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Beyond BMI: Comparative Performance of Six Anthropometric Indices for Cardiometabolic Risk Prediction in a Primary Care Population of Madeira Island, Portugal

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ABSTRACT

Background: *Central obesity is strongly associated with cardiometabolic risk (CMR), but the optimal anthropometric index for routine clinical screening remains uncertain. This study compared the discriminative performance of six anthropometric indices for predicting CMR in a primary care population from Madeira Island, Portugal.*

Methods: *A cross-sectional study was conducted including 198 adults aged 30–74 years attending primary health centres in Madeira Island. Body mass index (BMI), waist circumference (WC), waist-to-height ratio (WHtR), waist-to-hip ratio (WHR), a body shape index (ABSI), and body roundness index (BRI) were evaluated. CMR was defined as Framingham score ≥10% and/or FINDRISC score ≥12. Correlation analyses and receiver operating characteristic (ROC) curves were used to assess associations and discriminative capacity, with area under the curve (AUC) values and 95% confidence intervals calculated, where an AUC of 1.0 indicates perfect discrimination and AUC <0.5 no better than chance.*

Results: *WHtR (AUC=0.859; 95% CI: 0.806–0.912) and BRI (AUC=0.860; 95% CI: 0.807–0.912) showed the highest discriminative capacity for overall CMR and type 2 diabetes risk (T2DM), outperforming BMI (AUC=0.790). WC also demonstrated strong predictive ability (AUC=0.838). For cardiovascular risk specifically, ABSI and WHR performed best, although no index showed clear superiority. The strongest correlations with overall CMR were observed for BRI (ρ=0.617) and WHtR (ρ=0.616). Optimal cut-offs for CMR prediction were WHtR ≥ 0.555 and BRI ≥ 4.50.*

Conclusions: *WHtR and BRI showed numerically higher discriminative capacity than BMI for CMR prediction in this primary care population. Given its equivalent predictive performance, simpler calculation, and a widely validated cut-off (≥ 0.5), WHtR may represent a practical screening tool for routine clinical use, pending confirmation in larger prospective cohorts.*

Keywords
Anthropometry, Body roundness index, Cardiometabolic risk, Obesity screening, Waist-to-height ratio, Waist circumference.

Introduction
The global prevalence of obesity has more than doubled since 1990, affecting over 890 million adults worldwide in 2022 [1]. Rising obesity rates have contributed to a worldwide pandemic of metabolic syndrome, characterised by central obesity, hyperglycaemia, dyslipidaemia and hypertension, which increases the risk of cardiovascular disease (CVD) and T2DM [2-4]. Visceral adipose tissue plays a central pathophysiological role, producing inflammatory mediators that promote insulin resistance, dyslipidaemia and hypertension [5,6].

Although computed tomography and magnetic resonance imaging are gold standards for visceral fat quantification, their cost and limited availability preclude routine clinical use [7,8]. In addition to the previously referred methods, dual-energy X-ray absorptiometry, despite being the most reliable method in the evaluation of fat mass, cannot distinguish visceral from subcutaneous fat [9]. Anthropometric indices therefore remain the cornerstone of cardiometabolic screening in clinical practice. Of these, BMI is the most widely used, yet it cannot discriminate fat mass from lean mass or reflect fat distribution [1,3,9-11]. WC captures abdominal adiposity more directly [7,8,10,12] but may misclassify risk in individuals of extreme stature [13], a limitation that prompted the development of WHtR. This index has demonstrated consistently higher predictive performance than WC and BMI across multiple populations [14,15], and a 2023 systematic review and meta-analysis further confirmed that higher WHtR is independently associated with all-cause mortality, extending its clinical utility beyond cross-sectional risk prediction [16]. Two newer indices, ABSI [11] and BRI [17], were developed as geometrical refinements of WC and recent prospective data confirm BRI's associations with CVD, T2DM and all-cause mortality [18]. Despite a substantial body of literature, no global consensus exists on the optimal anthropometric screening tool for CMR, and no study has examined this question in the population of Madeira Island, which may have specific epidemiological, genetic and lifestyle characteristics influencing the applicability of internationally validated cut-offs. The objective of this study was to identify the best anthropometric predictor of CMR in adults from Madeira Island, using validated cardiovascular and T2DM risk scores as the reference standard.

