DOI:10.11817/j.issn.1672-7347.2024.240259

Role of waist circumference-to-height ratio in assessing adiposity, predicting type 2 diabetes mellitus and other cardiometabolic diseases

ZHANG Xinyi[1,2], LU Xi[1,2], PAN Xiaohui[1,2], SHEN Sumin[1], TONG Nanwei[1,2]

(1. Department of Endocrinology and Metabolism, West China Hospital of Sichuan University, Chengdu 610041; 2. Center for Diabetes and Metabolism Research, West China Hospital of Sichuan University, Chengdu 610213, China)

ABSTRACT Although body mass index (BMI) is widely used as a simple tool to evaluate obesity, some drawbacks and inaccuracies have been shown. It is known that visceral adipose tissue is more closely related to cardiometabolic risks and all-cause mortality; however, accurate measurement methods of visceral fat (magnetic resonance imaging and computed tomography) cannot be widely used. Therefore, simple but accurate alternatives are valuable. Studies have shown that waist circumference-to-height ratio (WHtR) might be a superior and more accurate variable in assessing central or visceral adiposity as well as predicting risks of diabetes and other cardiometabolic diseases. In addition, it has the same threshold for the overall population irrespective of ethnicity, age and sex. Therefore, because of its advantages, WHtR is worth popularization and application. In this review, we will focus on the evidence on WHtR as a better and simpler anthropometric index comparing with other indices in assessing adiposity, and predicting type 2 diabetes and other cardiometabolic diseases.

KEY WORDS waist circumference-to-height ratio; body mass index; diabetes; cardiometabolic diseases; central adiposity

腰围身高比在评估肥胖、预测2型糖尿病和其他心血管代谢性疾病中的作用

张心怡[1,2]，陆茜[1,2]，潘晓晖[1,2]，沈苏敏[1]，童南伟[1,2]

Date of reception: 2024-04-12

First author: ZHANG Xinyi, Email: zhangxinyi.joy@foxmail.com, ORCID: 0000-0003-0762-1814

Corresponding author: TONG Nanwei, Email: tongnw@scu.edu.cn, ORCID: 0000-0002-5395-3660

Foundation item: This work was supported by the 1·3·5 project for disciplines of excellence, West China Hospital, Sichuan University, China (ZYGD18017).

(1. 四川大学华西医院内分泌代谢科，成都 610041；2. 四川大学华西医院糖尿病与代谢研究室，成都 610213)

[摘 要] 尽管体重指数(body mass index，BMI)作为评估肥胖的简便工具被广泛应用，但其也存在一些缺点和不准确之处。据研究报道，内脏脂肪组织与心血管代谢性疾病风险和全因死亡率的关系更为密切；然而，精准测量内脏脂肪含量的方法(磁共振成像和计算机断层扫描)却无法得到广泛应用。因此，寻找测量内脏脂肪含量的简便替代方法很有必要。研究表明，腰围身高比(waist circumference-to-height ratio，WHtR)可能是评估中心型或内脏脂肪型肥胖以及预测糖尿病和其他心血管代谢性疾病风险的一个更好、更准确的指标。此外，它对不同种族、年龄和性别的群体具有相同的临界值。因此，鉴于其优势，WHtR 值得推广和应用。在本综述中，我们将重点讨论有关WHtR在评估肥胖、预测 2 型糖尿病和其他心血管代谢性疾病中的作用，并且与其他人体测量学指标相比，WHtR具有更准确、更简便的优势。

[关键词] 腰围身高比；体重指数；糖尿病；心血管代谢性疾病；中心型肥胖

.

1 Introduction

Obesity is a chronic disease that refers to the presence of excessive fat mass or abnormal fat accumulation that might have a negative impact on health, reaching a pandemic level and becoming a huge burden worldwide. In the past 40 years, from 1975 to 2016, the global prevalence of obesity and body mass index (BMI)-based diagnosis has increased remarkably, from 3% to 11% in men and from 6% to 15% in women[1]. Obesity can impair body health by increasing the risk of a variety of diseases, including type 2 diabetes (T2D), hypertension, myocardial infarction, fatty liver disease, obstructive sleep apnea, dementia, stroke and several cancers, resulting in decreased quality of life and shortened life expectancy[2].

Although obesity has a negative impact on health, the different areas of excessive fat accumulation play different roles. Previous studies have shown that compared with subcutaneous adipose tissue, such as adipose tissue in the legs and buttocks, altered and ectopic fat distribution such as increased visceral adipose tissue and fat depots in liver and skeletal muscle, is related to higher total and cardiovascular mortality[3-5].

In clinical practice or population-based studies, there are several anthropometric measurements to define overweight and obesity. BMI is the most widely used measure and is calculated as one's weight in kilograms divided by the square of one's height in meters. However, although widely used, BMI is not an ideal estimate of overall adiposity because it cannot differentiate lean mass from fat mass, as well as different types of adipose tissue accumulation, such as visceral and subcutaneous depots. To detect obesity, BMI has a very high specificity (97%) but poor sensitivity (42%) and sometimes misclassifies individuals[6-7]. Other anthropometric indices, such as waist circumference (WC), are also used to detect obesity, especially central obesity, with a cutoff point of ⩾80 cm for women and ⩾94 cm for men in many populations and a cutoff point of ⩾88 cm for women and ⩾102 cm for men in the United States and Canada, according to the clinical practice guidelines given by the American Association of Clinical Endocrinologists (AACE) and the American College of Endocrinology (ACE)[8]. Waist to hip ratio (WHR) is also a simple tool to detect obesity and it also takes central adipose tissue mass into consideration. However, the cutoff points of WHR vary from 0.78–0.91 for women and 0.75–0.91 for men among different studies and different populations[9-11].

