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Association of Novel and Traditional Obesity Indices with Hypertension among Non-Obese Adults according to Physical Activity Level

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Abstract

Background: Individuals with comorbidities such as hypertension (HTN) have higher rates of obesity, caused by physical inactivity and lifestyle behaviors. Recently, novel obesity indices have demonstrated superior performance for HTN Although weight loss helps prevent chronic diseases, measuring traditional and novel obesity indices in non-obese adults remains important. Therefore, we aimed to investigate traditional and novel indices to differentiate HTN risk among non-obese Mongolian adults across physical activity levels.

Methods: We extracted data from the WHO STEP wise approach to noncommunicable disease risk factor surveillance (STEPS) in Mongolia in 2019. We included 3,031 participants. Exposures included the novel triglyceride- and triglyceride-glucose-derived obesity indices (TyG), triglyceride-glucose-body mass index (TyG), triglyceride-glucose-waist-to-height ratio (TyG-WHtR), and traditional anthropometric indices. We defined HTN as a mean systolic blood pressure of ≥130 mmHg, a mean diastolic blood pressure of ≥80 mmHg, a self-reported HTN diagnosis, or use of an antihypertensive drug. We used multivariable logistic regression to estimate the odds ratio (OR) and 95% confidence intervals (95% CI).

Results and Conclusion: 1,861 (61.4%) met the definition of HTN, and 1,170 (38.6%) were classified as non-hypertensive. The mean age of the study population was 40.9 ± 11.5 years, 51.0% were men, and 68.2% lived in urban areas. Among nonobese Mongolian adults, measures of central adiposity and body shape were consistently associated with HTN, supporting the hypothesis that BMI or obesity status alone may not adequately capture cardiometabolic risk. Waist circumference (WC), body round index (BRI), and TyG-derived anthropometric indices, particularly TyG-WHtR, showed consistent associations with hypertension across physical activity strata, while WC and BMI provided the greatest incremental improvement in HTN discrimination.

Keywords: Novel obesity indices; Physical inactivity; Central obesity; Hypertension.

Introduction

Hypertension (HTN) is a significant modifiable risk factor for cardiovascular disease and remains a leading cause of premature morbidity and mortality worldwide. In 2024, an estimated 1.4 billion individuals aged 30 to 79 years had HTN [1]. The prevalence of HTN is increasing rapidly in low- and middle-income countries [2]. In Mongolia, HTN and ischemic heart diseases constitute the primary types of cardiovascular diseases

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(CVD), accounting for more than 60 percent of CVD-related morbidity [3]. In 2013, HTN prevalence was 27.5 percent, with a mean systolic blood pressure of 127 mmHg and a mean diastolic blood pressure of 79.9 mmHg [4]. These rates are influenced by factors such as body weight, high salt intake, smoking, and elevated serum cholesterol among Mongolians [5]. Individuals with comorbidities such as HTN, stroke, and diabetes mellitus have higher rates of obesity, caused by physical inactivity and lifestyle behaviors [6]. Body mass index (BMI) is the most commonly used measure for obesity; however, it is less predictive of fat distribution. Traditional anthropometric measures, including BMI, waist circumference (WC), and waist-to-height ratio (WHtR), are widely used to assess obesity-related risk of HTN. More recently, novel obesity indices (NOIs), which integrate measures of visceral adiposity, insulin resistance, and lipid metabolism—such as the triglyceride-glucose (TyG) index, TyG-WHtR, TyG-WC, lipid accumulation product (LAP), visceral adiposity index (VAI), and cardiometabolic index (CMI)—have demonstrated superior predictive performance for HTN compared with conventional anthropometric measures. Previous studies have demonstrated that novel obesity measurements derived from the TyG index are positively associated with the prevalence of HTN. Additionally, both the TyG index and the non-HDL cholesterol-to-HDL cholesterol ratio serve as dose-dependent predictors of cardiometabolic diseases. Individuals with a high body fat percentage exhibit an increased risk of HTN, even when other measurements such as BMI and WHtR are lower [7-9]. Any intensity of physical activity was associated with lower CVD risk factors in obese adults [10]. Moreover, higher levels of physical activity were inversely related to low visceral adiposity index in overweight individuals [11]. Physical activity may have a protective and anti-inflammatory impact on novel obesity indices. Although reducing weight is effective for preventing chronic diseases, determining measurements such as traditional and novel obesity indices in non-obese adults is important. Therefore, we aimed to investigate traditional and novel indices to differentiate HTN risk among non-obese Mongolian adults across physical activity levels.

