

Novel anthropometric and metabolic indices for identifying insulin resistance and body-composition abnormalities in elderly patients with type 2 diabetes: a cross-sectional study

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Abstract

Background Insulin resistance (IR) and abnormalities in body composition are common in older adults with type 2 diabetes mellitus (T2DM), but the optimal screening indices remain uncertain. We compared anthropometric and metabolic composite indices for identifying IR, visceral obesity and dynapenia in this population.

Methods This cross-sectional study included 127 hospitalised patients with T2DM aged 65–80 years. Body Roundness Index (BRI), A Body Shape Index (ABSI), the triglyceride-glucose (TyG) index and its derivatives (TyG-WC, TyG-WHtR and TyG-BMI), visceral adiposity index, lipid accumulation product, neck-to-waist ratio and neck circumference were calculated. IR was defined as HOMA-IR ≥ 2.0 , visceral obesity as visceral fat area $\geq 100 \text{ cm}^2$, and dynapenia as grip strength $< 28 \text{ kg}$ in men or $< 18 \text{ kg}$ in women. Associations were analysed using Spearman's correlation, multivariable logistic regression per 1-SD increment, and receiver operating characteristic curve analysis with DeLong comparisons and bootstrapped confidence intervals.

Results IR was present in 68.5% of patients, visceral obesity in 38.6% and dynapenia in 28.3%, whereas sarcopenia was rare (0.8%). TyG-WC showed the strongest correlation with HOMA-IR ($\rho = 0.347$, $p < 0.001$) and the highest AUC for IR (0.660, 95% CI 0.568–0.761), although it was not significantly superior to the basic TyG index (AUC 0.654; DeLong $p = 0.897$). After adjustment for age, sex and BMI, only TyG-based indices remained independently associated with IR: TyG-WC (OR 2.186), TyG-WHtR (OR 1.995), TyG (OR 1.706) and TyG-BMI (OR 1.684), all $p \leq 0.023$ per 1-SD increment. For visceral obesity, waist circumference had the highest AUC (0.875), followed by BMI (0.809) and neck circumference (0.792); BRI was the strongest independent predictor (OR 6.480 per 1-SD increment, $p < 0.001$). Only TyG-based indices were significantly correlated with HbA1c.

Conclusions In older adults with T2DM, TyG-based indices, particularly TyG-WC, were the only indices independently associated with IR, although their advantage over the basic TyG index was not significant and their absolute discriminatory performance was modest. Waist and neck circumference are practical bedside markers of visceral obesity. The contrast between frequent dynapenia and rare sarcopenia highlights the value of grip-strength assessment in geriatric diabetes care.

Background

The global burden of type 2 diabetes mellitus (T2DM) is rising in parallel with population ageing. Older adults with T2DM represent a clinically distinct subgroup characterised by greater heterogeneity in body composition, sarcopenia and cardiometabolic risk [1, 2]. Insulin resistance (IR) is a central defect in T2DM and a key driver of hyperglycaemia, dyslipidaemia and cardiovascular complications [3]. Although the homeostasis model assessment of IR (HOMA-IR) is widely used, it requires fasting insulin measurement, which is costly and subject to assay variability, limiting its applicability in routine clinical screening [4].

Several anthropometric and metabolic composite indices have been proposed as practical surrogates for IR and cardiometabolic risk. The triglyceride-glucose (TyG) index, calculated as $\ln[(\text{triglycerides} \times \text{fasting glucose})/2]$, has been extensively validated as a simple IR marker that requires only routine laboratory tests [5, 6]. To enhance its discriminative ability, TyG has been combined with anthropometric parameters—including waist circumference (TyG-WC), waist-to-height ratio (TyG-WHtR) and body mass index (TyG-BMI)—yielding enhanced TyG indices that outperform the original TyG in predicting metabolic syndrome and cardiovascular events [7, 8, 9]. Concurrently, the body roundness index (BRI), derived from waist circumference and height to model body shape as an ellipse, has been shown to capture visceral adiposity and metabolic risk more accurately than BMI [10, 11, 12]. A body shape index (ABSI), which isolates the effect of waist circumference independent of BMI, together with the visceral adiposity index (VAI) and the lipid accumulation product (LAP), has also been proposed as metabolically informed adiposity markers [13, 14, 15].

Neck circumference, a simple bedside measurement reflecting upper-body subcutaneous fat deposition, has gained attention as an independent marker of metabolic syndrome and IR [16, 17]. The neck-to-waist ratio (NWR), a composite of two circumferential measurements, may capture body-shape information not reflected by either measure alone. However, these novel indices have not been systematically compared in the context of elderly T2DM, particularly in relation to direct body-composition assessment including visceral fat area (VFA), appendicular skeletal muscle mass (ASM) and grip strength.

Moreover, ageing is associated with sarcopenia and a shift towards central adiposity, both of which may exacerbate IR [18, 19]. The Asian Working Group for Sarcopenia (AWGS) 2019 criteria require low muscle mass plus low strength or low physical performance for a diagnosis of sarcopenia [20]. However, dynapenia—the age-related loss of muscle strength independent of muscle mass—may be more prevalent and more clinically relevant in elderly T2DM, because strength often declines faster than mass [21].

This study aimed to: (1) evaluate and compare novel anthropometric and metabolic composite indices (BRI, ABSI, enhanced TyG indices, VAI, LAP, NWR and neck circumference) against traditional measures for discriminating IR, visceral obesity and dynapenia in elderly T2DM; (2) assess whether these indices are independently associated with IR after adjustment for confounders; and (3) characterise the prevalence and interrelationships of metabolic and body-composition phenotypes in this population.

Methods

Study design and population

This cross-sectional study was conducted at The Affiliated People's Hospital of Fujian University of Traditional Chinese Medicine, Fuzhou, China, from March 2022 to February 2023. Consecutive inpatients aged 65–80 years with established T2DM were enrolled. Eligibility required: (1) a confirmed diagnosis of T2DM; (2) age 65–80 years; (3) informed consent and the ability to complete the study assessments; (4)

cardiac function of New York Heart Association class $\leq$ II, hepatic function with alanine or aspartate aminotransferase $\leq 3 \times$ upper limit of normal and total bilirubin $\leq 34.2 \mu\text{mol/L}$, and renal function with estimated glomerular filtration rate $\geq 60 \text{ mL/min/1.73 m}^2$; and (5) no participation in any drug clinical trial within the preceding 3 months.

Patients were excluded if they had type 1 or secondary (special-type) diabetes; a history of diabetic ketoacidosis or hyperosmolar hyperglycaemic state within the past 6 months; acute infection, malignancy, respiratory failure, heart failure, thyroid disorder, or myocardial infarction or acute stroke within the past 5 years; poor general health status on comprehensive geriatric assessment; metallic implants (e.g. stents or pacemakers) affecting body-composition measurement; use of muscle-affecting medications (e.g. baclofen or tizanidine); use of insulin therapy; or were judged unsuitable by the investigator.