Compared with BMI, WC and WHR, waist circumference-to-height ratio (WHtR) is a relatively less popular index and is less frequently used in clinical practice. However, studies have indicated that WHtR is better for assessing obesity, especially central adiposity[2]. In addition, as there is a close relationship between central adiposity and diabetes and other cardiometabolic diseases, WHtR also demonstrates a role in predicting risks of diabetes and other cardiometabolic diseases. Therefore, the aim of this review is to discuss the advantages of using WHtR to assess obesity, as well as its role in predicting the risk of diabetes and other cardiometabolic disease.

2 WHtR

WHtR is an anthropometric measurement that considers both WC and height to detect obesity. This metric is very simple and practical in evaluating obesity, especially central adiposity, and it has the same classification as the overall population, in spite of gender, age or ethnicity[2]. The National Institute for Health and Care Excellence (NICE) of the United Kingdom encourages children more than 5 years old, adolescents and adults with a BMI below 35 kg/m^2 to use this index to assess central adiposity, which indirectly reflects excessive fat accumulation in the abdominal area[2].

To calculate WHtR, WC needs to be measured precisely by measuring the waist midway between the bottom of the ribs and the top of the hips with natural breath[2]. WC and height need to be measured in the same units, and the calculation method of WHtR is to divide WC by height measurement.

3 WHtR and central adiposity

Some previous clinical studies have proven that WHtR is closely related to central adiposity. A cohort study by Staynor et al. [12] used dual energy X-ray absorptiometry (DXA) scans to measure the volume of visceral adipose tissue (VAT) in 677 males and 738 females aged 18-65 years old from Western Australia. Additionally, anthropometry variables, including BMI, WC, WHR and WHtR, were also measured. The results of Pearson's correlations and Spearman's correlations suggested that for both sexes, WHtR (r=0.72 for females, r=0.79 for males) and WC (r=0.69 for females, r=0.80 for males) were more closely correlated with VAT mass than BMI (r=0.67 for females, r=0.66 for males) (all P<0.000 08)[12]. Additionally, although WHR demonstrated a good correlation in males (r=0.74), it had a poor correlation in females (0.46) (all P<0.000 08)[12]. A cross-sectional study with 191 patients by Roriz et al.[13] also demonstrated a close relationship between WHtR and VAT area measured by computed tomography (CT): r=0.79 for 20- to 59-year-old men (P≤0.01), r=0.80 for men over 60 years old (P≤0.01); r=0.73 for 20- to 59-year-old women (P≤0.01) and r=0.64 for women over 60 years old (P≤0.01). (Table 1)

Table 1 Results of Pearson's correlations and Spearman's correlations between anthropometric indices (BMI, WC, WHR and WHtR) and volume of visceral adipose tissue

Year & Author	BMI		WC		WHR		WHtR			
	female	male	female	male	female	male	female		male	
2020 Staynor [12]	r=0.67	r=0.66	r=0.69	r=0.80	r=0.46	r=0.74	r=0.72		r=0.79	
2014 Roriz [13]	/		/		/		female (20~59 years old)	female (≥60 years)	male (20~59 years old)	male (≥60 years)
			r=0.73	r=0.64	r=0.79	r=0.80				

Abbreviations: BMI: body mass index, WC: waist circumference, WHR: waist-to-hip ratio, WHtR: waist circumference-to-height ratio.

Several previous systematic reviews have also indicated that WHtR is more accurate in assessing central adiposity than BMI and other anthropometric indices. For example, a systematic literature review by Correa et al. [14], which included a total of 16 papers, compared the roles of WHtR and other anthropometric indices in assessing obesity and predicting chronic noncommunicable disease. The study demonstrated that five manuscripts (four cross-sectional studies and one prospective study) reported that WHtR was the best anthropometric index to evaluate adiposity and showed the best correlation with the onset of cardiometabolic diseases.

In addition, a newest clinical guideline of obesity identification, assessment and management, released by NICE, also recommended using WHtR to estimate central adiposity in adults, especially those with BMI under 35 kg/m^2, as obesity defined by BMI needs to be interpreted with caution in individuals with a South Asian, Chinese, other Asian, Middle Eastern, Black African or African-Carribbean family background, or those with high muscle mass[2]. In addition, the WHtR is also a very simple and easily understood tool in clinical practice because doctors only need to tell patients to try to keep their WC to half their height (a WHtR under 0.5)[2].

Since WHtR has a better ability in assessing central adiposity than BMI, WHtR may also have a closer capacity in predicting diabetes and other cardiometabolic diseases, because central obesity or visceral obesity has a closer asscociation with cardiometabolic diseases. Subcutaneous adipose tissue (SAT) and VAT has different impacts on the risks of cardiometabolic diseases. Since VAT locates inside the abodomen, it has a close impact on abdominal organs. For example, since VAT is mostly drained by the portal vein, it can increase free fatty acid concentrations in the portal vein, subsequently spilling over excessive free fatty acids to the liver. Free fatty acid influx of the liver can influence gene transcription of a couple of enzymes involved with triglyceride syntehsis, leading to hypertriglyceridemia[15-16]. Excessive VAT can also lead to macrophage infiltration, causing increased secretion of inflammatory cytokines and decreased secretion of adiponection (a protective adipokine). Therefore, the increased inflammation level can have a detrimental effect on metabolic organs in the abdomen[15].

4 WHtR and the risk of T2D

Since obesity has a close relationship with insulin resistance, obese individuals are at a great risk of developing T2D in their lifetime. Therefore, despite assessing adiposity, WHtR also shows an ability to predict T2D. NICE[2] defines people with a WHtR of 0.4 to 0.49 as having healthy central adiposity with no increased health risks, while a WHtR of 0.5 to 0.59 indicates increased central adiposity and elevated health risks, and a WHtR of 0.6 or more indicates high central adiposity and further increased health risks. The health risks include T2D, hypertension and cardiovascular disease.

Although some previous studies have proposed several risk models[17-20] to predict the onset of diabetes in the future, these risk models need to evaluate several indices and complex account, and to some extent, they are not easily available for patients. In addition, although these risk models include obesity as a risk factor for diabetes, most of them use BMI to identify obesity. However, since central adiposity is more closely related to cardiometabolic diseases such as T2D, WHtR may be a better choice than BMI in assessing the risk of T2D occurrence.

