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Assessing the Predictive Accuracy of the Body Roundness Index for Prediabetes in Indonesian Adults

Analisis Prediksi Body Roundness Index *untuk Prediabetes pada Orang Dewasa di Indonesia*

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ABSTRACT

Background: Anthropometric measurements for identifying body fat could be used to screen individuals with prediabetic risk.
Objectives: To evaluate and compare the diagnostic accuracy of body roundness index (BRI), conicity index (C-index), body mass index (BMI), waist circumference, and waist-to-height ratio (WHtR) as predictors of prediabetes in the adult population of Indonesia.
Methods: This study employs a cross-sectional design and uses secondary data from the Baseline Health Research (Ind: Riskesdas) 2018. As many as 12.327 samples were subjected to descriptive analysis, and the area under the curve (AUC) was utilised to assess the diagnostic potential of anthropometric measures in predicting prediabetes.
Results: The five anthropometric parameters have a very weak ability as a prediabetic predictor. The WHtR and BRI (AUC_{men}=0.571; AUC_{women}=0.573) were significantly better than the other anthropometric parameters. In contrast, the C-index values for women (AUC_{women}=0.548) were considerably lower than other anthropometric parameters. However, there was no significant difference between the C-index for men (AUC_{men}=0.560) and the waist circumference (AUC=0.564) and BMI (AUC=0.559) values.
Conclusions: The body roundness index has the same ability to predict prediabetes with WHtR, while the C-index in women is weaker than waist circumference and BMI.

INTRODUCTION

Indonesia is a nation that holds the fifth position in terms of the highest prevalence of diabetes worldwide, with a staggering population of 19.5 million individuals affected by the condition, while 14.3 million of them have undiagnosed diabetes in 2021[1]. That implies an urgent need to increase prediabetes screening in Indonesia. Prediabetes refers to a condition in which an individual exhibits Impaired Fasting Glucose Levels (IFG) and possibly impaired glucose tolerance (IGT), characterized by blood sugar examination values that do not meet the standards for diabetes but are elevated above the range deemed normal[1,2]. Early detection is essential as a prediabetic condition indicates the potential of acquiring diabetes later in life, since the longer it is left undiagnosed, the more it will increase the risk of complications leading to the increasing use of health services and medical expenses, decreasing productivity, even causing disability and premature death[3].

Overweight, especially abdominal obesity, is highly correlated with insulin resistance, the primary precursor of diabetes[4]. Anthropometric parameters for estimating excess body fat may be considered a non-invasive, effortless approach to assessing body fat. Body Mass Index (BMI) and Waist Circumference (WC) are simple anthropometric parameters commonly used to predict cardiometabolic risk. BMI doesn't differentiate among body fat, muscle mass, or bone mass; it also doesn't offer any insight into how body fat is distributed among individuals. Simultaneously, waist circumference shows central fat deposition without accounting for differences in height among ethnicities as a factor[5,6]. Another simple anthropometric parameter commonly used is the waist-to-height ratio (WHtR), which has been shown to be superior to both BMI and WC in terms of its effectiveness, as it accounts for central fat deposition and height differences among individuals[6,7].

Anthropometric parameters derived from basic anthropometry (waist circumference, weight, and height) have been developed to detect obesity and body fat distribution, such as BRI and conicity index (C-index). Research has shown that BRI has the optimal ability to

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identify insulin resistance[8]. Similarly, the C-index is positively associated with insulin resistance, hypertension, and dyslipidemia[9]. Aside from being used to estimate visceral adipose tissue and body fat percentage, BRI can compare an individual's body type visualisation with a healthy body roundness reference range[10].

BRI has shown superior predictive power compared to other derived anthropometric measures, including the Abdominal Volume Index, Body Adiposity Index, and Body Shape Index. It is also comparable to WHtR in predicting diabetes[11–13]. On the other hand, studies related to the C-index have not yielded consistent results. For example, studies in Asian populations have shown that the C-index is not superior to the BRI or the WHtR. Still, research in the US shows that the C-index is a better predictor of diabetes than the WHtR[11,14,15].

