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Original article

Comparative utility of body fat, visceral fat, BMI, and waist circumference in predicting metabolic syndrome: a cross-sectional analysis of over 8,500 Spanish workers

Utilidad comparativa de la grasa corporal, la grasa visceral, el IMC y el perímetro de cintura para predecir el síndrome metabólico: un análisis transversal de más de 8,500 trabajadores españoles

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Abstract

Background: The identification of individuals at risk for metabolic syndrome (MetS) is essential for preventing cardiometabolic complications. Traditional anthropometric indices such as body mass index (BMI) and waist circumference (WC) are widely used, but the potential utility of bioimpedance-derived total and visceral fat is gaining interest.

Objective: To compare the predictive value of body fat, visceral fat, BMI, and WC in diagnosing MetS according to NCEP ATP III, IDF, and JIS criteria in a large cohort of Spanish workers.

Methods: A cross-sectional study was conducted in 8,590 Spanish adults (4,104 men and 4,486 women). Anthropometric measurements and bioimpedance analysis were performed. MetS was classified using NCEP ATP III, IDF, and JIS definitions. ROC curve analyses were applied to determine diagnostic accuracy.

Results: WC exhibited the highest predictive performance for MetS in both sexes across all criteria (AUCs up to 0.947 in men and 0.937 in women). Visceral fat also showed high discriminative ability (AUCs up to 0.927), surpassing BMI and body fat in several models. Optimal cut-off points varied by sex and criterion. Agreement among MetS definitions was high (Cohen's Kappa > 0.85).

Conclusion: Visceral fat measured by bioimpedance provides significant discriminatory power in identifying MetS but does not outperform WC. WC remains the most practical and effective tool in occupational health screening.

Keywords: Metabolic syndrome. Body fat. Visceral fat. Body mass index. Waist circumference. Bioelectrical impedance.

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Resumen

Antecedentes: La identificación de individuos en riesgo de síndrome metabólico (SM) es esencial para prevenir complicaciones cardiometabólicas. Los índices antropométricos tradicionales, como el índice de masa corporal (IMC) y el perímetro de cintura (PC), se utilizan ampliamente, pero la posible utilidad de la grasa corporal total y visceral derivada de la bioimpedancia está despertando un creciente interés.

Objetivo: Comparar el valor predictivo de la grasa corporal, la grasa visceral, el IMC y el PC en el diagnóstico de SM según los criterios del NCEP ATP III, IDF y JIS en una amplia cohorte de trabajadores españoles.

Métodos: Se realizó un estudio transversal en 8,590 adultos españoles (4,104 hombres y 4,486 mujeres). Se efectuaron mediciones antropométricas y análisis de bioimpedancia. El SM se clasificó según las definiciones del NCEP ATP III, IDF y JIS. Se aplicaron análisis de curvas ROC para determinar la precisión diagnóstica.

Resultados: El PC mostró el mejor rendimiento predictivo para el SM en ambos sexos y según todos los criterios (AUC de hasta 0.947 en hombres y 0.937 en mujeres). La grasa visceral también presentó una alta capacidad discriminativa (AUC de hasta 0.927), superando al IMC y a la grasa corporal total en varios modelos. Los puntos de corte óptimos variaron según el sexo y el criterio utilizado. La concordancia entre las definiciones de SM fue elevada (Kappa de Cohen > 0.85).

Conclusión: La grasa visceral medida mediante bioimpedancia ofrece un poder discriminativo significativo para identificar el SM, pero no supera al PC. El PC sigue siendo la herramienta más práctica y eficaz en los programas de cribado en salud laboral.

Palabras clave: Síndrome metabólico. Grasa corporal. Grasa visceral. Índice de masa corporal. Perímetro de cintura. Bioimpedancia eléctrica.

Introduction

Metabolic syndrome (MetS) is a major public health challenge globally due to its strong association with type 2 diabetes mellitus, cardiovascular disease, and all-cause mortality[1]. It represents a cluster of metabolic abnormalities, including central obesity, dyslipidemia, hypertension, and hyperglycemia. The global prevalence of MetS continues to increase, driven by urbanization, sedentary lifestyles, and rising obesity rates[2,3]. Among European adults, the estimated prevalence ranges from 20% to 30%, although this can vary depending on diagnostic criteria and population characteristics[4,5].

Three widely accepted criteria are used for the diagnosis of MetS: the National Cholesterol Education Program Adult Treatment Panel III (NCEP ATP III)[6], the International Diabetes Federation (IDF)[7], and the Joint Interim Statement (JIS)[8]. While they share core metabolic components, their differing thresholds for waist circumference and other factors result in modest discrepancies in classification, which may have implications for early detection and intervention strategies[9].

Traditionally, anthropometric indicators such as body mass index (BMI) and waist circumference (WC) have been utilized to assess obesity and associated metabolic risks. BMI, though widely adopted, has limitations in differentiating between fat mass and lean body mass, as well as in identifying fat distribution[10]. WC has gained recognition as a better predictor of visceral adiposity and cardiometabolic risk[11], and recent studies consistently affirm its strong association with metabolic syndrome components[12].