Materials and Methods

Study design and participants

In this study, we extracted data from the WHO STEPwise approach to noncommunicable disease risk factor surveillance (STEPS) in Mongolia in 2019. The response rate was 98.1% [12]. Participants with missing data, or pregnancy were excluded. Additionally, individuals with a history of stroke or cardiovascular diseases, including myocardial infarction or angina pectoris, were not included. The final analysis comprised 3,031 participants. The study protocols received approval from the Ethical Review Committee of the Western Pacific Regional Office of the WHO and the Ministry of Health Medical Ethical Committee in Mongolia, in accordance with the Declaration of Helsinki. All participants also provided written informed consent [13-15]. The STEPS survey is a standardized instrument developed and approved by the World Health Organization (WHO). Step 1 is a questionnaire-based interview that includes sociodemographic characteristics and risk factors for NCDs. Step 2 involves physical measurements, such as blood pressure, height, weight, and WC. Step 3 involves biochemical measurements, including blood glucose, blood lipid levels, and urinary sodium levels [13-15].

Measurements

Body weight was measured using electronic 'GIMA' scales (Italy). The 'GIMA' device is a research-grade bioimpedance instrument that assesses body weight, body fat percentage, and water, muscle, and bone mass with 0.1% precision. Body height was measured using the 'Somatometre-Stanley 04-116' device, designed for research and providing millimeter precision. All anthropometric measurements, including body weight and height, were collected by trained personnel. BMI was calculated by dividing body weight (in kilograms) by the square of body height (in meters). Physical activity levels were measured using the Global Physical Activity Questionnaire (GPAQ) [16]. According to the WHO guidelines, recommendations for moderate-intensity physical activity (MPA) per week were categorized into three groups. Those are: low-moderate intensity physical activity (1–149 min/week), recommended level (150–299 min/week), and high-moderate intensity physical activity (≥300 min/week). High-intensity physical activity was defined as ≥75 minutes of vigorous physical activity per week [19]. Sociodemographic questionnaires were used to collect information on age range, education (categorized in 9 groups: no formal schooling, less than primary school, primary school completed, secondary school completed, high school completed, college completed, university completed, postgraduate degree, refused to answer), and family monthly income. Anthropometric measurements, such as blood pressure, obtained with the OMRON Model M5 automatic blood pressure monitor, were averaged over the last 2 readings for analysis. Smoking status was determined by the question, “Do you currently smoke tobacco products daily? Yes/No.” Drinking status was assessed with, “Have you ever consumed any alcoholic drink? Yes/No.” Diabetes status was defined by the response to, “Have you ever been told by a doctor or other health worker that you have raised blood sugar or diabetes? Yes/No.” WC was measured using a 'GIMA tape meter', a non-stretch tape accurate to the millimeter and assessed by placing the tape around the bare abdomen just above the upper hip bone. Central obesity was defined as a WC of more than 90 cm for men and 80 cm for women, according to the interim lower cut-offs for Asians recommended by the World Health Organization (WHO) [13-15].

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Exposure

The exposures include the novel triglyceride- and triglyceride-glucose-derived obesity indices (lipid accumulation product, LAP, visceral adiposity index, VAI, cardiometabolic index, CMI), triglyceride-glucose-derived obesity indices (triglyceride glucose-body mass index (TyG-BMI), triglyceride-glucose-waist-to-height ratio (TyG-WHtR)), traditional anthropometric indices. The novel obesity indices were calculated, and details are provided in supplementary materials.

Outcome

The outcome of HTN was defined as a mean systolic blood pressure of ≥130 mmHg, a mean diastolic blood pressure of ≥80 mmHg, a self-reported HTN diagnosis, or the use of an antihypertensive drug.