Studies in South Korea and Peru showed that an anthropometric parameter could have different predictive power and appropriate cut-off values[16,17]. Based on those studies, it seems that the same approach could be implemented across different ethnicities. Studies on derived anthropometric parameters in Indonesia are insufficient; specifically, none have examined their ability to predict prediabetes. The study aims to achieve its objectives by 1) finding the diagnostic ability of derived anthropometric parameters (BRI and C-index), which their calculation is more complicated; 2) finding if the diagnostic ability of derived anthropometric parameters is better than the basic anthropometric parameters (WC, WHtR, and BMI); and 3) determining the appropriate cut-off as a prediabetic predictor in Indonesian adults.

METHODS

Study Design

This cross-sectional study was conducted in June and September 2022, utilising available data from the Baseline Health Research (Riskesdas) in 2018. The Ethical Commission of Health Research has authorised this study, National Institute of Health Research and Development, Ministry of Health of the Republic of Indonesia, with the registration number LB.02.01/2/KE.024/2018. The Health Development Policy Agency has approved the use of data for this study under registration number 2980/UN7.5.4.2/DL/2022, dated April 6, 2022.

Subjects and Sampling

The subjects of this study were subsamples representing the national level from the Riskesdas 2018. The minimum number of subjects required was 3,621, according to the sample calculation formula for AUC comparison analysis (see Appendix 1). The inclusion criteria of this study were: (1) individuals ≥19 years old, (2) non-hypoglycemic nor diabetic (diabetes mellitus) individuals (FPG level 70-125 mg/dL and PPG level 70-199 mg/dL), (3) having data on age and sex, and (4) having realistic anthropometric data. The flow chart of sample selection is shown in Figure 1, in which 12,327 samples that fulfilled the inclusion criteria were then analysed.

Data Collection

The independent variables in this current investigation were the anthropometric parameters (WHtR, BRI, WC, BMI, and C-index). The BMI measures overall body adiposity, derived by dividing an individual's body weight in kilograms (kg) by the square of their height in meters (m^2). Meanwhile, WC and WHtR serve as reliable measures for assessing central adiposity[5,6]. The BRI serves as a predictive measure of both body fat percentage and visceral adipose tissue, and examines the relationship between body circumference and height by modelling the human body as an ellipse or oval. The C-index is a metric used to assess obesity and body fat distribution. It assumes that individuals with significant fat accumulation in the abdominal region exhibit a double-cone shape, whereas those with minimal fat storage in this area exhibit a cylindrical shape [10,18]. The formulas used to determine the body roundness index and C-index are as follows:

$$\mathrm{BRI}^{10} = 364.2 - 365 \times \sqrt{1-\frac{(\mathrm{WC}/2\pi)^2}{(0.5 \times \mathrm{height})^2}}$$

$$C-index^{18} = \frac{\mathrm{WC\ (m)}}{0.109\sqrt{\frac{\mathrm{weight\ (kg)}}{\mathrm{height\ (m)}}}}$$

The dependent variable in this study was plasma glucose levels. The criteria of the American Diabetes Association were used to determine the diagnosis of IFG and IGT, in which samples with Fasting Plasma Glucose (FPG) level of 100-125 mg/dL and/or 2-hour Postprandial Plasma Glucose (PPG) level of 140-199 mg/dL were categorised as prediabetes[19]. All the data used in this study were secondary data collected previously by the Riskesdas team through interviews (age, sex, and smoking habits), blood glucose tests, and anthropometric measurements. The blood glucose test was conducted using the Accucheck Performa device, while the anthropometric parameters were measured using a digital body weight (accuracy of 0.1 kg), stadiometer (accuracy of 1 mm) to measure height, and non-elastic tape (accuracy of 1 mm) to measure waist circumference[20].

Data Analysis

The data were presented as medians and interquartile ranges for numerical variables, and as sums and percentages for categorical variables. The men and women samples were evaluated regarding their characteristics using statistical tests appropriate for the analysed variable. The Mann-Whitney U-test was employed for numerical variables, while the chi-square test was utilised for categorical variables. The diagnostic tests carried out in this study were 'receiver operating characteristic' curve analysis to find the AUC and the cut-off values, and 2×2 table analysis to find predictive values and likelihood ratios[21]. The diagnostic ability of anthropometric measures as predictors of prediabetes was evaluated using the area under the curve (AUC), in which the AUC values were classified into very weak (0.5-0.6), weak (0.6-0.7), moderate (0.7-0.8), good (0.8-0.9),

