ACADEMIC JOURNAL OF HEALTH SCIENCES
MEDICINA BALEAR

Original article

Insulin resistance risk assessed by TyG, METS-IR, and SPISE-IR scores and its association with sociodemographic and lifestyle factors in a large cohort of mechanics

Riesgo de resistencia a la insulina evaluado mediante los índices TyG, METS-IR y SPISE-IR y su asociación con factores sociodemográficos y de estilo de vida en una amplia cohorte de mecánicos

Alberto Ramírez Gallegos[1]*, Pedro Juan Tárraga López[2], José Ignacio Ramírez Manent[1,3,4], Andrea del Amo Río[1], Irene Coll Campayo[3], Miguel García Samuelsson[3], Ángel Arturo López González[1,3]

1. Servei de Salut Illes Balears, Palma, España
2. Facultado de Medicina, Universidad de la Castilla de la Mancha, Albacete, España
3. ADEMA, Grupo de Salud IUNICS, España
4. Facultad de Medicina, Universidad de las Islas Baleares, Palma, España

Received: 07-21-2025
Accepted: 07-29-2025
Published: 08-21-2025

***Corresponcence:** Alberto Ramírez Gallegos. albertoramirezgallegos@outlook.es

Abstract

Introduction: insulin resistance (IR) is a key metabolic disorder with significant implications for cardiovascular and hepatic health. While surrogate indices such as the triglyceride-glucose index (TyG), METS-IR, and SPISE-IR have been validated in various populations, their utility in physically demanding occupations remains underexplored.

Objective: to assess IR risk using TyG, METS-IR, and SPISE-IR scores in a large cohort of automotive mechanics, and to examine associations with sociodemographic and lifestyle factors.

Materials and method: a cross-sectional study was conducted among 39,120 mechanics (34,896 men; 4,224 women) aged 18–65 years across Spain. IR risk was estimated using TyG, METS-IR, and SPISE-IR indices based on fasting biochemical and anthropometric data. Logistic regression models evaluated associations with age, sex, education, smoking, physical activity, and adherence to the Mediterranean diet.

Results: male workers exhibited significantly higher TyG and METS-IR scores and lower SPISE-IR values than females ($p < 0.001$). IR prevalence increased with age and was inversely associated with educational attainment. Smoking, low physical activity, and poor adherence to the Mediterranean diet were independently associated with elevated IR scores. Notably, SPISE-IR and METS-IR were more sensitive to lifestyle factors than TyG. Multivariate models confirmed sex, age, and lifestyle behaviors as strong predictors of IR risk.

Cite as: Ramírez Gallegos A, Tárraga López JP, Ramírez Manent JI, Del Amo Río A, Coll Campayo I, García Samuelsson M, et al. Insulin resistance risk assessed by TyG, METS-IR, and SPISE-IR scores and its association with sociodemographic and lifestyle factors in a large cohort of mechanics. Acad J Health Sci 2025; 40(6):78-90. Available from: https://doi.org/10.3306/AJHS.2025.40.06.7

Acad J Health Sci 2025; 40(6):78-90
https://doi.org/10.3306/AJHS.2025.40.06.7
www.ajhealthsciences.com

© 2025 Royal Academy of Medicine of the Balearic Islands. This is an open access article under the license **CC BY 4.0.** Published with index

Conclusions: this study reveals a high burden of IR among automotive mechanics, particularly in older, male, and less-educated workers with unhealthy behaviors. The combined use of TyG, METS-IR, and SPISE-IR offers a robust framework for metabolic risk screening in occupational settings, supporting the need for targeted preventive strategies.

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

Resumen

Introducción: la resistencia a la insulina (RI) es un trastorno metabólico clave con importantes implicancias para la salud cardiovascular y hepática. Si bien los índices indirectos como el índice triglicéridos-glucosa (TyG), METS-IR y SPISE-IR han sido validados en diversas poblaciones, su utilidad en ocupaciones físicamente exigentes sigue siendo poco explorada.

Objetivo: evaluar el riesgo de RI mediante los puntajes TyG, METS-IR y SPISE-IR en una amplia cohorte de mecánicos automotrices, y examinar su asociación con factores sociodemográficos y de estilo de vida.

Materiales y método: se realizó un estudio transversal en 39.120 mecánicos (34.896 hombres y 4.224 mujeres) de entre 18 y 65 años en toda España. El riesgo de RI se estimó utilizando los índices TyG, METS-IR y SPISE-IR, calculados a partir de datos bioquímicos y antropométricos en ayunas. Se aplicaron modelos de regresión logística para evaluar asociaciones con edad, sexo, nivel educativo, tabaquismo, actividad física y adherencia a la dieta mediterránea.

Resultados: los trabajadores varones presentaron puntajes significativamente más altos en TyG y METS-IR, y valores más bajos en SPISE-IR en comparación con las mujeres ($p < 0,001$). La prevalencia de RI aumentó con la edad y se asoció de forma inversa con el nivel educativo. El tabaquismo, la baja actividad física y la escasa adherencia a la dieta mediterránea se asociaron de manera independiente con puntajes elevados de RI. Cabe destacar que los índices SPISE-IR y METS-IR fueron más sensibles a los factores relacionados con el estilo de vida que el TyG. Los modelos multivariados confirmaron que el sexo, la edad y los comportamientos de estilo de vida son fuertes predictores del riesgo de RI.

