

Original Research Article

Differential predictive ability of the novel obesity indices on hypertension among non-obese adults stratified by metabolic health

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Received: 28 September 2026

Revised: 23 October 2026

Accepted: 26 October 2026

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ABSTRACT

Background: Novel obesity indices that integrate visceral adiposity, insulin resistance, and lipid metabolism may predict hypertension (HTN) better than conventional anthropometric measures. We compared novel and traditional obesity indices for HTN among non-obese Mongolian adults according to metabolic health status.

Methods: We used data from the 2019 Mongolian WHO STEPwise survey (STEPS) and included adults aged 18-65 years with a body mass index (BMI) <30 kg/m². Exposures were triglyceride- and triglyceride-glucose (TyG)-derived indices, including the TyG-waist-to-height ratio (TyG-WHtR), and traditional anthropometric indices; the outcome was HTN. Participants with diabetes or dyslipidemia were classified as metabolically unhealthy (MUI) and the remainder as metabolically healthy (MHI). Multivariable logistic regression and receiver operating characteristic (ROC) analyses were performed.

Results: Of 3,031 participants, 61.4% had HTN, and the mean age was 40.9 (SD 11.5) years. TyG-WHtR had the largest odds ratio (OR) for HTN in both MHI (OR 1.68, 95% CI 1.43-1.97) and MUI (OR 1.72, 95% CI 1.46-2.04), followed by the body roundness index (BRI). Indices based mainly on lipids and glucose were not positively associated with HTN. Discrimination was modest; the highest areas under the curve (AUC) were for BMI (0.657) among MHI and for BRI and WHtR (0.691) among MUI.

Conclusions: Among non-obese adults, anthropometric and TyG-anthropometric indices, particularly TyG-WHtR, were associated with HTN regardless of metabolic status, whereas lipid-only indices were not. Discrimination was modest and greater in MUI, and simple measures such as BMI and waist circumference performed as well as the novel indices.

Keywords: Anthropometry, Hypertension, Insulin resistance, Metabolic health, Mongolia, Obesity

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 were affected by HTN.¹ The prevalence of HTN is increasing rapidly in low- and middle-income countries.² In Mongolia, HTN and ischemic heart disease constitute the primary types of cardiovascular diseases (CVD), accounting for more than 60% of CVD-related morbidity.³ In 2013, the prevalence of HTN was 27.5%,

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 Comorbidities such as HTN, stroke, and diabetes mellitus are more common among individuals with obesity, which is driven by physical inactivity and other lifestyle behaviors.⁶ Body mass index (BMI) is the most commonly used measure for obesity; however, it does not reflect fat distribution. Traditional anthropometric measures, including BMI, waist circumference (WC), and the waist-to-height ratio (WHtR), are widely used to assess obesity-related HTN risk. Other body-shape indices, such as the body roundness index (BRI), a body shape index (ABSI), the conicity index (CI), and the ponderal index (PI), better reflect central fat distribution. More recently, novel obesity indices that integrate measures of visceral adiposity, insulin resistance, and lipid metabolism have been proposed. These include the triglyceride-glucose (TyG) index and its combinations with anthropometric measures (TyG-BMI, TyG-WC, and TyG-WHtR), the TyG-non-high-density lipoprotein to high-density lipoprotein cholesterol ratio (TyG-NHHR), the lipid accumulation product (LAP), the visceral adiposity index (VAI), and the cardiometabolic index (CMI). Several studies have reported that these indices predict HTN better than conventional anthropometric measures.⁷

Previous studies have demonstrated that novel obesity measurements derived from the triglyceride-glucose index are positively associated with the prevalence of HTN. Additionally, both the triglyceride-glucose 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 body mass index (BMI) and waist-hip ratio are lower.⁷⁻⁹ Any intensity of physical activity was associated with lower CVD risk factors in obese adults.^{10,11} Although weight reduction is effective for preventing chronic diseases, identifying which traditional and novel obesity indices best capture HTN risk in non-obese adults remains important. Therefore, we aimed to investigate traditional and novel indices to differentiate HTN risk among non-obese Mongolian adults according to metabolic health status.