Statistical analysis

Continuous variables are described by mean, standard deviation, and median range; categorical variables are described by number and percentage. A students' t-test was used to analyze mean differences between years; a Kruskal-Wallis test was used to analyze median differences; and the chi-square test was used for categorical variables. Multivariable logistic regression analysis conducted for estimating odds ratio (OR) and 95% confidence intervals (95%CI) adjusting for covariates including age, sex, residential area, marital status, education level, smoking and drinking habits, moderate intensity physical activity level and urinary sodium. Receiver operating characteristics curve (ROC) analysis was performed to assess the predictive accuracy of the novel and traditional obesity induced indices and HTN status by physical activity level.

Results

Participant characteristics

A total of 3,031 participants were included in the analysis, of whom 1,861 (61.4%) met the definition of HTN and 1,170 (38.6%) were classified as non-hypertensive. The mean age of the study population was 40.9 ± 11.5 years, 51.0% were men, and 68.2% lived in urban areas. Nearly half of the participants had completed college or university education (47.8%), and approximately three-quarters were currently married (76.0%). Current smoking and alcohol consumption were reported by 31.7% and 61.4% of participants, respectively. Median MPA was 0 min/week (IQR, 0–90 min/week). Participants with HTN were older than those without HTN (43.6 ± 11.2 and 36.7 ± 10.6 years, p<0.001), and men accounted for a greater proportion of the hypertensive group (56.7% and 42.1%, p<0.001). HTN status also differed according to residential area, educational attainment, marital status, current smoking, and alcohol consumption. In contrast, family income and moderate-intensity physical activity did not differ significantly according to HTN status. Participants with HTN also had greater body weight (p<0.001). Fasting glucose, total cholesterol, triglycerides, and HDL cholesterol did not differ significantly between the groups. Although urinary sodium differed statistically between HTN groups, the absolute difference was small. Additional lifestyle characteristics are presented in Table 1. Household salt-use patterns differed according to HTN status (p=0.009), whereas personal salt use and consumption of processed foods high in salt did not differ significantly. Fruit and vegetable intake was also comparable between the HTN groups.

Table 1: Baseline characteristics of the participants across hypertension status.

Variables	Total	Hypertensive	Non-hypertensive	p-value
Age, years	40.94 (11.46)	43.63 (11.17)	36.67 (10.6)	<.0001
Sex				<0.001
Men	1547 (51.04)	1055 (56.69)	492 (42.05)	
Women	1484 (48.96)	806 (43.31)	678 (57.95)	
Area				0.04
Rural	965 (31.84)	627 (33.69)	338 (28.89)	
Urban	2066 (68.16)	1234 (66.31)	832 (71.11)	
Education				<0.001
No formal schooling	34 (1.12)	25 (1.34)	9 (0.77)	
Less than primary school	43 (1.42)	28 (1.5)	15 (1.28)	
Primary school completed	142 (4.68)	107 (5.75)	35 (2.99)	

Secondary school completed	445 (14.68)	306 (16.44)	139 (11.88)	
High school completed	770 (25.4)	500 (26.87)	270 (23.08)	
College/University completed	1449 (47.81)	816 (43.85)	633 (54.1)	
Post graduate degree	148 (4.88)	79 (4.25)	69 (5.9)	
Marital status				<0.001
Never married	373 (12.31)	165 (8.87)	208 (17.78)	
Currently married	2303 (75.98)	1484 (79.74)	819 (70)	
Separated	43 (1.42)	29 (1.56)	14 (1.2)	
Divorced	70 (2.31)	42 (2.26)	28 (2.39)	
Widowed	89 (2.94)	72 (3.87)	17 (1.45)	
Cohabitating	153 (5.05)	69 (3.71)	84 (7.18)	
Smoking, current				0.001
Yes	962 (31.74)	634 (34.07)	328 (28.03)	
No	2069 (68.26)	1227 (65.93)	842 (71.97)	
Alcohol consumption				<0.001
Yes	1862 (61.43)	1202 (64.59)	660 (56.41)	
No	1169 (38.57)	659 (35.41)	510 (43.59)	
Education, years	11.62 (4.12)	11.26 (4.38)	12.19 (3.59)	<.0001
Income, USD	388.65 (233.19, 660.71)	388.65 (194.33, 660.71)	388.65 (233.19, 621.84)	0.13
Moderate intensity physical activity, minutes per week	0 (0, 90)	0 (0, 80)	0 (0, 90)	0.67
Systolic blood pressure, mmHg	122.87 (18.24)	131.21 (17.5)	109.59 (9.37)	<0.001
Diastolic blood pressure, mmHg	79.69 (11.98)	85.58 (11.1)	70.32 (5.72)	<0.001
Blood pressure medication	1.87 (0.34)	1.79 (0.41)	2 (0)	<0.001
Fasting blood glucose, mmol/L	6.08 (4.31)	6.19 (4.31)	5.91 (4.3)	0.08
Weight, kg	71.54 (18.14)	75.38 (20.28)	65.43 (11.74)	0.003
Waist circumference, cm	89.77 (13.44)	93.44 (13.26)	83.94 (11.55)	<0.001
Total cholesterol, mmol/L	5.07 (6.24)	5.18 (6.12)	4.9 (6.42)	0.07
Triglycerides, mmol/L	4.41 (14.2)	4.02 (12.79)	5.04 (16.17)	0.25
HDL-cholesterol	2.77 (10.19)	2.93 (10.84)	2.51 (9.05)	0.86
Urinary sodium, mmol/l	113.91 (57.61)	114.07 (57.6)	113.67 (57.65)	0.022