Conclusiones: este estudio revela una alta carga de RI entre los mecánicos automotrices, especialmente en los trabajadores mayores, varones y con menor nivel educativo que presentan conductas no saludables. El uso combinado de los índices TyG, METS-IR y SPISE-IR ofrece un marco sólido para la detección del riesgo metabólico en entornos laborales, respaldando la necesidad de estrategias preventivas dirigidas.

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

Introduction

Insulin resistance (IR) is a central metabolic disturbance characterized by a suboptimal response of peripheral tissues—primarily skeletal muscle, liver, and adipose tissue—to the action of insulin, resulting in impaired glucose uptake, increased lipolysis, and hepatic glucose output[1,2]. IR represents a pathophysiological hallmark of type 2 diabetes *mellitus* (T2DM), but its clinical relevance extends far beyond glycemic control, encompassing cardiovascular disease (CVD), non-alcoholic fatty liver disease (NAFLD), chronic kidney disease, and other components of cardiometabolic risk[3,4]. Its multifactorial origin is driven by complex interactions among genetic predisposition, visceral adiposity, mitochondrial dysfunction, inflammation, oxidative stress, and lifestyle-related behaviors[5-7].

The increasing prevalence of IR worldwide is a reflection of global trends in obesity, physical inactivity, and unhealthy dietary habits[8]. Estimates suggest that between 15% and 30% of adults in high-income countries exhibit some degree of insulin resistance, often without overt hyperglycemia[9]. Early identification of IR is thus essential for the prevention of downstream metabolic and vascular complications, particularly in populations exposed to occupational or socioeconomic risk factors[10].

Traditionally, IR is assessed through gold-standard techniques such as the hyperinsulinemic-euglycemic clamp or the intravenous glucose tolerance test. Although highly accurate, these methods are invasive, costly, and unfeasible for routine screening or large-scale epidemiological studies[11,12]. As a result, surrogate indices based on fasting biochemical and anthropometric parameters have gained prominence due to their simplicity, reproducibility, and clinical applicability[13].

Among these indices, the triglyceride-glucose index (TyG), calculated using fasting plasma triglycerides and glucose, has shown a strong correlation with clamp-derived insulin sensitivity and predictive value for incident T2DM, metabolic syndrome, and cardiovascular events[14,15]. The metabolic score for insulin resistance (METS-IR), which integrates TyG,

HDL-cholesterol, and body mass index (BMI), has demonstrated superior predictive capacity for NAFLD and subclinical atherosclerosis[16,17]. Meanwhile, the Single Point Insulin Sensitivity Estimator (SPISE), derived from triglycerides, HDL-c, and BMI, has gained attention for its validity in pediatric, adolescent, and adult populations, particularly in contexts where insulin assays are unavailable[18-20].

These non–insulin-based indices have been validated in diverse ethnic groups and occupational cohorts, offering an efficient approach for evaluating IR risk in both clinical and public health settings[21]. However, their diagnostic performance and clinical interpretation can be influenced by age, sex, educational attainment, and modifiable lifestyle factors such as diet quality, smoking status, and physical activity[22-24]. Notably, increasing evidence suggests that unhealthy behaviors—particularly low adherence to the Mediterranean diet, tobacco use, and sedentary lifestyles—exacerbate insulin resistance even in the absence of obesity, emphasizing the importance of incorporating behavioral and sociodemographic determinants in IR risk assessments[25-27].

Occupational health research has traditionally focused on sedentary or white-collar professions, such as office workers, healthcare providers, and administrative employees[28-30]. However, labor-intensive and predominantly male-dominated occupations such as automotive mechanics have received comparatively less attention, despite potential exposure to unique metabolic stressors. Automotive mechanics are frequently subject to physically demanding tasks, irregular schedules, prolonged standing, and occupational exposure to environmental pollutants such as solvents and heavy metals, all of which may influence cardiometabolic health[31,32]. Furthermore, socioeconomic characteristics common in this workforce—such as lower educational levels, higher smoking prevalence, and limited access to preventive health services—may compound their metabolic risk profile[33,34].

The male predominance in the automotive sector introduces additional biological and behavioral considerations. Evidence indicates that men may exhibit greater susceptibility to visceral fat accumulation and earlier onset of insulin resistance than women, independent of total body fat percentage[35,36]. Hormonal and metabolic differences, such as lower estrogen levels and higher androgen activity, contribute to sex-specific variations in insulin signaling, lipid metabolism, and inflammatory responses[37]. Moreover, sex disparities in health-seeking behaviors, dietary patterns, and physical activity levels may further influence cardiometabolic outcomes[38].

Lifestyle factors are especially relevant in this context. Adherence to the Mediterranean diet, characterized by high intake of fruits, vegetables, legumes, whole grains, olive oil, and fish, has been consistently associated with improved insulin sensitivity, lower systemic inflammation, and reduced incidence of metabolic syndrome and T2DM[39,40]. Conversely, poor dietary quality—common in shift-based or time-constrained professions—has been linked to higher TyG and METS-IR values, independent of BMI[41]. Similarly, smoking has been shown to induce IR through mechanisms involving oxidative stress, inflammation, and endothelial dysfunction, while regular physical activity exerts protective effects by enhancing glucose uptake, increasing mitochondrial biogenesis, and modulating adipokine profiles[42-44].