METHODS

Study design and participants

This was a nationwide observational study. In this study, we included all participants' data available from the WHO STEPwise approach to noncommunicable disease risk factor surveillance (STEPS) in Mongolia in 2019. This study was based on nationally representative data from the 2019 WHO STEPwise approach to noncommunicable disease risk factor surveillance (STEPS) survey in Mongolia, which commenced in

September 2019. The response rate was 98.1%.¹² The study followed a quantitative, observational, cross-sectional design. Participants with missing data or who were pregnant were excluded. Additionally, individuals with a history of stroke or cardiovascular diseases, including myocardial infarction or angina pectoris, were not included.

Rationale for exclusion criteria

Pregnant participants were excluded because pregnancy-related changes in body weight, body mass index (BMI), and metabolic parameters may affect assessment of obesity indices. Participants with self-reported history of a myocardial infarction or angina were excluded because pre-existing cardiovascular disease and subsequent treatment or lifestyle modifications may influence obesity-related risk profiles and the associations between obesity indices and hypertension's final analysis comprised of 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 waist circumference. 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 Based on WHO recommendations, weekly moderate-intensity physical activity (MPA) was categorized into three groups: low-moderate intensity physical activity (1-149 minutes/week), recommended level (150-299 minutes/week), and high-moderate intensity physical activity (≥ 300 minutes/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, education (categorized into nine 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. Blood pressure was measured with an OMRON M5 automatic blood pressure monitor, and the mean of the last two readings was used 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 waist circumference of ≥ 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

Exposure

The exposures included novel triglyceride-derived obesity indices [lipid accumulation product (LAP), visceral adiposity index (VAI), and cardiometabolic index (CMI)], triglyceride-glucose (TyG)-derived indices [TyG index, TyG-body mass index (TyG-BMI), TyG-waist circumference (TyG-WC), TyG-waist-to-height ratio (TyG-WHtR), and TyG-non-HDL-to-HDL cholesterol ratio (TyG-NHHR)], and traditional anthropometric indices [BMI, WC, WHtR, body roundness index (BRI), a body shape index (ABSI), conicity index (CI), and ponderal index (PI)]. The novel obesity indices were calculated, and details are provided in supplementary materials.

Metabolic health status

Diabetes was defined as a self-reported history of diabetes, use of diabetes medication in the past 2 weeks, current insulin use, glucose-lowering medication taken on the day of the survey, or fasting plasma glucose ≥ 7.0 mmol/l. Dyslipidemia was defined as total cholesterol ≥ 6.2 mmol/l, triglycerides ≥ 1.7 mmol/l, HDL-c < 1.03 mmol/l in men or < 1.29 mmol/l in women, or use of lipid-lowering medication in the past 2 weeks (self-reported or reported at the biochemical measurement). Participants with neither diabetes nor dyslipidemia were classified as metabolically healthy, and those with diabetes, dyslipidemia, or both were classified as metabolically unhealthy.

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. This definition

follows the 2017 American College of Cardiology/American Heart Association (ACC/AHA) guideline.²⁵ Because earlier Mongolian STEPS surveys, including the 2013 survey, defined HTN as blood pressure $\geq 140/90$ mmHg, the HTN prevalence in the present study (61.4%) is not directly comparable with the 27.5% reported in 2013.

Statistical analysis

Continuous variables are presented as mean and standard deviation (SD) or median and interquartile range (IQR), and categorical variables as number and percentage. Differences between participants with and without HTN were compared using Student's t-test for normally distributed variables, the Kruskal-Wallis test for skewed variables, and the chi-square test for categorical variables. Multivariable logistic regression was used to estimate odds ratios (ORs) and 95% confidence intervals (CIs) for HTN per unit increase in each index, adjusting for age, sex, residential area, marital status, education level, smoking, alcohol consumption, moderate-intensity physical activity, and urinary sodium. All analyses were stratified by metabolic health status. The discriminatory ability of each index was assessed using receiver operating characteristic (ROC) curve analysis and the area under the curve (AUC). Optimal cut-off values were determined by maximizing the Youden index (sensitivity + specificity - 1). Incremental predictive value was assessed by adding each index to the base model and calculating the change in AUC (Δ AUC), and AUCs were compared using the DeLong test. Survey weights were applied. A two-sided p value < 0.05 was considered statistically significant. All analyses were performed using SAS version 9.4 (SAS Institute Inc., Cary, NC, USA).

