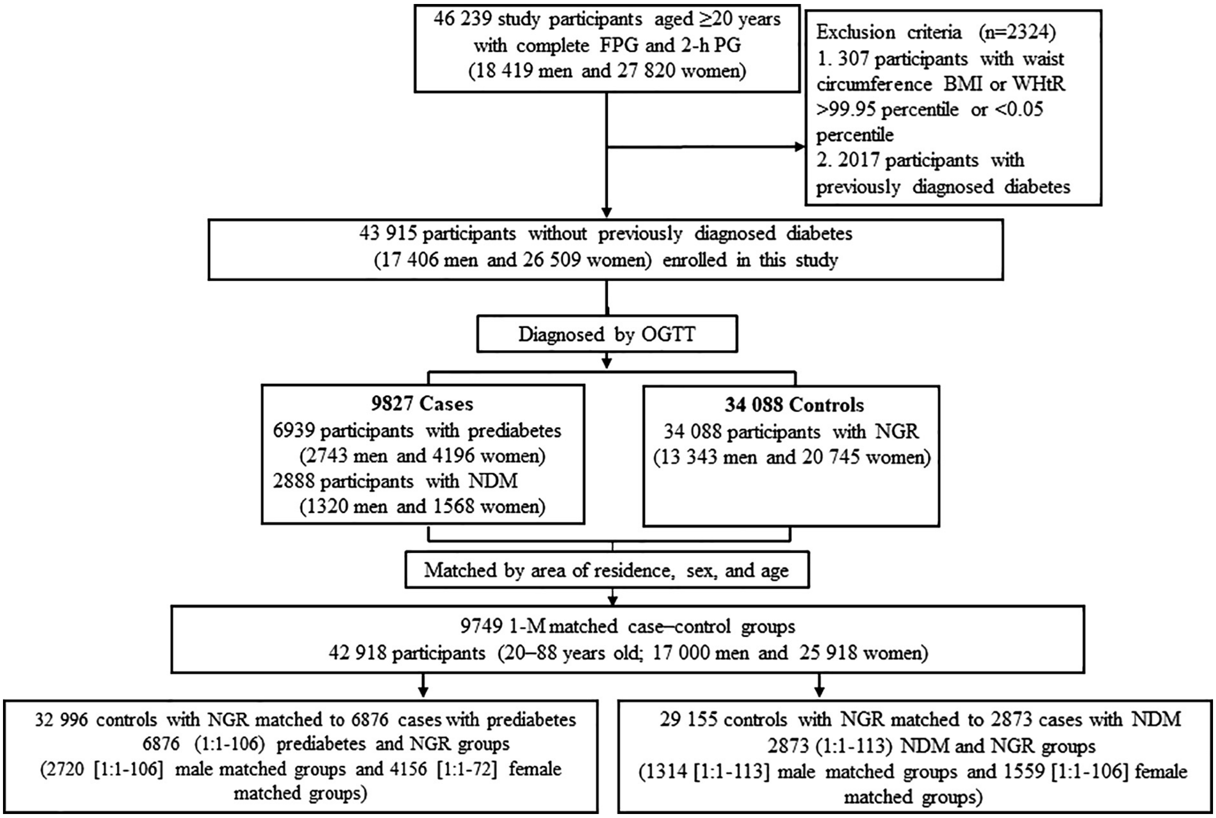

Fig. 1 – Flow chart of selection of matched case and control groups. 2-h PG = 2-hour plasma glucose. FPG = fasting plasma glucose. NDM = newly-diagnosed diabetes mellitus. NGR = normal glucose regulation.

2.3. *Statistical analysis*

Means (95% confidence intervals, CIs) for continuous variables were reported. As ≥ 1 controls were matched to one case, the mean values of continuous variables for the controls in each stratum was calculated by the AVG function of Structured Query Language Script. The means (95% CIs) were then calculated for the control and case groups respectively, and the differences in means between matched cases and controls were tested using the paired *t*-test. Categorical variables were presented as frequencies (percentages).

Conditional logistic regression was used to evaluate the associations of waist circumference, WHtR, and BMI (as standardized variables) with the risk of prediabetes or NDM [12]. The dependent variables were prediabetes or NDM. Two models were constructed according to the independent variables entered. In Model 1, the independent variable was each one of the anthropometric indices without adjustment variables (a); in Model 2, the independent variables were each one of the anthropometric indices and the following adjustment variables, which included smoking status, alcohol consumption status, physical activity, education levels, and family history of diabetes (b). In addition, conditional logistic regression was conducted to assess the risk of prediabetes or NDM on different categories of waist circumference and height, and the odds ratio (OR) and 95% CI were then determined.