Clinical and laboratory measurements

Demographic and clinical data—including age, sex, diabetes duration, smoking history, physical activity and comorbidities—were collected from medical records. Anthropometric measurements were performed by trained nurses using standardised protocols, with each measurement repeated three times and the mean recorded. Participants were measured in light clothing without shoes after voiding. Height was measured with a wall-mounted stadiometer and weight with an electronic scale; BMI was calculated as weight (kg) / height (m)² and categorised as underweight (< 18.5), normal (18.5–23.9), overweight (24.0–27.9) and obese (≥ 28.0) kg/m² [24]. Waist circumference was measured at the midpoint between the lowest rib and the iliac crest, hip circumference at the maximum gluteal circumference, neck circumference at the level of the thyroid cartilage, and head and calf circumferences at their maximum. Blood pressure and heart rate were measured after 10 min of rest.

Blood samples were collected after an overnight fast of at least 8 h. Fasting plasma glucose (FPG), triglycerides (TG), total cholesterol, high-density lipoprotein cholesterol (HDL-c), low-density lipoprotein cholesterol, HbA1c, fasting insulin, haemoglobin, and liver and renal function tests were measured using standard laboratory methods. HOMA-IR was calculated as FPG (mmol/L) $\times$ fasting insulin ($\mu\text{IU/mL}$) / 22.5 [22].

Body-composition assessment

Body composition—including body fat percentage, fat mass, muscle mass, ASM, ASM index (ASMI = ASM / height²), VFA and subcutaneous fat area—was measured by bioelectrical impedance analysis (BIA). VFA was measured with a visceral fat scanner with the participant supine and relaxed. Handgrip strength was measured with a digital dynamometer; participants performed six trials (three per hand) and the highest value was recorded. Physical performance was assessed by the five-time chair stand test (cut-off ≥ 12 s) and the 6-m gait-speed test (cut-off ≥ 6 s).

Calculation of composite indices

The following indices were calculated:

1. $TyG = \ln[(TG \text{ (mg/dL)} \times FPG \text{ (mg/dL)}) / 2]$, where TG and FPG were converted from mmol/L to mg/dL by multiplying by 88.57 and 18.0, respectively [5]
2. $TyG-WC = TyG \times \text{waist circumference (cm)}$ [7]
3. $TyG-WHtR = TyG \times \text{waist-to-height ratio}$ [8]
4. $TyG-BMI = TyG \times BMI$ [9]
5. $BRI = 364.2 - 365.5 \times \sqrt{(1 - (WC / (\pi \times \text{height}))^2)}$, where WC and height are expressed in metres [10]
6. $ABSI = WC \text{ (m)} / (BMI^{(2/3)} \times \text{height (m)}^{(1/2)})$ [11]
7. $VAI \text{ (men)} = WC / (39.68 + 1.88 \times BMI) \times (TG / 1.03) \times (1.31 / HDL-c)$; $VAI \text{ (women)} = WC / (36.58 + 1.89 \times BMI) \times (TG / 0.81) \times (1.52 / HDL-c)$ [14]
8. $LAP \text{ (men)} = TG \times (WC - 58)$; $LAP \text{ (women)} = TG \times (WC - 63)$ [15]
9. $NWR = \text{neck circumference} / \text{waist circumference}$
10. $\text{Waist-to-hip ratio (WHR)} = \text{waist circumference} / \text{hip circumference}$
11. $\text{Waist-to-height ratio (WHtR)} = \text{waist circumference} / \text{height}$

Outcome definitions

Insulin resistance was defined as $HOMA-IR \geq 2.0$ [22] and visceral obesity as $VFA \geq 100 \text{ cm}^2$ [23]. In accordance with the AWGS 2019 criteria [20], dynapenia was defined as maximum grip strength $< 28 \text{ kg}$ in men or $< 18 \text{ kg}$ in women; low muscle mass as $ASMI < 7.0 \text{ kg/m}^2$ in men or $< 5.4 \text{ kg/m}^2$ in women; low physical performance as a five-time chair stand test $\geq 12 \text{ s}$ or a 6-m gait-speed test $\geq 6 \text{ s}$; and sarcopenia as low muscle mass plus low grip strength or low physical performance.

Statistical analysis

Continuous variables are expressed as mean $\pm$ SD or median (interquartile range, IQR); the reporting format for each variable was determined by the Shapiro–Wilk normality test ($\alpha = 0.05$), with skewed variables reported as median (IQR). Categorical variables are expressed as counts (percentages). Between-group comparisons used Student's t test or the Mann–Whitney U test for continuous variables and the χ^2 test for categorical variables. Spearman rank correlation was used to assess associations between indices and metabolic or body-composition outcomes.

Multivariable logistic regression was performed for each index to assess independent associations with IR and visceral obesity; odds ratios (OR) with 95% confidence intervals (CI) are reported per 1-SD increment to allow comparison across indices. Models for IR were adjusted for age, sex and BMI, except for TyG-BMI and BMI themselves, which incorporate BMI and were therefore adjusted for age and sex only to avoid collinearity; models for visceral obesity were adjusted for age and sex. Discriminative ability was assessed by the area under the receiver operating characteristic curve (AUC), with 95% CI estimated from 500 bootstrap resamples; pairwise comparisons of AUCs were performed with the DeLong test. Optimal cut-off values were identified by the Youden index, and the corresponding sensitivity, specificity, positive predictive value (PPV) and negative predictive value (NPV) were computed.

Statistical analyses were performed using Python (pandas, statsmodels and scipy). A two-sided p value < 0.05 was considered statistically significant.

Results

Study population

A total of 127 elderly patients with T2DM were included (Table 1). The mean age was 70.2 ± 4.0 years (range 65–80), 66 (52.0%) were men, and the median diabetes duration was 123.0 (45.5–196.0) months. The mean BMI was 24.6 ± 3.4 kg/m², the median HbA1c 7.9 (6.8–9.5)% and the median HOMA-IR 2.7 (1.7–5.2). The cohort carried a high burden of cardiometabolic comorbidity: hypertension was present in 58.3% of patients and 53.5% had low physical performance.

Table 1
Baseline characteristics and novel composite indices of the study population (n = 127)

Variable	Total (n = 127)	Men (n = 66)	Women (n = 61)
Age (years)	70.2 ± 4.0	70.8 ± 4.1	69.6 ± 3.8
Diabetes duration (months)	123.0 (45.5–196.0)	124.0 (56.8–190.5)	98.0 (41.0–197.0)
BMI (kg/m ²)	24.6 ± 3.4	24.3 ± 3.2	25.0 ± 3.6
Waist circumference (cm)	89.6 ± 10.3	91.0 ± 11.7	88.1 ± 8.3
Neck circumference (cm)	36.0 ± 3.1	37.8 ± 2.5	34.2 ± 2.5
HbA1c (%)	7.9 (6.8–9.5)	8.4 (7.0–10.0)	7.6 (6.7–9.0)
Fasting plasma glucose (mmol/L)	8.1 (6.6–10.4)	8.0 (6.5–10.5)	8.5 (6.8–10.3)
Fasting insulin (μIU/mL)	8.6 (5.0–13.0)	8.8 (5.0–13.6)	8.6 (5.1–12.2)
HOMA-IR	2.7 (1.7–5.2)	2.8 (1.6–5.3)	2.6 (1.9–5.1)
Triglycerides (mmol/L)	1.4 (1.0–2.5)	1.3 (1.0–2.4)	1.6 (1.0–2.6)
HDL-c (mmol/L)	1.1 ± 0.3	1.0 ± 0.3	1.2 ± 0.3
VFA (cm ²)	89.6 ± 36.8	93.5 ± 40.2	85.5 ± 32.5
ASM (kg)	20.7 ± 4.0	23.4 ± 3.0	17.8 ± 2.6
ASMI (kg/m ²)	8.0 ± 1.1	8.5 ± 0.9	7.4 ± 0.9
Maximum grip strength (kg)	27.1 ± 9.0	33.0 ± 8.1	20.8 ± 4.6
BRI	4.6 ± 1.5	4.4 ± 1.7	4.8 ± 1.3
TyG	9.3 ± 0.8	9.2 ± 0.7	9.3 ± 0.8
TyG-WC	831.0 ± 116.8	839.3 ± 122.9	822.0 ± 110.1
TyG-WHtR	5.2 ± 0.8	5.1 ± 0.8	5.3 ± 0.8
TyG-BMI	228.8 ± 38.7	224.0 ± 34.6	234.0 ± 42.3
ABSI	0.083 ± 0.006	0.082 ± 0.006	0.084 ± 0.006
VAI	2.3 (1.5–4.4)	1.9 (1.3–3.7)	3.1 (1.6–5.3)

