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ABSTRACT

Introduction: insulin resistance is a key contributor to cardiometabolic diseases, yet it remains understudied among domestic workers. This study evaluates the usefulness of the TyG, METS-IR, and SPISE indices as non-invasive tools to estimate insulin resistance risk in this population.

Background: insulin resistance (IR) is a major precursor of type 2 diabetes and cardiovascular disease, yet its prevalence and associated factors remain underexplored in informal labor sectors. This study aimed to evaluate the prevalence of elevated IR scores using validated non-invasive indices (TyG, METS-IR, and SPISE) and their association with sociodemographic and lifestyle variables in a large cohort of Spanish female domestic workers.

Methods: a cross-sectional analysis was conducted using health examination data from 6,321 adult female domestic workers in Spain. IR was assessed using three surrogate indices: the triglyceride-

glucose index (TyG), the metabolic score for insulin resistance (METS-IR), and the single-point insulin sensitivity estimator (SPISE). Participants were classified into quartiles based on each index. Associations with age, smoking status, physical activity (IPAQ-SF), and adherence to the Mediterranean diet were evaluated using logistic regression models adjusted for potential confounders.

Results: a high proportion of participants were in the highest-risk quartile for TyG (25.3 %), METS-IR (24.9 %), and the lowest-risk quartile for SPISE (26.8 %). Older age, smoking, low physical activity, and low Mediterranean diet adherence were significantly associated with unfavorable IR profiles across all three indices. Multivariate logistic regression showed that physical inactivity was strongly associated with high TyG (OR = 3.12), high METS-IR (OR = 3.28), and low SPISE (OR = 4.07) scores. The prevalence of high IR scores increased with age and was notably higher among smokers and individuals with poor dietary habits.

Conclusions: this study reveals a concerning prevalence of elevated insulin resistance among female domestic workers in Spain and identifies modifiable lifestyle factors associated with metabolic risk. The use of simple, cost-effective indices such as TyG, METS-IR, and SPISE offers a valuable opportunity for early identification of cardiometabolic risk in underserved labour populations. Targeted interventions promoting physical activity, dietary improvement, and smoking cessation are urgently needed to reduce long-term health disparities in this occupational group.

Keywords: Insulin resistance. TyG index. METS-IR. SPISE. Mediterranean diet. Physical activity.

Introducción: la resistencia a la insulina es un factor clave en el desarrollo de enfermedades cardiometabólicas, pero su presencia y determinantes en trabajadoras del hogar han sido poco estudiados. Este trabajo evalúa la utilidad de los índices TyG, METS-IR y SPISE

como herramientas no invasivas para estimar el riesgo de resistencia a la insulina en esta población.

Antecedentes: la resistencia a la insulina (RI) es un precursor importante de la diabetes de tipo 2 y de las enfermedades cardiovasculares; sin embargo, su prevalencia y factores asociados en sectores laborales informales siguen poco explorados. El objetivo de este estudio fue evaluar la prevalencia de valores elevados de RI mediante índices no invasivos validados (TyG, METS-IR y SPISE) y su asociación con variables sociodemográficas y de estilo de vida en una amplia cohorte de trabajadoras del hogar en España.

Métodos: se realizó un análisis transversal utilizando datos de exámenes de salud de 6321 mujeres adultas trabajadoras del hogar en España. La RI se evaluó mediante tres índices sustitutos: el índice triglicéridos-glucosa (TyG), el puntaje metabólico de resistencia a la insulina (METS-IR) y el estimador puntual de sensibilidad a la insulina (SPISE). Las participantes fueron clasificadas en cuartiles según cada índice. Se analizaron asociaciones con edad, tabaquismo, actividad física (IPAQ-SF) y adherencia a la dieta mediterránea mediante modelos de regresión logística ajustados por posibles factores de confusión.