The statistical analyses were performed using Stata/SE (version 13.1, StataCorp LP, College Station, Texas, USA). $P < 0.05$ for a two-sided test was statistically significant.

3. Results

3.1. *Comparisons of demographic and clinical characteristics*

Table 1 presented the demographic and clinical characteristics of the study participants with prediabetes or NDM and their NGR controls. Participants of both sexes with prediabetes or NDM and their controls were of comparable age. For both sexes, the participants with prediabetes or NDM had significantly higher FPG, 2-h PG, total cholesterol, triglyceride, low-density lipoprotein cholesterol, systolic blood pressure, and diastolic blood pressure than their NGR controls (all $P < 0.001$).

3.2. *Comparisons of waist circumference, WHtR, and BMI*

Compared with their respective NGR controls, the participants with prediabetes or NDM had significantly larger obesity indices, and their corresponding mean differences (SD) are as follows: waist circumference (cm), 3.5 (0.33SD) and 5.0 (0.47SD); WHtR, 0.023 (0.36SD) and 0.032 (0.50SD); and BMI (kg/m^2), 1.3 (0.36SD) and 1.7 (0.47SD) (all $P < 0.001$) (Table 2).

Table 1 – Characteristics of prediabetes or NDM cases and their NGR controls.

Characteristics	Mean (95% CI)		*P* value	Mean (95% CI)		*P* value
	NGR	Prediabetes		NGR	NDM	
Men	2720 matched groups			1314 matched groups		
N	12 849	2720		11 531	1314	
Age (years)	49.3(48.8–49.8)	49.4(48.9–49.9)	<0.001	51.3(50.6–52)	51.4(50.7–52.1)	<0.001
SBP (mmHg)	125.8(125.3–126.3)	130.1(129.4–130.8)	<0.001	127.0(126.4–127.6)	133.9(132.8–135.0)	<0.001
DBP (mmHg)	80.7(80.4–81.0)	83.2(82.7–83.6)	<0.001	81.3(81.0–81.7)	84.9(84.3–85.5)	<0.001
FPG (mg/dL)	90.6(90.5–91.0)	102.4(101.8–102.9)	<0.001	90.6(90.5–91.0)	139.1(136.8–141.5)	<0.001
2-h PG (mg/dL)	101.5(100.9–102.0)	148.5(147.4–149.6)	<0.001	102.0(101.5–102.7)	244.5(240.0–249.0)	<0.001
TC (mg/dL)	183.3(182.5–184.1)	191.4(189.9–192.6)	<0.001	184.5(183.7–185.6)	197.6(195.7–199.9)	<0.001
TG (mg/dL)	144.3(141.7–146.1)	179.7(174.4–184.2)	<0.001	145.2(142.6–147.9)	198.3(190.4–206.3)	<0.001
HDL-C (mg/dL)	49.9(49.5–50.3)	49.1(48.3–49.5)	0.008	49.9(49.5–50.3)	49.1(48.7–49.9)	0.171
LDL-C (mg/dL)	108.3(107.5–109.4)	112.9(111.8–114.5)	<0.001	110.2(109.0–111.4)	116.8(114.5–119.1)	<0.001
Women	4156 matched groups			1559 matched groups		
N	20 147	4156		17 624	1559	
Age (years)	49.6(49.3–50.0)	49.7(49.4–50.1)	<0.001	53.1(52.5–53.7)	53.3(52.7–53.9)	<0.001
SBP (mmHg)	122.3(121.9–122.8)	128.2(127.5–128.8)	<0.001	124.7(124.1–125.3)	133.1(132–134.1)	<0.001
DBP (mmHg)	77.5(77.3–77.7)	80.0(79.7–80.4)	<0.001	78.2(77.9–78.5)	81.8(81.2–82.3)	<0.001
FPG (mg/dL)	90.3(90.1–90.5)	101.3(100.7–101.6)	<0.001	90.5(90.1–90.6)	140.2(137.9–142.7)	<0.001
2-h PG (mg/dL)	105.8(105.4–106.1)	151.4(150.6–152.1)	<0.001	106.7(106.1–107.0)	252.1(247.4–256.8)	<0.001
TC (mg/dL)	187.2(186.4–187.9)	194.5(193.4–195.7)	<0.001	191.0(189.9–192.2)	201.5(199.5–203.4)	<0.001
TG (mg/dL)	125.7(124.0–127.5)	155.8(153.2–159.4)	<0.001	129.3(127.5–131.0)	178.0(172.7–184.2)	<0.001
HDL-C (mg/dL)	54.1(54.1–54.5)	52.2(51.8–52.6)	<0.001	54.5(54.1–54.9)	52.2(51.4–52.6)	<0.001
LDL-C (mg/dL)	109.8(109.0–110.6)	115.2(114.1–116.4)	<0.001	112.1(111.0–112.9)	117.2(115.2–119.5)	<0.001