Some large clinical trials have demonstrated the role of WHtR in predicting diabetes. A case–control study consisting of 42 918 participants made by Hou et al.[21], which included an individually matched cohort of region, sex and age, found that WC and WHtR were more closely associated with newly diagnosed diabetes mellitus (NDDM) than BMI in Chinese adults aged 20–88 years old. The multivariable-adjusted odds ratio (OR) of NDDM was 1.88 (95% confidence interval [*CI*] 1.80–1.97) for WHtR, 1.87 (95% *CI* 1.79–1.97) for WC and 1.67 (95% *CI* 1.60–1.74) for BMI. A cross-sectional study that included 21 109 participants by Lo et al.[22] illustrated that among BMI, WC and WHtR, WHtR had the best predictive ability for diabetes, with an adjusted OR of 3.16 (95% *CI* 2.53–3.95), while that of WC was 2.27 (95% *CI* 2.05–2.51) and that of BMI (per 5-unit increase) was 1.40 (95% *CI* 1.36–1.45). Furthermore, a national longitudinal cohort study with 10 521 participants by Lu et al.[23] reported that in unadjusted logistic regression models, WHtR (OR: 2.19, 95% *CI* 1.35–3.55) was more closely related to the risk of cardiometabolic multimorbidity (CM) than BMI (*OR*: 1.85, 95% *CI* 1.27–2.68). In addition, the correlation between WHtR and CM risk persisted after multivariate adjustments (*OR*: 1.76, 95% *CI* 1.05–2.97). Additionally, our small sample study, a community-based prospective cohort study of a total of 1 885 residents, also suggested that among BMI, WC, WHR and WHtR, WHtR performed the best in predicting the development of isolated impaired fasting glucose (IFG) or impaired glucose tolerance (IGT), IFG+IGT and NDDM[24].

The diabetes prediction function of WHtR has also been proven by some meta-analyses (Table 2). First, in 2008, a meta-analysis by Lee et al.[25] was conducted to compare which of the four anthropometric indices of overweight and obesity (BMI, WC, WHR, WHtR) discriminate hypertension, T2D and dyslipidemia best. Studies conducted on adults that used receiveroperating characteristic (ROC) curve analysis with the area under the ROC curve (AUC) to compare the discriminatory power were included, and available data for T2D were obtained from nine studies (one longitudinal and eight cross-sectional studies). The results showed that compared with BMI, indices that measured abdominal obesity tended to have higher AUCs in both sexes, with WHtR having the highest pooled AUC (0.73 for males and 0.76 for females) and BMI having the lowest pooled AUC (0.67 for males and 0.69 for females). In 2011, another systematic review and meta-analysis by Ashwell et al. [26] included 20 studies for men and 22 studies for women to compare the role between BMI, WC and WHtR in discriminating diabetes risk. The results illustrated that the pooled AUC for both men and women was highest for WHtR (mean AUC: 0.711 for men and 0.752 for women, 95% *CI* 0.694–0.728 for men and 0.728–0.775 for women) and lowest for BMI (mean AUC: 0.663 for men and 0.699 for women, 95% *CI* 0.639–0.686 for men and 0.668–0.730 for women) and intermediate for WC (mean AUC: 0.669 for men and 0.742 for women, 95% *CI* 0.680–0.718 for men and 0.720–0.765 for women). In addition, a meta-analysis that contained 15 prospective studies by Kodama et al[27] in 2012 aimed to determine the incident diabetes risk prediction power among WHtR, BMI, WC and WHR and the strength of the estimated pooled relative risk. A bivariate random-effects model was used to compare the estimated pooled relative risk ratio for a 1-standard deviation (SD) increase in each indicator (expressed as RRWHR, RRBMI, RRWC, and RRWHR). The results demonstrated that the incremental diabetes risk was 1.62 (95% *CI* 1.48, 1.78) for RRWHtR, 1.55 (95% *CI* 1.43, 1.69) for RRBMI, 1.63 (95% *CI* 1.49, 1.79) for RRWC, and 1.52 (95% *CI* 1.40, 1.66) for RRWHR. Therefore, compared with BMI, WHtR showed modest but statistically great power in the prediction of diabetes. In 2013, Savva et al. [28] conducted a meta-analysis with 19 eligible studies (14 cross-sectional and five prospective studies) aiming to compare the link between BMI and WHtR with cardiometabolic risks by using the estimated pooled relative risk ratio (rRR) (rRR=RRBMI/RRWHtR). The overall rRR clearly indicates that WHtR is superior to BMI in detecting DM (rRR: 0.71, 95% *CI* 0.59–0.84). The association of WHtR with diabetes was also stronger for both Asians (rRR: 0.64, 95% *CI* 0.50–0.83) and non-Asians (rRR: 0.79, 95% *CI* 0.63–0.99). Finally, in 2022, Jayedi et al. [29] conducted the largest systematic review as well as a dose–response meta-analysis of a total of 216 cohort studies with 2.3 million individuals, reporting the correlation between T2D incidence and different anthropometric indices, including BMI, hip circumference, WC, thigh circumference, WHR, WHtR, body adiposity index, body shape index and body fat percentage (BFP). For BMI, a total of 182 cohort studies including 5,585,850 participants were analyzed, showing that each 5-unit increase (one SD) in BMI was associated with a 72% higher risk of type 2 diabetes (RR 1.72, 95% *CI* 1.65 to 1.81, I^2=99%). For WHtR, there were 25 cohort studies with 2, 100, 053 individuals included, and the results revealed that each 0.1-unit increase (one SD) in WHtR was linked with a 73% higher risk of T2D (RR 1.73, 95% *CI* 1.51 to 1.98, I^2=97%). Therefore, WHtR was superior to BMI in predicting the risk of T2D.