Material and Methods

Study design and participants

This descriptive cross-sectional observational study used convenience sampling. Adults aged 30–74 years of both sexes were recruited from primary health centres, between February and June 2018. Individuals were excluded if they had a prior diagnosis of CVD or T2DM, chronic diseases affecting metabolic status or body composition (malabsorption syndromes, Crohn's disease, coeliac disease, or cystic fibrosis), a history of bariatric or intestinal surgery, active oncological disease, or current pregnancy.

A formal a priori sample size calculation (α=0.05; power 80%; minimum detectable correlation |r|=0.2) indicated a minimum of 194 individuals; the final sample of 198 exceeded this threshold. The marked female predominance (83.3%) reflects the typical demographic profile of nutrition outpatient consultations in Portuguese primary care, where women constitute the majority of attendees.

Anthropometric measurements

Weight and height were measured without shoes and in light clothing using a TANITA TBF300 scale and a SECA 222 stadiometer. All measurements were performed by a single observer following ISAK standards [19], eliminating inter-observer variability. WC was measured at the midpoint between the lower border of the last rib and the iliac crest at the end of normal expiration. Hip circumference (HC) was measured at the level of maximum gluteal protrusion solely for WHR calculation although HC was not included as an independent index given its consistently limited discriminatory capacity for CMR in the published literature [20]. Derived indices were

calculated as $ABSI = \frac{WC}{BMI^{\frac{2}{3}} \times height^{\frac{1}{2}}}$ [11]; $BRI = 364.2 - 365.5 \times \sqrt{(1 - \frac{(\frac{WC}{2\pi})^2}{0.5 \times height^2}}$ [17].

Biochemical, clinical and risk data

Fasting glycaemia, total cholesterol (TC), LDL cholesterol (LDL-c), HDL cholesterol (HDL-c) and triglycerides (TG) were retrieved from each participant's most recent blood test within the preceding 12 months, performed using standardised enzymatic colorimetric methods with internal and external quality control. LDL-c was calculated using the Friedewald equation when TG <400 mg/dL. SBP and DBP were measured on-site on the non-dominant arm after ≥2–3 minutes of rest using a validated digital tensiometer (OMRON M7 Intelli IT) where the mean of two consecutive readings was recorded.

CMR was defined as a composite endpoint: Framingham score ≥10% (moderate-to-high 10-year coronary disease risk, classified as low <10%, moderate 10–20%, or high >20% [21] and/or FINDRISC score ≥12 (moderate-to-very high 10-year T2DM risk, classified as low <7, slightly elevated 7–11, moderate 12–14, high 15–20, or very high >20 [22]. An important limitation is that the Framingham score was developed for North American populations, and the European Society of Cardiology currently recommends SCORE2 for European populations, but this was not available at the time of data collection (2018).

Statistical analysis

Statistical analysis was performed using IBM SPSS Statistics v25.0. Normality was evaluated by symmetry and kurtosis coefficients; all variables followed approximately normal distributions except HDL-c and TG. Between-group comparisons used Student's t-test or Mann–Whitney test as appropriate, and Pearson (R) or Spearman (ρ) correlations were calculated between anthropometric indices and biochemical/clinical variables and risk scores. ROC curve analysis assessed discriminative capacity for CMR, CV risk and T2DM risk, with AUC values and 95% confidence intervals calculated, where an AUC of 1.0 indicates perfect discrimination and AUC <0.5 no better than chance. Optimal cut-offs were derived from the Youden index. A significance threshold of α=0.05 was applied throughout.

Ethics approval was obtained from the Ethics Committee of the Health Service of the Autonomous Region of Madeira (48/2017) and all participants provided written informed consent prior to enrolment.

Results

Sample characterisation

The sample comprised of 198 individuals: 33 men (16.7%) and 165 women (83.3%), mean age 52.4 years (SD=10.8; range 30–74). Clinically, 46.0% had arterial hypertension (82.4% medicated), 51.5% had dyslipidaemia (53% medicated), and 15.7% were smokers. Regular physical activity was reported by 61.6% (mean 3.91 h/week). Notably, 82.3% had overweight or obesity (BMI ≥25 kg/m²), substantially higher than the Portuguese national average of ~57% [23], likely reflecting the clinical setting (nutrition consultations). Anthropometric and biochemical characteristics by sex are shown in Table 1. Men were significantly heavier and taller, with greater WC, WHR and ABSI; at the biochemical level, men had significantly lower HDL-c and higher TG and fasting glycaemia compared to women. No significant differences were observed for BMI, WHtR, BRI, DBP, TC or LDL-c.