In this context, evaluating IR risk in mechanics provides a unique opportunity to explore the interplay between occupational demands, sociodemographic factors, and health behaviors. To date, few studies have comprehensively examined IR using validated non-invasive indices in this population, and even fewer have stratified findings by sex, education, diet, smoking, or physical activity levels. Understanding these associations is crucial not only for early identification of high-risk individuals, but also for designing targeted workplace health interventions aimed at preventing T2DM and related cardiometabolic diseases.

Therefore, the present study aims to assess the prevalence of elevated insulin resistance risk using three validated surrogate indices —TyG, METS-IR, and SPISE— in a large cohort of mechanics. Additionally, we investigate how sociodemographic characteristics (sex, age, education level) and lifestyle habits (smoking status, physical activity, Mediterranean diet adherence) are associated with IR risk. By integrating occupational health surveillance data with epidemiological methods, this study seeks to generate actionable insights that can inform public health strategies and clinical screening protocols within labor-intensive professions.

Materials and method

Study design and population

A cross-sectional study was conducted among mechanics employed at major service centers throughout mainland Spain between January and December 2024. Eligible participants were adults aged 18 to 65 years who had been continuously employed in mechanical work for at least one year, were free of acute illness at the time of assessment, and provided written informed consent. Of the 40,125 eligible workers,

39,120 (97.7%) met the inclusion criteria and agreed to participate, comprising 34,896 men and 4,224 women. The study protocol was approved by the Balearic Health Research Ethics Committee and complied with the principles outlined in the Declaration of Helsinki.

Inclusion and Exclusion Criteria (Figure 1)

Inclusion criteria

- Adults aged 18–65 years
- Continuous employment as mechanics for at least one year
- Provision of written informed consent
- Absence of acute illness at the time of clinical and laboratory evaluation

Exclusion Criteria

- Missing or incomplete anthropometric, biochemical, or lifestyle data (n = 512)
- Pregnancy at the time of data collection (n = 68)
- Diagnosed endocrine or metabolic disorders, such as thyroid dysfunction or uncontrolled diabetes (n = 213)
- Irregular or undocumented employment status (n = 212)

Data collection and measurements

Sociodemographic variables included age, sex, and educational attainment (primary, secondary, or university). Anthropometric measurements were obtained by trained healthcare professionals using standardized protocols. Body weight and height were measured with subjects wearing light clothing and no shoes, and body mass index (BMI) was calculated as weight (kg) divided by height in meters squared (m²). Waist circumference (WC) was measured at the midpoint between the lower rib and the iliac crest.

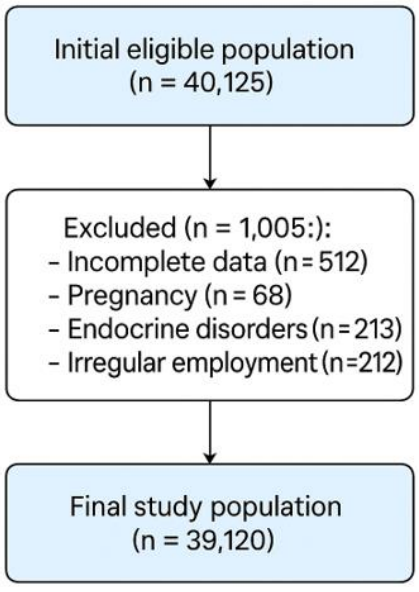

Figure 1. Flowchart of participant selection process.

Venous blood samples were collected after an overnight fast of at least 8 hours. Biochemical parameters included fasting plasma glucose, triglycerides, high-density lipoprotein cholesterol (HDL-c), and total cholesterol. All samples were analyzed in different certified laboratories, which will use the same technique using automated enzymatic methods with internal and external quality controls.

Insulin resistance risk indices

Three non–insulin-based surrogate markers were used to estimate insulin resistance risk:

- The triglyceride-glucose (TyG) index was calculated as:*Ln [fasting triglycerides (mg/dL) × fasting glucose (mg/dL)/2]*[45].
- The Metabolic Score for Insulin Resistance (METS-IR) was defined as:*Ln [(2 × fasting glucose) + triglycerides] × BMI / [Ln (HDL-c)]*[46].
- The Single Point Insulin Sensitivity Estimator (SPISE) was calculated as:$600 \times HDL\text{-}c^{0.18} / (triglycerides^{0.28} \times BMI^{0.29})$[47].

These indices have demonstrated strong correlations with the hyperinsulinemic-euglycemic clamp and are widely used in epidemiological and occupational health research.

Lifestyle and behavioral variables

Smoking status was classified as non-smoker, former smoker, or current smoker. Adherence to the Mediterranean diet was assessed using a simplified 9-item score based on consumption frequency of fruits, vegetables, legumes, fish, whole grains, red meat, dairy, olive oil, and alcohol[48]. Physical activity was categorized as low, moderate, or high according to the International Physical Activity Questionnaire (IPAQ) short form criteria[49].

Statistical analysis

Descriptive statistics were reported as mean ± standard deviation (SD) for continuous variables and as percentages for categorical variables. Group comparisons were conducted using Student's t-test or ANOVA for continuous data and the chi-squared test for categorical variables. Participants were stratified by sex, age group, and education level to assess potential interactions.