Table 2 Systematic reviews and meta analysis which reported the WHtR's roles in predicting diabetes

Year & Author	Number of participants (*n*)	Articles included	Anthropometric indices	Results
2008 Lee et al. [25]	total: 83 957 Chinese 59 971 African ancestry 728 Iranian 10 522 Vietnamese 1 488 Chinese, Malay, Indian 566 Thai 5 305 Japanese 4 557 German 5 377	one longitudinal study eight cross-sectional studies	BMI, WC, WHR, WHtR	AUC: WHtR: male 0.726 (95% *CI* 0.698, 0.754) female 0.756 (95% *CI* 0.700, 0.811) WHR: male 0.721 (95% *CI* 0.664, 0.778) female 0.748 (95% *CI* 0.687, 0.810) WC: male 0.701 (95% *CI* 0.670, 0.732) female 0.744 (95% *CI* 0.695, 0.794) BMI: male 0.672 (95% *CI* 0.646, 0.697) female 0.693 (95% *CI* 0.629, 0.757)

Table 2 (continued)

Year & Author	Number of participants (*n*)	Articles included	Anthropometric indices	Results
2011 Ashwell et al. [26]	total: 197 000 Thai 9 232; Turkish 1,692; Spanish 6 729 Aboriginal 330; Chinese 153 221 Brazilian 968; Chilean 13 054 Korean 7 001; Australian 9 206 Non-Hispanic White, non-Hispanic Black and Mexican Americans: 6 277 Indigenous Australian 1 352; Iraqi 12 986 Iranian 16 091; Italian 1,104 Japanese 2 935; American mixed 45 563 African ancestry 728 Chinese, Malay, Indian: 566 Mainly Caucasian 5 377 Maori and White 1 539	20 cross-sectional studies three prospective studies	BMI, WC, WHtR	AUC: WHtR: male 0.711 (95% *CI* 0.680, 0.728) female 0.752 (95% *CI* 0.728, 0.775) WC: male 0.699 (95% *CI* 0.680, 0.718) female 0.742 (95% *CI* 0.720, 0.765) BMI: male 0.663 (95% *CI* 0.639, 0.686) female 0.699 (95% *CI* 0.668, 0.730)
2012 Kodama et al. [27]	total: 120 102 >50% white 40 168 >50% black 2 164 other 77 770	15 prospective studies	BMI, WC, WHR WHtR	Overall RR for each SD increase: WHtR: 1.62 (95% *CI* 1.48, 1.78) WC: 1.63 (95% *CI* 1.49, 1.79) BMI: 1.55 (95% *CI* 1.43, 1.69) WHR: 1.52 (95% *CI* 1.40, 1.66)
2013 Savva et al. [28]	total: 512 809 Asian 315 299 non-Asian 197 510	14 cross-sectional studies five prospective studies	BMI, WHtR	rRR (RR_{BMI}/RR_{WHtR}): Overall 0.71 (95%CI: 0.59, 0.84) Asians 0.64 (95%CI: 0.50, 0.83) Non-Asians 0.79 (95%CI: 0.63, 0.99)
2022 Jayedi et al. [29]	total: 28,177,748 Australian 23,217; Thai 11,578 Canadian 22,080; American 818,093 Korean 23,084,465; Chinese 2,664,153 Iranian 33,238; Japanese 418,072 British 428,885; Norwegian 102,760 Brazilian 6,025; Spanish 60,135 Swedish 16,788; German 42,252 Danish 122,925; Finish 38,762 Israeli 164,052; Dutch 25,568 Indian 2,995; other 91,705	190 prospective cohorts studies 26 retrospective cohort studies	BMI, WC, WHR,WHtR, BFP	Overall RR for each SD increase: BMI: overall 1.72 (95%CI: 1.65, 1.81) male 1.75 (95%CI: 1.64, 1.86) female 1.69 (95%CI: 1.61, 1.79) WC: overall 1.61 (95%CI: 1.52, 1.70) male 1.68 (95%CI: 1.54, 1.82) female 1.68 (95%CI: 1.56, 1.81) WHR: overall 1.63 (95%CI: 1.50, 1.78) male 1.67 (95%CI: 1.47, 1.90) female 1.71 (95%CI: 1.54, 1.90) WHtR: overall 1.73 (95%CI: 1.51, 1.98) male 1.74 (95%CI: 1.62, 1.90) female 1.72 (95%CI: 1.61, 1.86) BFP: overall 2.05 (95%CI: 1.41, 2.98)

Abbreviations: BMI: body mass index, WC: waist circumference, WHR: waist-to-hip ratio, WHtR: waist circumference-to-height ratio, AUC: area under the receiver operating characteristics curve, CI: confidence interval, RR: relative risk, SD: standard deviation, rRR: relative risk ratio, BFP: body fat percentage.

5 WHtR and the risks of other cardiometabolic diseases

Despite diabetes, obesity patients are also prone to have other other cardiometabolic diseases, including hypertension, dyslipidemia, metabolic syndrome (MS) and cardiovascular disease (CVD). Although previous studies have suggested roles of different anthropometric indices (BMI, WC and WHR) in predicting future risks of other cardiometabolic diseases[30-31], recent studies have suggested WHtR as an emerging anthropometric parameter for detecting risks of cardiometabolic diseases of obesity patients[2, 25, 32-36].

5.1 WHtR and the risk of hypertension

According to previous studies, WHtR has a good capacity to predict future hypertension risk for obesity patients. Jayedi et al. [37] once conducted a systematic review and dose-response meta-analysis of 57 prospective cohort studies, and found that among several different anthropometric indices, WHtR showed the greatest RR for hypertension: 1.74 (95% *CI* 1.35, 2.13; I^2=58.9%, number of studies (n)=4) for a 0.1-unit increment, while the RRs were 1.49 (95% *CI* 1.41, 1.58; I^2=97.4%, *n*=50) for a five-unit increment in BMI, 1.37 (95% *CI* 1.24, 1.51; I^2=76.4%, *n*=8) for a 0.1-unit increment in WHR, 1.27 (95% *CI* 1.15, 1.39; I^2=95.0%, *n*=14) for a 10 cm increment in WC, and 1.16 (95% *CI* 1.09, 1.23; I^2=77.8%, *n*=5) for weight gain equal to a one-unit increment in BMI. Wang *et al.* [38] analyzed the date from a prospective cohort of 4458 individuals, and found that compared with the group with lower WHtR, those with higher WHtR had a higher incidence of hypertension ($P<0.001$). Furthermore, multivariate Cox regression analysis demonstrated that the hypertension risk was 1.45 times higher in the group with high WHtR than in the group with low WHtR. Every 0.1 unit increase in WHtR would increase the hypertension risk by 30.4% ($P<0.001$). ROC analyses also indicated that WHtR was a superior indice than BMI in predicting new-onset hypertension (AUC: 0.626 vs. 0.607, *P*=0.009).