Note: Continuous variables are described by mean, standard deviation, and median range; categorical variables are described by number and percentage. A students' t-test was used to analyse mean differences between years; a Kruskal-Wallis test was used to analyze median differences; and the chi-square test was used for categorical variables. Two-sided p value <0.05 defined as statistically significant.

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Associations of obesity indices with HTN according to physical activity

Among non-obese adults, several traditional anthropometric and combined TyG–anthropometric indices were significantly associated with HTN in both physically active and physically inactive participants (Table 2). TyG-WHtR was associated with higher odds of HTN among physically active participants (OR=1.86, 95% CI [1.59–2.16], p<0.001) and physically inactive participants (OR=1.51, 95% CI [1.27–1.81], p<0.001). TyG-BMI and TyG-WC were likewise positively associated with HTN in both physical-activity strata. Similar associations were observed for the anthropometric indices. Each unit increase in BRI was associated with higher odds of HTN among both physically active (OR=1.51, 95% CI [1.39–1.64]) and inactive participants (OR=1.31, 95% CI [1.19–1.44]; both p<0.001). PI was also positively associated with HTN in the active (OR=1.24, 95% CI [1.19–1.30]) and inactive groups (OR=1.20, 95% CI [1.14–1.26]). Corresponding associations were observed for WC (OR=1.06 and 1.04 per cm, respectively) and BMI (OR=1.16 and 1.14 per kg/m², respectively; all p<0.001). The conicity index showed a strong but imprecisely estimated association among physically active participants (OR=34.60, 95% CI [10.47–114.27], p<0.001), whereas the association was not statistically significant among inactive participants (OR=2.62, 95% CI [0.78–8.79], p=0.12). In contrast, the TyG index alone, LAP, CMI, and TyG-NHHR were not significantly associated with HTN in either physical-activity group. VAI showed a small inverse association in physically inactive participants (p=0.03), but not in physically active participants (p=0.10).

Predictive performance according to physical activity

ROC analysis demonstrated modest discriminatory ability for most obesity indices, with generally greater discrimination among physically inactive participants (Supplemental Figure 1). Among physically active participants, the largest areas under the ROC curve shown in the figure were observed for BMI (AUC=0.690), TyG-BMI (AUC=0.686), TyG-WC (AUC=0.685), BRI and WHtR (both AUC=0.683), and TyG-WHtR (AUC=0.677). Among physically inactive participants, BMI had an AUC of 0.707, while BRI and WHtR each had an AUC of 0.705, followed by TyG-WC (AUC=0.699) and TyG-BMI (AUC=0.693). The ROC analyses therefore

Table 2: Association between obesity induced indices and risk of hypertension among nonobese adults stratified by moderate intensity physical activity.