Data are presented as mean ± SD or median (interquartile range) for continuous variables, with the reporting format determined by the Shapiro–Wilk test, and as n (%) for categorical variables. ABSI a body shape index, ASM appendicular skeletal muscle mass, ASMI appendicular skeletal muscle mass index, AWGS Asian Working Group for Sarcopenia, BMI body mass index, BRI body roundness index, HDL-c high-density lipoprotein cholesterol, HOMA-IR homeostasis model assessment of insulin resistance, LAP lipid accumulation product, NWR neck-to-waist ratio, TyG triglyceride-glucose index, VAI visceral adiposity index, VFA visceral fat area

Variable	Total (n = 127)	Men (n = 66)	Women (n = 61)
LAP	43.6 (28.0–68.2)	47.3 (30.7–75.7)	39.8 (23.1–64.4)
NWR	0.405 ± 0.036	0.419 ± 0.038	0.389 ± 0.026
Insulin resistance (HOMA-IR ≥ 2.0), n (%)	87 (68.5)	45 (68.2)	42 (68.9)
Visceral obesity (VFA ≥ 100 cm ²), n (%)	49 (38.6)	31 (47.0)	18 (29.5)
Dynapenia, n (%)	36 (28.3)	19 (28.8)	17 (27.9)
Sarcopenia (AWGS 2019), n (%)	1 (0.8)	1 (1.5)	0 (0.0)
Data are presented as mean ± SD or median (interquartile range) for continuous variables, with the reporting format determined by the Shapiro–Wilk test, and as n (%) for categorical variables. ABSI a body shape index, ASM appendicular skeletal muscle mass, ASMI appendicular skeletal muscle mass index, AWGS Asian Working Group for Sarcopenia, BMI body mass index, BRI body roundness index, HDL-c high-density lipoprotein cholesterol, HOMA-IR homeostasis model assessment of insulin resistance, LAP lipid accumulation product, NWR neck-to-waist ratio, TyG triglyceride-glucose index, VAI visceral adiposity index, VFA visceral fat area			

Prevalence of metabolic and body-composition phenotypes

IR (HOMA-IR ≥ 2.0) was present in 68.5% of patients and visceral obesity (VFA ≥ 100 cm²) in 38.6% (Fig. 1). Dynapenia was common (28.3%), whereas low muscle mass (0.8%) and sarcopenia (0.8%) were rare, consistent with a pattern of strength–mass dissociation.

Correlations between indices and metabolic outcomes

Enhanced TyG indices showed the strongest correlations with HOMA-IR (TyG-WC: $\rho = 0.347$, $p < 0.001$; TyG-WHtR: $\rho = 0.333$, $p < 0.001$; TyG: $\rho = 0.330$, $p < 0.001$; TyG-BMI: $\rho = 0.282$, $p = 0.001$) (Fig. 4, Table 2). Traditional anthropometric indices (BRI: $\rho = 0.183$; WHtR: $\rho = 0.183$; BMI: $\rho = 0.179$; WHR: $\rho = 0.167$) showed only weak correlations with HOMA-IR, and neck circumference was not significantly correlated ($\rho = 0.053$). ABSI showed no significant correlation with HOMA-IR ($\rho = 0.097$, $p = 0.279$).

For HbA1c, only TyG-based indices were significantly correlated (TyG: $\rho = 0.302$, $p < 0.001$; TyG-WC: $\rho = 0.212$, $p = 0.017$; TyG-WHtR: $\rho = 0.202$, $p = 0.023$), whereas all anthropometric indices showed no significant association.

For VFA, waist circumference showed the strongest correlation ($\rho = 0.741$, $p < 0.001$), followed by BMI ($\rho = 0.653$), BRI and WHtR (both $\rho = 0.624$), hip circumference ($\rho = 0.600$), TyG-WC ($\rho = 0.560$) and neck circumference ($\rho = 0.546$) (all $p < 0.001$). ABSI correlated only weakly with VFA ($\rho = 0.224$, $p = 0.011$). Neck circumference was the strongest correlate of ASMI ($\rho = 0.689$, $p < 0.001$) and of grip strength ($\rho = 0.633$, $p < 0.001$), indicating that it reflects overall body size and muscularity rather than adiposity alone.

Discriminative ability for insulin resistance

Among all indices, TyG-WC had the highest AUC for IR discrimination (0.660, 95% CI 0.568–0.761, $p = 0.004$), followed by TyG (0.654, 95% CI 0.545–0.761), TyG-WHtR (0.645, 95% CI 0.545–0.747), TyG-BMI (0.636, 95% CI 0.523–0.745), LAP (0.632) and VAI (0.618) (Fig. 2, Table 2). Traditional anthropometric indices showed poor discrimination: BMI (0.596), waist circumference (0.589), BRI and WHtR (both 0.583), WHR (0.562) and neck circumference (0.553). DeLong comparison showed that TyG-WC was not significantly superior to the basic TyG index ($p = 0.897$) or to TyG-BMI ($p = 0.466$), but was significantly higher than BRI and WHtR (both $p = 0.048$).

Table 2
Discriminative performance of the indices for the identification of insulin resistance

Index	AUC (95% CI)	p	Optimal cut-off	Sensitivity	Specificity	PPV	NPV
TyG-WC	0.660 (0.568– 0.761)	0.004	830.4	0.598	0.650	0.788	0.426
TyG	0.654 (0.545– 0.761)	0.006	9.08	0.655	0.625	0.792	0.455
TyG-WHtR	0.645 (0.545– 0.747)	0.009	5.57	0.402	0.850	0.854	0.395
TyG-BMI	0.636 (0.523– 0.745)	0.014	227.1	0.621	0.650	0.794	0.441
LAP	0.632 (0.524– 0.737)	0.017	43.2	0.598	0.675	0.800	0.435
VAI	0.618 (0.507– 0.730)	0.033	2.18	0.609	0.650	0.791	0.433
BMI	0.596 (0.484– 0.709)	0.084	23.6	0.701	0.550	0.772	0.458
Waist circumference	0.589 (0.494– 0.701)	0.107	89.0	0.644	0.550	0.757	0.415
BRI	0.583 (0.476– 0.693)	0.134	4.07	0.713	0.475	0.747	0.432
WHtR	0.583 (0.476– 0.693)	0.134	0.54	0.713	0.475	0.747	0.432
WHR	0.562 (0.455– 0.681)	0.266	0.86	0.954	0.200	0.722	0.667
Optimal cut-off values were determined by the Youden index. 95% CI were estimated from 500 bootstrap resamples; p values were derived from the Mann–Whitney U test comparing index values between patients with and without insulin resistance. ABSI a body shape index, AUC area under the receiver operating characteristic curve, BMI body mass index, BRI body roundness index, CI confidence interval, LAP lipid accumulation product, NPV negative predictive value, NWR neck-to-waist ratio, PPV positive predictive value, TyG triglyceride-glucose index, VAI visceral adiposity index, WHR waist-to-hip ratio, WHtR waist-to-height ratio							