However, not all studies reported that WHtR performed better than other indices, for example, the systematic review and meta-analysis by Galderon-Garcia et al. [39], which included 12 cross-sectional studies and one prospective study, suggested that BMI, WC and WHtR had similar AUC in predicting hypertension: 0.67 (95% *CI* 0.64 – 0.69) of BMI, 0.68 (95% *CI* 0.66 – 0.70) of WC and 0.68 (95% *CI* 0.66 – 0.71) of WHtR. Tao et al. [40] who analyzed 21 cross-sectional studies, also reported that for boys, pooled AUC and 95% *CI* for BMI, WC and WHtR to detect hypertension were 0.68 (0.64, 0.72), 0.69 (0.64, 0.74) and 0.67 (0.63, 0.71); for girls, pooled AUC and 95% CI for BMI, WC and WHtR to detect hypertension were 0.70 (0.66, 0.75), 0.69 (0.64, 0.75) and 0.67 (0.63, 0.72).

5.2 WHtR and the risk of MS

Results from the meta-analysis of Ochoa et al. [41], which involved 31 studies with 66.912 subjects, demonstrated that elevated WHtR (cut-off point: 0.5) was related to a four-fold increased risk of MS (odds ratio [OR] 4.15, 95% *CI* 2.69 to 6.42) and two-fold increased risk after adjusted by general obesity (adjusted OR 2.26, 95% *CI* 1.29 to 3.98). Meanwhile, the cut-off point of 0.5 had a sensitivity of 60% (95% *CI* 50% to 68.8%) and a specificity of 79% (95% *CI* 71.6% to 83.9%). Savva et al. [28] also drew a conclusion that WHtR had a greater association than BMI with MS (rRR: 0.92, 95% *CI* 0.89 – 0.96) in cross-sectional studies.

5.3 WHtR and the risk of CVD

It is suggested that obesity is an independent risk factor for CVD, which mainly includes coronary heart disease (CHD), cerebrovascular disease, peripheral arterial disease and rheumatic heart disease. Evidence has showed that WHtR are associated with increased CVD risks. Feng et al. [42] used date from a prospective cohort study of the UK Biobank, and found a consistenly positive linear correlation of WHtR with incident ischemic CVD, myocardial infarction (MI), and ischemic stroke (IS). Additionally, compared with women with low WHtR (<0.5), women with high WHtR (⩾0.5) demonstrated 49%, 54%, and 48% higher risks of ischemic CVD, MI, and IS. For the male, there were also 41%, 52%, and 19% higher risks of ischemic CVD, MI, and IS in high WHtR group (⩾0.5) than low WHtR group (<0.5).

Quite a few research suggested that WHtR might be a better screening tool than BMI in predicting CVD risks. A systematic review of 22 prospective studies and 44 cross-sectional studies by Browning et al. [43] concluded that WHtR and WC were stronger predictors than BMI for CVD. Ashwell et al' s[26] study also demonstrated that WHtR had greater AUC than WC and BMI in predicting CVD risks. Furthermore, results from Savva et al.[28] also showed that in prospective studies, it seemed that WHtR was better than BMI in detecting CVD outcomes, including incident CVD, mortality of CVD and all-cause mortality. Feng et al. [42] also suggested that solely depending on WC may lead to overlooked obese individuals, because there are 32% participants had high WHtR but normal WC. And these people with normal WC but increased WHtR are more vulnerable to CVD diseases.

6 Discussion

There are several different athropometric metrics used to indirectly assess adiposity, including BMI, WC, WHR and WHtR. To begin with, it is noted that BMI is most frequent used parameter in assessing overweight and obesity. However, there are some drawbacks. First, unlike WHtR and WC, BMI does not distinguish whether the increase in whole body weight is due to an increase in adipose tissue mass, especially abdominal fat mass, or an increase in other tissue mass, for example, muscle mass. Therefore, some mistakes are made in predicting cardiometabolic disease risks if based on BMI alone. Additionally, because different ethnic groups have different cutoff points of BMI, in regard to application, BMI is not as comparable as WHtR in epidemiologic research. In addition, BMI cannot capture age-related changes in the body well. NICE agreed that the BMI results may not be accurate in people older than 65 because their functional capacity may be reduced owing to conditions including sarcopenia. In addition, it is also recognized that a slightly higher BMI in older people may have a protective role in reducing the risk of all-cause mortality and preventing undernutrition[2]. This paradox is probably owing to that elder people with lower BMI have less muscle mass and a decreased muscle mass to adipose tissue mass ratio. Meanwhile, this kind of “obesity” (relatively higher BMI) paradox phenomenon in the elderly also exists in using BMI to assess obesity-related risks of cardiovascular diseases. The research by Antonopoulos et al.[44] reported that the association between BMI and mortality in CVD patients is U-shaped, and it is also observed that the nadir of mortality risk seems to be located at the overweight ranged, not the recommended BMI levels. Nevertheless, when researchers used other non-BMI indices for defining obesity, there was no ‘obesity paradox’ [45]. Anthropometric measurements including WC and WHR both were independently linearly correlated with increased mortality risk[5].