Variables	Physically active		Physically inactive	
Indices	OR (95% CI)	p-value	OR (95% CI)	p-value
TyG − NHHR	1.001 (0.998, 1.004)	0.83	0.998 (0.99, 1)	0.56
TyG − WHtR	1.86 (1.59, 2.16)	<0.001	1.51 (1.27, 1.81)	<0.001
TyG − BMI	1.01 (1.01, 1.02)	<0.001	1.01 (1.01, 1.02)	<0.001
TyG − WC	1 (1, 1.01)	<0.001	1 (1, 1)	<0.001
TyG index	0.97 (0.87, 1.09)	0.63	0.99 (0.86, 1.14)	0.91
CMI	0.99 (0.97, 1.01)	0.26	0.98 (0.96, 1)	0.11
VAI	1.00 (0.99, 1.00)	0.1	0.99 (0.98, 1)	0.03
LAP	1.00 (1.00, 1.00)	0.88	1 (1, 1)	0.84
BRI	1.51 (1.39, 1.64)	<0.001	1.31 (1.19, 1.44)	<0.001
CI	34.6 (10.47, 114.27)	<0.001	2.62 (0.78, 8.79)	0.12
PI	1.24 (1.19, 1.30)	<0.001	1.2 (1.14, 1.26)	<0.001
WC, cm	1.06 (1.05, 1.07)	<0.001	1.04 (1.03, 1.05)	<0.001
BMI, kg/m²	1.16 (1.13, 1.19)	<0.001	1.14 (1.1, 1.18)	<0.001

Note: Multivariable logistic regression analysis conducted for estimating odds ratio (OR) and 95% confidence intervals (95%CI) adjusting for covariates including age, sex, residential area, marital status, education level, smoking and drinking habits, moderate intensity physical activity level and urinary sodium.

Abbreviations: BMI, body mass index; BRI, body roundness index; CI, confidence interval; CMI, cardiometabolic index; HDL-C, high-density lipoprotein cholesterol; LAP, lipid accumulation product; NHHR, non-high-density lipoprotein cholesterol to high-density lipoprotein cholesterol ratio; OR, odds ratio; PI, ponderal index; TG, triglycerides; TyG, triglyceride-glucose index; TyG-BMI, triglyceride-glucose index–body mass index; TyG-NHHR, triglyceride-glucose index–non-HDL-C/HDL-C ratio; TyG-WC, triglyceride-glucose index–waist circumference; TyG-WHtR, triglyceride-glucose index–waist-to-height ratio; VAI, visceral adiposity index; WC, waist circumference; WHtR, waist-to-height ratio.

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showed greater discrimination for anthropometric and TyG–anthropometric measures than for TyG alone or ABSI. Supplemental Fig. 1 presents the ROC curves for the two physical-activity strata. At the selected ROC thresholds, TyG-BMI had the largest Youden index among physically active participants (0.30; sensitivity 0.55 and specificity 0.76), although BMI, BRI, WC, and WHtR produced similar Youden indices of approximately 0.29. Among physically inactive participants, WC produced the largest Youden index (0.33; sensitivity 0.65 and specificity 0.68), followed by BRI and WHtR (0.32 each) and BMI (0.31). CMI and VAI were characterized by very high sensitivity but low specificity in both groups.

Table 3: ROC Cutoff, Sensitivity, Specificity, and Youden Index.

Obesity indices	Physically active individuals			
	Cutoff	**Sensitivity**	**Specificity**	**Youden Index**
ABSI	0.59	0.56	0.57	0.12
BMI	0.57	0.64	0.66	0.29
BRI	0.55	0.67	0.62	0.29
CI	0.59	0.61	0.62	0.23
CMI	0.57	0.98	0.04	0.02
LAP	0.58	0.67	0.6	0.27
PI	0.58	0.61	0.64	0.25
TyG	0.58	0.57	0.61	0.17
TyG-BMI	0.61	0.55	0.76	0.3
TyG-NHHR	0.57	0.66	0.51	0.17
TyG-WC	0.55	0.7	0.58	0.28
TyG-WHtR	0.53	0.74	0.55	0.28
VAI	0.49	0.99	0.04	0.03
WC	0.62	0.54	0.75	0.29
WHtR	0.56	0.67	0.62	0.29
	Physically inactive individuals			
ABSI	0.65	0.55	0.64	0.19
BMI	0.62	0.65	0.67	0.31
BRI	0.6	0.69	0.63	0.32
CI	0.64	0.64	0.64	0.28
CMI	0.62	0.98	0.04	0.02
LAP	0.63	0.62	0.63	0.25
PI	0.62	0.64	0.65	0.29
TyG	0.63	0.53	0.63	0.16
TyG-BMI	0.61	0.67	0.63	0.3
TyG-NHHR	0.64	0.52	0.68	0.19
TyG-WC	0.63	0.63	0.67	0.3
TyG-WHtR	0.61	0.67	0.62	0.29
VAI	0.57	0.98	0.04	0.03
WC	0.64	0.65	0.68	0.33
WHtR	0.61	0.69	0.63	0.32