Abbreviations: 2-h PG = 2-hour plasma glucose. DBP = diastolic blood pressure. FPG = fasting plasma glucose. HDL-C = high-density lipoprotein cholesterol. LDL-C = low-density lipoprotein cholesterol. NDM = newly diagnosed diabetes mellitus. NGR = normal glucose regulation. SBP = systolic blood pressure. TC = total cholesterol. TG = triglycerides.
Data are presented as means (95% CIs) or frequencies; *P* value from paired *t*-test for mean difference.

Meanwhile, the mean differences in waist circumference and BMI between participants with NDM and their NGR controls were largest at younger ages and decreased with age in both genders, and were larger in the southern population than in the northern population. Comparison of waist circumference, WHtR, and BMI in each center was presented in Table S1. Among the participants of each center, except for Shanxi, the participants with prediabetes or NDM had significantly larger obesity indices than their respective NGR controls. The mean differences in the obesity indices between participants with NDM and their NGR controls were larger than those between participants with prediabetes and their NGR controls, except for the two centers of Shanxi and Sichuan.

3.3. *Associations of anthropometric indicators with prediabetes or NDM*

Among the total population, waist circumference or WHtR was more strongly associated with NDM risk than BMI per SD increase, with the multivariable-adjusted ORs (95% CIs) of NDM being 1.87 (1.79–1.97) for waist circumference, 1.88 (1.80–1.97) for WHtR, and 1.67 (1.60–1.74) for BMI in Model 2 (Fig. 2b). Similar trends were also observed in each center (except for Hunan), in men, in women, and in each age group (Figs. S1 and 2b). However, there were no significant differences in the associations of each SD increase in waist circumference, WHtR, and BMI with the risk of prediabetes; the corresponding adjusted ORs (95% CIs) were 1.56 (1.51–1.61), 1.58 (1.53–1.63), and 1.49 (1.45–1.54) in Model 2 (Fig. 2b). We also presented the associations of anthropometric indicators with NDM according to different centers in Fig. S1.

3.4. *Risk of prediabetes or NDM on different categories of waist circumference and height*

The risk of prediabetes or NDM was positively associated with waist circumference among participants with different levels of height, but was inversely associated with height among those with different levels of waist circumference. For a given quartile of height, the adjusted ORs of prediabetes and NDM significantly increased to 3.2–3.8 times and 4.5–6.1 times, respectively, when waist circumference increased from the lower quartile to the upper quartile; on the other hand, for a given quartile of waist circumference, the adjusted ORs of prediabetes and NDM decreased by 25–40% and 26–47%, respectively, when height increased from the lower quartile to the upper quartile (Fig. 3, Table S3).

3.5. *Unmatched analysis found online*

Using the same dataset, a total of 43 915 adults with waist circumference, WHtR, and BMI from the 0.05 to 99.95 percentile, and without any previous diagnosis of diabetes were selected to conduct an unmatched analysis. First, we investigated the characteristics of the study participants with prediabetes, NDM, or NGR (Table S4), and the levels of the three anthropometric indicators among the participants with prediabetes,

Table 2 – Waist circumference, WHtR, and BMI in prediabetes or NDM cases and their controls.