Table 1: Sample characterisation by sex (mean ± SD).

Variable	Male (n=33) Mean (SD)	Female (n=165) Mean (SD)	p-value
Age (years)	52.8 (9.9)	52.3 (11.0)	0.821
Weight (kg)	90.4 (15.2)	74.7 (14.8)	<0.001*
Height (m)	1.72 (0.07)	1.59 (0.06)	<0.001*
BMI (kg/m²)	30.6 (4.8)	29.6 (5.6)	0.348
WC (cm)	104.1 (12.5)	93.0 (13.4)	<0.001*
HC (cm)	107.3 (7.9)	107.8 (11.4)	0.837
WHtR	0.61 (0.08)	0.59 (0.09)	0.189
WHR	0.97 (0.09)	0.86 (0.08)	<0.001*
ABSI	0.081 (0.004)	0.077 (0.005)	<0.001*
BRI	5.7 (1.8)	5.2 (1.9)	0.208
SBP (mmHg)	135.3 (15.8)	128.4 (16.8)	0.031*
DBP (mmHg)	79.4 (10.7)	76.9 (9.5)	0.181
Fasting glycaemia (mg/dL)	92.9 (15.3)	87.8 (12.4)	0.038*
Total cholesterol (mg/dL)	186.5 (33.8)	197.9 (38.7)	0.118
LDL-c (mg/dL)	105.9 (29.6)	116.7 (33.7)	0.087
HDL-c (mg/dL)	46.1 (10.4)	56.7 (13.4)	<0.001†
Triglycerides (mg/dL)	170.7 (92.7)	122.7 (56.1)	0.002†

*p<0.05 (Student's t-test); †p<0.05 (Mann–Whitney test). BMI: body mass index; WC: waist circumference; HC: hip circumference; WHtR: waist-to-height ratio; WHR: waist-to-hip ratio; ABSI: a body shape index; BRI: body roundness index; SBP/DBP: systolic/diastolic blood pressure; LDL-c/HDL-c: LDL/HDL cholesterol; TG: triglycerides.

Cardiovascular and T2DM risk profiles

Mean 10-year coronary disease risk was 6.16%, significantly higher in men than women (9.58%±5.86 vs 5.48%±4.02; p<0.001), where 16.7% had a Framingham score ≥10%. Using FINDRISC, 55.6% scored ≥12 (moderate-to-very high T2DM risk: 25.3% moderate, 24.7% high, 5.6% very high), with no significant sex difference. Overall CMR was present in 57.1% of the sample.

Correlations between anthropometric indices and cardiometabolic variables

All indices showed statistically significant positive correlations with fasting glycaemia, TG and SBP, and negative correlations with HDL-c. TC and LDL-c showed no significant correlations with any index. The strongest correlation was WC–HDL-c (ρ=−0.469; p<0.001). For overall CMR, the highest correlations were BRI (ρ=0.617) and WHtR (ρ=0.616), followed by WC (ρ=0.580). For T2DM risk, BRI (ρ=0.712) and WHtR (ρ=0.709) led. For cardiovascular risk, WHR (ρ=0.524) and ABSI (ρ=0.521) performed best, while BMI showed the weakest association (ρ=0.268). All significant correlations were weak to moderate in magnitude. Full correlation data are shown in Tables 2 and 3.

Table 3: Spearman correlations between anthropometric indices and risk scores.

Index	CV Risk (ρ)	T2DM Risk (ρ)	CMR (ρ)
BMI	0.268***	0.593***	0.498***
WC	0.435***	0.671***	0.580***
WHtR	0.450***	0.709***	0.616***
WHR	0.524***	0.487***	0.430***
ABSI	0.521***	0.419***	0.379***
BRI	0.455***	0.712***	0.617***

***p<0.001. CV: cardiovascular; T2DM: type 2 diabetes mellitus; CMR: cardiometabolic risk (combined).

Anthropometric indices by CMR status

All anthropometric measures and age were significantly higher in individuals with CMR compared to those without (all p<0.001). Height did not differ between groups (p=0.413). Table 4 shows values by CMR status.