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and very good (0.9-1)[21] In addition to descriptive analysis, a comparative analysis of AUC between anthropometric parameters was also conducted in this study. Data analysis in this study was carried out using SPSS Statistics version 25 (IBM Corp., Armonk, NY, USA) and STATA (Version 16; StataCorp LLC, College Station, TX), and p-values less than 0.05 were deemed significant. The optimal cut-off value was determined based on the Youden index (J) using the equation:

$$(\text{Jmax.} = \text{sensitivity} + \text{specificity} - 1)$$[21]

RESULTS AND DISCUSSIONS

This investigation included 12.327 samples (4,296 men and 8,031 women) aged 19-50. The prevalence of prediabetes in this study was 47.5%, and its prevalence increased with increasing age (Figure 1). Moreover, the occurrence of prediabetes also demonstrated an upward trend in correspondence with escalating levels of body adiposity, in which the obese group mostly experienced prediabetes compared to other nutritional status groups (Figure 2). The sample characteristics by sex are provided in Table 1, showing that men were significantly older and had higher FPG levels. Meanwhile, women had a higher 2-hour PPG level and anthropometric values (BMI, WC, WHtR, BRI, and C-index) than men. Significant sex-based differences were observed in all anthropometric indices, such as body weight, body height, BMI, waist circumference, waist-to-hip ratio, body roundness index, and the C index, with men generally weighing more and taller, while women had a higher BMI, larger waist circumference, waist-to-hip ratio, BRI, and C-index.

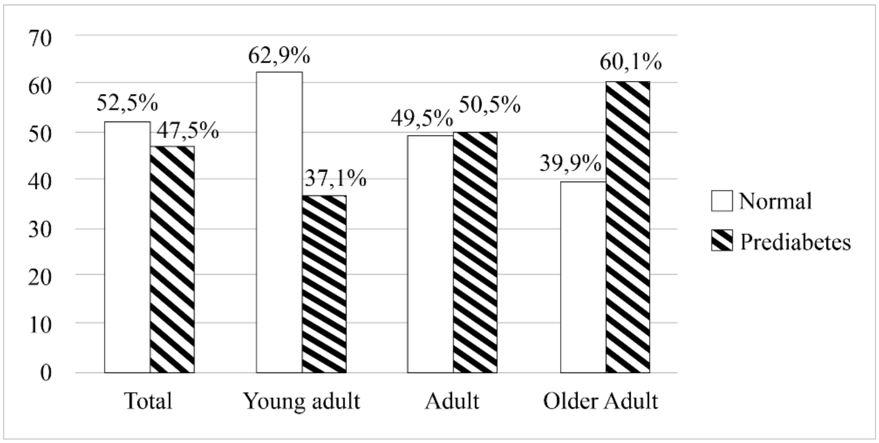

Figure 1. The prevalence of prediabetes stratified by age group. Notes: young adult=19-29 years old, adult=30-49 years old, older adult=50-64 years old

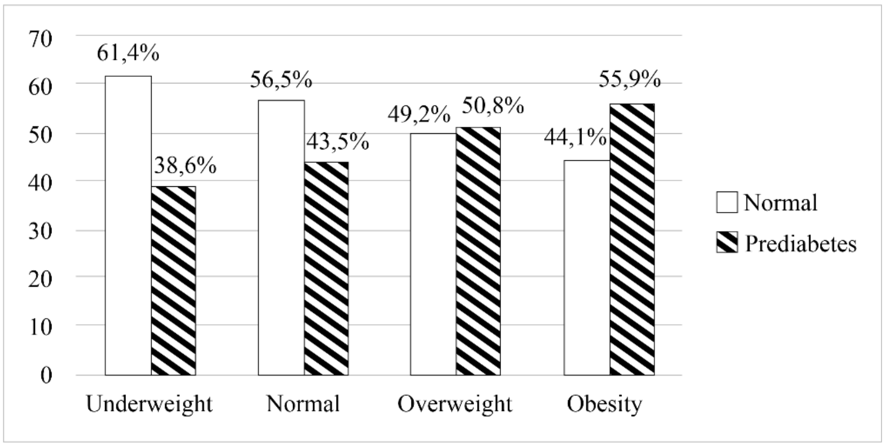

Figure 2. The prevalence of prediabetes. Notes: BMI categorisation according to the Ministry of Health of the Republic of Indonesia[22]