It is believed that WC is related to abdominal obesity, however, it mistakenly assumes that people harboring the same WC have the same health risks because it does not consider the influences of different heights. Diabetes has been shown to be more prevalent in short-stature patients than in taller patients, even after adjusting for confounders[46-47], this might be the shorter ones had higher WHtR. As for WHR, some previous studies have suggested that it did not demonstrate a close association with obesity-related cardiometabolic disease[11]. The study of Khader et al. [48] which included 1193 men and 2863 women reported that WHR had both lower sensitivity and specificity than WHtR. Research from Sekgala et al. [49] also reported similar results. Although both WHR and WHtR are related to WC, compared with WHR, WHtR is a more stable and more reliable index because height remains constant in adults, while hip circumference can increase or decrease proportionally when there is a change in body size[2, 43]. In addition, for the measurement itself, the accuracy and repeatability of hip circumference are not as good as those of height.

According to most of the observational studies and systematic reviews mentioned above[21-29], compared with other simple anthropometric indices, including BMI, WHR and WC, WHtR might be a more accurate way to indirectively assess adiposity, especially central adiposity, as well as to predict the risk of adiposity-related cardiometabolic diseases such as T2D. However, there might still be some controversy about whether WHtR is superior to other anthropometric methods in assessing adiposity and predicting diabetes. Although the largest systematic review of Jayedi et al. [29] suggested that WHtR had a closer association with type 2 diabetes: RR for each one SD increase was 1.73 (1.51 to 1.98; n=25) for WHtR, while 1.72 (95% CI 1.65 to

1.81) for BMI, this superiority of WHtR over BMI is slight with overlapping 95% CIs. In addition, since there were 167 studies included for analysing the capacity of BMI in predicting diabetes, while only 19 studies for WHtR, this difference can also have some bias on the RR results. Therefore, further studies with a larger sample size, aiming to compare the different anthropometric measurements' capacities in predicting diabetes or other cardiometabolic disease, are needed.

However, compared with other anthropometric indices, WHtR does show several advantages. First of all, for recognizing abdominal adiposity, BMI is a less specific measure because it cannot equally reflect the specific changes in body fat, while WHtR is a better indicator. Additionally, WHtR has the same classification as the overall population, in spite of gender, age or ethnicity[2]. Therefore, WHtR is more convenient and has good application prospects in clinical practice and population-based studies and is worthy of popularization.

Contributions: ZHANG Xinyi and TONG Nanwei contributed to the conception and design of the manuscript. ZHANG Xinyi, LU Xi, PAN Xiaohui, SHEN Sumin contributed to literature searching, data aquisition, data analysis and interpretation. ZHANG Xinyi and LU Xi contributed to drafting of the manuscript. TONG Nanwei contributed to revision of the manuscript. The final version of the manuscript has been approved and read by all authors

Conflict of interest: The authors declare that they have no conflicts of interest to disclose.

References

[1] NCD Risk Factor Collaboration (NCD-RisC). Worldwide trends in body-mass index, underweight, overweight, and obesity from 1975 to 2016: a pooled analysis of 2416 population-based measurement studies in 128·9 million children, adolescents, and adults[J]. Lancet, 2017, 390(10113): 2627-2642. https://doi.org/10.1016/S0140-6736(17)32129-3.

[2] National Institute for Health and Care Excellence (NICE). Obesity: identification, assessment and management (CG189). Last updated 8 September 2022. 2022. https://www.nice.org.uk/terms-and-condition#notice-of-rights

[3] Oliveros E, Somers VK, Sochor O, et al. The concept of normal weight obesity[J]. Prog Cardiovasc Dis, 2014, 56(4): 426-433. https://doi.org/10.1016/j.pcad.2013.10.003.

[4] Sahakyan KR, Somers VK, Rodriguez-Escudero JP, et al. Normal-weight central obesity: implications for total and cardiovascular mortality[J]. Ann Intern Med, 2015, 163(11): 827-835. https://doi.org/10.7326/M14-2525.

[5] Coutinho T, Goel K, Corrêa de Sá D, et al. Combining body mass index with measures of central obesity in the assessment of mortality in subjects with coronary disease: role of "normal weight central obesity" [J]. J Am Coll Cardiol, 2013, 61(5): 553-560. https://doi.org/10.1016/j.jacc.2012.10.035.

[6] Romero-Corral A, Somers VK, Sierra-Johnson J, et al. Accuracy of body mass index in diagnosing obesity in the adult general population[J]. Int J Obes (Lond), 2008, 32(6): 959-966. https://doi.org/10.1038/ijo.2008.11.

[7] Okorodudu DO, Jumean MF, Montori VM, et al. Diagnostic performance of body mass index to identify obesity as defined by body adiposity: a systematic review and meta-analysis[J]. Int J Obes (Lond), 2010, 34(5): 791-799. https://doi. org/10.1038/ijo.2010.5.

[8] Garvey WT, Mechanick JI, Brett EM, et al. American association of clinical endocrinologists and American college of endocrinology comprehensive clinical practice guidelines for medical care of patients with obesity[J]. Endocr Pract, 2016, 22(Suppl 3): 1-203. https://doi. org/10.4158/EP161365.GL.

[9] Tutunchi H, Ebrahimi-Mameghani M, Ostadrahimi A, et al. What are the optimal cut-off points of anthropometric indices for prediction of overweight and obesity? Predictive validity of waist circumference, waist-to-hip and waist-to-height ratios[J]. Health Promot Perspect, 2020, 10(2): 142-147. https://doi.org/10.34172/hpp.2020.23.

[10] Al-Lawati JA, Jousilahti P. Body mass index, waist circumference and waist-to-hip ratio cut-off points for categorisation of obesity among Omani Arabs[J]. Public Health Nutr, 2008, 11(1): 102-108. https://doi.org/10.1017/S1368980007000183.

[11] Meseri R, Ucku R, Unal B. Waist: height ratio: a superior index in estimating cardiovascular risks in Turkish adults[J]. Public Health Nutr, 2014, 17(10): 2246-2252. https://doi.org/10.1017/S136898001300267X.

[12] Staynor JMD, Smith MK, Donnelly CJ, et al. DXA reference values and anthropometric screening for visceral obesity in Western Australian adults[J]. Sci Rep, 2020, 10(1): 18731. https://doi.org/10.1038/s41598-020-73631-x.