Index	AUC (95% CI)	p	Optimal cut-off	Sensitivity	Specificity	PPV	NPV
Neck circumference	0.553 (0.447– 0.646)	0.338	38.0	0.356	0.775	0.775	0.356
ABSI	0.531 (0.419– 0.640)	0.577	0.083	0.563	0.550	0.731	0.367
NWR	0.399 (0.289– 0.500)	0.067	0.36	0.931	0.125	0.698	0.455
Optimal cut-off values were determined by the Youden index. 95% CI were estimated from 500 bootstrap resamples; p values were derived from the Mann–Whitney U test comparing index values between patients with and without insulin resistance. ABSI a body shape index, AUC area under the receiver operating characteristic curve, BMI body mass index, BRI body roundness index, CI confidence interval, LAP lipid accumulation product, NPV negative predictive value, NWR neck-to-waist ratio, PPV positive predictive value, TyG triglyceride-glucose index, VAI visceral adiposity index, WHR waist-to-hip ratio, WHtR waist-to-height ratio							

Multivariable-adjusted associations with insulin resistance

After adjustment for age, sex and BMI (age and sex only for TyG-BMI and BMI), enhanced TyG indices remained independently associated with IR: TyG-WC (OR 2.186 per 1-SD increment, 95% CI 1.196–3.995, $p = 0.011$), TyG-WHtR (OR 1.995, 95% CI 1.099–3.621, $p = 0.023$), TyG (OR 1.706, 95% CI 1.111–2.618, $p = 0.015$) and TyG-BMI (OR 1.684, 95% CI 1.110–2.553, $p = 0.014$) (Fig. 3, Table 3). In contrast, BRI ($p = 0.541$), WHtR ($p = 0.512$), WHR ($p = 0.470$), neck circumference ($p = 0.969$), VAI ($p = 0.168$), LAP ($p = 0.269$), ABSI ($p = 0.525$) and NWR ($p = 0.364$) were not independently associated with IR after adjustment.

Table 3

Multivariable-adjusted associations of the indices with insulin resistance and visceral obesity (per 1-SD increment)

Index	Insulin resistance, OR (95% CI) ^a	p	Visceral obesity, OR (95% CI) ^b	p
TyG-WC	2.186 (1.196–3.995)	0.011*	3.423 (1.953–6.001)	< 0.001***
TyG-WHtR	1.995 (1.099–3.621)	0.023*	2.916 (1.735–4.903)	< 0.001***
TyG-BMI	1.684 (1.110–2.553)	0.014*	3.212 (1.889–5.462)	< 0.001***
TyG	1.706 (1.111–2.618)	0.015*	0.972 (0.673–1.406)	0.882
VAI	1.394 (0.869–2.235)	0.168	0.953 (0.646–1.405)	0.807
LAP	1.325 (0.804–2.182)	0.269	1.182 (0.815–1.714)	0.377
BRI	1.239 (0.624–2.460)	0.541	6.480 (3.123–13.446)	< 0.001***
WHtR	1.254 (0.637–2.466)	0.512	6.250 (3.044–12.832)	< 0.001***
WHR	1.173 (0.761–1.810)	0.470	2.455 (1.443–4.178)	< 0.001***
Neck circumference	1.013 (0.532–1.930)	0.969	5.344 (2.665–10.715)	< 0.001***
NWR	0.795 (0.484–1.305)	0.364	0.335 (0.189–0.594)	< 0.001***
BMI	1.386 (0.930–2.065)	0.109	5.447 (2.830–10.483)	< 0.001***
Waist circumference	1.405 (0.692–2.854)	0.347	11.911 (4.823–29.415)	< 0.001***
ABSI	1.147 (0.751–1.752)	0.525	1.551 (0.978–2.460)	0.062

^aModels adjusted for age, sex and body mass index, except for TyG-BMI and body mass index, which incorporate body mass index and were adjusted for age and sex only to avoid collinearity. ^bModels adjusted for age and sex.

*p < 0.05, **p < 0.01, ***p < 0.001. ABSI a body shape index, BMI body mass index, BRI body roundness index, CI confidence interval, LAP lipid accumulation product, NWR neck-to-waist ratio, OR odds ratio, TyG triglyceride-glucose index, VAI visceral adiposity index, WHR waist-to-hip ratio, WHtR waist-to-height ratio

Associations with visceral obesity

For visceral obesity ($VFA \geq 100 \text{ cm}^2$), waist circumference showed the highest AUC (0.875, 95% CI 0.802–0.932), followed by BMI (0.809), neck circumference (0.792, 95% CI 0.707–0.871), BRI (0.784) and WHtR (0.784) (Table 4). Neck circumference therefore offers a simple alternative that can be obtained at the bedside without a height measurement. In multivariable analysis, BRI showed the strongest independent association (OR 6.480 per 1-SD increment, 95% CI 3.123–13.446, $p < 0.001$), followed by WHtR (OR 6.250, $p < 0.001$) and neck circumference (OR 5.344, 95% CI 2.665–10.715, $p < 0.001$) (Table 3). Notably, and in contrast to the findings for IR, several TyG indices were also significantly associated with visceral obesity (TyG-WC: OR 3.423, $p < 0.001$; TyG-BMI: OR 3.212, $p < 0.001$; TyG-WHtR: OR 2.916, $p < 0.001$), and TyG-WC reached an AUC of 0.756 (95% CI 0.670–0.838), although waist circumference remained superior (DeLong $p < 0.001$).

Table 4
Discriminative performance of the indices for the identification of visceral obesity

Index	AUC (95% CI)	p	Optimal cut-off	Sensitivity	Specificity	PPV	NPV
Waist circumference	0.875 (0.802– 0.932)	< 0.001	94.0	0.714	0.897	0.814	0.833
BMI	0.809 (0.743– 0.883)	< 0.001	24.0	0.857	0.641	0.600	0.877
Neck circumference	0.792 (0.707– 0.871)	< 0.001	37.0	0.694	0.769	0.654	0.800
BRI	0.784 (0.708– 0.863)	< 0.001	4.78	0.714	0.769	0.660	0.811
WHtR	0.784 (0.708– 0.863)	< 0.001	0.57	0.714	0.769	0.660	0.811
TyG-WC	0.756 (0.670– 0.838)	< 0.001	850.6	0.714	0.718	0.614	0.800
TyG-BMI	0.728 (0.647– 0.808)	< 0.001	257.8	0.449	0.897	0.733	0.722
WHR	0.724 (0.633– 0.819)	< 0.001	0.97	0.551	0.846	0.692	0.750
TyG-WHtR	0.697 (0.607– 0.789)	< 0.001	5.06	0.796	0.500	0.500	0.796
LAP	0.647 (0.552– 0.752)	0.005	20.5	1.000	0.256	0.458	1.000
ABSI	0.593 (0.485– 0.688)	0.079	0.081	0.878	0.372	0.467	0.829