ROC curve analysis

For overall CMR, BRI (AUC=0.860 [95% CI: 0.807–0.912]) and WHtR (AUC=0.859 [95% CI: 0.806–0.912]) showed the highest observed discriminative capacity, followed by WC (AUC=0.838), while BMI was lowest (AUC=0.790). The same pattern held for T2DM risk. For cardiovascular risk, no index was markedly superior; ABSI (0.762) and WHR (0.758) led while BMI (0.669) performed worst. Full AUC values are shown in Table 5. Optimal

Table 2: Correlations between anthropometric indices and cardiometabolic risk variables (Pearson R or Spearman ρ).

Index	Glycaemia	TC	LDL-c	HDL-c	TG	SBP	DBP
BMI	R=0.205**	R=0.027	R=0.099	ρ=−0.369***	ρ=0.213**	R=0.256***	R=0.257***
WC	R=0.300***	R=−0.011	R=0.063	ρ=−0.469***	ρ=0.291***	R=0.328***	R=0.202**
WHtR	R=0.278***	R=0.009	R=0.085	ρ=−0.417***	ρ=0.281***	R=0.327***	R=0.168*
WHR	R=0.300***	R=−0.041	R=0.009	ρ=−0.435***	ρ=0.335***	R=0.280***	R=0.067
ABSI	R=0.254***	R=−0.045	R=−0.009	ρ=−0.302***	ρ=0.267***	R=0.237**	R=−0.050
BRI	R=0.281***	R=0.006	R=0.077	ρ=−0.414***	ρ=0.282***	R=0.324***	R=0.164*

*p<0.05; **p<0.01; ***p<0.001; ns: non-significant. TC: total cholesterol; LDL-c/HDL-c: LDL/HDL cholesterol; TG: triglycerides; SBP/DBP: systolic/diastolic blood pressure.

Youden-derived cut-offs for CMR were: BRI ≥4.50 (sensitivity 85.0%, specificity 75.3%), WHtR ≥0.555 (sensitivity 86.7%, specificity 70.6%), WC ≥89.5 cm (sensitivity 84.1%, specificity 68.2%), and BMI ≥30.0 kg/m² (sensitivity 63.7%, specificity 87.1%).

Table 4: Anthropometric and age characteristics by CMR status (mean ± SD; Student's t-test).

Variable	Without CMR (n=85) Mean (SD)	With CMR (n=113) Mean (SD)	p-value
Age (years)	47.0 (9.8)	56.4 (9.6)	<0.001*
Weight (kg)	69.8 (13.9)	83.0 (15.1)	<0.001*
BMI (kg/m²)	26.7 (4.6)	32.0 (5.0)	<0.001*
WC (cm)	85.8 (11.1)	101.6 (11.6)	<0.001*
WHtR	0.53 (0.07)	0.63 (0.07)	<0.001*
WHR	0.83 (0.08)	0.91 (0.08)	<0.001*
ABSI	0.076 (0.005)	0.080 (0.005)	<0.001*
BRI	4.0 (1.4)	6.3 (1.7)	<0.001*

*p<0.001. CMR: Cardiometabolic risk.

Discussion

In this primary care sample from Madeira Island, WHtR and BRI consistently showed the highest observed discriminative capacity for overall CMR and T2DM risk, with AUC values approximately 0.07 units higher than BMI. This pattern is consistent with published evidence [14,16,18] and supports WHtR as a pragmatic screening tool for cardiometabolic risk, given its widely validated cut-off of ≥0.5.

Before interpreting these findings, an important methodological caveat should be noted: FINDRISC incorporates both BMI and WC in its calculation, which introduces circularity and may have systematically favoured WC-derived indices, including WHtR and BRI. This should be considered when evaluating all comparative performance data in this study.

Sample cardiometabolic burden

As expected in a nutrition outpatient setting, 82.3% of participants had overweight or obesity, considerably above the Portuguese national average of ~57% [23], a figure that underscores the well-documented association between obesity and cardiometabolic morbidity and mortality [24]. The composite CMR outcome was largely driven by T2DM risk classification (FINDRISC ≥12: 55.6%) rather than cardiovascular risk (Framingham ≥10%: 16.7%). This should be borne in mind when interpreting the findings, as the composite outcome does not provide an equal balance between cardiovascular and metabolic risk endpoints.