Table 1. Characteristics of study samples based on sex

Characteristics	Median (Min-Max)	Men	Women	p-value
Age (years)	37 (19-50)	38 (19-50)	37 (19-50)	0.001[s]
Plasma Glucose				
FPG (mg/dL)	93 (49-125)	94 (63-125)	92 (49-125)	<0.001[s]
2H PPG (mg/dL)	128 (41-199)	122 (43-199)	131 (41-199)	
Anthropometric Parameters				
Body Weight (kg)	57.7 (29-124.4)	59 (29.6-124.4)	56.9 (29-112.2)	<0.001[s]
Body Height (cm)	154.7 (114.5-189.5)	163 (115-185.2)	151.3 (114.5-189.5)	

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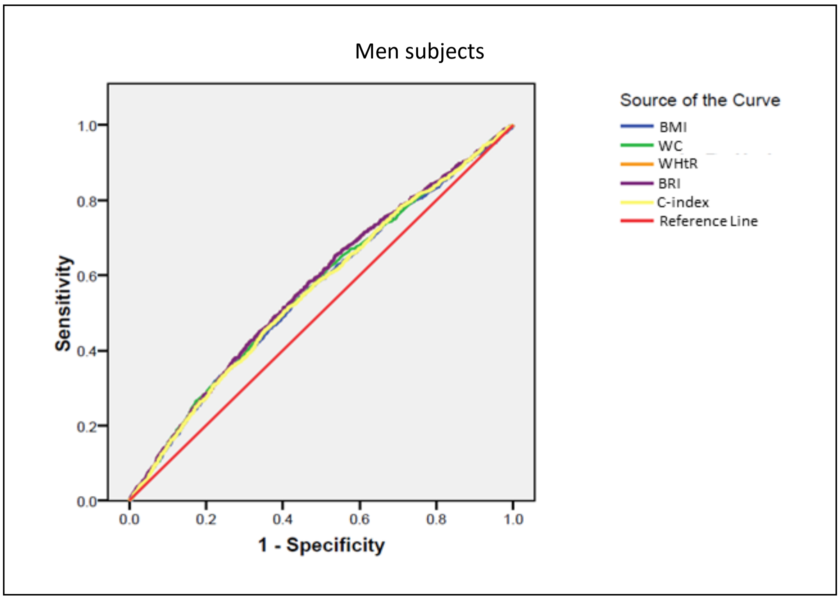
Characteristics	Median (Min-Max)	Men	Women	p-value
BMI (kg/m^2)	23.91 (12.06-46.43)	22.18 (12.06-40.21)	24.86 (13.04-46.43)	
Waist Circumference (cm)	79.2 (50-124.5)	77 (50-124.5)	80.2 (50-123)	
Waist-to-Hip Ratio	0.51 (0.30-0.82)	0.47 (0.30-0.73)	0.53 (0.32-0.82)	
BRI	4.09 (0.91-11.75)	3.38 (0.91-9.13)	4.46 (1.10-11.75)	
C-Index ($m^{3/2}/kg^{1/2}$)	1.19 (0.77-1.60)	1.18 (0.78-1.54)	1.20 (0.77-1.60)	
Smoking Habits*				
Yes	3566 (28.9%)	3266 (76%)	300 (3.7%)	<0.001^s
No	8761 (71.1%)	1030 (24%)	7731 (96.3%)	

FPG=Fasting Plasma Glucose, 2H PPG=2 Hours Postprandial Plasma Glucose, BMI=Body Mass Index, BRI=Body Roundness Indeks, *) Data is presented as a sum (percentage); the superscripted 'S' showed a significant difference

Figure 3 and Table 2 show WHtR, WC, BRI, BMI, and C-index diagnostic test results as prediabetic predictors. In general, the five anthropometric parameters had a very weak ability to predict prediabetes (AUC=0.5-0.6). The WHtR and BRI (AUC_{men}=0.571; AUC_{women}=0.573) were significantly better than other anthropometric parameters (p-value<0.0001). Meanwhile, the C-index (AUC_{men}=0.560; AUC_{women}=0.548) was considerably weaker than other anthropometric parameters in women, but it was not significantly different from the WC (AUC=0.564) and BMI (AUC=0.559) in men (p-value=0.111).