RESULTS

Participant characteristics

A total of 3,031 participants were included in the analysis (Table 1), 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.²⁴ 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 moderate-intensity physical activity was 0 minute/week (IQR, 0-90 minutes/week). Participants with HTN were older than those without HTN (43.6 ± 11.2 versus 36.7 ± 10.6 years, $p < 0.001$), and men accounted for a greater proportion of the hypertensive group (56.7% versus 42.1%, $p < 0.001$). HTN status also differed according to residential area, educational attainment, marital status, current smoking, and alcohol consumption, whereas family income and

moderate-intensity physical activity did not differ significantly. Participants with HTN also had greater body weight (75.4 versus 65.4 kg, $p=0.003$). 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. Regarding dietary habits (Table 1), household salt-use patterns differed according to HTN status ($p=0.009$), whereas personal salt use, consumption of processed foods high in salt, and fruit and vegetable intake did not differ significantly.

Table 1: Baseline characteristics of the participants.

Variables	Total	Hypertensive	Non-hypertensive	P value
Height, cm	163.71 (8.61)	164.07 (8.88)	163.13 (8.13)	0.003
Weight, kg	71.54 (18.14)	75.38 (20.28)	65.43 (11.74)	0.003
Salt use personal				0.180
Always	225 (7.42)	136 (7.31)	89 (7.61)	
Often	419 (13.82)	251 (13.49)	168 (14.36)	
Sometimes	730 (24.08)	440 (23.64)	290 (24.79)	
Rarely	667 (22.01)	444 (23.86)	223 (19.06)	
Never	986 (32.53)	588 (31.6)	398 (34.02)	
Do not know	4 (0.13)	2 (0.11)	2 (0.17)	
Salt use at household				0.009
Always	621 (20.49)	374 (20.1)	247 (21.11)	
Often	537 (17.72)	341 (18.32)	196 (16.75)	
Sometimes	606 (19.99)	352 (18.91)	254 (21.71)	
Rarely	553 (18.24)	365 (19.61)	188 (16.07)	
Never	705 (23.26)	423 (22.73)	282 (24.1)	
Do not know	9 (0.3)	6 (0.32)	3 (0.26)	
Processed food high in salt				0.09
Always	64 (2.11)	37 (1.99)	27 (2.31)	
Often	299 (9.86)	185 (9.94)	114 (9.74)	
Sometimes	1096 (36.16)	643 (34.55)	453 (38.72)	
Rarely	1196 (39.46)	743 (39.92)	453 (38.72)	
Never	372 (12.27)	251 (13.49)	121 (10.34)	
Do not know	4 (0.13)	2 (0.11)	2 (0.17)	
HTN history				<0.001
Unknown	750 (24.74)	367 (19.72)	383 (32.74)	
Yes	990 (32.66)	990 (53.2)	. (.)	
No	1291 (42.59)	504 (27.08)	787 (67.26)	
HTN last 12 months				
Unknown	2041 (67.34)	871 (46.8)	1170 (100)	
Yes	459 (15.14)	459 (24.66)		
No	531 (17.52)	531 (28.53)		
HTN drug last 2 weeks				<0.001
Unknown	2041 (67.34)	871 (46.8)	1170 (100)	
Yes	496 (16.36)	496 (26.65)		
No	494 (16.3)	494 (26.54)		
Traditional healer for HTN				<0.001
Unknown	2041 (67.34)	871 (46.8)	1170 (100)	
Yes	126 (4.16)	126 (6.77)		
No	864 (28.51)	864 (46.43)		
Fruit servings per week	1 (0, 2)	1 (0, 2)	1 (0, 2)	0.73
Fruit servings per day	2 (1, 3)	2 (1, 3)	2 (1, 3)	0.88
Vegetable servings per week	7 (3, 7)	7 (3, 7)	7 (3, 7)	0.71
Vegetable servings per day	2 (1, 3)	2 (1, 4)	2 (1, 3)	0.81

Continuous variables are described by mean and standard deviation or median and interquartile range; categorical variables are described by number and percentage. t-test was used to analyze mean differences between HTN groups; a Kruskal-Wallis test was used to analyze median differences; and the chi-square test was used for categorical variables.

Table 2: Association between obesity-related indices and risk of hypertension among non-obese adults stratified by metabolic health.