Population	Matched groups	Mean (95% CI)			Matched groups	Mean (95% CI)		
		NGR	Prediabetes	Difference[a]		NGR	NDM	Difference[a]
Waist circumference (cm)								
Overall	6876	81.8(81.7–82.0)	85.3(85.1–85.6)	3.5(3.2–3.7)[b]	2873	82.9(82.7–83.1)	87.9(87.5–88.3)	5.0(4.6–5.4)[b]
Men	2720	84.8(84.5–85.0)	88.4(88.1–88.8)	3.6(3.2–4.1)[b]	1314	85.4(85.1–85.6)	90.6(90.0–91.1)	5.2(4.6–5.8)[b]
Women	4156	79.9(79.7–80.1)	83.3(83.0–83.6)	3.4(3.0–3.7)[b]	1559	80.8(80.5–81.1)	85.6(85.1–86.1)	4.8(4.4–5.3)[b]
Men								
20–39 years	692	83.1(82.7–83.5)	88.6(87.8–89.4)	5.5(4.6–6.3)[b]	242	83.6(83.0–84.2)	90.7(89.3–92.0)	7.0(5.6–8.4)[b]
40–59 years	1341	85.7(85.4–86.1)	88.9(88.3–89.4)	3.1(2.5–3.7)[b]	698	86.0(85.6–86.4)	91.3(90.5–92.0)	5.3(4.5–6.0)[b]
60–88 years	687	84.7(84.1–85.3)	87.5(86.7–88.2)	2.8(2.0–3.6)[b]	374	85.3(84.6–85.9)	89.3(88.3–90.3)	4.0(2.9–5.1)[b]
Women								
20–39 years	910	75.1(74.8–75.4)	79.0(78.3–79.6)	3.9(3.2–4.5)[b]	211	75.0(74.6–75.4)	81.0(79.6–82.5)	6.0(4.6–7.4)[b]
40–59 years	2309	80.5(80.2–80.7)	83.8(83.5–84.2)	3.4(3.0–3.8)[b]	853	80.7(80.4–81.0)	85.6(85.0–86.2)	4.9(4.3–5.5)[b]
60–88 years	937	83.3(82.8–83.7)	86.1(85.5–86.7)	2.8(2.1–3.6)[b]	495	83.4(82.9–83.9)	87.6(86.7–88.5)	4.2(3.3–5.1)[b]
Region								
Northern	4529	83.2(83.0–83.4)	86.6(86.3–86.9)	3.3(3.0–3.7)[b]	1861	84.3(84.0–84.5)	89.0(88.5–89.5)	4.7(4.3–5.2)[b]
Southern	2347	79.2(79.0–79.5)	82.9(82.5–83.3)	3.7(3.3–4.2)[b]	1012	80.3(80.0–80.6)	85.8(85.2–86.4)	5.5(4.9–6.1)[b]
WHtR								
Overall	6876	0.509(0.508–0.510)	0.531(0.530–0.533)	0.023(0.021–0.024)[b]	2873	0.514(0.512–0.515)	0.546(0.543–0.548)	0.032(0.030–0.034)[b]
Men	2720	0.507(0.505–0.508)	0.529(0.527–0.532)	0.023(0.020–0.025)[b]	1314	0.510(0.508–0.512)	0.541(0.538–0.544)	0.031(0.028–0.034)[b]
Women	4156	0.510(0.509–0.512)	0.533(0.531–0.535)	0.023(0.021–0.025)[b]	1559	0.517(0.515–0.519)	0.550(0.547–0.553)	0.033(0.030–0.036)[b]
Men								
20–39 years	692	0.490(0.488–0.493)	0.524(0.520–0.529)	0.034(0.029–0.039)[b]	242	0.493(0.490–0.497)	0.535(0.527–0.542)	0.041(0.033–0.049)[b]
40–59 years	1341	0.512(0.510–0.513)	0.531(0.528–0.534)	0.019(0.016–0.023)[b]	698	0.512(0.510–0.514)	0.543(0.539–0.548)	0.031(0.027–0.035)[b]