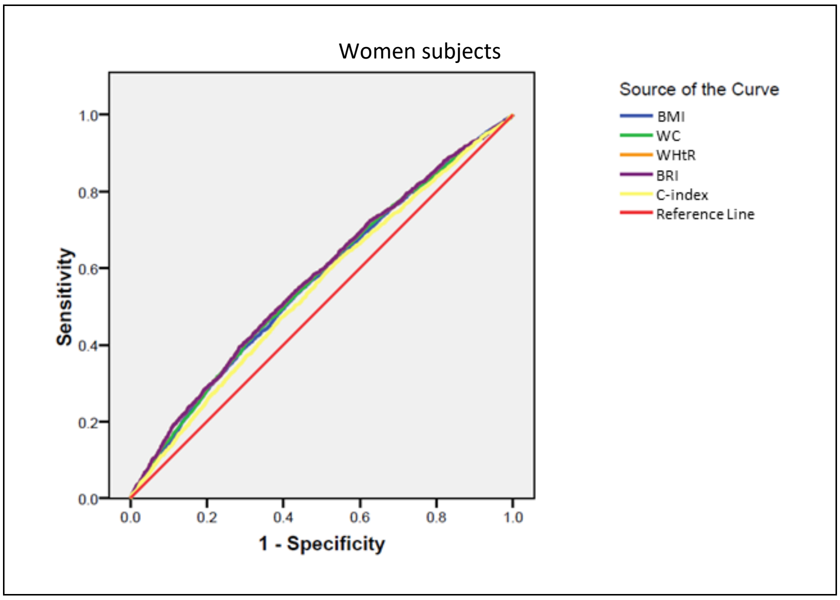


Figure 3. ROC Curves of Anthropometric Indices for Predicting Prediabetes Stratified by Sex

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Table 2. The area under the curve, optimal cut-off, sensitivity, specificity, positive predictive value, negative predictive value, positive likelihood ratio, and negative likelihood ratio of anthropometric parameters as prediabetic predictors

Anthropometric Parameters	AUC	95% Confidence Interval	p-value*	Cut-off Point	Se	Sp	PPV	NPV	LR+	LR-
Men			<0.001							
BMI	0.559^{a}	0.542-0.576		22.34 kg/m^2	0.54	0.56	0.48	0.61	1.23	0.82
WC	0.564^{a}	0.547-0.582		79.1 cm	0.49	0.61	0.49	0.61	1.26	0.84
WHtR	0.571^{b}	0.554-0.589		0.46	0.65	0.46	0.48	0.63	1.20	0.76
BRI	0.571^{b}	0.554-0.589		3.12	0.65	0.46	0.48	0.63	1.20	0.76
C-index	0.560^{a}	0.543-0.578		1.19 m$^{3/2}$/kg$^{1/2}$	0.51	0.60	0.48	0.61	1.28	0.82
Women			<0.001							
BMI	0.564^{b}	0.552-0.577		25.06 kg/m^2	0.53	0.57	0.55	0.55	1.23	0.82
WC	0.566^{b}	0.554-0.579		84 cm	0.44	0.67	0.56	0.54	1.33	0.84
WHtR	0.573^{c}	0.560-0.585		0.55	0.48	0.63	0.56	0.55	1.30	0.83
BRI	0.573^{c}	0.560-0.585		4.76	0.48	0.63	0.56	0.55	1.30	0.83
C-index	0.548^{a}	0.535-0.560		1.19 m$^{3/2}$/kg$^{1/2}$	0.60	0.48	0.53	0.54	1.15	0.83

BMI=Body Mass Index, WC=Waist Circumference, WHtR=Waist-to-Height Ratio, BRI=Body Roundness Index, Se=Sensitivity, Sp=Specificity, PPV=Positive Predictive Value, NPV=Negative Predictive Value, LR+=Positive Likelihood Ratio, LR-=Negative Likelihood Ratio. Different superscript letters show significant differences in AUC among anthropometric parameters. *) The AUC difference of anthropometric parameters with reference line.