Optimal cut-off values were determined by the Youden index. 95% CI were estimated from 500 bootstrap resamples; p values were derived from the Mann–Whitney U test comparing index values between patients with and without visceral obesity. ABSI a body shape index, AUC area under the receiver operating characteristic curve, BMI body mass index, BRI body roundness index, CI confidence interval, LAP lipid accumulation product, NPV negative predictive value, NWR neck-to-waist ratio, PPV positive predictive value, TyG triglyceride-glucose index, VAI visceral adiposity index, WHR waist-to-hip ratio, WHtR waist-to-height ratio

Index	AUC (95% CI)	p	Optimal cut-off	Sensitivity	Specificity	PPV	NPV
VAI	0.519 (0.417– 0.631)	0.716	0.95	0.959	0.154	0.416	0.857
TyG	0.488 (0.389– 0.598)	0.822	9.80	0.306	0.769	0.455	0.638
NWR	0.363 (0.268– 0.454)	0.009	–	0.000	1.000	–	0.614
Optimal cut-off values were determined by the Youden index. 95% CI were estimated from 500 bootstrap resamples; p values were derived from the Mann–Whitney U test comparing index values between patients with and without visceral obesity. ABSI a body shape index, AUC area under the receiver operating characteristic curve, BMI body mass index, BRI body roundness index, CI confidence interval, LAP lipid accumulation product, NPV negative predictive value, NWR neck-to-waist ratio, PPV positive predictive value, TyG triglyceride-glucose index, VAI visceral adiposity index, WHR waist-to-hip ratio, WHtR waist-to-height ratio							

Body composition and grip strength

The marked discrepancy between the prevalence of dynapenia (28.3%) and that of sarcopenia (0.8%) indicates that muscle strength declined substantially in this cohort while muscle mass was largely preserved. Neck circumference was the strongest anthropometric correlate of grip strength ($p = 0.633$, $p < 0.001$), followed by head circumference ($p = 0.467$, $p < 0.001$) and calf circumference ($p = 0.333$, $p < 0.001$), suggesting that these simple measurements serve as proxies for overall muscularity. NWR was also positively correlated with grip strength ($p = 0.380$, $p < 0.001$), reflecting the contribution of neck size to overall body strength (Fig. 4).

Discussion

This study systematically compared novel anthropometric and metabolic composite indices for identifying IR and body-composition abnormalities in elderly patients with T2DM. The principal findings were: (1) enhanced TyG indices—particularly TyG-WC—yielded the highest AUC for IR discrimination and were the only indices independently associated with IR after full adjustment, although their advantage over the basic TyG index was not statistically significant; (2) waist circumference and, as a practical bedside alternative, neck circumference were the most effective anthropometric markers of visceral obesity; (3) TyG-based indices uniquely correlated with glycaemic control as reflected by HbA1c, whereas traditional anthropometric indices did not; and (4) dynapenia was far more prevalent than sarcopenia in this population, supporting the clinical importance of strength assessment.

Enhanced TyG indices for insulin-resistance screening

Our finding that enhanced TyG indices—particularly TyG-WC—yielded the highest AUC for IR discrimination (0.660, 95% CI 0.568–0.761) and were the only indices independently associated with IR after full adjustment is consistent with the emerging literature. The TyG index, originally proposed as a simple IR surrogate [5], integrates two metabolic pathways—lipotoxicity (triglycerides) and glucotoxicity (fasting glucose)—and its enhancement with anthropometric parameters adds a body-size dimension that captures the metabolic–structural interaction [7, 8, 9]. In our elderly cohort with T2DM, all four TyG-based indices remained independently associated with IR after adjustment. However, the discriminative advantage of TyG-WC over the basic TyG index was not statistically significant (DeLong $p = 0.897$), indicating that anthropometric enhancement contributes limited incremental value beyond the metabolic TyG component for IR screening. The absolute AUC values (approximately 0.65–0.66) reflect only modest discrimination; accordingly, these indices are best interpreted as continuous risk markers within multivariable models rather than as standalone screening tests. This distinction is clinically relevant because TyG-based indices require only routine laboratory tests and a tape measure, making them feasible for bedside or outpatient use without the need for insulin measurement.

Traditional anthropometric indices (BRI, WHR, WHtR and BMI) were not independently associated with IR after adjustment for BMI. This probably reflects how, in established and largely treated elderly T2DM, adiposity is already entrenched and its metabolic consequences are mediated through glycaemic pathways. In this context, metabolic indices such as TyG rather than structural indices such as anthropometry carry the residual discriminative signal for IR.

Body roundness index and neck circumference for visceral obesity

Waist circumference showed the strongest discriminative performance for visceral obesity (AUC 0.875), consistent with its direct anatomical relationship to abdominal visceral fat. BRI demonstrated the strongest independent association with visceral obesity (OR 6.480 per 1-SD increment, $p < 0.001$), in line with its validation against imaging-based measures of visceral fat [10, 11, 12]. The BRI model captures body roundness, a geometric property that correlates with visceral fat distribution more closely than linear measurements such as waist circumference alone. Neck circumference, with an AUC of 0.792 for visceral obesity, offers a simple alternative that can be obtained at the bedside without a height measurement and was independently associated with visceral obesity (OR 5.344, $p < 0.001$) after adjustment. This finding aligns with previous reports identifying neck circumference as an independent marker of metabolic syndrome and visceral adiposity, including a meta-analysis in adults [16] and a study of Chinese adults with T2DM in which neck circumference combined with waist circumference outperformed traditional anthropometric indices [17].

Neck circumference correlated strongly with VFA ($p = 0.546$) but also with grip strength ($p = 0.633$) and ASMI ($p = 0.689$), suggesting that it reflects overall body size and muscularity rather than adiposity alone. This dual association may explain why neck circumference was not independently associated with IR, as it captures both adiposity and muscularity, which exert opposing effects on insulin sensitivity.

NWR, which normalises neck size to waist size, showed an inverse correlation with VFA ($\rho = -0.325$) and a positive correlation with grip strength ($\rho = 0.380$), suggesting that it may distinguish body-shape phenotypes relevant to the obesity paradox in older populations.

Strength–mass dissociation

The 28.3% prevalence of dynapenia in contrast to only 0.8% for sarcopenia replicates and extends our earlier observation in a smaller cohort. This pattern, in which grip strength declines substantially while muscle mass is preserved, is increasingly recognised in elderly T2DM and may reflect neuropathy, impaired insulin signalling in muscle or physical inactivity rather than pure muscle loss [18, 19, 21]. The very low absolute rate of sarcopenia is lower than the rates reported in some community-based cohorts and most probably reflects the AWGS 2019 definition, which requires low muscle mass in addition to low strength or low physical performance, so that patients with isolated strength loss are classified as dynapenic rather than sarcopenic. It may also reflect the composition of our sample, recruited at a single tertiary centre serving permanent residents of Fuzhou, a relatively affluent coastal region of China, where better nutritional intake and healthcare access may help preserve muscle mass. The clinical implication is that sarcopenia screening based solely on muscle-mass criteria may miss a substantial proportion of functionally impaired patients, and that grip-strength assessment should be incorporated into routine diabetes care for older adults.