Resultados: una alta proporción de participantes se ubicó en el cuartil de mayor riesgo para TyG (25,3 %), METS-IR (24,9 %) y en el cuartil de menor sensibilidad para SPISE (26,8 %). La edad avanzada, el tabaquismo, la baja actividad física y la escasa adherencia a la dieta mediterránea se asociaron significativamente con perfiles desfavorables de RI en los tres índices. En la regresión logística multivariante, la inactividad física se asoció fuertemente con valores elevados de TyG (OR = 3,12), METS-IR (OR = 3,28) y SPISE (OR = 4,07). La prevalencia de valores altos de RI aumentó con la edad y fue mayor entre fumadoras y mujeres con hábitos alimentarios pobres.

Conclusiones: este estudio muestra una preocupante prevalencia de resistencia a la insulina en trabajadoras del hogar en España e

identifica factores de estilo de vida modificables asociados al riesgo metabólico. El uso de índices simples y rentables como TyG, METS-IR y SPISE ofrece una herramienta útil para la identificación temprana del riesgo cardiometabólico en poblaciones laborales poco atendidas. Intervenciones dirigidas a promover la actividad física, mejorar la alimentación y reducir el tabaquismo son necesarias para disminuir desigualdades de salud a largo plazo en este grupo ocupacional.

Palabras clave: Resistencia a la insulina. Índice TyG. METS-IR. SPISE. Dieta mediterránea. Actividad física.

INTRODUCTION

Insulin resistance (IR) plays a pivotal role in the early development of several chronic metabolic diseases, most notably type 2 diabetes mellitus (T2DM), cardiovascular disease (CVD), and non-alcoholic fatty liver disease (NAFLD) (1). IR is defined by a reduced physiological response to insulin in its target tissues -primarily skeletal muscle, liver, and adipose tissue- leading to impaired glucose uptake, lipid dysregulation, and chronic low-grade inflammation (2,3). This dysfunction is driven by multiple interrelated mechanisms including intracellular lipid accumulation, mitochondrial abnormalities, proinflammatory cytokines, and hormonal imbalances (4).

Epidemiological estimates indicate that up to 25 % of adults in industrialized nations may be insulin resistant despite having normoglycemia, underscoring the silent nature of the condition and its potential for underdiagnosis (5). Importantly, insulin resistance can be present in individuals with normal body weight, particularly in those with visceral adiposity or low muscle mass, revealing the limitations of conventional anthropometric indicators such as body mass index (BMI) (6).

The gold standard for quantifying insulin sensitivity -the hyperinsulinemic-euglycemic clamp- is rarely used outside research settings due to its technical complexity and cost (7). While alternative

tests such as the oral glucose tolerance test (OGTT) and intravenous glucose tolerance test (IVGTT) offer more accessible options, they remain impractical for large-scale or routine occupational health assessments (8). As a result, surrogate indices derived from fasting glucose, triglycerides, and other basic parameters have gained relevance for identifying individuals at high metabolic risk (9).

Among these, the triglyceride-glucose index (TyG) is a widely used marker that correlates strongly with insulin resistance measured by clamp techniques and is predictive of future diabetes and cardiovascular events (10). The Metabolic Score for Insulin Resistance (METS-IR) improves upon TyG by incorporating BMI and HDL-cholesterol, enhancing its predictive utility in diverse populations (11). Another promising tool, the Single Point Insulin Sensitivity Estimator (SPISE**)**, is based on BMI, HDL-c, and triglycerides, and has shown good performance in adolescents and adults for estimating insulin sensitivity without requiring insulin assays (12).

While most large-scale studies on IR have focused on sedentary professions such as office workers (13), there is limited evidence on IR risk in labour-intensive occupations such as domestic work. This group, predominantly composed of women, often performs physically demanding tasks under precarious or informal employment conditions, which may impact health outcomes differently than in other populations (14). Moreover, socioeconomic disparities, lower health literacy, and limited access to preventive care could exacerbate cardiometabolic vulnerability in this group (15).

Beyond biological and occupational factors, lifestyle behaviors such as diet, smoking, and physical activity are known to influence insulin sensitivity (16). In particular, low adherence to the Mediterranean diet and insufficient physical activity have been consistently associated with increased IR risk, independently of adiposity (17,18). Understanding how these modifiable factors interact with sociodemographic variables in the context of domestic work is essential for developing effective public health strategies.