However, advances in body composition assessment methods, particularly bioelectrical impedance analysis (BIA), have facilitated the estimation of total body fat and visceral fat with relative ease and low cost. Bioimpedance-based estimates of adiposity have been proposed as potentially superior markers of metabolic health compared to traditional measures[13,14]. Visceral fat, in particular, has drawn attention due to its endocrine and inflammatory roles, which may directly contribute to insulin resistance and metabolic dysregulation[15,16].

Several recent studies have explored the relationship between visceral adiposity measured by BIA and the risk of MetS. In a Chinese cohort, visceral fat area demonstrated stronger associations with MetS than BMI and WC[17]. Likewise, in Korean adults, visceral fat assessed by dual bioelectrical impedance was independently associated with increased cardiometabolic risk[18]. Nonetheless, the generalizability of such findings across different populations and clinical settings remains to be fully clarified, particularly in European occupational cohorts.

Spain presents an important context for MetS research due to the growing burden of obesity and metabolic disorders, even in working-age adults[19]. Occupational health assessments provide a unique opportunity to implement early detection strategies at the population level. Yet, few large-scale studies have comprehensively evaluated and compared the utility of conventional and bioimpedance-derived

adiposity indices in Spanish workers. Additionally, it remains unclear whether newer metrics such as visceral fat or total body fat offer clinically meaningful advantages over simpler anthropometric measures like WC or BMI.

To date, the comparative diagnostic value of these indicators—body fat percentage, visceral fat, BMI, and WC—has not been adequately evaluated using robust, standardized criteria for MetS in large occupational settings. Furthermore, most prior studies have lacked simultaneous assessment of all three major definitions of MetS (NCEP ATP III, IDF, and JIS), limiting their interpretability and practical application[20,21].

Understanding which adiposity index most accurately predicts MetS across various definitions and population subgroups has critical implications for both clinical and public health practice. In occupational medicine, time-efficient, cost-effective, and reproducible tools are essential for early risk stratification and health promotion. If more sophisticated markers such as visceral fat offer no clear advantage over WC, the latter may remain the most pragmatic option in large-scale screenings.

This study aims to fill these knowledge gaps by analyzing a large cohort of over 8,500 Spanish workers who underwent comprehensive health assessments, including bioimpedance-based body composition. We compare the ability of four indicators— BMI, WC, total body fat, and visceral fat—to predict MetS using three established definitions. We further determine optimal cut-off points, assess diagnostic performance using receiver operating characteristic (ROC) analysis, and examine concordance between definitions.

The hypothesis underpinning this study is that although visceral fat and body fat measured via bioimpedance may provide significant information, traditional anthropometric measures—especially WC—will exhibit comparable or superior predictive power for MetS in this occupational cohort. Our findings aim to inform both clinical practice and public health strategies, particularly in the field of workplace health surveillance and preventive care.

Given the increasing deployment of BIA devices in occupational settings, our results will also contribute to the debate over the added value and cost-effectiveness of incorporating advanced body composition metrics in routine health check-ups. By clarifying the relative performance of these measures, this study seeks to support evidence-based recommendations for MetS screening protocols tailored to working populations.

Materials and methods

Study design and population

This cross-sectional study was conducted within the framework of routine occupational health evaluations of Spanish workers between 2020 and 2024. A total of 8,590 adult employees (4,104 men and 4,486 women) from various sectors including industry, commerce, and public services were included. Participants underwent anthropometric, clinical, and laboratory assessments as part of their mandatory health check-ups in certified occupational health centers.

Inclusion criteria

Participants were eligible if they met the following criteria:

1. Aged between 18 and 69 years.
2. Undergoing a complete occupational health assessment including anthropometry, laboratory tests, and body composition analysis.
3. Provided informed consent for secondary use of anonymized health data.

The inclusion of working-age adults aligns with recommendations for early identification of metabolic risk in employed populations[22,23].

Exclusion criteria

Subjects were excluded from the study if they:

1. Had incomplete or missing data for metabolic syndrome components or body composition indices.
2. Were pregnant at the time of evaluation.
3. Had known chronic diseases that could significantly affect body composition (e.g., cancer, severe renal failure, or liver cirrhosis).
4. Were on corticosteroid therapy or medications with significant metabolic effects.

These exclusion criteria are consistent with previous large-scale epidemiological studies to minimize confounding[24,25].

Figure 1 illustrates the recruitment and selection process of the study population. It visually summarizes the total number of individuals initially assessed, exclusions due to missing or incomplete data, and the final sample size stratified by sex (4,104 men and 4,486 women). This flow diagram is essential for understanding the methodological rigor and sample derivation, ensuring transparency and reproducibility.