Note: Receiver operating characteristics curve (ROC) analysis was performed to assess the predictive accuracy of the novel and traditional obesity induced indices and HTN status by physical activity level.

ABSI, A Body Shape Index; BMI, body mass index; BRI, body roundness index; CI, confidence interval; CMI, cardiometabolic index; HDL-C, high-density lipoprotein cholesterol; LAP, lipid accumulation product; NHHR, non-high-density lipoprotein cholesterol to high-density lipoprotein cholesterol ratio; OR, odds ratio; PI, ponderal index; TG, triglycerides; TyG, triglyceride-glucose index; TyG-BMI, triglyceride-glucose index–body mass index; TyG-NHHR, triglyceride-glucose index–non-HDL-C/HDL-C ratio; TyG-WC, triglyceride-glucose index–waist circumference; TyG-WHtR, triglyceride-glucose index–waist-to-height ratio; VAI, visceral adiposity index; WC, waist circumference; WHtR, waist-to-height ratio.

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Incremental prediction of HTN according to physical activity

Addition of obesity indices to multivariable models resulted in varying improvements in discrimination (Table 4). Among physically active participants, addition of BMI produced an adjusted AUC of 0.76 (95% CI [0.73–0.78]) and the largest increase in AUC (ΔAUC=0.034). PI (adjusted AUC=0.75, ΔAUC=0.029), TyG-BMI (0.75, ΔAUC=0.028), and WC (0.75, ΔAUC=0.025) provided smaller improvements. BRI and WHtR each increased the AUC by 0.021. In comparison, CI, VAI, CMI, TyG-NHHR, ABSI, LAP, and TyG alone produced little or no additional discrimination. Incremental gains were somewhat greater among physically inactive participants. WC produced an adjusted AUC of 0.78 (95% CI [0.75–0.80]) with ΔAUC=0.042, followed by BMI (adjusted AUC=0.78, ΔAUC=0.040), BRI and WHtR (both adjusted AUC=0.77, ΔAUC=0.040), and PI (adjusted AUC=0.77, ΔAUC=0.036). TyG-BMI, TyG-WC, and TyG-WHtR provided more modest improvements, whereas VAI, TyG, CMI, LAP, and TyG-NHHR provided essentially no incremental discrimination. Overall, anthropometric measures and TyG-derived indices incorporating anthropometric parameters were consistently associated with HTN among non-obese adults across physical-activity strata. BMI, WC, BRI, WHtR, PI, TyG-BMI, TyG-WC, and TyG-WHtR showed the most consistent associations, whereas TyG alone, LAP, CMI, VAI, and TyG-NHHR generally showed weaker or inconsistent associations.

ABSI, A Body Shape Index; BMI, body mass index; BRI, body roundness index; CI, confidence interval; CMI, cardiometabolic index; HDL-C, high-density lipoprotein cholesterol; LAP, lipid accumulation product; NHHR, non-high-density lipoprotein cholesterol to high-density lipoprotein cholesterol ratio; OR, odds ratio; PI, ponderal index; TG, triglycerides; TyG, triglyceride-glucose index; TyG-BMI, triglyceride-glucose index–body mass index; TyG-NHHR, triglyceride-glucose index–non-HDL-C/HDL-C ratio; TyG-WC, triglyceride-glucose index–waist circumference; TyG-WHtR, triglyceride-glucose index–waist-to-height ratio; VAI, visceral adiposity index; WC, waist circumference; WHtR, waist-to-height ratio.