Biochemical correlations

As previously reported in comparable populations [25,26], none of the indices correlated significantly with TC or LDL-c. By contrast, WC showed the strongest negative correlation with HDL-c (ρ=−0.469), confirming the well-established link between central adiposity and reduced HDL-c [9,27]. The slightly weaker associations observed for WHR are discussed further in the context of its overall performance below.

Performance of BMI

Among all indices evaluated, BMI showed the weakest correlation with cardiovascular risk (ρ=0.268) and the lowest AUC for CMR (0.790), consistent with its documented inability to differentiate fat mass from lean mass or capture fat distribution [1,3,9-11]. Although Mooney et al. [28] found BMI to predict metabolic syndrome components with accuracy equivalent to WC, WHtR or fat mass percentage, the superiority of WC-based indices in the present study was consistent across all outcomes. These results reinforce the view that BMI should be supplemented with a central adiposity measure rather than used alone [5,27].

Performance of WC, WHtR, WHR and BRI

WC remained a strong CMR predictor (AUC=0.838; ρ=0.580) [7,8,10,12], thus be consistent with a Vietnamese cohort where WC was the index most strongly associated with cardiovascular risk in men [29]. WHR showed the strongest correlation with cardiovascular risk (ρ=0.524) and a reasonable AUC (0.758) but performed less well for overall CMR (AUC=0.751), possibly because hip circumference partly captures gluteal lean mass rather than visceral fat, thereby diluting the abdominal signal [20,30].

The near-identical performance of BRI and WHtR likely reflects the fact that both indices are primarily driven by central adiposity and incorporate waist circumference relative to body size, making them mathematically related expressions of the same underlying physiological construct. The optimal WHtR cut-off in this sample (≥0.555) is slightly above the universal ≥0.5 boundary, in line with values reported in other Southern European and Mediterranean populations [31] and likely reflecting the high prevalence of overweight and obesity in this clinical setting, a context where a more conservative threshold may be clinically appropriate.

Table 5: AUC values from ROC curve analysis for each anthropometric index.

Index	CV Risk AUC (95% CI)	T2DM Risk AUC (95% CI)	CMR AUC (95% CI)	Note
BMI	0.669 (0.585–0.754)	0.797 (0.735–0.859)	0.790 (0.727–0.854)	—
WC	0.741 (0.655–0.828)	0.839 (0.784–0.894)	0.838 (0.782–0.894)	—
WHtR	0.754 (0.669–0.839)	0.864 (0.813–0.916)	0.859 (0.806–0.912)	Best CMR
WHR	0.758 (0.669–0.846)	0.746 (0.677–0.814)	0.751 (0.683–0.819)	—
ABSI	0.762 (0.669–0.855)	0.717 (0.646–0.788)	0.721 (0.650–0.792)	Best CV
BRI	0.756 (0.670–0.842)	0.866 (0.815–0.917)	0.860 (0.807–0.912)	Best T2DM

Optimal cut-offs (Youden index) for CMR: BRI ≥4.50 (Sn 85.0%, Sp 75.3%), WHtR ≥0.555 (Sn 86.7%, Sp 70.6%), WC ≥89.5 cm (Sn 84.1%, Sp 68.2%), BMI ≥30.0 kg/m² (Sn 63.7%, Sp 87.1%), WHR ≥0.84 (Sn 85.0%, Sp 42.4%), ABSI ≥0.0795 (Sn 57.5%, Sp 76.5%). CV: cardiovascular; T2DM: type 2 diabetes mellitus; CMR: cardiometabolic risk (combined).

The corresponding BRI cut-off (≥4.50) offered marginally better specificity (75.3% vs 70.6%) at comparable sensitivity. It is worth noting that this screening cut-off is lower than BRI values associated with the lowest mortality risk in prospective cohorts (~5.16–5.54 [18]), a difference that reflects the distinct goals of screening sensitivity versus long-term survival optimisation.