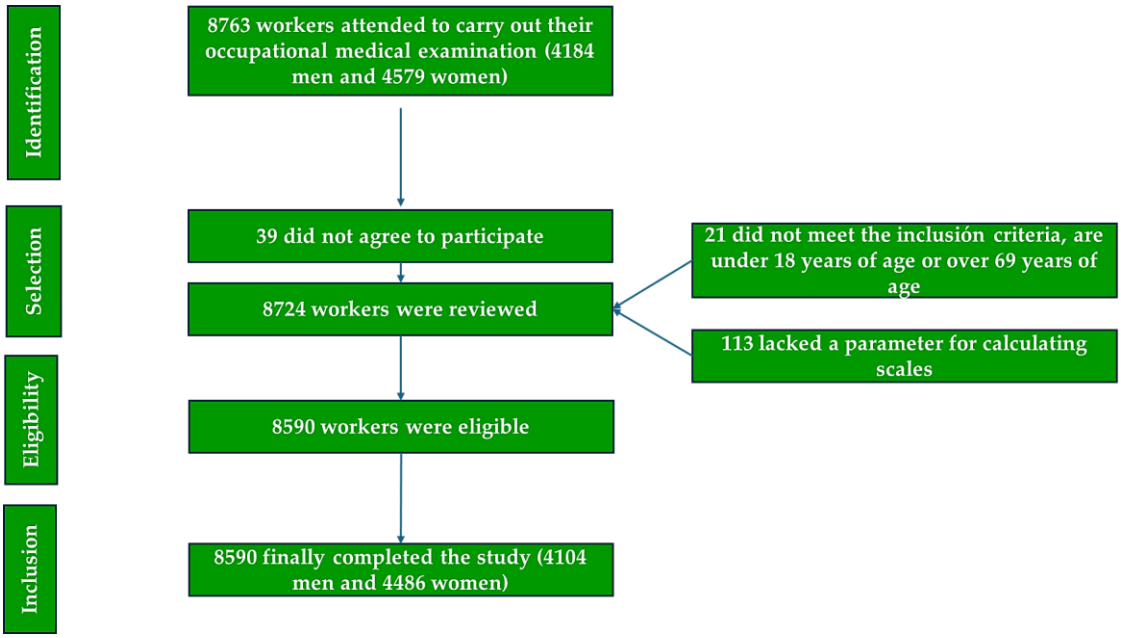

Figure 1. Flowchart of Study Participants.

Anthropometric and body composition measurements

Height and weight were measured using a SECA 700 stadiometer and scale (SECA, Chino, CA, USA), with participants barefoot and in light clothing. BMI was calculated as weight in kilograms divided by height in meters squared. Waist circumference was measured with a SECA tape measure (SECA, Chino, CA, USA), with the subject standing upright, feet together, and abdomen relaxed. The tape was positioned horizontally at the midpoint between the lowest rib and the iliac crest, following international guidelines[26]. Hip circumference was also recorded to assess waist-to-hip ratios.

Total body fat percentage and visceral fat level were estimated using multi-frequency bioelectrical impedance analysis (BIA) with validated device using a TANITA MC-780 S MA bioimpedance meter (TANITA Corporation, Tokyo, Japan). Participants were instructed to fast for at least 8 hours and to avoid physical activity and alcohol 24 hours prior to the measurement, as per standard BIA protocols[27].

Biochemical and blood pressure assessment

Blood samples were drawn via venipuncture following a 12 hours fasting period. Laboratory tests included plasma glucose, triglycerides, HDL-cholesterol, total and LDL-cholesterol, and hepatic enzymes (GGT, ALT, AST).

Blood pressure was measured using a calibrated automatic sphygmomanometer (OMRON M3) (OMRON, Osaka, Japan) after the participant had rested in a seated position for at least 10 min, with the average of three readings used for analysis.

These procedures are aligned with standardized occupational health protocols and comparable with national epidemiological surveillance methods[28,29].

Definition of metabolic syndrome

Metabolic syndrome was defined using three internationally recognized criteria:

- NCEP ATP III**:** Presence of three or more of the following: WC ≥102 cm (men) or ≥88 cm (women), triglycerides ≥150 mg/dL, HDL-C <40 mg/dL (men) or <50 mg/ dL (women), blood pressure ≥130/85 mmHg, fasting glucose ≥100 mg/dL[6].
- IDF**:** Central obesity (WC ≥94 cm in men, ≥80 cm in women) plus two of the above risk factors[7].
- JIS**:** Three or more of the same five components as NCEP ATP III, with WC cut-offs adapted to population-specific values[8].

These criteria were simultaneously applied to ensure comparability and assess agreement levels.

Lifestyle and sociodemographic variables

Data on age, sex, occupational sector, social class (based on occupation), and smoking status were collected via structured interviews. Smoking was classified as current smoker or non-smoker.

Physical activity was assessed using the short version of the International Physical Activity Questionnaire (IPAQ-SF), validated for use in adult populations

across diverse cultures and occupational contexts[30]. Participants were categorized into three groups: inactive (no activity reported), moderately active (1–3 days/week), and highly active (>3 days/week). This classification corresponds to current WHO physical activity recommendations[31].

The IPAQ has demonstrated acceptable reliability and validity in epidemiological and occupational settings, although its accuracy may vary across populations[32].

Statistical analysis

Descriptive statistics were computed separately for men and women. Continuous variables are presented as means and standard deviations, while categorical variables are shown as percentages. Comparisons between groups were made using t-tests and chi-square tests as appropriate.

ROC curve analyses were performed to evaluate the diagnostic performance of BMI, WC, body fat percentage, and visceral fat in predicting MetS across the three definitions. The area under the ROC curve (AUC) was used to assess discriminatory power. Optimal cut-off values were determined using the Youden index. Agreement between MetS definitions was evaluated using Cohen's Kappa statistic.