Table 4: Incremental Prediction of Hypertension.

Indices	Physically active individuals		
	Base model AUC	Adjusted AUC (95% CI)	ΔAUC
BMI	4.71	0.76 (0.73, 0.78)	0.034
PI	8.71	0.75 (0.72, 0.78)	0.029
TyG-BMI	10.71	0.75 (0.72, 0.78)	0.028
WC	11.71	0.75 (0.72, 0.77)	0.025
BRI	12.71	0.74 (0.72, 0.77)	0.021
WHtR	13.71	0.74 (0.72, 0.77)	0.021
TyG-WC	14.71	0.74 (0.71, 0.76)	0.016
TyG-WHtR	15.71	0.73 (0.71, 0.76)	0.014
CI	16.71	0.72 (0.7, 0.75)	0.003
VAI	17.71	0.72 (0.7, 0.75)	0.002
CMI	18.71	0.72 (0.7, 0.75)	0.002
TyG-NHHR	19.71	0.72 (0.69, 0.75)	0
ABSI	20.71	0.72 (0.69, 0.75)	0
LAP	21.71	0.72 (0.69, 0.75)	0
TyG	22.71	0.72 (0.69, 0.75)	0

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	Physically inactive individuals		
WC	23.71	0.78 (0.75, 0.8)	0.042
BMI	24.71	0.78 (0.75, 0.8)	0.04
BRI	25.71	0.77 (0.75, 0.8)	0.04
WHtR	26.71	0.77 (0.75, 0.8)	0.04
PI	27.71	0.77 (0.75, 0.79)	0.036
TyG-BMI	28.71	0.77 (0.74, 0.79)	0.031
TyG-WC	29.71	0.76 (0.74, 0.79)	0.027
TyG-WHtR	30.71	0.76 (0.74, 0.78)	0.027
CI	31.71	0.75 (0.73, 0.78)	0.017
ABSI	32.71	0.74 (0.71, 0.76)	0.003
VAI	33.71	0.74 (0.71, 0.76)	0
TyG	34.71	0.74 (0.71, 0.76)	0
CMI	35.71	0.74 (0.71, 0.76)	0
LAP	36.71	0.73 (0.71, 0.76)	0
TyG-NHHR	37.71	0.73 (0.71, 0.76)	0

Note: Base model includes age, sex, residential area, education, marital status, smoking status, alcohol usage, moderate intensity physical activity, and urinary sodium.

ABSI, A Body Shape Index; BMI, body mass index; BRI, body roundness index; CI, confidence interval; CMI, cardiometabolic index; HDL-C, high-density lipoprotein cholesterol; LAP, lipid accumulation product; NHHR, non-high-density lipoprotein cholesterol to high-density lipoprotein cholesterol ratio; OR, odds ratio; PI, ponderal index; TG, triglycerides; TyG, triglyceride-glucose index; TyG-BMI, triglyceride-glucose index–body mass index; TyG-NHHR, triglyceride-glucose index–non-HDL-C/HDL-C ratio; TyG-WC, triglyceride-glucose index–waist circumference; TyG-WHtR, triglyceride-glucose index–waist-to-height ratio; VAI, visceral adiposity index; WC, waist circumference; WHtR, waist-to-height ratio.

Discussion

The present study provides a detailed evaluation of both new and traditional obesity-related measures for predicting the risk of HTN in nonobese adults. We investigated physical activity levels to assess the optimal diagnostic cutoffs, clinical usefulness as predictors, and risk levels. The results offer several important clinical insights. Most importantly, our data show that central adiposity and body shape measures, especially WC, BRI, and TyG-WHtR, are strong indicators of HTN risk even in people considered "nonobese" by global standards. Our analysis also highlights unexpected differences in how physical activity affects the risk and predictive value of these biomarkers.