60–88 years	687	0.514(0.510–0.517)	0.532(0.528–0.536)	0.018(0.013–0.023)[b]	374	0.516(0.512–0.520)	0.540(0.534–0.546)	0.024(0.018–0.031)[b]
Women								
20–39 years	910	0.474(0.472–0.476)	0.500(0.496–0.504)	0.026(0.022–0.030)[b]	211	0.474(0.471–0.477)	0.514(0.505–0.523)	0.040(0.031–0.049)[b]
40–59 years	2309	0.512(0.510–0.514)	0.535(0.532–0.537)	0.023(0.020–0.025)[b]	853	0.513(0.511–0.515)	0.547(0.543–0.551)	0.033(0.029–0.037)[b]
60–88 years	937	0.540(0.537–0.543)	0.560(0.556–0.564)	0.019(0.014–0.024)[b]	495	0.541(0.538–0.545)	0.571(0.565–0.576)	0.029(0.023–0.036)[b]
Region								
Northern	4529	0.515(0.514–0.516)	0.537(0.535–0.539)	0.022(0.020–0.024)[b]	1861	0.520(0.519–0.522)	0.550(0.547–0.553)	0.030(0.027–0.033)[b]
Southern	2347	0.496(0.495–0.498)	0.521(0.518–0.523)	0.024(0.022–0.027)[b]	1012	0.501(0.499–0.503)	0.538(0.534–0.541)	0.036(0.033–0.040)[b]
BMI (kg/m^2)								
Overall	6876	24.1(24.0–24.1)	25.4(25.3–25.4)	1.3(1.2–1.4)[b]	2873	24.2(24.2–24.3)	25.9(25.8–26.1)	1.7(1.5–1.8)[b]
Men	2720	24.3(24.2–24.3)	25.5(25.4–25.7)	1.3(1.1–1.4)[b]	1314	24.4(24.3–24.5)	26.1(25.9–26.3)	1.7(1.5–1.9)[b]
Women	4156	24.0(23.9–24.1)	25.3(25.1–25.4)	1.3(1.1–1.4)[b]	1559	24.1(24.0–24.2)	25.8(25.6–26.0)	1.6(1.5–1.8)[b]
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40–59 years	1341	24.5(24.4–24.6)	25.6(25.5–25.8)	1.1(0.9–1.3)[b]	698	24.6(24.5–24.7)	26.4(26.1–26.6)	1.8(1.5–2.1)[b]
60–88 years	687	23.9(23.7–24.1)	24.8(24.6–25.1)	0.9(0.6–1.2)[b]	374	24.0(23.8–24.2)	25.2(24.9–25.6)	1.2(0.8–1.6)[b]
Women								
20–39 years	910	22.8(22.7–22.9)	24.4(24.1–24.7)	1.6(1.3–1.9)[b]	211	22.8(22.6–23.0)	25.0(24.5–25.6)	2.3(1.7–2.8)[b]
40–59 years	2309	24.3(24.2–24.3)	25.5(25.3–25.6)	1.2(1.1–1.4)[b]	853	24.3(24.2–24.4)	25.9(25.7–26.1)	1.6(1.4–1.9)[b]
60–88 years	937	24.5(24.3–24.7)	25.5(25.3–25.7)	1.0(0.7–1.3)[b]	495	24.4(24.2–24.7)	25.8(25.5–26.2)	1.4(1–1.8)[b]
Region								
Northern	4529	24.5(24.4–24.6)	25.7(25.6–25.8)	1.2(1.1–1.3)[b]	1861	24.6(24.6–24.7)	26.2(26.1–26.4)	1.6(1.4–1.8)[b]
Southern	2347	23.3(23.2–23.4)	24.7(24.5–24.8)	1.4(1.2–1.5)[b]	1012	23.5(23.4–23.6)	25.4(25.1–25.6)	1.9(1.6–2.1)[b]