Analyses were conducted using SPSS v.29.0 (IBM Corp.®, Armonk, NY), with significance set at $p<0.05$.

Results

Table 1 provides the descriptive statistics of the study population, comparing anthropometric, clinical, biochemical, and lifestyle variables between men and women. Statistically significant sex differences are observed in all parameters except for age and smoking prevalence. Women presented with lower waist circumference, blood pressure, and liver enzymes but higher HDL-cholesterol levels. Physical activity patterns and social class distribution also differed significantly by sex ($p < 0.001$), emphasizing the need for sex-specific analyses in metabolic risk prediction.

The **Table 2** compares the mean values of body fat and visceral fat among participants with and without metabolic syndrome (MS) based on three criteria: NCEP ATP III, IDF, and JIS. In both men and women, significantly higher values of body and visceral fat were consistently observed in participants classified with MS under all definitions ($p < 0.001$). These findings suggest a robust association between adiposity, especially visceral fat, and the presence of MS.

Table 1. Baseline Characteristics of Study Participants by Sex.

	Men n=4104	Women n=4486	
	Mean (SD)	Mean (SD)	p-value
Age (years)	41.6 (10.6)	41.5 (10.5)	0.492
Height (cm)	175.8 (7.2)	162.5 (6.1)	<0.001
Weight (kg)	81.2 (14.8)	63.9 (13.6)	<0.001
Waist circumference (cm)	89.8 (12.5)	77.0 (12.0)	<0.001
Hip circumference (cm)	101.8 (8.7)	99.6 (10.9)	<0.001
Systolic blood pressure (mmHg)	128.6 (13.3)	117.2 (14.1)	<0.001
Diastolic blood pressure (mmHg)	79.9 (10.2)	74.9 (9.9)	<0.001
Glycaemia (mg/dL)	93.4 (17.8)	88.9 (12.6)	<0.001
Total cholesterol (mg/dL)	191.8 (36.0)	189.0 (34.8)	<0.001
HDL-cholesterol (mg/dL)	49.2 (11.3)	59.5 (12.8)	<0.001
LDL-cholesterol (mg/dL)	124.0 (54.6)	113.8 (30.7)	<0.001
Triglycerides (mg/dL)	107.8 (69.4)	81.5 (46.3)	<0.001
GGT (UI)	31.5 (30.0)	18.5 (15.9)	<0.001
AST (UI)	24.4 (17.3)	18.2 (7.7)	<0.001
ALT (UI)	29.3 (34.9)	17.3 (13.4)	<0.001

...continuation table 1.

	Men n=4104	Women n=4486	
	%	%	p-value
18-29 years	15.5	16.8	0.005
30-39 years	27.8	25.1	
40-49 years	32.7	34.4	
50-59 years	19.0	19.7	
60-69 years	5.0	4.0	
Social class I	57.1	50.8	<0.001
Social class II	20.2	23.8	
Social class III	22.7	25.4	
Non-smokers	84.5	84.2	0.348
Smokers	15.5	15.8	
Non-physical activity	25.9	35.1	<0.001
Physical activity 1-3 days/week	27.0	26.5	
Physical activity more 3 days/week	47.1	38.4	

Table 2. Mean Body Fat and Visceral Fat Values According to Metabolic Syndrome Status and Diagnostic Criteria.

		Men			Women	
Body fat	**n**	**Mean (SD)**	**p-value**	**n**	**Mean (SD)**	**p-value**
No MS NCEP ATPIII	341 4	18.3 (7.1)	<0.001	4104	28.2 (7.2)	<0.001
MS NCEP ATPIII	690	28.1(6.4)		382	40.3 (6.3)	
No MS IDF	337 2	18.1(7.1)	<0.001	4038	28.1 (7.2)	<0.001
MS IDF	732	28.7 (5.3)		448	39.8 (5.9)	
No MS JIS	326 4	18.0 (7.1)	<0.001	4016	28.1 (7.2)	<0.001
MS JIS	840	27.6 (6.0)		470	39.3 (6.3)	
Visceral fat	**n**	**Mean (SD)**	**p-value**	**n**	**Mean (SD)**	**p-value**
No MS NCEP ATPIII	341 4	6.8(4.0)	<0.001	4104	4.2(2.8)	<0.001
MS NCEP ATPIII	690	13.3 (4.5)		382	10.0 (3.4)	
No MS IDF	337 2	6.6(3.9)	<0.001	4038	4.2(2.7)	<0.001
MS IDF	732	13.9 (3.7)		448	9.6(3.3)	
No MS JIS	326 4	6.6(3.9)	<0.001	4016	4.2(2.7)	<0.001
MS JIS	840	13.1 (4.2)		470	9.4(3.4)	

Table 3 shows the prevalence of very high body fat and visceral fat among those with and without MS. A striking contrast is seen between MS and non-MS groups. In men, over 40% of those with MS had very high body fat and over 50% had high visceral fat, while the corresponding values in women were around 45–49% and 20–25% respectively. The marked difference in visceral adiposity prevalence, particularly

in men, highlights its relevance as a marker for MS risk.