Logistic regression models were constructed to evaluate the associations between sociodemographic

and lifestyle variables and elevated IR risk (defined according to established cut-off values for each index). Adjusted odds ratios (ORs) with 95% confidence intervals (CIs) were reported. A two-sided p-value < 0.05 was considered statistically significant. All analyses were performed using IBM SPSS Statistics v29.0 (IBM Corp., Armonk, NY, USA).

Results

Table 1 presents the baseline characteristics of the study population, stratified by sex. Male participants displayed significantly higher mean values for weight, waist circumference, fasting glucose, and triglycerides, while females had higher HDL-cholesterol levels and lower TyG and METS-IR scores. The SPISE index, which is inversely related to insulin resistance, was also higher among women, suggesting greater insulin sensitivity. These findings align with prior research indicating a more adverse cardiometabolic profile in male workers, potentially attributable to differences in fat distribution, hormonal profiles, and lifestyle habits. The data reinforce the need for sex-specific strategies in workplace health surveillance and metabolic risk prevention.

Table 2 highlights the proportion of participants exhibiting elevated or altered values in the TyG, METS-IR, and SPISE indices across sociodemographic and behavioral categories. Advancing age, lower educational attainment, current smoking, low adherence

Table 1. Sociodemographic, anthropometric, and biochemical characteristics of participants by sex.

	Men n=34896	Women n=4224	
Variables	**Mean (SD)**	**Mean (SD)**	**p-value**
Age (years)	39.8 (10.0)	37.7 (8.6)	0.350
Height (cm)	174.0 (6.7)	162.9 (6.2)	<0.001
Weight (kg)	83.2 (14.3)	68.2 (14.5)	<0.001
Waist (cm)	88.8 (9.2)	74.9 (9.2)	<0.001
Hip (cm)	100.6 (8.6)	98.0 (9.5)	<0.001
Systolic BP (mm Hg)	124.6 (15.1)	112.6 (12.7)	<0.001
Diastolic BP (mm Hg)	75.7 (10.7)	68.7 (9.1)	<0.001
Cholesterol (mg/dL)	198.5 (38.8)	196.1 (37.6)	<0.001
HDL-c (mg/dL)	51.2 (6.9)	54.8 (7.5)	<0.001
LDL-c (mg/dL)	121.9 (37.6)	122.7 (37.0)	0.180
Triglycerides (mg/dL)	128.4 (90.9)	92.9 (50.3)	<0.001
Glucose (mg/dL)	89.5 (12.9)	84.5 (11.3)	<0.001
Variables	**n (%)**	**n (%)**	**p-value**
18-25 years	2,648 (7.6)	192 (4.6)	<0.001
26-35 years	9,996 (28.7)	1,656 (39.2)	
36-45 years	11,804 (33.8)	1,512 (35.8)	
46-55 years	8,112 (23.2)	744 (17.6)	
>55 years	2,336 (6.7)	120 (2.8)	
Elementary school	19,840 (56.9)	3,120 (73.9)	<0.001
High school	15,056 (43.1)	1,104 (26.1)	
Smokers	12,664 (36.3)	1,848 (43.8)	<0.001
Yes physical activity	14,168 (40.6)	1,920 (45.5)	<0.001
Yes Mediterranean diet	12,720 (36.5)	2,040 (48.3)	<0.001

Notes: BP Blood pressure. HDL High density lipoprotein. LDL Low density lipoprotein. SD Standard deviation.

Table 2. Prevalence of altered insulin resistance indices according to sociodemographic and lifestyle variables.

		TyG	METS-IR	SPISE-IR
Men	**n**	**Mean (SD)**	**Mean (SD)**	**Mean (SD)**
18-25 years	2,648	8.1 (0.5)	34.2 (6.5)	1.4 (0.4)
26-35 years	9,996	8.3 (0.6)	37.8 (7.2)	1.6 (0.5)
36-45 years	11,804	8.5 (0.6)	40.8 (7.6)	1.8 (0.5)
46-55 years	8,112	8.6 (0.6)	42.6 (7.3)	1.9 (0.5)
>55 years	2,336	8.7 (0.5)	44.1 (7.4)	2.0 (0.5)
Elementary school	19,840	8.5 (0.6)	40.8 (7.7)	1.8 (0.5)
High school	15,056	8.4 (0.6)	39.1 (7.8)	1.7 (0.5)
Non-smokers	22,232	8.4 (0.6)	39.6 (7.8)	1.7 (0.5)
Smokers	12,664	8.5 (0.6)	40.3 (7.8)	1.8 (0.5)
Yes Mediterranean diet	12,720	8.1 (0.4)	33.9 (3.6)	1.4 (0.2)
Non Mediterranean diet	22,176	8.7 (0.6)	43.6 (7.3)	2.0 (0.5)
Yes physical activity	14,168	8.1 (0.4)	33.9 (3.6)	1.4 (0.2)
Non physical activity	20,728	8.7 (0.6)	44.3 (7.0)	2.0 (0.5)
Women	**n**	**Mean (SD)**	**Mean (SD)**	**Mean (SD)**
18-25 years	192	8.1 (0.4)	30.8 (4.3)	1.2 (0.2)
26-35 years	1,656	8.1 (0.5)	35.4 (8.7)	1.4 (0.5)
36-45 years	1,512	8.2 (0.5)	35.5 (7.6)	1.5 (0.5)
46-55 years	744	8.3 (0.5)	37.9 (6.6)	1.6 (0.4)
>55 years	120	8.4 (0.5)	38.7 (5.5)	1.7 (0.4)
Elementary school	3,120	8.2 (0.5)	36.4 (7.5)	1.5 (0.5)
High school	1,104	8.0 (0.5)	35.6 (8.0)	1.5 (0.5)
Non-smokers	2,376	8.1 (0.5)	35.2 (7.7)	1.5 (0.5)
Smokers	1,848	8.2 (0.5)	36.5 (8.0)	1.6 (0.5)
Yes Mediterranean diet	2,040	7.9 (0.4)	31.1 (3.9)	1.2 (0.2)
Non Mediterranean diet	2,184	8.3 (0.5)	40.2 (8.1)	1.8 (0.5)
Yes physical activity	1,920	7.9 (0.4)	30.2 (3.5)	1.2 (0.2)
Non physical activity	2,304	8.4 (0.5)	40.5 (7.4)	1.8 (0.5)