Highly predictable biomarkers for physically active and inactive nonobese individuals were BMI and WC. For physically inactive adults, BRI and WHtR were more predictive measures for the risk of HTN. Moderate-to-high-intensity physical activity improves endothelial function and insulin sensitivity, reducing visceral adipose tissue and thereby lowering cardiovascular risk (17, 18). Therefore, fat distribution markers are less predictable than in inactive individuals. The above results show that combining the marker with central obesity measurement may indicate a risk for comorbidity. Visceral fat accumulation accelerates systemic inflammation, resulting in arterial stiffness and promoting the development of HTN in nonobese adults (19). TyG-WHtR was associated with multimorbidity and may be a useful measure for evaluating vascular injury risk (20, 21). Furthermore, CI showed extremely high relative risk, showing that even for nonobese adults, CI is a highly sensitive marker for HTN risk (Among MHO adults: OR: 22.13 (95% CI: 6.08; 80.63); among physically active nonobese adults: OR: 34.6 (95%CI: 10.47; 114.27)). Interestingly, the prior study also revealed that CI was more strongly associated with pre-hypertensive risk (OR: 102.57 (95%CI: 14.06-747.37)) than with hypertensive risk (22). As in previous cohort studies, the present study showed that BRI was strongly associated with HTN (23). Although BMI and WC have shown sensitive, predictive effects for HTN risk, the present study included nonobese individuals. Therefore, the above measurements could not indicate being overweight. However, high risk shown by CI, TyG-WHtR, and BRI may indicate that abdominal and visceral fat distributions are

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more related to the hidden risk of HTN. Moreover, for lean, highly active individuals, the Conicity Index is preferable, and for nonobese healthy adults, waist circumference, body roundness index, and triglyceride-glucose-waist-to-height ratio should be used in clinical practice rather than traditional measures. In contrast, other novel indices, such as the lipid accumulation product, TyG-NHHR, and the Triglyceride-Glucose index, did not show significant associations among nonobese individuals, regardless of physical activity. The present study has several strengths and notable limitations. First, it used nationally representative STEPS surveys conducted according to standardized WHO protocols at three time points over a decade. Second, anthropometric measurements were objectively assessed by trained personnel rather than self-reported. Third, the large sample size enabled detailed subgroup analyses by sex and age. However, several limitations should be considered. First, the cross-sectional design precludes causal inference about the relationship between physical activity and BMI. Second, physical activity was self-reported using the GPAQ questionnaire and may be subject to recall or reporting bias. Third, dietary intake and sedentary behavior were not comprehensively assessed, and therefore, residual confounding may remain. Finally, because BMI does not distinguish between fat and lean mass, some misclassification of adiposity may have occurred. Despite these limitations, the findings have important public health implications. The concurrent increase in BMI and decline in physical activity highlight the urgent need for national strategies promoting active lifestyles in Mongolia. Public health interventions to increase physical activity, particularly among inactive adults and middle-aged adults, may help reduce the burden of obesity-related diseases. Policies supporting active transportation, community-based exercise programs, and workplace physical activity promotion could contribute substantially to NCD prevention.

Conclusions

Among nonobese Mongolian adults, measures of central adiposity and body shape were consistently associated with HTN, supporting the hypothesis that BMI or obesity status alone may not adequately capture cardiometabolic risk. WC, BRI, and TyG-derived anthropometric indices, particularly TyG-WHtR, showed consistent associations with HTN across physical activity strata, while WC and BMI provided the greatest incremental improvement in HTN discrimination. These findings suggest that simple measures of abdominal adiposity may complement conventional BMI-based assessment for identifying HTN risk among individuals without general obesity. However, the cross-sectional design precludes conclusions regarding temporality or causality, and the findings should be interpreted within the context of the Mongolian population studied. Prospective studies are warranted to determine whether these indices predict incident HTN and whether incorporating central adiposity measures into routine screening improves early cardiovascular risk identification.

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Statements and Declarations

Competing interests: The authors have no relevant financial or non-financial interests to disclose.

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Ethical Approval and Informed Consent Statements

The 2019 Mongolia WHO STEPS survey was approved by the Ethical Review Committee of the WHO Regional Office for the Western Pacific and the Medical Ethics Committee of the Ministry of Health of Mongolia. Written informed consent was obtained from all participants before data collection [13-15]. The present study used anonymized secondary data, and participant confidentiality was maintained in accordance with the Declaration of Helsinki.

Data Availability Statement

The data source is the World Health Organization NCD Microdata Repository (URL: https://extranet.who.int/ncdsmicrodata/index.php/catalog).

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