TyG indices and glycaemic control

The significant correlation of TyG-based indices with HbA1c, in the absence of any such association for anthropometric indices, suggests that TyG captures the metabolic burden driving chronic hyperglycaemia. This is consistent with the role of the TyG index as an integrator of insulin resistance and β -cell dysfunction, both of which determine glycaemic control. From a clinical perspective, TyG-WC may serve as a simple surrogate for both IR and glycaemic control in settings where HbA1c or insulin measurement is not readily available.

Strengths and limitations

The strengths of this study include the simultaneous comparison of a comprehensive panel of composite indices against directly measured body composition, the use of standardised OR per 1-SD increment to allow comparison across indices, and the reporting of bootstrap CI, DeLong comparisons and full diagnostic performance metrics.

Several limitations should nevertheless be acknowledged. First, the cross-sectional design precludes causal inference. Second, the sample size ($n = 127$) is modest, which may limit statistical power for some subgroup analyses. Third, body composition was assessed by BIA rather than by dual-energy X-ray absorptiometry or computed tomography, which are considered reference standards. Fourth, although insulin therapy was an exclusion criterion (so HOMA-IR was not confounded by exogenous insulin), detailed histories of other glucose-lowering agents were not systematically collected and may influence glycaemic outcomes. Fifth, the study population consisted of hospitalised elderly patients with T2DM

recruited at a single tertiary centre serving permanent residents of Fuzhou, Fujian Province, a relatively affluent coastal region of China; this single-region and sociodemographically homogeneous sample may limit generalisability to less affluent or rural populations, and the very low prevalence of sarcopenia ($n = 1$) precluded any meaningful subgroup or inferential analysis of sarcopenia, so that dynapenia was used as the primary functional outcome. Finally, the cut-off values for the novel indices were derived within this cohort by the Youden index and require external validation, and the modest AUC values for IR discrimination indicate that these indices should be used as continuous risk markers rather than as standalone diagnostic tests. Future multicentre studies across several regions are warranted to validate these findings and to confirm their generalisability across diverse socioeconomic and geographical populations.

Conclusions

In elderly patients with T2DM, TyG-based indices—particularly TyG-WC—provide the highest AUC for the identification of IR and are the only indices independently associated with IR after full adjustment, although their advantage over the basic TyG index is not statistically significant. Waist circumference and neck circumference are practical bedside markers of visceral obesity. The high prevalence of dynapenia (28.3%), contrasted with the rarity of sarcopenia (0.8%), underscores the value of grip-strength assessment in geriatric diabetes care. These findings support the use of novel composite indices as continuous risk markers within multivariable models for risk stratification in elderly T2DM.

Abbreviations

ABSI: A body shape index; ASM: Appendicular skeletal muscle mass; ASMI: Appendicular skeletal muscle mass index; AUC: Area under the receiver operating characteristic curve; AWGS: Asian Working Group for Sarcopenia; BIA: Bioelectrical impedance analysis; BMI: Body mass index; BRI: Body roundness index; CI: Confidence interval; FPG: Fasting plasma glucose; HbA1c: Glycated haemoglobin; HDL-c: High-density lipoprotein cholesterol; HOMA-IR: Homeostasis model assessment of insulin resistance; IQR: Interquartile range; IR: Insulin resistance; LAP: Lipid accumulation product; NPV: Negative predictive value; NWR: Neck-to-waist ratio; OR: Odds ratio; PPV: Positive predictive value; SD: Standard deviation; T2DM: Type 2 diabetes mellitus; TG: Triglycerides; TyG: Triglyceride-glucose index; VAI: Visceral adiposity index; VFA: Visceral fat area; WC: Waist circumference; WHR: Waist-to-hip ratio; WHtR: Waist-to-height ratio

Declarations

Ethics approval and consent to participate

The study was approved by the Institutional Review Board of The Affiliated People's Hospital of Fujian University of Traditional Chinese Medicine (approval no. YJS2022-065-002) and was conducted in

accordance with the Declaration of Helsinki. Written informed consent was obtained from all participants.

Consent for publication

Not applicable.

Availability of data and materials

The datasets generated and analysed during the current study are not publicly available because they contain information that could compromise the privacy of participants, but are available from the corresponding author on reasonable request.

Competing interests

The authors declare that they have no competing interests.

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This study received no external funding.

Authors' contributions

CRedit Authorship Contribution Statement

Rongkun Xu: Conceptualization, Methodology, Formal analysis, Data curation, Writing – original draft, Writing – review & editing.

Chen Qiu: Investigation, Data curation, Writing – review & editing.

Jinghui Li: Investigation, Data curation, Writing – review & editing.

Lu Lin: Investigation, Data curation, Writing – review & editing.

Mingqian Jiang: Investigation, Data curation, Writing – review & editing.

Binhua Ye: Conceptualization, Supervision, Funding acquisition, Resources, Writing – review & editing.

All authors read and approved the final manuscript and agree to be accountable for all aspects of the work.

Clinical trial number

Not applicable.