Figure 2 presents the ROC curves for body fat, visceral fat, BMI, and waist circumference in predicting MS under the NCEP ATP III, IDF, and JIS criteria, stratified by sex. The curves visually demonstrate the diagnostic performance of each indicator, with area under the curve (AUC) values summarized in Table 4. Waist circumference consistently exhibited the highest AUCs, suggesting superior predictive accuracy for MS across both sexes.

This table displays the AUC values and 95% confidence intervals for each adiposity index in predicting MS across the three criteria. Waist circumference had the highest AUCs in both men (up to 0.947) and women (up to 0.937), followed by visceral fat and body fat. These results reinforce the clinical utility of waist circumference as a practical and effective screening tool for MS.

Table 5 provides sex-specific diagnostic cut-offs for body fat, visceral fat, BMI, and waist circumference to predict MS, including corresponding sensitivity, specificity, and Youden index values. For instance, in men, a visceral fat threshold of 11.0 yielded a sensitivity of 87.7% and specificity of 86.9% (IDF criteria), while in women, a waist circumference cut-off of 88.0 cm produced the highest Youden index (0.771). These findings offer clinically relevant benchmarks for risk stratification.

Table 6 assesses the concordance between the three MS diagnostic criteria using Cohen's Kappa. Agreement was substantial to almost perfect in both sexes, with highest kappa values observed between IDF and JIS (κ = 0.973 for women, κ = 0.915 for men). The results support the consistency and overlap of these definitions, although slight variations in classification remain.

Discussion

This study evaluated and compared the diagnostic performance of body fat, visceral fat (both estimated via bioimpedance), body mass index (BMI), and waist circumference (WC) in predicting metabolic syndrome (MetS) across three widely used definitions: NCEP ATP III, IDF, and JIS. Using a large sample of over 8,500 Spanish workers, we found that WC consistently demonstrated the highest discriminative capacity, closely followed by visceral fat. These findings underscore the relevance of central obesity in the pathogenesis of MetS and highlight the continued clinical utility of WC as a primary screening tool in occupational and general health settings.

Comparison with previous literature

Waist circumference showed the highest area under the curve (AUC) across all MetS definitions and in both sexes. This result aligns with extensive evidence supporting W as a strong predictor of metabolic and cardiovascular risk[33,34]. WC is a simple, cost- effective, and reproducible measure that correlates closely with visceral adiposity, the fat depot most strongly associated with insulin resistance and metabolic dysregulation[35,36].

Visceral fat, as estimated by bioelectrical impedance analysis (BIA), also demonstrated robust

Table 3. Proportion of Participants with Very High Body or Visceral Fat by MS Status and Criteria.

	Men			Women		
Body fat very high	**n**	**%**	**p-value**	**n**	**%**	**p-value**
No MS NCEP ATPIII	341 4	6.9	<0.001	4104	6.2	<0.001
MS NCEP ATPIII	690	46.1		382	48.7	
No MS IDF	337 2	6.4	<0.001	4038	6.0	<0.001
MS IDF	732	45.9		448	43.8	
No MS JIS	326 4	6.6	<0.001	4016	6.1	<0.001
MS JIS	840	40.0		470	41.7	
Visceral fat high	**n**	**%**	**p-value**	**n**	**%**	**p-value**
No MS NCEP ATPIII	341 4	8.6	<0.001	4104	0.6	<0.001
MS NCEP ATPIII	690	52.2		382	24.6	
No MS IDF	337 2	6.8	<0.001	4038	0.6	<0.001
MS IDF	732	58.2		448	21.0	
No MS JIS	326 4	7.0	<0.001	4016	0.6	<0.001
MS JIS	840	50.7		470	20.0	