[13] Roriz AKC, Passos LCS, de Oliveira CC, et al. Evaluation of the accuracy of anthropometric clinical indicators of visceral fat in adults and elderly[J]. PLoS One, 2014, 9(7): e103499. https://doi.org/10.1371/journal.pone.0103499.

[14] Corrêa MM, Thumé E, De Oliveira ERA, et al. Performance of the waist-to-height ratio in identifying obesity and predicting non-communicable diseases in the elderly population: a systematic literature review[J]. Arch Gerontol Geriatr, 2016, 65: 174-182. https://doi.org/10.1016/j.archger.2016.03.021.

[15] Neeland IJ, Ross R, Després JP, et al. Visceral and ectopic fat,

atherosclerosis, and cardiometabolic disease: a position statement[J]. Lancet Diabetes Endocrinol, 2019, 7(9): 715-725. https://doi.org/10.1016/S2213-8587(19)30084-1.

[16] Neeland IJ, Hughes C, Ayers CR, et al. Effects of visceral adiposity on glycerol pathways in gluconeogenesis[J]. Metabolism, 2017, 67: 80-89. https://doi. org/10.1016/j.metabol.2016.11.008.

[17] Schwatka NV, Smith DE, Golden A, et al. Development and validation of a diabetes risk score among two populations[J]. PLoS One, 2021, 16(1): e0245716. https://doi. org/10.1371/journal.pone.0245716.

[18] Lindström J, Tuomilehto J. The diabetes risk score: a practical tool to predict type 2 diabetes risk[J]. Diabetes Care, 2003, 26 (3): 725-731. https://doi.org/10.2337/diacare.26.3.725.

[19] Tabák AG, Herder C, Rathmann W, et al. Prediabetes: a high-risk state for diabetes development[J]. Lancet, 2012, 379(9833): 2279-2290. https://doi.org/10.1016/S0140-6736(12)60283-9.

[20] Collins JJ, Baase CM, Sharda CE, et al. The assessment of chronic health conditions on work performance, absence, and total economic impact for employers[J]. J Occup Environ Med, 2005, 47(6): 547-557. https://doi.org/10.1097/01.jom.0000166864.58664.29.

[21] Hou XH, Chen SY, Hu G, et al. Stronger associations of waist circumference and waist-to-height ratio with diabetes than BMI in Chinese adults[J]. Diabetes Res Clin Pract, 2019, 147: 9-18. https://doi.org/10.1016/j.diabres.2018.07.029.

[22] Lo K, Huang YQ, Shen G, et al. Effects of waist to height ratio, waist circumference, body mass index on the risk of chronic diseases, all-cause, cardiovascular and cancer mortality[J]. Postgrad Med J, 2021, 97(1147): 306-311. https://doi. org/10.1136/postgradmedj-2020-137542.

[23] Lu YQ, Liu SY, Qiao YN, et al. Waist-to-height ratio, waist circumference, body mass index, waist divided by height 0.5 and the risk of cardiometabolic multimorbidity: a national longitudinal cohort study[J]. Nutr Metab Cardiovasc Dis, 2021, 31 (9): 2644-2651. https://doi.org/10.1016/j.numecd.2021.05.026.

[24] Zhang F, Wan Q, Cao HY, et al. Identical anthropometric characteristics of impaired fasting glucose combined with impaired glucose tolerance and newly diagnosed type 2 diabetes: anthropometric indicators to predict hyperglycaemia in a community-based prospective cohort study in Southwest China[J]. BMJ Open, 2018, 8(5): e019735. https://doi. org/10.1136/bmjopen-2017-019735.

[25] Lee CMY, Huxley RR, Wildman RP, et al. Indices of abdominal obesity are better discriminators of cardiovascular risk factors than BMI: a meta-analysis[J]. J Clin Epidemiol, 2008, 61(7): 646-653. https://doi. org/10.1016/j. jclinepi. 2007.08.012.

[26] Ashwell M, Gunn P, Gibson S. Waist-to-height ratio is a better screening tool than waist circumference and BMI for adult cardiometabolic risk factors: systematic review and meta-analysis[J]. Obes Rev, 2012, 13(3): 275-286. https://doi.org/10.1111/j.1467-789X.2011.00952.x.

[27] Kodama S, Horikawa C, Fujihara K, et al. Comparisons of the strength of associations with future type 2 diabetes risk among anthropometric obesity indicators, including waist-to-height ratio: a meta-analysis[J]. Am J Epidemiol, 2012, 176(11): 959-969. https://doi.org/10.1093/aje/kws172.

[28] Savva SC, Lamnisos D, Kafatos AG. Predicting cardiometabolic risk: waist-to-height ratio or BMI. A meta-analysis[J]. Diabetes Metab Syndr Obes, 2013, 6: 403-419. https://doi.org/10.2147/DMSO.S34220.

[29] Jayedi A, Soltani S, Motlagh SZ, et al. Anthropometric and adiposity indicators and risk of type 2 diabetes: systematic review and dose-response meta-analysis of cohort studies[J]. BMJ, 2022, 376: e067516. https://doi. org/10.1136/bmj-2021-067516.

[30] Kim MS, Kim WJ, Khera AV, et al. Association between adiposity and cardiovascular outcomes: an umbrella review and meta-analysis of observational and Mendelian randomization studies[J]. Eur Heart J, 2021, 42(34): 3388-3403. https://doi.org/10.1093/eurheartj/ehab454.

[31] Larsson SC, Burgess S. Causal role of high body mass index in multiple chronic diseases: a systematic review and meta-analysis of Mendelian randomization studies[J]. BMC Med, 2021, 19(1): 320. https://doi.org/10.1186/s12916-021-02188-x.

[32] Man REK, Gan ATL, Fenwick EK, et al. The relationship between generalized and abdominal obesity with diabetic kidney disease in type 2 diabetes: a multiethnic Asian study and meta-analysis[J]. Nutrients, 2018, 10(11): 1685. https://doi.org/10.3390/nu10111685.