This study aims to evaluate the prevalence of elevated insulin resistance scores -TyG, METS-IR, and SPISE- in a large cohort of Spanish female domestic workers. We also examine how these indices vary across age groups and lifestyle profiles, with the goal of identifying high-risk subgroups and informing occupational health interventions tailored to this underserved population.

METHODS

Study Design and Population

This cross-sectional investigation analyzed health surveillance data collected from female domestic workers in Spain between January 2021 and December 2022. The dataset originated from routine occupational health evaluations conducted by an accredited occupational risk prevention service. Participants were exclusively women employed in household and caregiving roles, a labour sector characterized by physically demanding yet often informal working conditions.

Initially, 8,045 records were screened. After applying the inclusion and exclusion criteria detailed below, a total of 7,568 women aged 18 to 69 years were included in the final analysis (Fig. 1).

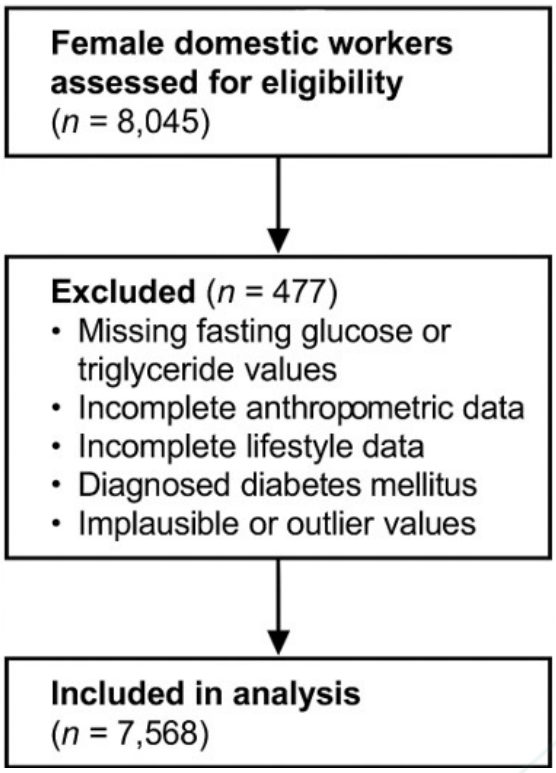

Figure 1. Flowchart of participant selection.

Inclusion criteria:

- Female sex.
- Age between 18 and 69 years.
- Active employment as a domestic worker during the assessment period.
- Availability of complete anthropometric, clinical, and lifestyle data.

Exclusion criteria:

- Missing fasting glucose or triglyceride values.
- Incomplete anthropometric records (*e.g.,* missing weight, height, or waist circumference).
- Missing responses on physical activity, smoking status, or dietary intake.
- Known diagnosis of type 1 or type 2 diabetes *mellitus.*

- Implausible or outlier values based on clinical thresholds.

Ethical approval and informed consent

The study protocol was reviewed and approved by the Research Ethics Committee of the Balearic Islands (CEI-IB), under approval number IB 4383/20. All participants received detailed information about the study procedures and objectives, and each woman provided written informed consent prior to participation. The study followed the ethical principles outlined in the Declaration of Helsinki.

Anthropometric and clinical assessments

Trained healthcare professionals conducted all measurements following standardized protocols. Body weight and height were measured using calibrated digital scales and stadiometers, with participants in light clothing and no shoes. Waist and hip circumferences were measured using flexible, non-elastic tape at predefined anatomical landmarks. Blood pressure was recorded in triplicate in a seated position after a 5-minute rest using automated devices approved by European Society of Hypertension standards.

Fasting venous blood samples were obtained after an overnight fast of at least 8 hours. Laboratory tests included fasting plasma glucose, total cholesterol, HDL-cholesterol, LDL-cholesterol (calculated using the Friedewald formula), and triglycerides. All biochemical analyses were performed in ISO 9001-certified laboratories.