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Figures

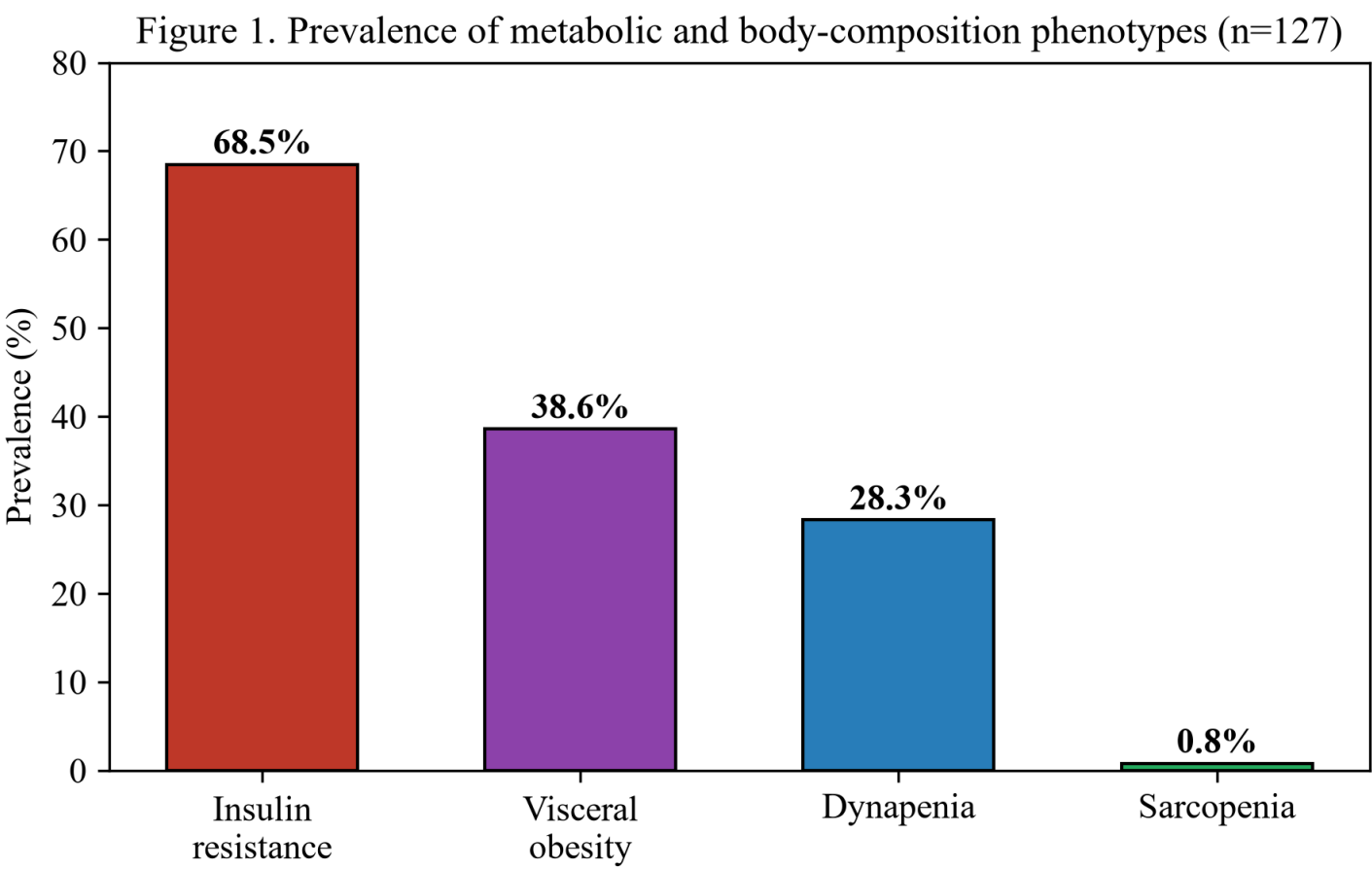


Figure 1

Prevalence of metabolic and body-composition phenotypes in elderly patients with type 2 diabetes (n = 127). Insulin resistance was defined as HOMA-IR ≥ 2.0 , visceral obesity as visceral fat area $\geq 100\text{ cm}^2$, dynapenia as maximum grip strength $< 28\text{ kg}$ in men or $< 18\text{ kg}$ in women, and sarcopenia according to the Asian Working Group for Sarcopenia 2019 criteria

Figure 2. ROC curves for insulin-resistance discrimination

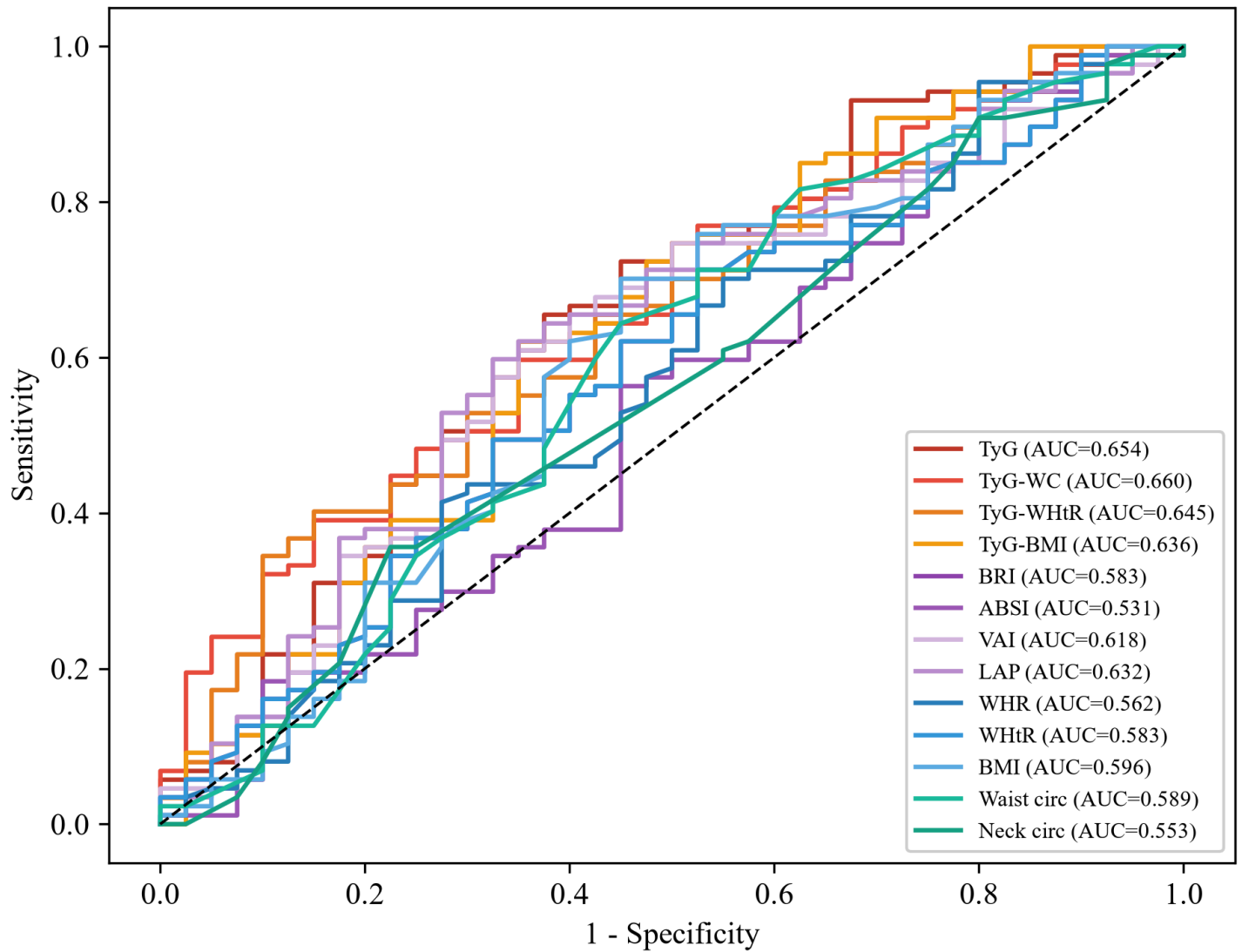


Figure 2

Receiver operating characteristic curves of composite and traditional indices for the identification of insulin resistance ($\text{HOMA-IR} \geq 2.0$). The area under the curve is shown for each index in the legend

Figure 3. Multivariable-adjusted associations (odds ratio per 1 SD increase)