Indices	Metabolically healthy		Metabolically unhealthy	
	OR (95% CI)	P value	OR (95% CI)	P value
TyG-NHHR	1.00 (0.99, 1.00)	0.68	0.998 (0.99, 1)	0.50
TyG-WHtR	1.68 (1.43, 1.97)	<0.001	1.72 (1.46, 2.04)	<0.001
TyG-BMI	1.01 (1.01, 1.01)	<0.001	1.01 (1.01, 1.02)	<0.001
TyG-WC	1.00 (1.00, 1.00)	<0.001	1.00 (1.00, 1.01)	<0.001
TyG index	0.91 (0.82, 1.02)	0.10	1.06 (0.92, 1.22)	0.43
CMI	0.98 (0.96, 1)	0.04	0.99 (0.96, 1.02)	0.51
VAI	0.99 (0.99, 1)	0.00	0.99 (0.98, 1.00)	0.24
LAP	1.00 (0.99, 1.00)	0.56	1.00 (0.99, 1.01)	0.8
BRI	1.47 (1.35, 1.6)	<0.001	1.39 (1.27, 1.52)	<0.001
CI	22.13 (6.08, 80.63)	<0.001	5.38 (1.69, 17.18)	0.005
PI	1.23 (1.18, 1.29)	<0.001	1.23 (1.17, 1.29)	<0.001
WC, cm	1.01 (1.00, 1.02)	<0.001	1.02 (1.01, 1.03)	<0.001
BMI, kg/m²	1.06 (1.04, 1.07)	<0.001	1.04 (1.03, 1.06)	<0.001

Multivariable logistic regression analysis was conducted to estimate odds ratios (ORs) and 95% confidence intervals (95% CIs), adjusting for covariates including age, sex, residential area, marital status, education level, smoking and drinking habits, hyphenation consistency - physical activity level and urinary sodium.

Table 3: ROC cut-off values, sensitivity, specificity and Youden index of obesity indices for hypertension, by metabolic health status.

	Metabolically healthy individuals			
	Cutoff	Sensitivity	Specificity	Youden Index
Obesity indices				
ABSI	0.522	0.523	0.589	0.112
BMI	0.549	0.493	0.734	0.227
BRI	0.508	0.616	0.615	0.231
CI	0.534	0.528	0.661	0.189
CMI	0.511	0.989	0.025	0.014
LAP	0.509	0.987	0.022	0.009
PI	0.502	0.616	0.593	0.209
TyG	0.51	0.796	0.289	0.084
TyG-BMI	0.523	0.558	0.667	0.225
TyG-NHHR	0.518	0.103	0.917	0.02
TyG-WC	0.529	0.563	0.675	0.238
TyG-WHtR	0.517	0.596	0.619	0.216
VAI	0.515	0.977	0.039	0.016
WC	0.55	0.556	0.711	0.267
WHtR	0.515	0.616	0.615	0.231
Metabolically unhealthy individuals				
ABSI	0.717	0.592	0.569	0.161
BMI	0.684	0.722	0.569	0.291
BRI	0.724	0.611	0.691	0.302
CI	0.712	0.652	0.593	0.245
CMI	0.629	0.981	0.071	0.052
LAP	0.715	0.961	0.081	0.042
PI	0.714	0.603	0.637	0.241
TyG	0.689	0.962	0.091	0.052
TyG-BMI	0.681	0.715	0.549	0.264
TyG-NHHR	0.719	0.4	0.75	0.15
TyG-WC	0.731	0.571	0.74	0.311
TyG-WHtR	0.706	0.647	0.627	0.274
VAI	0.599	0.983	0.071	0.054
WC	0.746	0.575	0.76	0.335
WHtR	0.732	0.611	0.691	0.302

Table 4: Incremental prediction of hypertension by obesity indices added to the base model, by metabolic health status.