Biochemical analyses were performed using automated enzymatic colorimetric assays. Fasting glucose, total cholesterol, HDL-c, LDL-c (calculated using the Friedewald formula), and triglycerides were measured with the Roche/Hitachi Cobas C702 analyzer (Roche Diagnostics, Basel, Switzerland) using standardized reagent kits provided by the manufacturer. All laboratory procedures followed ISO 9001–certified quality control protocols.

Insulin resistance indices

Three validated surrogate markers were used to estimate insulin resistance:

- Triglyceride-glucose index (TyG):

  TyG = Ln (fasting triglycerides (mg/dl) ×

  fasting glucose (mg/dl)2) is considered high risk at 8.5.

- Metabolic Score for Insulin Resistance (METS-IR):

  METS-IR = Ln(2 × glucose) + triglycerides × BMI)/(Ln(HDL-c).

  High values are defined as 50 and above.

- Single Point Insulin Sensitivity Estimator (SPISE) and its inverse, SPISE-IR:

  SPISE = (= 600 × $HDL^{0.185}$/$triglycerides^{0.2}$ × $BMI^{1.338}$). SPISE-IR = 10/SPISE is considered high risk at 1.51.

These indices have shown high concordance with gold-standard insulin sensitivity assessments such as the hyperinsulinemic-euglycemic clamp in prior validation studies (19-21) (Fig. 2).

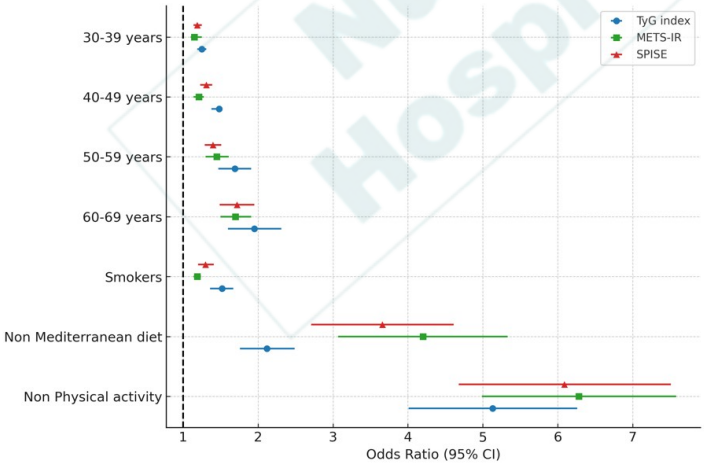

Figure 2. Forest plot of insulin resistance indices.

Lifestyle and sociodemographic variables

Participants completed a structured health questionnaire administered during their clinical evaluations. The following variables were included:

- Age group: categorized in 10-year intervals.
- Smoking status: current smoker *vs.* non-smoker.
- Physical activity: assessed using the short version of the International Physical Activity Questionnaire (IPAQ-SF). Participants were classified as physically active if they met minimum WHO recommendations (≥ 150 min/week of moderate or ≥ 75 min/week of vigorous activity, or an equivalent combination) (22).
- Adherence to the Mediterranean diet: evaluated via a validated 14-item questionnaire. A score ≥ 9 was used as the threshold for good adherence (23)

Statistical analysis

Quantitative variables were expressed as means and standard deviations (SD), and categorical variables as frequencies and percentages. Descriptive analyses stratified by age, lifestyle, and clinical characteristics were performed. The prevalence of high IR risk was calculated separately for each index using previously validated thresholds.

Associations between age, smoking, dietary pattern, physical activity, and the probability of elevated IR scores were examined using multivariate logistic regression models. Odds ratios (ORs) and 95 % confidence intervals (CIs) were reported. All models were adjusted for potential confounders including age, lifestyle variables, and anthropometric measures.

Anthropometric variables such as BMI, waist circumference, and waist-to-hip ratio were incorporated as adjustment covariates in the multivariate models rather than as grouping variables, as the main objective of the study was to evaluate lifestyle- and age-related differences in insulin resistance indices.

Statistical significance was defined as a two-sided *p*-value < 0.05. Analyses were performed using IBM SPSS Statistics version 29.0 (IBM Corp., Armonk, NY, USA).