[33] Zhao QY, Yi XY, Wang ZH. Meta-analysis of the relationship between abdominal obesity and diabetic kidney disease in type 2 diabetic patients[J]. Obes Facts, 2021, 14(4): 338-345. https://doi.org/10.1159/000516391.

[34] Han CY, Liu Y, Sun XZ, et al. Prediction of a new body shape index and body adiposity estimator for development of type 2 diabetes mellitus: the rural Chinese cohort study[J]. Br J Nutr, 2017, 118(10): 771-776. https://doi. org/10.1017/S0007114517002859.

[35] Wang F, Chen YT, Chang Y, et al. New anthropometric indices or old ones: which perform better in estimating cardiovascular risks in Chinese adults[J]. BMC Cardiovasc Disord, 2018, 18 (1): 14. https://doi.org/10.1186/s12872-018-0754-z.

[36] Schneider HJ, Friedrich N, Klotsche J, et al. The predictive value of different measures of obesity for incident cardiovascular events and mortality[J]. J Clin Endocrinol Metab, 2010, 95(4): 1777-1785. https://doi. org/10.1210/jc.2009-1584.

[37] Jayedi A, Rashidy-Pour A, Khorshidi M, et al. Body mass index, abdominal adiposity, weight gain and risk of developing hypertension: a systematic review and dose-response meta-analysis of more than 2.3 million participants[J]. Obes Rev, 2018, 19(5): 654-667. https://doi.org/10.1111/obr.12656.

[38] Wang ZW, Shi Q, Yan XJ, et al. There was a similar U-shaped nonlinear association between waist-to-height ratio and the risk

of new-onset hypertension: findings from the CHNS[J]. Front Nutr, 2023, 10: 1304521. https://doi. org/10.3389/fnut. 2023. 1304521.

[39] Calderón-García JF, Roncero-Martín R, Rico-Martín S, et al. Effectiveness of body roundness index (BRI) and a body shape index (ABSI) in predicting hypertension: a systematic review and meta-analysis of observational studies[J]. Int J Environ Res Public Health, 2021, 18(21): 11607. https://doi. org/10.3390/ijerph182111607.

[40] Tao JM, Wei W, Ma XY, et al. Diagnostic accuracy of anthropometric indices for discriminating elevated blood pressure in pediatric population: a systematic review and a meta-analysis[J]. BMC Pediatr, 2022, 22(1): 19. https://doi.org/10.1186/s12887-021-03062-8.

[41] Ochoa Sangrador C, Ochoa-Brezmes J. Waist-to-height ratio as a risk marker for metabolic syndrome in childhood. A meta-analysis[J]. Pediatr Obes, 2018, 13(7): 421-432. https://doi.org/10.1111/ijpo.12285.

[42] Feng Q, Bešević J, Conroy M, et al. Waist-to-height ratio and body fat percentage as risk factors for ischemic cardiovascular disease: a prospective cohort study from UK biobank[J]. Am J Clin Nutr, 2024, 119(6): 1386-1396. https://doi. org/10.1016/j.ajcnut.2024.03.018.

[43] Browning LM, Hsieh SD, Ashwell M. A systematic review of waist-to-height ratio as a screening tool for the prediction of cardiovascular disease and diabetes: 0·5 could be a suitable global boundary value[J]. Nutr Res Rev, 2010, 23(2): 247-269. https://doi.org/10.1017/S0954422410000144.

[44] Antonopoulos AS, Tousoulis D. The molecular mechanisms of obesity paradox[J]. Cardiovasc Res, 2017, 113(9): 1074-1086. https://doi.org/10.1093/cvr/cvx106.

[45] de Koning L, Merchant AT, Pogue J, et al. Waist circumference and waist-to-hip ratio as predictors of cardiovascular events: meta-regression analysis of prospective studies[J]. Eur Heart J, 2007, 28(7): 850-856. https://doi.org/10.1093/eurheartj/ehm026.

[46] Lara-Esqueda A, Aguilar-Salinas CA, Velazquez-Monroy O, et al. The body mass index is a less-sensitive tool for detecting cases with obesity-associated co-morbidities in short stature subjects[J]. Int J Obes Relat Metab Disord, 2004, 28(11): 1443-1450. https://doi.org/10.1038/sj.ijo.0802705.

[47] Piqueras P, Ballester A, Durá -Gil JV, et al. Anthropometric indicators as a tool for diagnosis of obesity and other health risk factors: a literature review[J]. Front Psychol, 2021, 12: 631179. https://doi.org/10.3389/fpsyg.2021.631179.

[48] Khader Y, Batieha A, Jaddou H, et al. The performance of anthropometric measures to predict diabetes mellitus and hypertension among adults in Jordan[J]. BMC Public Health, 2019, 19(1): 1416. https://doi.org/10.1186/s12889-019-7801-2.

[49] Sekgala MD, Sewpaul R, Opperman M, et al. Comparison of the ability of anthropometric indices to predict the risk of diabetes mellitus in South African males: SANHANES-1[J]. Int J Environ Res Public Health, 2022, 19(6): 3224. https://doi.org/10.3390/ijerph19063224.

(Edited by GUO Zheng)

本文引用: 张心怡, 陆茜, 潘晓晖, 沈苏敏, 童南伟. 腰围身高比在评估肥胖、预测2型糖尿病和其他心血管代谢性疾病中的作用[J]. 中南大学学报(医学版), 2024, 49(7): 1061-1071. DOI: 10.11817/j.issn.1672-7347.2024.240259

Cite this article as: ZHANG Xinyi, LU Xi, PAN Xiaohui, SHEN Sumin, TONG Nanwei. Role of waist circumference-to-height ratio in assessing adiposity, predicting type 2 diabetes mellitus and other cardiometabolic diseases[J]. Journal of Central South University. Medical Science, 2024, 49(7): 1061-1071. DOI: 10.11817/j.issn.1672-7347.2024.240259