Notes: TyG Triglyceride glucose. METS-IR Metabolic score for insulin resistance. SPISE-IR Single point insulin sensitivity- insulin resistance. SD Standard deviation.

to the Mediterranean diet, and low physical activity levels were consistently associated with a higher prevalence of IR-related alterations. These results emphasize the multifactorial nature of insulin resistance and the substantial influence of modifiable lifestyle factors. Particularly concerning is the heightened prevalence of IR in individuals with unfavorable socioeconomic profiles, underscoring the importance of targeted interventions within occupational settings.

Table 3 illustrates the percentage of male and female automotive mechanics presenting elevated values in three validated insulin resistance indices —TyG, METS-IR, and SPISE-IR— across key sociodemographic and lifestyle categories. A

Table 3. Prevalence of elevated insulin resistance scores (TyG, METS-IR, SPISE-IR) by age, education, smoking, diet, and physical activity, stratified by sex.

		TyG high	METS-IR high	SPISE-IR high
Men	**n**	**%**	**%**	**%**
18-25 years	2,648	7.5	3.0	5.4
26-35 years	9,996	18.1	7.1	10.9
36-45 years	11,804	31.0	11.1	19.5
46-55 years	8,112	37.5	15.2	23.1
>55 years	2,336	39.4	19.9	24.0
Elementary school	19,840	24.8	9.3	19.0
High school	15,056	29.8	12.1	14.7
Non-smokers	22,232	25.5	10.3	16.8
Smokers	12,664	31.3	11.2	17.6
Yes Mediterranean diet	12,720	3.6	3.5	5.3
Non Mediterranean diet	22,176	41.4	14.5	20.2
Yes physical activity	14,168	2.9	3.0	4.1
Non physical activity	20,728	44.5	15.9	23.9
Women	**n**	**%**	**%**	**%**
18-25 years	192	5.8	1.5	2.3
26-35 years	1,656	13.0	3.9	7.5
36-45 years	1,512	12.7	5.2	9.5
46-55 years	744	20.0	7.3	9.7
>55 years	120	25.8	8.9	20.0
Elementary school	3,120	17.7	6.9	9.2
High school	1,104	10.9	6.2	8.7
Non-smokers	2,376	14.1	5.1	8.1
Smokers	1,848	18.2	7.8	10.4
Yes Mediterranean diet	2,040	3.5	3.9	3.9
Non Mediterranean diet	2,184	27.5	8.9	14.1
Yes physical activity	1,920	2.8	3.1	3.2
Non physical activity	2,304	28.4	10.2	16.4

Notes: TyG Triglyceride glucose. METS-IR Metabolic score for insulin resistance. SPISE-IR Single point insulin sensitivity- insulin resistance.

progressive increase in IR prevalence is observed with advancing age in both sexes, particularly marked in men aged 46 years and older. Lower educational attainment (elementary school), current smoking, low adherence to the Mediterranean diet, and absence of regular physical activity are all associated with a higher proportion of individuals exhibiting elevated IR scores. Notably, the contrast between those adhering to the Mediterranean diet versus those who do not, and between physically active versus inactive workers, is stark—exceeding a tenfold difference in prevalence. These findings reinforce the central role of modifiable lifestyle behaviors in insulin resistance development, and they underscore the need for targeted health promotion strategies in high-risk occupational settings.

Table 4. Multivariate logistic regression for elevated TyG, METS-IR, and SPISE-IR scores according to sociodemographic and lifestyle factors.

	TyG high OR (95% CI)	METS-IR high OR (95% CI)	SPISE-IR high OR (95% CI)
Women	1	1	1
Men	2.03 (1.84-2.23)	1.46 (1.32-1.61)	1.73 (1.54-1.93)
18-25 years	1	1	1
26-35 years	1.11 (1.07-1.15)	1.34 (1.22-1.46)	1.09 (1.06-1.12)
36-45 years	1.21 (1.14-1.28)	1.52 (1.35-1.69)	1.19 (1.13-1.25)
46-55 years	1.72 (1.55-1.89)	1.67 (1.48-1.87)	1.36 (1.25-1.47)
56-69 years	2.41 (2.03-2.79)	2.69 (2.08-3.29)	1.85 (1.61-2.09)
High school	1	1	1
Elementary school	1.14 (1.10-1.19)	1.15 (1.10-1.21)	1.20 (1.13-1.27)
Non-smokers	1	1	1
Smokers	1.55 (1.47-1.63)	1.19 (1.13-1.25)	1.15 (1.10-1.19)
Yes Mediterranean diet	1	1	1
Non Mediterranean diet	2.35 (2.01-2.70)	5.25 (4.01-6.50)	6.98 (5.17-8.78)
Yes physical activity	1	1	1
Non physical activity	6.18 (4.89-7.47)	9.33 (7.35-11.32)	10.35 (8.16-12.56)

Notes: TyG Triglyceride glucose. METS-IR Metabolic score for insulin resistance. SPISE-IR Single point insulin sensitivity- insulin resistance. OR Odds ratio.