	Metabolically healthy individuals		
	Base model AUC	Adjusted AUC (95% CI)	ΔAUC
Indices			
BMI	0.71	0.75 (0.72, 0.77)	0.040
PI	0.71	0.74 (0.72, 0.77)	0.034
TyG-BMI	0.71	0.74 (0.72, 0.76)	0.033
WC	0.71	0.74 (0.71, 0.76)	0.030
BRI	0.71	0.73 (0.71, 0.76)	0.026
WHtR	0.71	0.73 (0.71, 0.76)	0.026
TyG-WC	0.71	0.73 (0.7, 0.75)	0.021
TyG-WHtR	0.71	0.73 (0.7, 0.75)	0.019
CI	0.71	0.71 (0.69, 0.74)	0.004
VAI	0.71	0.71 (0.68, 0.73)	0.001
CMI	0.71	0.71 (0.68, 0.73)	0.000
TyG-NHHR	0.71	0.71 (0.68, 0.73)	0.000
TyG	0.71	0.71 (0.68, 0.73)	0.000
ABSI	0.71	0.71 (0.68, 0.73)	0.000
LAP	0.71	0.71 (0.68, 0.73)	0.000
Metabolically unhealthy individuals			
WC	0.71	0.77 (0.74, 0.79)	0.056
BMI	0.71	0.77 (0.74, 0.79)	0.055
WHtR	0.71	0.76 (0.74, 0.79)	0.054
BRI	0.71	0.76 (0.74, 0.79)	0.053
PI	0.71	0.76 (0.74, 0.79)	0.051
TyG-BMI	0.71	0.75 (0.72, 0.78)	0.040
TyG-WC	0.71	0.74 (0.71, 0.77)	0.031
TyG-WHtR	0.71	0.74 (0.71, 0.77)	0.030
CI	0.71	0.73 (0.7, 0.76)	0.019
VAI	0.71	0.71 (0.68, 0.74)	0.002
ABSI	0.71	0.71 (0.68, 0.74)	0.002
CMI	0.71	0.71 (0.68, 0.74)	0.001
TyG	0.71	0.71 (0.68, 0.74)	0.001
LAP	0.71	0.71 (0.68, 0.74)	0.000
TyG-NHHR	0.71	0.71 (0.68, 0.74)	0.000

Base model includes age, sex, residential area, education, marital status, smoking status, alcohol usage, hyphenation consistency physical activity, and urinary sodium.

Associations according to metabolic health status

The associations were generally consistent when participants were stratified according to metabolic health (Table 2). TyG-WHtR was positively associated with HTN in both metabolically healthy [OR=1.68, 95% CI (1.43-1.97)] and metabolically unhealthy participants [OR=1.72, 95% CI (1.46-2.04); both $p<0.001$]. Significant positive associations were also observed for TyG-BMI, TyG-WC, BRI, PI, WC, and BMI in both groups. BRI was associated with HTN among metabolically healthy [OR=1.47, 95% CI (1.35-1.60)] and metabolically unhealthy participants [OR=1.39, 95% CI (1.27-1.52)]. Similarly, PI showed nearly identical associations across metabolic-health strata (OR=1.23 in both groups). The conicity index was also positively associated with HTN in both groups, although the

estimates were accompanied by wide confidence intervals. TyG alone, LAP, and TyG-NHHR were not significantly associated with HTN in either metabolic-health group. CMI and VAI showed small inverse associations among metabolically healthy participants but not among metabolically unhealthy participants.

Predictive performance according to metabolic health status

The ROC curves indicated that discrimination was generally greater among metabolically unhealthy participants than among metabolically healthy participants (Figure 1). Among metabolically healthy participants, the strongest discrimination among the indices displayed in the figure was observed for BMI (AUC=0.657), followed closely by TyG-WC

(AUC=0.651), TyG-BMI (AUC=0.649), and BRI/WHtR (AUC=0.645). Among metabolically unhealthy participants, BRI and WHtR showed AUCs of approximately 0.691, followed by BMI (AUC=0.686), TyG-WC (AUC=0.674), and TyG-BMI (AUC=0.670). Figure 1 displays the corresponding ROC curves across metabolic-health strata. Consistent with the ROC curves (Table 3), WC had the largest Youden index among

metabolically healthy participants (0.267), followed by TyG-WC (0.238), BRI and WHtR (0.231 each), and BMI (0.227). Among metabolically unhealthy participants, WC again had the largest Youden index (0.335), followed by TyG-WC (0.311), BRI and WHtR (0.302 each), and BMI (0.291). Indices such as CMI, LAP, VAI, and TyG showed high sensitivity but very low specificity at their selected thresholds.