RESULTS

Table I provides an overview of the anthropometric, clinical, and lifestyle characteristics of the study cohort. The mean age was 42.6 years, with a predominance of women in the 30-49 age range. While average anthropometric parameters such as BMI-related indicators (weight, waist and hip circumference) appear within normal ranges, lifestyle data reveal that 35.3 % of the participants are smokers and less than half report adherence to a Mediterranean diet or regular physical activity -factors known to influence metabolic health. These results underscore the need to assess cardiometabolic risk beyond traditional anthropometry, especially in vulnerable populations such as domestic workers.

BMI and anthropometric indices were not used to stratify the tables because they were incorporated as covariates in the multivariate models rather than primary grouping variables.

Table I. Descriptive Characteristics of the Study Population (*n* = 7,568, female domestic workers)

Women *n* = 7568	**Mean (SD)**
Age (years)	42.6 (10.3)
Height (cm)	159.3 (6.7)
Weight (kg)	67.2 (14.5)
Waist circumference (cm)	75.5 (8.5)
Hip circumference (cm)	98.9 (9.7)
Systolic BP (mm Hg)	118.2 (15. 4)
Diastolic BP (mm Hg)	72.0 (10.6)
Total cholesterol	198.1 (37.

(mg/dl)	5)
HDL-cholesterol (mg/dl)	52.0 (7.1)
LDL-cholesterol (mg/dl)	127.9 (37.6)
Triglycerides (mg/dl)	90.6 (50.0)
Glucose (mg/dl)	84.2 (12.7)
Women *n* = 7568	***n* (%)**
20-29 years	864 (11.4)
30-39 years	2096 (27.7)
40-49 years	2416 (31.9)
50-59 years	1840 (24.3)
60-69 years	352 (4.7)
Smokers	2672 (35.3)
Yes Mediterranean diet	3152 (41.6)
Yes physical activity	2976 (39.3)

BP: blood pressure; HDL: high density lipoprotein; LDL: low density lipoprotein; SD: standard deviation.

The Table II presents the mean values of three validated surrogate insulin resistance indices –TyG, METS-IR, and SPISE– stratified by age and modifiable lifestyle factors. All three indices show a progressive increase in IR risk with advancing age. Striking differences are observed between subgroups: individuals reporting physical activity or adherence to the Mediterranean diet show significantly lower IR scores, while smokers and those not following healthy lifestyle habits exhibit elevated values. These patterns reinforce the known metabolic benefits of healthy behaviors and validate the sensitivity of these indices in detecting subclinical metabolic alterations across diverse subpopulations. Table II presents descriptive distributions without statistical comparisons, as inferential analysis was performed using the adjusted logistic regression models shown later; therefore, unadjusted comparisons were not included to avoid redundancy.

Table II. Distribution of TyG, METS-IR, and SPISE Scores by age and lifestyle factors

		TyG index	**METS-IR**	**SPISE-IR**
	n	**Mean (SD)**	**Mean (SD)**	**Mean (SD)**
20-29 years	864	7.8 (0.4)	32.5 (7.6)	1.3 (0.4)
30-39 years	2096	8.0 (0.5)	37.2 (9.9)	1.5 (0.6)
40-49 years	2416	8.1 (0.5)	37.6 (8.1)	1.6 (0.5)
50-59 years	1840	8.2 (0.5)	38.9 (7.3)	1.7 (0.4)
60-69 years	352	8.3 (0.4)	39.9 (6.1)	1.7 (0.4)
Non-smokers	4896	8.1 (0.5)	36.1 (7.7)	1.5 (0.5)
Smokers	2672	8.2 (0.5)	38.0 (8.9)	1.6 (0.5)
Yes Mediterranean diet	3152	7.9 (0.4)	31.4 (3.9)	1.2 (0.2)
Non Mediterranean diet	4416	8.3 (0.5)	41.6 (8.5)	1.8 (0.5)
Yes physical activity	2976	7.8 (0.4)	30.7 (3.4)	1.2 (0.2)
Non physical activity	4592	8.3 (0.5)	41.6 (8.1)	1.8 (0.5)
		TyG index high	**METS-IR high**	**SPISE-IR high**
	n	**%**	**%**	**%**
20-29 years	864	2.1	2.6	5.6
30-39 years	2096	8.4	7.3	9.3
40-49 years	2416	16.6	7.8	12.2
50-59 years	1840	19.3	9.1	13.0
60-69 years	352	20.2	9.9	13.6
Non-smokers	4896	11.8	6.6	10.5
Smokers	2672	15.0	8.8	11.4
Yes Mediterranean	3152	2.0	2.7	3.9