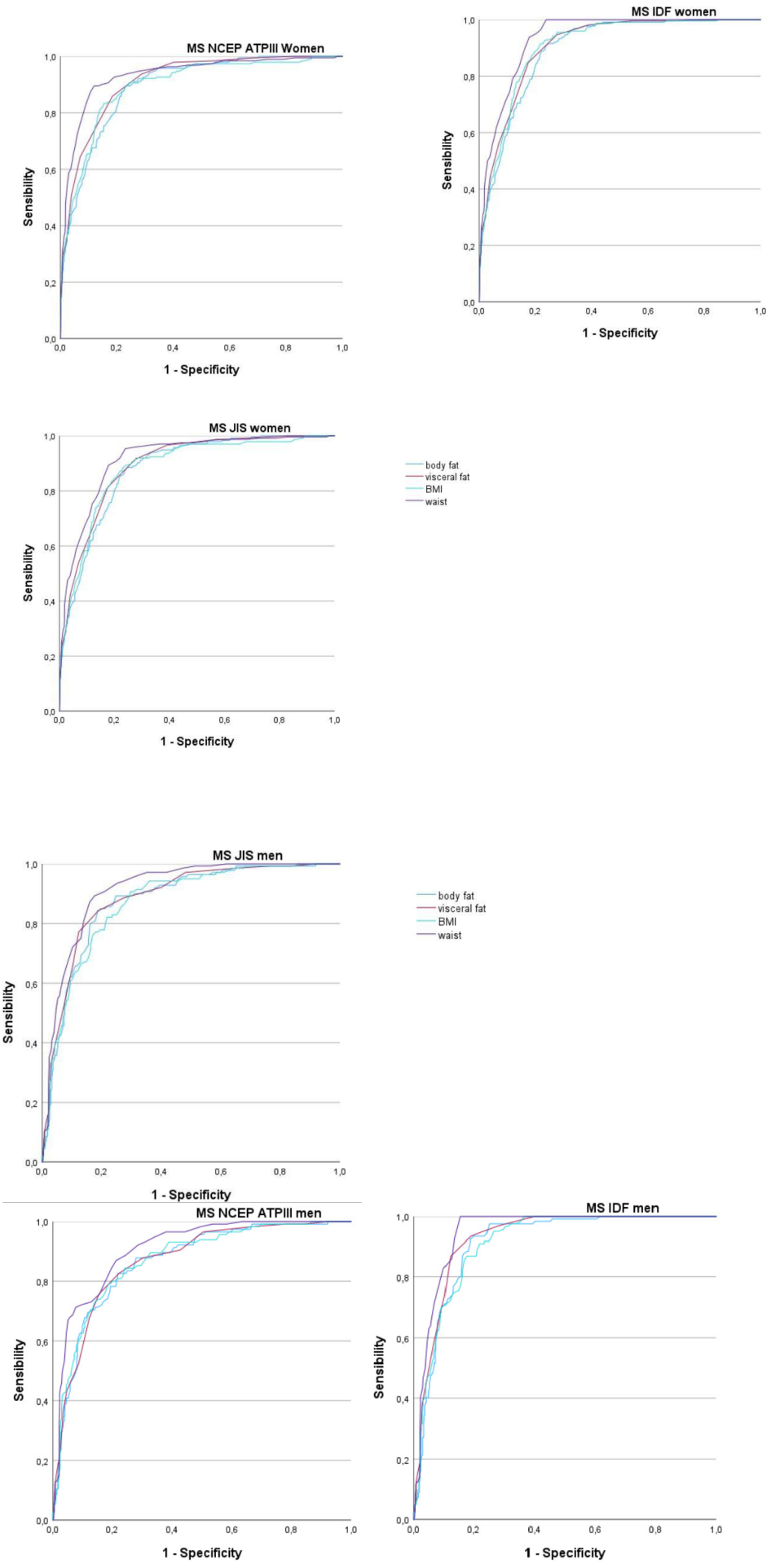

Figure 2. Receiver Operating Characteristic (ROC) Curves for Adiposity Indicators in Predicting Metabolic Syndrome.

Tabla 4. Diagnostic accuracy (AUC) of body composition and anthropometric measures for metabolic syndrome.

	Body fat	Visceral fat	BMI	Waist
Women	**AUC (95% CI)**	**AUC (95% CI)**	**AUC (95% CI)**	**AUC (95% CI)**
MS NCEP ATPIII	0.895	0.912	0.890	0.933 (0.919-0.947)
MS IDF	0.907	0.908	0.897	0.937 (0.930-0.945)
MS JIS	0.891	0.894	0.884	0.916 (0.903-0.928)
Men n=4104	**AUC (95% CI)**	**AUC (95% CI)**	**AUC (95% CI)**	**AUC (95% CI)**
MS NCEP ATPIII	0.876	0.879	0.870	0.909 (0.898-0.920)
MS IDF	0.912	0.927	0.911	0.947 (0.940-0.953)
MS JIS	0.875	0.885	0.870	0.914 (0.905-0.923)

Table 5. Optimal Cut-Offs, Sensitivity, Specificity, and Youden Index for Adiposity Markers in MS Detection.

	Body fat	Visceral fat	BMI	Waist
Women	**cut-off-sens-specif-**	**cut-off-sens-specif-**	**cut-off-sens-specif-**	**cut-off-sens-specif-**
MS NCEP	34.4-84.1-83.2-0.67	6.0-85.9-83.5-0.694	27.2-83.8-83.1-0.6	88.0-88.6-88.5-0.77
MS IDF	34.4-83.9-83.4-0.67	6.0-84.8-82.7-0.675	27.1-83.1-82.8-0.6	85.0-86.1-83.2-0.69
MS JIS	34.1-82.0-81.7-0.63	6.0-82.5-81.3-0.638	26.8-81.8-81.7-0.6	85.0-84.7-84.0-0.68
Men	**cut-off-sens-specif-**	**cut-off-sens-specif-**	**cut-off-sens-specif-**	**cut-off-sens-specif-**
MS NCEP	23.7-80.5-80.3-0.60	10.0-81.2-80.2-0.61	27.8-80.0-80.0-0.6	95.0-82.1-81.6-0.63
MS IDF	24.1-84.9-84.5-0.69	11.0-87.7-86.9-0.74	28.0-83.6-83.5-0.6	96.0-89.4-88.0-0.77
MS JIS	23.6-82.1-81.8-0.63	10.0-84.3-81.8-0.66	27.3-80.5-79.7-0.6	95.0-85.0-83.9-0.68

Table 6. Agreement between different diagnostic criteria for metabolic syndrome using Cohen's Kappa.