Abbreviations: BMI = body mass index. NDM = newly diagnosed diabetes mellitus. NGR = normal glucose regulation. WHtR = waist-to-height ratio.
Data are expressed as mean (95% CI).
[a] P value from the paired *t*-test for mean difference.
[b] P value < 0.001.

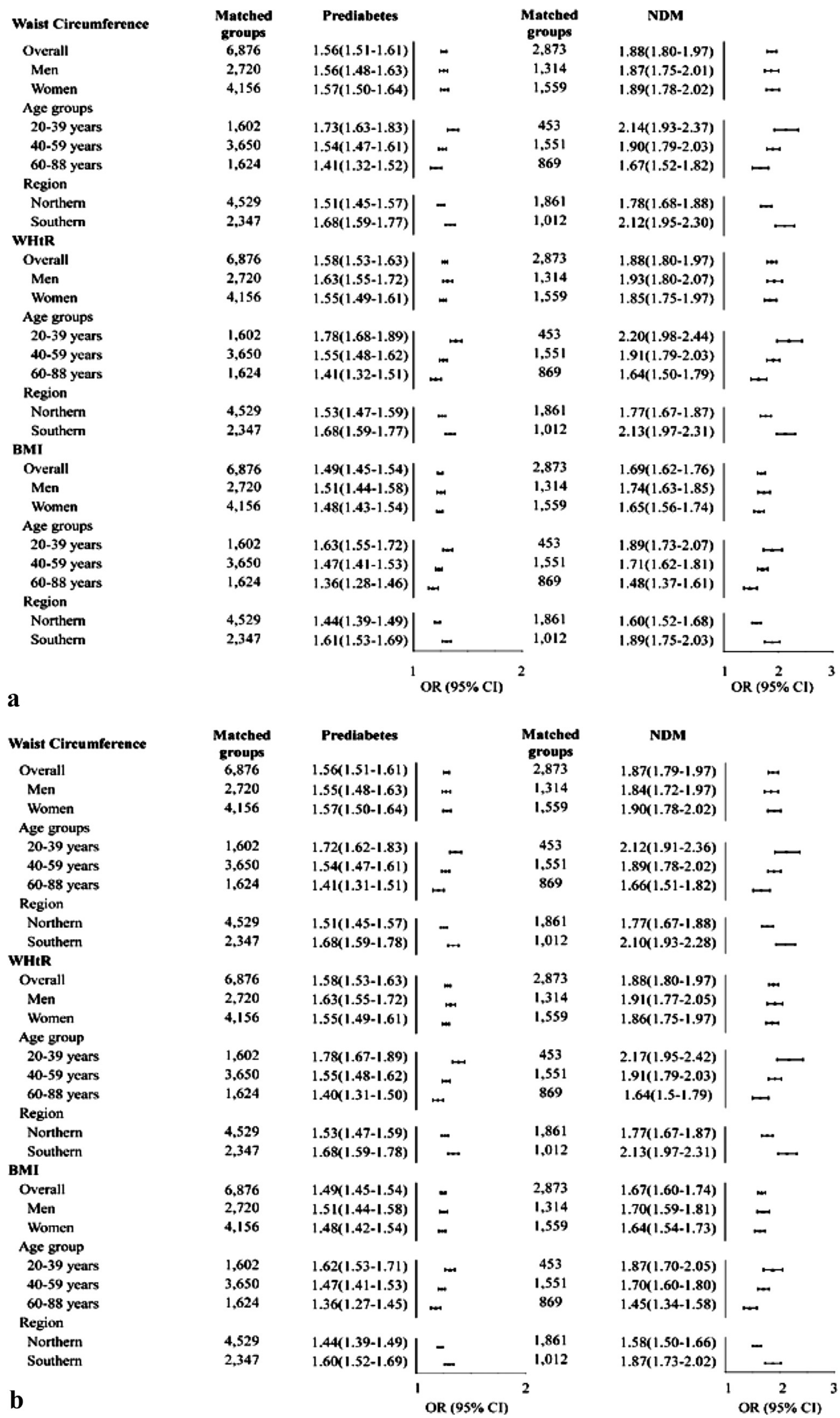

Fig. 2 – Associations of anthropometric indicators with prediabetes or NDM assessed by conditional logistic regression. In Model 1, the independent variable was each one of the anthropometric indices without adjustment variables (a); in Model 2, the independent variables were each one of the anthropometric indices and the following adjustment variables, which included smoking status, alcohol consumption status, physical activity, education levels, and family history of diabetes (b).