diet				
Non Mediterranean diet	4416	20.7	11.1	15.5
Yes physical activity	2976	1.2	2.2	3.1
Non physical activity	4592	20.6	12.5	17.5

TyG: triglyceride glucose; METS-IR: metabolic score for insulin resistance; SPISE-IR: single point insulin sensitivity- insulin resistance; SD: standard deviation.

Table III details the odds of having elevated insulin resistance scores (defined as high TyG, METS-IR, and SPISE) by age group, smoking status, diet, and physical activity. A clear dose-response relationship is observed with age, with progressively higher ORs across age strata. Lifestyle variables exert a strong impact: lack of physical activity is associated with more than a 5-fold increased risk across all indices, while non-adherence to the Mediterranean diet more than doubles the odds. Smoking is also significantly associated with increased IR risk. These findings confirm the importance of behavioral factors in modulating insulin sensitivity, and highlight the potential utility of these indices in preventive occupational health settings.

Table III. Adjusted odds ratios for high TyG, METS-IR, and SPISE Scores according to age and lifestyle characteristics

	TyG index high	**METS-IR high**	**SPISE-IR high**
	OR (95 % CI)	**OR (95 % CI)**	**OR (95 % CI)**
20-29 years	1	1	1
30-39 years	1.25 (1.19-1.31)	1.15 (1.10-1.25)	1.19 (1.14-1.25)
40-49 years	1.48 (1.38-1.49)	1.21 (1.14-1.28)	1.31 (1.23-1.39)
50-59 years	1.69 (1.47-1.91)	1.45 (1.30-1.61)	1.40 (1.29-1.51)
60-69 years	1.95 (1.60-2.31)	1.70 (1.50-1.91)	1.72 (1.49-1.95)

Non-smokers	1	1	1
Smokers	1.52 (1.36 (1. 67)	1.19 (1.14-1.24)	1.30 (1.20-1.41)
Yes Mediterranean diet	1	1	1
Non Mediterranean diet	2.12 (1.76-2.49)	4.20 (3.07-5.33)	3.66 (2.71-4.61)
Yes physical activity	1	1	1
Non physical activity	5.13 (4,01-6.26)	6.28 (4.99-7.58)	6.09 (4.68-7.51)

TyG: triglyceride glucose; METS-IR: metabolic score for insulin resistance; SPISE-IR: Single point insulin sensitivity-insulin resistance; OR: odds ratio.

DISCUSSION

In this comprehensive cross-sectional study of Spanish female domestic workers, we identified a notable prevalence of elevated insulin resistance (IR) scores (TyG, METS-IR, SPISE), particularly among participants of advanced age, smokers, those with sedentary lifestyles, and individuals with limited adherence to the Mediterranean diet. These outcomes align with findings in office-based cohorts but shed light on distinct occupational and lifestyle stressors characteristic of domestic work.

Recent studies further substantiate these observations. A Spanish analysis involving 3,401 participants from the EVA, MARK, and EVIDENT cohorts reported that greater adherence to the Mediterranean diet correlated with lower TyG values and improved vascular function, reinforcing the metabolic and cardiovascular advantages of this dietary pattern across varied insulin resistance levels (24). Moreover, a randomized clinical trial comparing a fasting-mimicking diet (FMD) with a Mediterranean diet demonstrated that three FMD cycles effectively reduced insulin resistance and hepatic fat –common contributors to elevated IR scores– underscoring the potential metabolic benefit of periodic fasting interventions in non-clinical settings (25). Additionally, other investigation revealed that periodic FMD cycles not only reduced IR but also decreased liver fat and biological age in adults, suggesting a profound systemic

impact of structured dietary interventions beyond conventional nutrition strategies (26).