Women	**MS NCEP ATPIII**	**MS IDF**	**MS JIS**
MS NCEP ATPIII	1	0.854	0.886
MS IDF		1	0.973
MS JIS			1
Men	**MS NCEP ATPIII**	**MS IDF**	**MS JIS**
MS NCEP ATPIII	1	0.781	0.880
MS IDF		1	0.915
MS JIS			1

discriminative ability for MetS (AUCs > 0.91 for IDF in men and > 0.90 for NCEP ATP III in women). These results are consistent with recent findings in Korean and Chinese populations, where visceral fat independently predicted MetS and its components beyond BMI or WC[37–39]. However, the slightly lower predictive performance of visceral fat compared to WC in our cohort suggests that bioimpedance- derived measures may not provide substantial clinical

advantage over simpler anthropometric tools in large-scale screenings.

Body fat percentage and BMI showed lower AUC values across all models. These results reinforce the limitations of BMI in distinguishing between fat and lean mass and in assessing fat distribution, especially in physically active populations[40]. While body fat percentage offers a more accurate estimation of total adiposity, its predictive utility for MetS is limited, as it does not specifically reflect central or visceral fat accumulation, which is more metabolically deleterious[41].

Our study also confirms previous findings regarding sex differences in fat distribution and MetS risk. Women presented higher total body fat and lower visceral fat than men, yet showed comparable or higher prevalence of MetS under some criteria. These differences may reflect the complex interplay of sex hormones, adipose tissue function, and cardiometabolic regulation[42]. Furthermore, diagnostic thresholds such as WC cut-offs may require sex-specific adjustments to optimize sensitivity and specificity[43].

Comparison of MetS definitions

The highest agreement was observed between IDF and JIS criteria (Cohen's Kappa > 0.91 in men and > 0.97 in women), consistent with prior studies reporting strong concordance between these definitions[44]. In contrast, lower agreement was seen between NCEP ATP III and IDF, attributable to the differing WC thresholds and their centrality in the IDF definition[45].

Although the JIS definition aims to harmonize existing criteria, discrepancies persist in populations with heterogeneous adiposity profiles. For example, JIS classifies more individuals as having MetS than NCEP ATP III, particularly in women and younger adults[46]. These variations may impact prevalence estimates and complicate inter-study comparisons. Nonetheless, the consistent performance of WC and visceral fat across definitions suggests that adiposity markers remain robust predictors regardless of the diagnostic framework used.

Cut-Off points and practical implications

Our analyses identified optimal cut-off points for each adiposity measure using Youden's index. In men, a WC of 95–96 cm offered the best balance of sensitivity and specificity, while in women the cut-off was slightly lower (85–88 cm), consistent with previous European recommendations[47]. For visceral fat, thresholds of 10.0–11.0 in men and 6.0 in women provided high discriminatory power.

These sex-specific cut-offs are clinically relevant, particularly in occupational health, where rapid and accurate risk stratification is crucial. Importantly, WC remains an accessible tool for clinicians and occupational health professionals and does not require specialized equipment or training.

The added value of BIA-derived visceral fat is more debatable. Although accurate and reproducible, BIA devices entail higher costs and may be affected by hydration status, recent physical activity, and device calibration. While visceral fat estimation may be useful in specific contexts (e.g., research, high-risk patients, or individualized interventions), its routine use as a screening tool for MetS in general populations may not be justified without clear superiority over WC[48].

What is novel about our study is that it emphasizes the added value of incorporating bioelectrical impedance analysis (BIA) into the evaluation of cardiometabolic risk. This approach complements the traditional use of waist circumference (WC), which remains the most practical, effective, and cost-efficient tool for metabolic syndrome screening in both clinical and occupational settings.

BIA allows for a more comprehensive and specific assessment of body composition by differentiating visceral fat, subcutaneous fat, lean mass, and total body water. This level of detail is clinically meaningful, as visceral adiposity has been more directly linked to chronic low-grade inflammation, insulin resistance, endothelial dysfunction, and a higher risk of cardiovascular disease—relationships that are not fully captured by WC alone.

In contrast to WC, which cannot distinguish between different fat compartments, BIA provides quantitative estimates of visceral fat, thus enabling more precise cardiometabolic risk stratification. This is especially relevant for detecting metabolically unfavourable phenotypes, such as individuals with normal BMI but excess visceral adiposity—commonly referred to as "TOFI" (thin outside, fat inside)—who may be overlooked by conventional anthropometric measures.

In addition, BIA is a rapid, non-invasive, reproducible technique that can be implemented in various clinical and epidemiological settings with minimal training. Its use facilitates longitudinal tracking of body composition, allowing healthcare professionals to monitor changes over time in response to nutritional, pharmacological, or physical activity interventions.

From a motivational and psychoeducational perspective, our study suggests that delivering personalized

and quantifiable information on body composition—including parameters such as total body fat percentage, visceral fat, waist-to-height ratio, and muscle mass—can enhance patients' awareness of their individual health status. This objective and easily understandable visualization of biometric data supports greater risk perception, promotes active patient involvement in behavioural change, and may significantly improve adherence to lifestyle-based intervention programs aimed at preventing chronic cardiometabolic conditions.