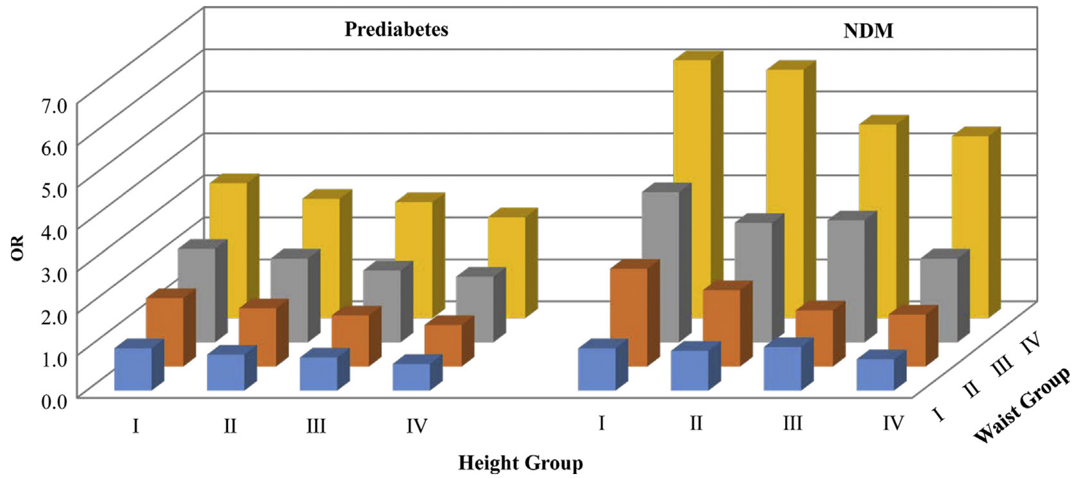

Fig. 3 – Risk of prediabetes or NDM with different combinations of waist circumference and height assessed by conditional logistic regression. We transformed the variables of waist and height into standardized forms and divided them into a 4-level categorical variable by quartile, and then obtained a 16-level categorical variable by combining the two 4-level categorical variables. The dependent variable was prediabetes or NDM. The independent variables were the 16-level categorical variable and the following adjustment variables (smoking status, alcohol consumption status, physical activity, education levels, and family history of diabetes). Abbreviations: NDM = newly diagnosed diabetes mellitus.

NDM, or NGR (Table S5). Second, multinomial logistic regression analysis was conducted to compare the associations of these indicators with prediabetes or NDM under the same increase of SD (Fig. S2).

4. Discussion

This individually matched analysis showed that mean differences in waist circumference, WHtR, and BMI increased from the prediabetes-NGR matched groups to the NDM-NGR matched groups (from 0.3SD to 0.5SD), and that the mean differences were larger in the younger population than in the elderly, and in the southern population than in the northern population. It also revealed that the multivariable-adjusted ORs (95% CIs) of NDM were 1.87 (1.79–1.97) for waist circumference, 1.88 (1.80–1.97) for WHtR, and 1.67 (1.60–1.74) for BMI, indicating that waist circumference and WHtR were associated with around a 20% greater risk of having NDM than BMI with the same SD increase among the total population.

4.1. *Validity of this matched case and control analysis*

To increase the validity of the comparison [11] and maximize utilization of the samples, we constructed a 1: 1-M matched case and control analysis, in which all controls were matched to prediabetes or NDM cases, and the numbers of controls varied across different matching strata [12]. About 99.9% of the study participants, who met the criteria for inclusion, were included in this matched analysis. Main confounders that often mask the real association between obesity and the risk of cardiometabolic diseases are age, gender, and area of residence, which were treated as the matching factors in this study [15]. There were more reasonable and smaller mean differences in the metabolic variables between cases and controls in this matched analysis (in Tables 1 and 2) than those in the unmatched analysis (in Tables S4 and S5) because the main confounding factors were balanced among the comparision groups [11]. Our matched approach was also demonstrated to be valid by comparing the results from two different approaches: the unadjusted ORs (waist circumference: 1.88, WHtR: 1.88, and BMI: 1.69) from the matched analysis were very close to the adjusted ORs (waist circumference: 1.88, WHtR: 1.88, and BMI: 1.71) after adjustment for matched variables (sex, age, and area of residence) from an unmatched analysis despite using different regression analysis methods, and the ORs mentioned above were obviously smaller than the crude ORs (waist circumference: 2.06, WHtR: 2.18, and BMI: 1.82) from the unmatched analysis.

4.2. *Mean differences in the obesity indices between cases and controls*

Note that due to the reduced effect of matching factors, we were able to present more reasonable and smaller mean differences in the obesity variables between cases and controls compared to the other research study [16]. Our findings regarding the mean and mean difference in obesity indices were as follows: (1) the mean differences in the three obesity indices between the matched prediabetes cases and NGR controls were smaller than those of the matched NDM cases and NGR controls in the total population and in subpopulations grouped by sex, age group, and area of residence; (2) the mean differences in waist circumference and BMI were largest at younger ages and decreased with age; (3) while the northern population with NGR, prediabetes, or NDM all had higher average obesity indices (obvious differences in the appearance of the northern and southern populations: the latter is typically smaller and more slender than the former) than their southern counterparts, the mean differences were larger in the southern population than in the northern population;

(4) for the youngest age group, the mean differences in the obesity indices between NDM and matched NGR control were larger in men than in women, while for the elderly, the mean differences were smaller in men than in women. Our findings were consistent with the previous two conclusions, the first being "mean BMI difference was most marked at younger ages and narrowed with advancing age in the English population" [17], and the other being "British elderly women had greater differences in BMI between diabetes and non-diabetes than elderly men of ages 60–79 years" [16].