Intervention studies have also shown the metabolic impact of dietary patterns: a controlled trial in a Middle Eastern cohort found that a Mediterranean diet significantly lowered fasting insulin, HOMA-IR, and TyG compared to a low-fat diet over six months, highlighting the diet's efficacy in improving IR-related biomarkers (27). Similarly, a community-based lifestyle intervention combining diet and physical activity, demonstrated marked improvements in SPISE and METS-IR scores, suggesting that multi-component interventions can favorably modify surrogate insulin sensitivity indices in female-dominant labour groups (28). In addition, a cross-sectional study from Portugal reported that higher serum vitamin D levels were inversely associated with TyG and HOMA-IR in women, indicating that micronutrient status may play a modulatory role in early insulin resistance phases (29).

Compared to more structured occupational settings, domestic workers often face precarious employment, limited health monitoring, and few opportunities for wellness programs. Our observed effect sizes –ORs > 3 for inactivity with high TyG and METS-IR and > 4 for SPISE– mirror those seen in office worker populations but magnify the urgency of lifestyle-focused interventions in this group.

Additionally, our findings underscore the well-documented impact of lifestyle and demographic factors on insulin resistance. Smoking remains a significant contributor to metabolic dysfunction, promoting oxidative stress, endothelial damage, and pro-inflammatory states that impair insulin signalling (30). Epidemiological studies have consistently shown a dose-response relationship between tobacco exposure and elevated IR indices, including TyG and HOMA-IR (31). This is particularly relevant in our cohort, where over one-third of participants reported active smoking, a proportion higher than that observed in comparable occupational groups.

Age was also independently associated with higher IR scores across all indices. Physiological aging is accompanied by reduced

mitochondrial efficiency, increased visceral adiposity, and chronic low-grade inflammation, which collectively impair insulin action in peripheral tissues (32). These changes may be compounded by declines in physical fitness and dietary quality observed in older populations, reinforcing the need for age-specific preventive strategies.

In contrast, adherence to the Mediterranean diet and engagement in regular physical activity demonstrated strong protective associations against insulin resistance. The Mediterranean diet –characterized by high intake of fruits, vegetables, legumes, whole grains, fish, and monounsaturated fats– has been linked to improved lipid profiles, reduced systemic inflammation, and better glycemic control (33,34). Moreover, recent intervention trials have demonstrated that this dietary pattern significantly lowers insulin resistance and hepatic steatosis when compared to low-fat diets (35).

Physical activity, both aerobic and resistance-based, enhances insulin-stimulated glucose uptake in skeletal muscle, improves lipid metabolism, and reduces abdominal fat stores (36). In our study, physically inactive women showed more than a fivefold increased risk of elevated IR scores across all indices, a finding that aligns with recent evidence from the PURE and NHANES cohorts (37,38). These results strongly support the incorporation of structured physical activity programs in preventive strategies targeting metabolic risk in underserved labour sectors.

Strengths and limitations

One of the main strengths of this study lies in the large sample size and the exclusive focus on female domestic workers, a population that has been largely underrepresented in metabolic and occupational health research. By analyzing three validated surrogate indices of insulin resistance (TyG, METS-IR, and SPISE) simultaneously, we provide a robust, multidimensional view of metabolic risk that encompasses glucose metabolism, lipid profile, and adiposity, without

relying on costly or invasive techniques. These indices have shown strong predictive value for type 2 diabetes and cardiovascular disease, and are increasingly recognized as reliable tools in large-scale epidemiological studies.

Furthermore, the standardized use of internationally validated instruments for assessing physical activity (IPAQ-SF) and adherence to the Mediterranean diet ensures comparability with national and international cohorts, while allowing for stratified analysis of lifestyle factors known to modulate insulin sensitivity. The inclusion of a relatively homogeneous cohort in terms of sex and occupation also minimizes residual confounding by occupational heterogeneity.