Using the Riskesdas 2018, this study compared diagnostic accuracy and determined appropriate cut-off values for BMI, WC, WHtR, BRI, and C-Index as predictors of prediabetes in Indonesian adults. The prevalence of prediabetes was 47.5% and increased with age. Consistent with this finding, previous studies have demonstrated a significant relationship between type 2 diabetes mellitus and age, showing that individuals aged ≥40 years are more likely to develop diabetes than younger age groups[22]. Several factors may partly explain, with increasing age, physical activity declines, leading to a decrease in lean body mass and an increase in adiposity (especially visceral adiposity), which is closely associated with insulin resistance. Moreover, physiological changes, comorbidities, and functional disorders that often occur in older adults exacerbate this condition[23].

The prevalence of prediabetes in Indonesian young adults in this study was 37.1%. This data is even higher than the incidence of prediabetes among young people in the US (24%)[24]. It indicates a very worrying threat, since, in this case, the demographic bonus, which is supposed to be an opportunity to become a developed country, can conversely be a disaster for Indonesia in the future due to the enormous economic burden of both immediate and unforeseen medical expenses caused by diabetes[25]. Therefore, it is necessary to implement both primary preventive measures, which involve health promotion, and secondary preventive measures, which entail early diagnosis and appropriate treatment, to halt the increase in prevalence and prevent further development of prediabetes in this age group.

The prevalence of prediabetes also increased with increasing body adiposity, where the obese group mainly experienced prediabetes compared to other nutritional status groups. The results presented here align with a study conducted in Iran that showed a correlation between obesity and the prevalence of prediabetes (25.17%), which was higher than the prevalence in people with nutritional status of overweight (17.95%) and normal (9.59%)[26]. This is due to excessive fat accumulation in obesity, which increases the release of free fatty acids and pro-inflammatory adipokines such as TNF-α, IL-6, leptin, resistin, MCP-1, MIF, and RBP4, thus contributing to the development of insulin resistance[27].

This study found that the predictive ability of the five investigated anthropometric parameters for prediabetes was very weak. In line with these results, previous studies on the diagnostic accuracy of BMI, waist circumference, and WHtR as prediabetic predictors in Indonesia also reported very weak results, with AUC values ranging from 0.5 to 0.6[28]. The predictive ability of BRI for prediabetes is equal to that of WHtR. However, it is better than WC, BMI, or even C-index. Consistent with this result, a study in a village population in Northeastern China also showed that BRI and WHtR had equal predictive ability for diabetes and were superior to WC, BMI, or body shape index (ABSI)[29]. The BRI is a geometric indicator that serves as an estimator of both visceral adipose tissue and the percentage of body fat. It is calculated using the individual's waist circumference and height as key variables, along with WHtR[10]. Moreover,

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the correlation test conducted in this study showed a close relationship between BRI and WHtR (r = 1; p-value<0.001), as did the study by Chang Y et al. (appendix 2)[29]. That may explain why the BRI and WHtR in this study have the same predictive ability for prediabetes.

Conversely, in women, the C-index was not better than WC and was even weaker than BMI. This result is consistent with an investigation of the Chinese population, which showed that the C-index's predictive capacity for diabetes was lower than that of WHtR, BRI, WC, and BMI[12]. On the contrary, a study in the United States of America demonstrated that the C-index performed better than WHtR, WC, BMI, and ABSI15 as a predictor of diabetes. The result was probably caused by variations in body composition and fat distribution among ethnic groups.

Although BMI has been widely used to categorize nutritional status, the anthropometric characteristics associated with central obesity have been identified as more effective screening tools for the detection of prediabetes in a multi-ethnic Asian population[30]. The findings of this research suggest that central obesity may contribute to the development of prediabetes using visceral fat, which exhibits greater metabolic activity compared to subcutaneous fat. Specifically, visceral fat is implicated in the secretion of non-esterified free fatty acids and pro-inflammatory adipokines, including Tumor Necrosis Factor (TNF)-α and Interleukin (IL)-6. These substances can potentially induce insulin resistance and harm pancreatic beta cells. This mechanism results in glucose intolerance and, ultimately, diabetes[27,31].