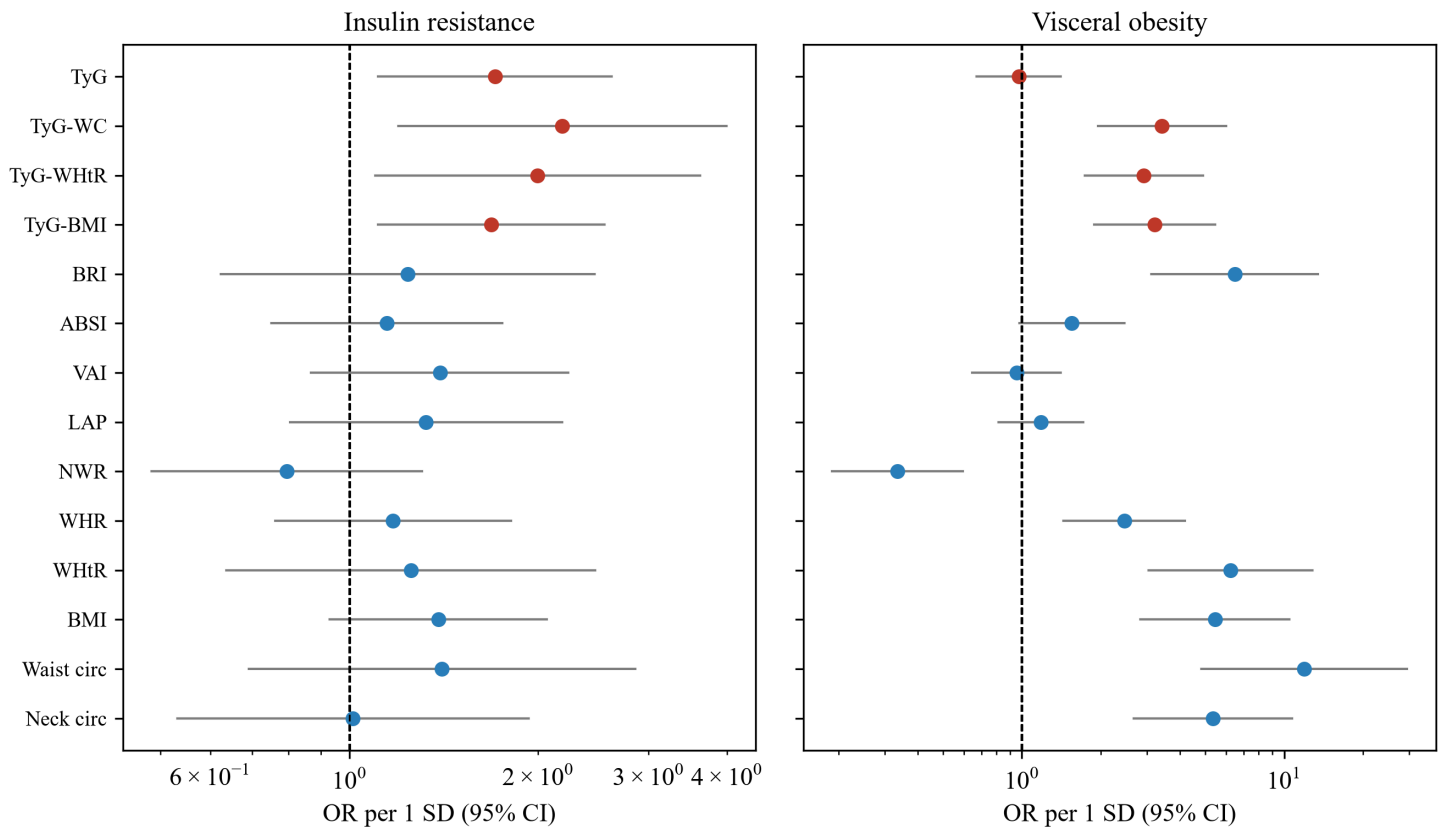


Figure 3

Forest plot of multivariable-adjusted odds ratios (per 1-SD increment) for the association of each index with insulin resistance. Models were adjusted for age, sex and body mass index, except for TyG-BMI and body mass index, which were adjusted for age and sex only. Horizontal bars denote 95% confidence intervals and the vertical dashed line indicates an odds ratio of 1

Figure 4. Spearman correlations: novel/traditional indices vs outcomes

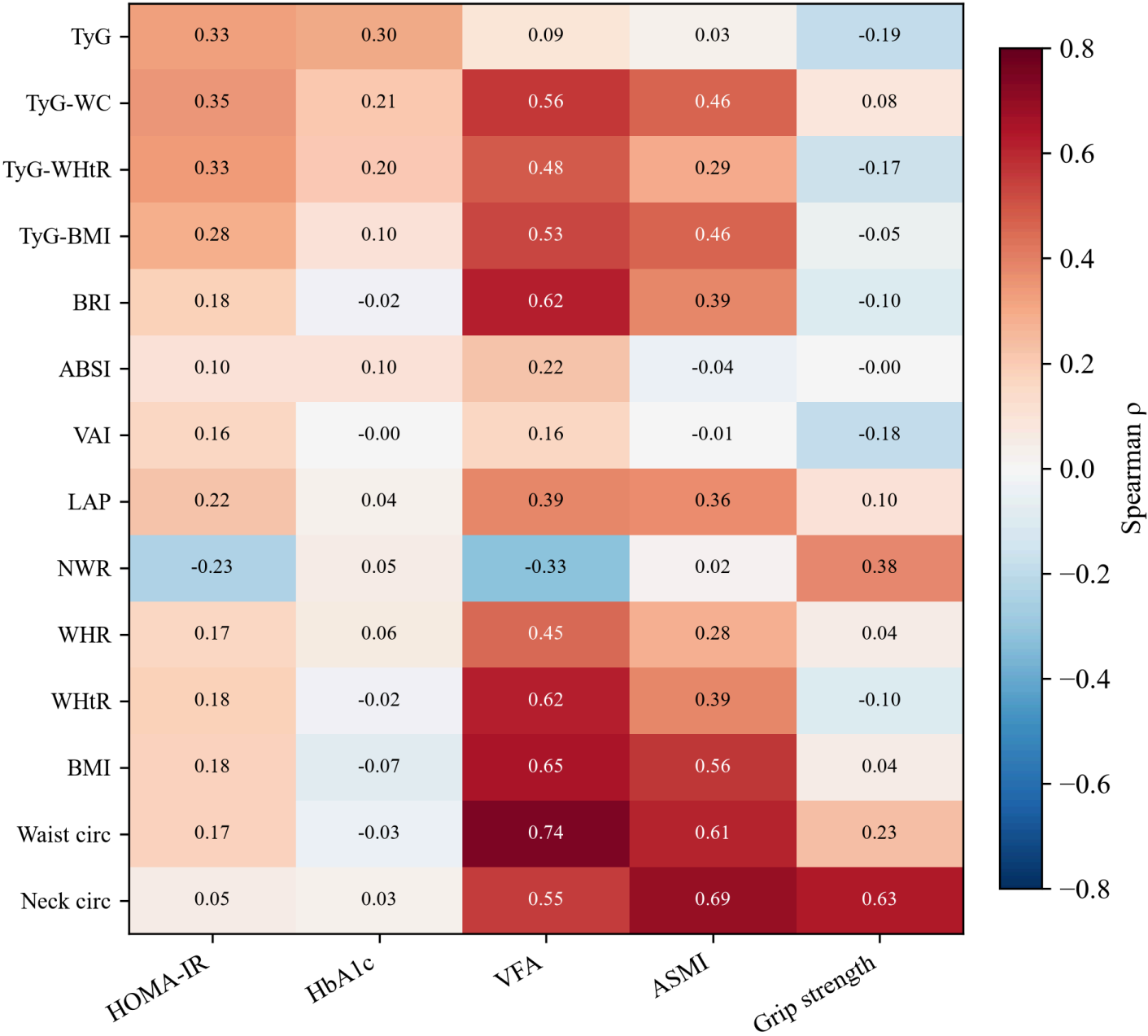


Figure 4

Heat map of Spearman correlation coefficients between the anthropometric and metabolic indices and the metabolic and body-composition outcomes. Warmer colours indicate stronger positive correlations and cooler colours stronger negative correlations

Supplementary Files

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