However, several limitations must be acknowledged. First, the cross-sectional design limits causal interpretation of the observed associations, and it remains unclear whether elevated IR scores are a consequence of current behaviors or the result of long-standing occupational and socioeconomic exposures. Second, the absence of direct insulin measurements (*e.g.,* HOMA-IR, clamp studies) precludes validation of the surrogate indices in this specific population. Third, although we controlled for major confounders, unmeasured variables such as sleep quality, chronotype, vitamin D levels, or micronutrient deficiencies (*e.g.,* selenium, magnesium) may have influenced both lifestyle patterns and IR status.

Additionally, data on duration and intensity of domestic work activities were not collected, limiting our ability to differentiate between subgroups with varying physical demands. Given that physical activity related to work may have distinct metabolic effects compared to leisure-time exercise, future research should incorporate objective measurements of physical exertion, sedentary behavior, and circadian disruption in this population.

Because this study used a cross-sectional design, it was not possible to determine whether the metabolic values observed could be partially influenced by previous occupations held by the participants before working as domestic workers. Although all women included

were actively employed as domestic workers at the time of evaluation, residual effects from prior jobs cannot be excluded.

Finally, although the cohort is large and representative at a national level, our findings may not be generalizable to domestic workers in other sociocultural or labour contexts, particularly those with more formalized labour protections or differing dietary patterns.

Clinical and public health implications

Our findings highlight the need for tailored occupational interventions for domestic workers. Initiatives could include nutritional counseling centered on Mediterranean diet principles, structured physical activity programs, and FMD cycles conducted under supervision. Regular monitoring using IR indices may facilitate early detection of metabolic disturbances and guide preventative measures.

Longitudinal studies are warranted to explore whether such interventions can attenuate IR trajectories. Incorporating biochemical markers like insulin, CRP, micronutrients, as well as circadian rhythm and sleep assessments, may deepen our understanding of the complex drivers of metabolic risk in this underserved labour sector.

CONCLUSIONS

This study shows a high prevalence of elevated insulin resistance indices (TyG, METS-IR, and SPISE) among female domestic workers in Spain and identifies significant associations with age, smoking, low physical activity, and low adherence to the Mediterranean diet. These findings highlight the metabolic vulnerability of this occupational group and underscore the importance of considering lifestyle factors when evaluating insulin resistance risk.

RECOMMENDATIONS

Based on the results of this study, the following recommendations are proposed:

- Promote interventions that encourage regular physical activity among domestic workers, given its strong protective association with insulin resistance indices.
- Facilitate access to nutritional education programs focused on improving adherence to the Mediterranean diet.
- Implement smoking-cessation support initiatives in occupational health settings, considering the observed association with higher insulin resistance.
- Incorporate simple and non-invasive indices (TyG, METS-IR, and SPISE) into routine occupational health assessments to improve early identification of metabolic risk.

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Ethical approval and regulatory compliance: the study followed all applicable national and international ethical guidelines for biomedical research, including the principles established in the Declaration of Helsinki. The design of the study guaranteed the protection of participants' rights, privacy, and anonymity throughout the process. Before enrollment, all individuals received detailed oral and written explanations concerning the aims, procedures, and scope of the research. Participation was entirely voluntary, and written informed consent was obtained from each participant prior to the collection of any data.

Ethical approval for the study was granted by the Research Ethics Committee of the Balearic Islands (Comité de Ética de la Investigación de las Islas Baleares, CEI-IB), under approval number IB 4383/20, dated 26 November 2020. To safeguard confidentiality, all personal identifiers were anonymized and replaced by encrypted codes accessible solely by the principal investigator. No identifiable personal information will be shared or published.

In compliance with Organic Law 3/2018 on the Protection of Personal Data and Guarantee of Digital Rights (Spain), as well as the EU General Data Protection Regulation (Regulation EU 2016/679), all participants were informed of their rights to access, rectify, erase, or object to the use of their personal data.

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