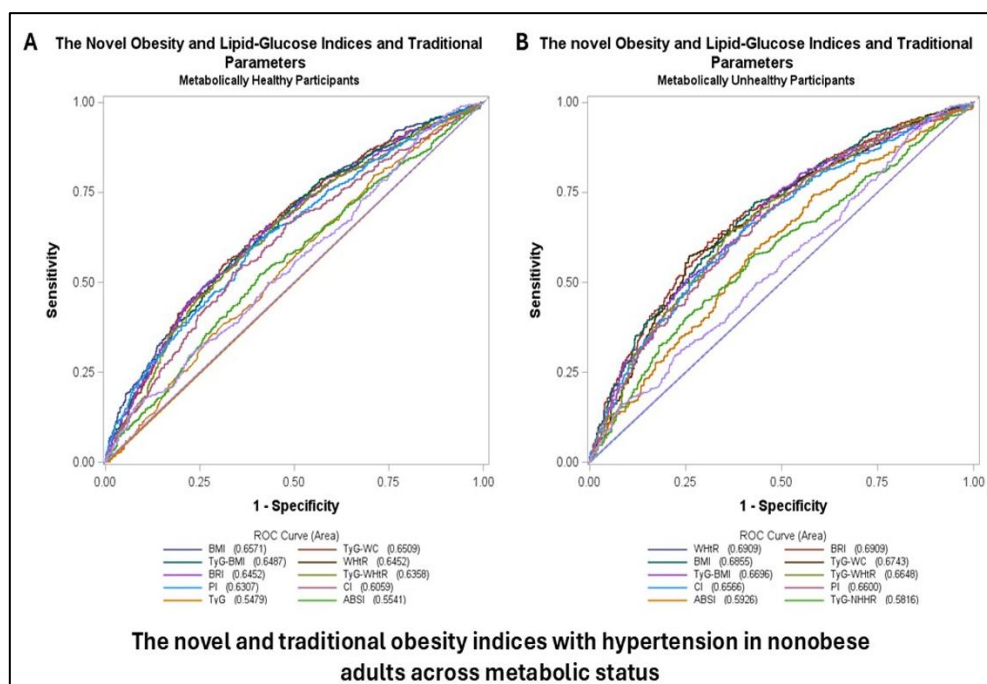


Figure 1: ROC curves for novel and traditional obesity indices for hypertension among non-obese adults.

The area under the ROC curve (AUC) for each index is presented in parentheses. Higher AUC values indicate greater discriminatory ability for hypertension.

Incremental prediction according to metabolic health status

In metabolically healthy participants, the multivariable base model had an AUC of 0.71 (Table 4). Addition of BMI resulted in the largest improvement, increasing the AUC to 0.75 [95% CI (0.72-0.77); Δ AUC=0.040]. PI and TyG-BMI increased the AUC to 0.74 (Δ AUC=0.034 and 0.033, respectively), while addition of WC yielded an adjusted AUC of 0.74 and Δ AUC=0.030. BRI, WHtR, TyG-WC, and TyG-WHtR produced smaller improvements, whereas the remaining indices added little or no predictive information. The incremental contribution of anthropometric indices was more pronounced among metabolically unhealthy participants. Addition of WC increased the AUC from 0.71 to 0.77 [95% CI (0.74-0.79); Δ AUC=0.056], while BMI resulted in an adjusted AUC of 0.77 (Δ AUC=0.055). WHtR, BRI, and PI increased the AUC to 0.76, with Δ AUC values of 0.054, 0.053, and 0.051, respectively. Among the combined TyG indices, TyG-BMI provided the greatest additional discrimination (adjusted AUC=0.75; Δ AUC=0.040), followed by TyG-WC and TyG-WHtR. Conversely, VAI, ABSI, CMI, TyG, LAP, and TyG-

NHHR produced minimal or no improvement over the base model.

DISCUSSION

The present study provides a detailed evaluation of both new and traditional obesity-related measures for predicting the risk of HTN in non-obese adults. We stratified participants by metabolic health status to assess optimal cut-offs, predictive usefulness, and risk estimates. 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 “non-obese” by global standards. Our analysis also highlights unexpected differences in how metabolic health affects the risk and predictive value of these biomarkers.

In both metabolically healthy and unhealthy adults, WC showed the best balance of sensitivity and specificity (highest Youden index), and BMI, WHtR, and BRI showed similar discriminatory ability, particularly among metabolically unhealthy adults. Indices based mainly on

lipids and glucose showed weaker discrimination. Overall, discrimination was greater among metabolically unhealthy participants, suggesting that adiposity is more closely related to HTN in the presence of metabolic abnormalities.