Performance of ABSI

For cardiovascular risk specifically, ABSI achieved the highest AUC (0.762) and the strongest correlation (ρ=0.521), in keeping with its established association with all-cause and cardiovascular mortality [11,32]. A systematic review by Ji et al. [33] found that each standard deviation increase in ABSI was associated with a 55% higher all-cause mortality risk and a 21% higher cardiovascular disease risk, evidence that supports ABSI as a mortality predictor even when its CMR screening performance is modest. Bertoli et al. [34] similarly reported ABSI's association with all metabolic syndrome components in a large Caucasian sample. Despite this, ABSI showed limited performance for overall CMR screening in the present study (AUC=0.721), and its routine clinical use for CMR prediction remains controversial [31,35,36].

Cut-off values

Turning to the Youden-derived cut-offs, the WC threshold of ≥89.5 cm falls between IDF thresholds for European women (≥80 cm) and men (≥94 cm) [5], which is consistent with the predominantly female sample composition. The BMI cut-off of ≥30.0 kg/m² corresponds precisely to the WHO obesity threshold, confirming its reasonable specificity (87.1%) but limited sensitivity (63.7%), reinforcing the argument for supplementing BMI with a central adiposity measure. All population-specific cut-offs require external validation before clinical adoption.

Strengths and limitations

To the authors' knowledge, this is the first study to compare multiple anthropometric indices for CMR prediction in the Madeiran population. Conducting all measurements through a single trained observer following ISAK standards eliminated inter-observer variability, and the simultaneous use of two validated complementary risk instruments, Framingham and FINDRISC, allowed assessment of both major CMR components. The final sample of 198 individuals exceeded the a priori calculated minimum of 194.

Several limitations should be acknowledged. The cross-sectional design precludes causal inference, and convenience sampling limits generalisability beyond this specific clinical setting. The sample is relatively small (n=198) with a marked female predominance (83.3%), a substantial imbalance that warrants caution, particularly for WHR, whose performance is strongly influenced by sex-specific fat distribution, and for male-specific cut-offs, which are poorly represented. Reliable sex-stratified analyses were not possible. The composite CMR outcome was dominated by T2DM risk, which may have limited statistical power for cardiovascular-specific analyses, and both outcomes were defined using risk scores rather than hard clinical endpoints. The use of the Framingham score, developed for North American populations and superseded in Europe by SCORE2 since 2021 [37], is an additional limitation, though SCORE2 was not available at the time of data collection. Similarly, the FINDRISC score, while widely validated in European primary care settings, was originally developed in Finland and may require recalibration before use in other populations, including Portuguese island populations [22]. Formal pairwise ROC curve comparisons were not performed, therefore, statistical superiority between AUCs cannot be formally established and should be addressed in future work.

In this sample, the optimal Youden-derived cut-off was WHtR≥0.555, consistent with values reported in other Southern European and Mediterranean populations, offering improved specificity (70.6%) at 86.7% sensitivity. These findings are consistent with a growing body of prospective and meta-analytic evidence from 2023–2025 confirming WHtR's independent association with mortality [16] and BRI's associations with cardiovascular disease and diabetes [18] and reinforce the case for incorporating WHtR into primary care cardiometabolic risk screening, while acknowledging the methodological limitations inherent to this exploratory, cross-sectional study. Confirmation in larger, prospective, sex-balanced cohorts remains a priority, as does evaluation of whether adding WHtR to validated risk algorithms such as SCORE2 [37] meaningfully improves risk stratification in European populations.

Conclusions

In this study, WHtR and BRI consistently showed the highest observed discriminative capacity for overall CMR and T2DM risk in this primary care population from Madeira Island, with AUC values approximately 0.07 units higher than BMI, followed by WC that also performed strongly. For cardiovascular risk, ABSI and WHR led, though no index achieved formal superiority in the absence of pairwise ROC comparisons. Given the negligible difference between BRI and WHtR, and WHtR's substantially simpler calculation and widely validated cut-off (≥0.5), WHtR appears to offer a practical balance between simplicity and discriminatory performance, supporting its use as a pragmatic screening tool alongside BMI in routine clinical CMR assessment.

Compliance with Ethical Standards

This study was approved by the Ethics Committee of the Health Service of Autonomous Region of Madeira (48/2017). Written informed consent was obtained from all participants prior to data collection.

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