Table 4 presents the adjusted odds ratios (ORs) and 95% confidence intervals for the likelihood of exhibiting elevated values in the TyG, METS-IR, and SPISE-IR indices. Men were significantly more likely than women to present insulin resistance across all three measures. Age showed a clear dose-response relationship, with increasing ORs across older age categories, particularly for METS-IR and SPISE-IR. Workers with only elementary education exhibited higher odds of IR compared to those with higher education. Lifestyle factors also showed strong independent associations: smoking increased the risk modestly, while low adherence to the Mediterranean diet and lack of physical activity showed extremely elevated ORs —particularly striking for METS-IR (OR: 5.25) and SPISE-IR (OR: 10.35). These results confirm the robustness of these surrogate indices for detecting insulin resistance and highlight lifestyle behaviors as dominant, independent predictors. Such evidence supports the implementation of preventive programs tailored to specific occupational subgroups at elevated cardiometabolic risk.

Discussion

This study assessed insulin resistance (IR) risk using three validated surrogate indices —TyG, METS-IR, and SPISE— in a large, occupationally active cohort of mechanics. The use of multiple indices provided a more comprehensive picture of insulin resistance. The TyG index, which integrates fasting glucose and triglycerides, is widely recognized as a reliable and cost-effective marker for IR in epidemiological settings. METS-IR incorporates HDL-cholesterol and BMI, offering a more nuanced reflection of metabolic dysfunction, particularly in relation to hepatic insulin resistance and NAFLD. SPISE, while less commonly applied in occupational studies, has shown promise for its simplicity and high sensitivity, especially in resource-limited settings where insulin assays are unavailable.

Our findings reveal notable sex-based differences in metabolic profiles, with male workers exhibiting significantly higher levels of waist circumference, triglycerides, and fasting glucose, resulting in elevated TyG and METS-IR scores and high SPISE-IR values.

These observations are consistent with prior studies indicating that men have a greater predisposition to visceral adiposity and insulin resistance, even at comparable levels of BMI[50,51].

The prevalence of altered IR indices increased with age and was inversely associated with educational attainment, supporting the notion that social determinants of health contribute significantly to metabolic risk[52]. Workers with lower education levels may have limited access to preventive care, lower health literacy, and a higher likelihood of adopting unhealthy behaviors such as smoking and poor diet[53]. These findings are particularly relevant in blue-collar occupations, where physical labor does not necessarily confer cardiometabolic protection in the absence of other healthy lifestyle practices.

The lifestyle factors evaluated—smoking status, physical activity, and adherence to the Mediterranean diet—showed consistent associations across all indices. Smoking was strongly linked to elevated TyG and METS-IR and to lower SPISE values, echoing evidence that tobacco use promotes insulin resistance through oxidative stress, systemic inflammation, and endothelial dysfunction[54]. Conversely, regular physical activity and adherence to the Mediterranean diet were associated with more favorable IR profiles. This dietary pattern has been shown to improve insulin sensitivity, modulate lipid metabolism, and reduce subclinical inflammation, even in non-obese individuals[55].

Interestingly, the protective role of physical activity was more pronounced in the models using METS-IR and SPISE than with TyG. This may reflect the broader cardiometabolic influence of aerobic and muscular conditioning beyond glycemic and lipid control[56]. Similarly, the effect of diet quality was consistently strong across all models, reinforcing dietary intervention as a cornerstone of metabolic health promotion.

Our study contributes to the limited literature on metabolic risk in labor-intensive, male-dominated occupations. While previous research has focused predominantly on office workers and healthcare personnel, mechanics have been relatively understudied, despite potentially higher exposure to cardiometabolic stressors such as physical strain, chemical agents, and irregular work hours. These occupational hazards, in conjunction with behavioral risk factors, may synergistically increase IR risk and warrant tailored preventive strategies.

Sex-stratified analysis revealed a more adverse IR profile in men, consistent with previous findings on sex hormones and fat distribution. Testosterone excess and lower estrogen levels in men have been associated with impaired insulin signaling and increased hepatic lipid synthesis[57]. Additionally, men are generally less likely to engage in preventive health behaviors, further compounding their risk.

The use of non–insulin-based indices also offers methodological advantages. Unlike the hyperinsulinemic-euglycemic clamp, which is laborious and costly, the indices used here are simple to calculate and rely on routine laboratory values. Their integration into occupational health assessments can facilitate early identification of high-risk individuals and guide personalized interventions.

However, certain limitations should be acknowledged. The cross-sectional nature of the study precludes causal inference. Additionally, residual confounding by unmeasured factors such as sleep quality, stress, or shift work schedule cannot be ruled out. Furthermore, while the indices are well validated, their cut-off values may vary by population and ethnicity, warranting further calibration in occupational cohort.