In the logistic regression analysis, each unit increase in TyG-WHtR was associated with 68% and 72% higher odds of HTN in metabolically healthy and metabolically unhealthy adults, respectively. This suggests that combining a marker of insulin resistance with a measure of central obesity may capture cardiometabolic risk that is not reflected by general adiposity alone. Visceral fat accumulation promotes systemic inflammation and arterial stiffness, which may contribute to the development of HTN even in non-obese adults.¹⁹ TyG-WHtR has also been associated with cardiometabolic multimorbidity and early arterial stiffness, supporting its potential role in assessing vascular risk.^{20,21} The conicity index was also positively associated with HTN in both metabolically healthy (OR 22.13, 95% CI 6.08-80.63) and metabolically unhealthy adults (OR 5.38, 95% CI 1.69-17.18). However, these large ORs with wide confidence intervals largely reflect the narrow numerical range of the index, in which a 1-unit increase is very large, rather than an exceptionally strong effect. A previous study similarly reported a stronger association of the conicity index with prehypertension than with hypertension.²² Consistent with previous cohort studies, BRI was also positively associated with HTN in the present study.²³

Although BMI and WC were sensitive predictors of HTN, all participants in this study were non-obese, so these measures reflect variation within the normal-to-overweight range rather than obesity itself. The positive associations observed for TyG-WHtR, BRI, and the conicity index suggest that abdominal and visceral fat distribution may contribute to a hidden risk of HTN in this population. In contrast, indices based mainly on lipids and glucose, such as LAP, TyG-NHHR, and the TyG index alone, were not significantly associated with HTN in non-obese adults, regardless of metabolic health status. Nevertheless, given the cross-sectional design and the modest discrimination of all indices (AUCs of approximately 0.65-0.69), our findings do not support replacing traditional measures with novel obesity indices in clinical practice, as BMI performed as well as or better than these indices. Rather, WC, BRI, and TyG-WHtR may be considered as complements to traditional measures.

The present study has several strengths and notable limitations. First, it used nationally representative STEPS survey data collected according to standardized WHO protocols. Second, anthropometric measurements were objectively assessed by trained personnel rather than self-reported. Third, the large sample size enabled subgroup analyses by metabolic health status. However, several limitations should be considered. First, the cross-sectional design precludes causal inference about the relationship

between obesity indices and HTN. Second, dietary intake and sedentary behavior were not comprehensively assessed, and therefore, residual confounding may remain. Third, blood pressure was measured at a single visit, which may have led to misclassification of hypertension status; diagnoses of hypertension and diabetes were partly self-reported and may be subject to recall bias; and fasting status could not be fully verified, so some glucose and triglyceride values, and the indices derived from them, may have been overestimated. 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 activity²⁴ 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.

CONCLUSION

Among non-obese Mongolian adults, measures of central adiposity and body shape were consistently associated with HTN, suggesting that cardiometabolic risk may not be fully captured by BMI or obesity status alone. WC, BRI, and TyG-derived anthropometric indices, particularly TyG-WHtR, were consistently associated with HTN in both metabolically healthy and metabolically unhealthy participants, whereas indices based mainly on lipids and glucose were not. Discrimination by all indices was modest and was greater among metabolically unhealthy participants, and BMI and WC 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 about temporality or causality, and the findings should be interpreted in the context of the Mongolian population studied. Prospective studies are needed to determine whether these indices predict incident HTN and whether incorporating central adiposity measures into routine screening improves early identification of cardiovascular risk.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge the Ministry of Health of Mongolia and the World Health Organization for conducting and making available the Mongolia WHO STEPS survey. The authors also thank the survey participants and the field staff involved in data collection and management. The authors thank Dr Namuun

Ganbaatar (Department of Physical and Occupational Therapy, School of Nursing, Mongolian National University of Medical Sciences, Ulaanbaatar, Mongolia) for providing support on statistical analysis and interpretation.

Funding: No funding sources

Conflict of interest: None declared

Ethical approval: The study 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

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Cite this article as: Byambajav T, Batbayar U, Enkhbaatar C, Enkhbold U. Differential predictive ability of the novel obesity indices on hypertension among non-obese adults stratified by metabolic health. *Int J Community Med Public Health* 2026;13:6357-66.