4.3. *Associations between the obesity indices and diabetes*

Of the main obesity indices, BMI has been used as a measure of general obesity, while waist circumference and WHtR have been used as measures of abdominal obesity. The latter two indices are more strongly correlated with intra-abdominal visceral fat. Visceral adipose tissue is closely associated with insulin resistance and diabetes [2,18]. However, there is still debate about which anthropometric indices of adiposity (waist circumference, WHtR, and BMI) are more strongly associated with diabetes risk [19–23]. Two meta-analyses of prospective studies regarding the association between different adiposity indicators and diabetes risk have drawn different conclusions [4,5]. One meta-analysis showed similar associations of incident diabetes with BMI and waist circumference per SD increase, with pooled relative risks (95% CIs) of 1.87 (1.67–2.10) for BMI and 1.87 (1.58–2.20) for waist circumference [4]. In another recent meta-analysis, Kodama et al. concluded that waist circumference or WHtR was more strongly associated with diabetes risk than BMI overall, in both genders and in white-dominant populations, but not in non-white-dominant populations [5]. Furthermore, they also pointed out that the previous meta-analysis [4] failed to make head-to-head comparisons in the same population, and the method was problematic and would distort the pooled estimate. Consistent with the latter meta-analysis results in the total population [5] and the two Chinese cohort studies conducted in a southern city [24] and a northern city [25] respectively, the present study found that waist circumference and WHtR had significantly stronger associations with NDM than BMI did. Waist circumference and WHtR were associated with around a 20% greater risk of having NDM than BMI with the same one SD increase among the total population.

Although WHtR is usually thought of as superior to waist circumference because it corrects the waist circumference for height of the individual, the effect of height on the association between waist circumference and the risk of diabetes is controversial [26,27]. Our results also showed that the risk of prediabetes or NDM was positively associated with waist circumference but negatively associated with height, while there was no significant superiority of WHtR over waist circumference as an indicator of diabetes risk in the present study. We need to develop a more effective predictive indicator for diabetes risk based on waist circumference and height.

According to the Chinese guidelines, the optimal cutoff of waist circumference for abdominal obesity is 90 cm for men and 85 cm for women in Chinese [28]. Considering that waist circumference and WHtR were more strongly associated with diabetes than BMI, and waist circumference is easier to measure, different cut-offs of waist circumference should be taken into consideration in the intervention of DM development for different subpopulations (people of northern or southern origin, and different age-groups).

4.4. *Study strengths and weaknesses*

This study had the following strengths: (1) the cases and controls were sampled from the general Chinese adult population; (2) using new cases diagnosed by oral glucose tolerance tests somewhat reduced misclassification and reduced the impact of diabetes duration on weight; (3) the matched case and control analysis gave the results more perceived validity and achieved comparable statistical efficacy with a smaller sample size than that of the unmatched analysis. This study also has the following weaknesses: (1) because this matched analysis was conducted after the data had been collected, the limitations of the original study, including oversampling of urban residents, a lower response rate in men than in women, and its cross-sectional property, remained; (2) this matched analysis resulted in the exclusion of some subjects who failed to be matched; (3) the effect of matching factors on outcome could not be analyzed in this matched analysis.

In conclusion, the individually matched case and control analysis revealed that there were increases of around 0.3 SD and around 0.5 SD in the three obesity indices (waist circumferences, WHtR, and BMI) between matched prediabetes cases and NGR controls, and between matched NDM cases and NGR controls. Larger mean differences were seen among the subpopulations at lower risk of diabetes and those with lower levels of obesity indices. Waist circumference and WHtR were more strongly associated with diabetes than BMI among Chinese adults.

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Contributions

XH, GH, and WJ contributed to the study concept and design. XH and SC performed the statistical analyses, interpreted the data, performed literature search, and wrote the manuscript. All authors contributed to discussion, reviewed the manuscript and approved the final version of this manuscript. WJ is the guarantor of this work and, as such, had full access to all the data in the study and takes responsibility for the integrity of the data and the accuracy of the data analysis.

Conflicts of interest

We declare that we have no conflicts of interest.

Appendix A. Supplementary material

Supplementary data associated with this article can be found, in the online version, at https://doi.org/10.1016/j.diabres.2018.07.029.

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