In this study, women demonstrated higher ideal cut-off values for anthropometric indicators of central obesity than men. This result aligns with sex-specific variations in adipose tissue distribution, wherein women predominantly accumulate fat in subcutaneous areas, especially the gluteofemoral region, which can sustain substantial fat deposits over time[32]. Studies showed that visceral fat is more highly correlated with cardiometabolic risks in women than in men[33]. That suggests that although overall women have less visceral fat than men, visceral fat accumulation in women poses a higher risk of cardiometabolic disorder development[33]. However, this study showed that women had higher optimal cut-off values for anthropometric parameters of the central obesity marker than men. This may be partly explained by the fact that most of the men in this study were active smokers. Nicotine (the main bioactive component of cigarette smoke) can activate the sympathetic nervous system, increasing lipolysis in white adipose tissue and thereby increasing free fatty acid release, contributing to insulin resistance and weight loss[34,35].

The optimal cut-off values for anthropometric parameters as prediabetic predictors were WHtR ≥0.46 in men and ≥0.55 in women, and BRI ≥3.12 in men and ≥4.76 in women. This study is the first to define the cut-off for BRI in the Indonesian population. At the same time, previous research by Djap HS et al. determined the appropriate cut-off value for WHtR as ≥0.46 in men and ≥0.51 in women[28]. Although both the present and previous studies were conducted in the same population, the difference in the WHtR cut-off in women might be due to age differences in the samples used, with the prior study encompassing individuals aged 15-65. Indeed, this can affect the optimal cut-off value of anthropometric parameters obtained according to the Regulation of the Minister of Health of the Republic of Indonesia Number 2 of 2020, nutritional status assessment for people aged 5-18 years old still uses the z-score index of BMI according to age (BMI/Age)[36].

Based on the predictive value, men and women with WHtR and BRI values exceeding the defined cut-off have a 48% and 56% chance, respectively, of being diabetic. Conversely, the samples of men and women with WHtR and BRI below the defined cut-off value have a 63% and 55% chance, respectively, of not having prediabetes (normal glucose). A diagnostic test is considered good if its sensitivity and specificity are at least 1.5[37]. Therefore, the defined cut-off values of WHtR and BRI in this study were less beneficial when applied, as the combination of sensitivity and specificity was only 1.11. Likewise, based on the likelihood ratio, in which the WHtR and BRI exceeded the defined cut-off value only minimally increased the likelihood of prediabetes, and vice versa (the positive likelihood ratio ranged from 1 to 2, while the negative likelihood ratio ranged from 0.5 to 1).

One strength of this study was its use of a large, community-based dataset (Riskesdas), providing a robust representation of the Indonesian population. Data collection by trained personnel also minimized measurement bias. However, the study had limitations, including the absence of data on medication use, which could influence body weight and glucose metabolism. Additionally, its cross-sectional design precludes causal inference and mechanistic insights. Post-diagnosis, behavioural changes among prediabetic individuals may also have influenced anthropometric values, potentially narrowing differences between groups.

CONCLUSIONS

The derived anthropometric parameters are not better than the basic anthropometric, in which BRI (with the best cut-off of ≥3.12 in men and ≥4.76 in women) has the same ability as a prediabetic/prediabetes predictor as WHtR (with the best cut-off of ≥0.46 in men and ≥0.55 in women). At the same time, C-index (with the best cut-off of ≥1.19 in both men and women) is weaker than waist circumference (with the best cut-off of ≥79.1 cm in men and ≥84 cm in women) and is even considered weaker compared to BMI (see Indonesian version) in women. The use of WHtR is preferred over BRI, even though both have the same ability to predict prediabetes. This may be due to that the BRI calculation is more complex, which can affect clinical applications. A prospective study must identify the longitudinal relationship between anthropometric parameters and prediabetes risk.

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CONFLICT OF INTEREST AND FUNDING DISCLOSURE

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AUTHOR CONTRIBUTIONS

AP: conceptualization, methodology, supervision, project administration, writing–original draft, review and editing; ENN: conceptualization, methodology, resources, software, validation, writing–original draft; FFD: data curation, visualization, formal analysis, writing–review and editing; DMK: software, resources, validation, writing-review and editing; AR: data curation, formal analysis, investigation, software, writing-review and editing.

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