Despite these limitations, our findings have important public health implications. Implementing metabolic screening protocols in industrial settings may enhance the early detection of insulin resistance and its downstream complications. Targeted health promotion strategies—such as smoking cessation programs, workplace physical activity initiatives, and nutritional education—can mitigate risk and improve long-term health outcomes in blue-collar populations.

In conclusion, this study highlights a high burden of insulin resistance among automotive mechanics, particularly among older, male, and less-educated workers with unhealthy lifestyle behaviors. The complementary use of TyG, METS-IR, and SPISE indices provides a robust framework for IR risk stratification in occupational settings. These findings underscore the urgent need for sex- and context-specific interventions to address the metabolic health disparities in labor-intensive professions.

We consider it of great interest to conduct a longitudinal follow-up of this cohort to evaluate the development of diabetes mellitus and cardiovascular events over time.

Conclusions

This study highlights a substantial burden of insulin resistance among automotive mechanics, a predominantly male and labor-intensive occupational group that has received limited attention in metabolic research. Using three validated surrogate indices —TyG, METS-IR, and SPISE— we identified a high prevalence of altered IR markers, particularly

among older participants, those with lower educational attainment, smokers, and individuals with poor dietary and physical activity habits.

The findings underscore the strong influence of sociodemographic and lifestyle factors on insulin resistance, even in physically active professions. The consistent associations observed across all three indices support their complementary utility for metabolic risk stratification in occupational health settings. In particular, the SPISE index may serve as a practical alternative when fasting glucose or insulin measurements are not available.

Given the modifiable nature of the main determinants identified—smoking, diet, and physical inactivity—our results provide a clear rationale for implementing tailored workplace interventions aimed at improving metabolic health. These strategies should be sex-sensitive and consider the specific demands and socioeconomic context of blue-collar workers.

Integrating simple, non-invasive IR screening tools into routine occupational health assessments could facilitate early identification of at-risk individuals, reduce the long-term burden of type 2 diabetes and cardiovascular disease, and promote health equity in vulnerable working populations.

Author contributions

ARG: Conceptualization, formal analysis, revision.

PJTL: Data collection and analysis, data curation, draft.

JIRM: Validation, revision.

ADAR: Data curation.

ICC: Data collection and analysis, draft, Methodology.

MGS: Methodology, draft.

AALG: Conceptualization, revision

All authors have read and agreed to the published version of the manuscript.

Fundings

This article has not received any specific grant from funding agencies in the public, commercial, or for-profit sectors.

Ethical considerations

The study adhered to all relevant national and international ethical standards for biomedical research, including the principles outlined in the Declaration of Helsinki. The study design ensured the full protection of participants' rights, privacy, and anonymity. Prior to inclusion, all participants received comprehensive oral and written information regarding the study's objectives, procedures, and scope. Participation was entirely voluntary, and written informed consent was obtained from each individual before any data collection.

Ethical approval 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 guarantee confidentiality, all personal identifiers were anonymized and replaced with encrypted codes accessible only to the principal investigator. No personally identifiable data will be disclosed or published.

In accordance with Organic Law 3/2018 on the Protection of Personal Data and Guarantee of Digital Rights (Spain), and the European Union's General Data Protection Regulation (Regulation EU 2016/679), all participants were informed of their rights to access, rectify, delete, or oppose the use of their personal data.

All participants provided written informed consent after receiving a thorough explanation of the study's objectives and procedures.

Data availability statement

All research data are securely stored at ADEMA University School and managed in full compliance with current data protection legislation. Data governance is overseen by the institution's designated Data Protection Officer, Ángel Arturo López González.

Conflict of interest

The authors declare no conflicts of interest.

References

1. Kosmas CE, Bousvarou MD, Kostara CE, Papakonstantinou EJ, Salamou E, Guzman E. Insulin resistance and cardiovascular disease. J Int Med Res 2023; 51(3):3000605231164548. Available from: https://doi.org/10.1177/03000605231164548.
2. Marušić M, Paić M, Knobloch M, Liberati Pršo AM. NAFLD, Insulin resistance, and diabetes mellitus Type 2. Can J Gastroenterol Hepatol 2021; 2021:6613827. Available from: https://doi.org/10.1155/2021/6613827.
3. Tanase DM, Gosav EM, Costea CF, Ciocoiu M, Lacatusu CM, Maranduca MA, et al. The intricate relationship between type 2 diabetes mellitus (T2DM), insulin resistance (IR), and nonalcoholic fatty liver disease (NAFLD). J Diabetes Res 2020; 2020:3920196. Available from: https://doi.org/10.1155/2020/3920196.
4. Scurt FG, Ganz MJ, Herzog C, Bose K, Mertens PR, Chatzikyrkou C. Association of metabolic syndrome and chronic kidney disease. Obes Rev 2024; 25(1):e13649. Available from: https://doi.org/10.1111/obr.13649.
5. Duarte GBS, Pascoal GFL, Rogero MM. Polymorphisms involved in insulin resistance and metabolic inflammation:

influence of nutrients and dietary interventions. Metabolites 2025; 15(4):245. Available from: https://doi.org/10.3390/metabo15040245.