Strengths and limitations strengths

1. Large sample size**:** the study includes over 8,500 participants, enhancing statistical power and generalizability within the working-age Spanish population.
2. Simultaneous assessment of multiple MetS definitions**:** by applying three established criteria, we ensured a comprehensive evaluation and inter-definition comparison, which is rarely done in large-scale occupational studies.
3. Use of bioimpedance-derived adiposity measures: the inclusion of both body fat and visceral fat allows for comparison with traditional anthropometric measures and evaluation of potential advantages of newer indices.
4. Sex-specific analyses**:** stratification by sex enabled the identification of key differences in fat distribution and diagnostic accuracy, adding value to preventive strategies.
5. Real-world occupational health settin**:** the findings have direct applicability to occupational medicine and health surveillance systems.

Limitations

1. Cross-sectional design: the study does not allow for causal inferences or longitudinal tracking of metabolic risk progression.
2. Reliance on bioimpedance**:** While BIA is validated and non-invasive, it may be affected by fluid shifts, recent food intake, and physical activity, potentially introducing measurement variability[49].
3. Lack of dietary data**:** diet is a major determinant of metabolic health, and its absence may represent residual confounding.
4. No validation against imaging methods**:** although BIA is practical, it was not validated against gold-standard methods such as DEXA or MRI for visceral fat, which could strengthen the findings[50].
5. Occupational selection bias**:** as the cohort includes employed individuals, the findings may not extend to unemployed, retired, or institutionalized populations, who may have different health profiles.

Public health and clinical implications

Our findings reaffirm the pivotal role of central adiposity—especially WC—in the pathophysiology and screening of MetS. In occupational health settings where rapid and inexpensive tools are required, WC remains the most valuable predictor. The use of visceral fat estimation, while promising, should be reserved for specific cases where additional precision is needed.

Given the increasing prevalence of MetS in working populations[51], implementing simple screening protocols using WC could facilitate early interventions and reduce the burden of cardiometabolic disease. Moreover, occupational health assessments provide a strategic platform to implement workplace wellness programs targeting abdominal obesity through nutrition, physical activity, and behavioral change.

Future research should explore longitudinal associations between WC, visceral fat, and hard outcomes such as cardiovascular events, diabetes onset, and mortality. Additionally, randomized trials assessing the utility of BIA-guided interventions in workplace health promotion are warranted.

Conclusions

This large-scale cross-sectional study among over 8,500 Spanish workers provides compelling evidence that waist circumference remains the most effective and practical tool for predicting metabolic syndrome across all major diagnostic criteria. Despite the growing interest in advanced body composition metrics such as visceral fat and total body fat obtained via bioelectrical impedance, these indicators did not outperform WC in discriminative ability. Visceral fat, while slightly superior to BMI and body fat percentage, offered only a modest advantage over WC and requires specialized equipment and standardization protocols that may limit its feasibility in routine occupational health assessments.

The consistent performance of WC—demonstrated by the highest area under the curve (AUC) values and optimal balance between sensitivity and specificity—reaffirms its role as a vital screening measure for cardiometabolic risk. Importantly, the identification of sex-specific cut-off values enhances its applicability in diverse workplace populations. These findings support current guidelines advocating the use of WC

as a primary risk marker and suggest that, even in the presence of more technologically advanced alternatives, WC remains the most cost-effective and accessible measure.

From a public health perspective, integrating waist circumference measurement into regular workplace health screenings could enable early detection of metabolic syndrome and facilitate timely interventions. Future research should investigate the longitudinal predictive value of WC and visceral fat for cardiovascular events and diabetes onset, as well as the effectiveness of intervention programs tailored to individuals identified at high risk using these measures.

In summary, while bioimpedance-derived measures provide additional insights, waist circumference remains the cornerstone of metabolic risk assessment in both clinical and occupational settings.

Author contributions

Conceptualization: Á.A.L.-G., J.I.R.-M. and M.G.S.; Data collection and analysis: Á.A.L.-G., M.G.S. and J.OdH.; Data curation: Á.A.L.-G., C.B-C., and A.R.G.; Methodology: J.I.R.-M. and Á.A.L.-G.; Validation: J.OdH., C.B-C. and P.J.T.L.; Formal analysis: Á.A.L.-G. and J.OdH.; Investigation: M.G.S., J.OdH. and P.J.T.L.; Draft: M.G.S. and A.R.M.; Revision: J.I.R.-M. and Á.A.L.-G. All authors have read and agreed to the published version of the manuscript.

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Institutional review board statement

This study was conducted in full accordance with the Declaration of Helsinki (2013) and all applicable ethical guidelines for human research. The confidentiality and anonymity of all participants were rigorously protected. Ethical approval was granted by the Research Ethics Committee of the Balearic Islands (CEI-IB) under protocol number IB 4383/20, dated 23 November 2020. Participants' data were anonymized and coded, with only the principal investigator having access to personal identifiers. All researchers complied with Organic Law 3/2018 of 5 December 2018, which regulates the protection of personal data and digital rights in Spain. This legislation ensures participants' right to access, rectify, erase, or oppose the processing of their personal data at any time.

Informed consent statement

Written informed consent was obtained from all participants involved in the study.

Data availability statement

The data supporting this study are stored in a secure database maintained by ADEMA University School, in accordance with current data protection regulations. The appointed Data Protection Officer is Ángel Arturo López González.

Conflicts of interest

The authors declare no conflicts of interest related to this work.

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