6. Yazıcı D, Demir SÇ, Sezer H. Insulin resistance, obesity, and lipotoxicity. Adv Exp Med Biol 2024; 1460:391-430. Available from: https://doi.org/10.1007/978-3-031-63657-8_14.
7. Du R, Bai Y, Li L, Shao Y, Wu N. Insulin resistance-induced mitochondrial dysfunction and pyroptosis in trophoblasts: protective role of metformin. BMC Pregnancy Childbirth 2025; 25(1):293. Available from: https://doi.org/10.1186/s12884-025-07419-0.
8. Wu C, Ke Y, Nianogo RA. Trends in hyperinsulinemia and insulin resistance among nondiabetic US adults, NHANES, 1999-2018. J Clin Med 2025; 14(9):3215. Available from: https://doi.org/10.3390/jcm14093215.
9. Freeman AM, Acevedo LA, Pennings N. Insulin Resistance. In: *StatPearls*. Treasure Island (FL): StatPearls Publishing. 2025.
10. Dong B, Chen Y, Yang X, Chen Z, Zhang H, Gao Y, et al. Estimated glucose disposal rate outperforms other insulin resistance surrogates in predicting incident cardiovascular diseases in cardiovascular-kidney-metabolic syndrome stages 0-3 and the development of a machine learning prediction model: a nationwide prospective cohort study. Cardiovasc Diabetol 2025; 24(1):163. Available from: https://doi.org/10.1186/s12933-025-02729-1.
11. Mir SA, Narasimhan K, Annadurai JK, Vaitheeswari JS, Cameron-Smith D, Eriksson JG, et al. Lipidomic Signatures of insulin resistance identified from hyperinsulinemic-euglycemic clamp studies in Asian Men. Diabetes 2025; db250010. Available from: https://doi.org/10.2337/db25-0010.
12. Eyth E, Basit H, Swift CJ. Glucose Tolerance Test. 2023. In: StatPearls. Treasure Island (FL): StatPearls Publishing; 2025.
13. Tárraga Marcos PJ, López-González ÁA, Martínez-Almoyna Rifá E, Paublini Oliveira H, Martorell Sánchez C, Tárraga López PJ, et al. Risk of insulin resistance in 44,939 Spanish healthcare workers: association with sociodemographic variables and healthy habits. Diseases 2025; 13(2):33. Available from: https://doi.org/10.3390/diseases13020033.
14. Sastre-Alzamora T, Tomás-Gil P, Paublini H, Pallarés L, Ramírez-Manent JI, López-González AA. Relationship between heart age and insulin resistance risk scales in 139634 Spanish workers. Acad J Health Sci 2024; 39 (1):16-22 Available from: https://doi.org/10.3306/AJHS.2024.39.01.16.
15. Sun Y, Ji H, Sun W, An X, Lian F. Triglyceride glucose (TyG) index: a promising biomarker for diagnosis and treatment of different diseases. Eur J Intern Med 2025; 131:3-14. Available from: https://doi.org/10.1016/j.ejim.2024.08.026.
16. Tosoratto J, Carriedo B, Cantón C. Cardiometabolic risk level in 43074 Spanish office workers: associated variables. Acad J Health Sci 2024; 39 (4): 48-56 Available from: https://doi.org/10.3306/AJHS.2024.39.04.48.
17. Zhou C, Zhang Y, Liu X, He C, Li S. Relationship of METS-IR with cardiometabolic multimorbidity in China: a nationwide longitudinal cohort study. Front Nutr 2025; 12:1518840. Available from: https://doi.org/10.3389/fnut.2025.1518840.
18. Vicente-Herrero MT, Gordito Soler M, García Agudo S, Vallejos D, López-González AA. Ramírez-Manent JI. Cardiometabolic risk level in 1136 Spanish professional musicians. Acad J Health Sci 2024; 39 (5): 59-66. Available from: https://doi.org/10.3306/AJHS.2024.39.05.59.
19. Tantari G, Bassi M, Pistorio A, Minuto N, Napoli F, Piccolo G, et al. SPISE INDEX (Single point insulin sensitivity estimator): indicator of insulin resistance in children and adolescents with overweight and obesity. Front Endocrinol 2024; 15:1439901. Available from: https://doi.org/10.3389/fendo.2024.1439901.
20. Vicente-Herrero MT, Egea-Sancho M, Ramírez Iñiguez de la Torre MV, López-González AA. Relación de los índices de adiposidad visceral (VAI) y adiposidad disfuncional (DAI) con las escalas de riesgo de resistencia a la insulina y prediabetes. Acad J Health Sci; 39 (2): 25-31. Available from: https://doi.org/10.3306/AJHS.2024.39.02.25.
21. Romero Aguirre AC, Olivier-Morillo V, Ortiz-Ortiz MTB, López-González AA. Sociodemographic and lifestyle determinants of insulin resistance scores in 273,154 Spanish workers. J Clin Trials Exp Investig 2025; 4(1):25–33.
22. Ciarambino T, Crispino P, Guarisco G, Giordano M. Gender differences in insulin resistance: new knowledge and perspectives. Curr Issues Mol Biol 2023; 45(10):7845-61. Available from: https://doi.org/10.3390/cimb45100496.
23. Aguiló Juanola MC, López-González AA, Tomás-Gil P, Paublini H, Tárraga-López PJ, Ramírez-Manent JI. Influence of tobacco consumption on the values of different insulin resistance risk scales and non-alcoholic fatty liver disease and hepatic fibrosis scales in 418,343 spanish people. Acad J Health Sci 2024; 39 (2):9-15 Available from: https://doi.org/10.3306/AJHS.2024.39.02.9.
24. Cao Y, Shrestha A, Janiczak A, Li X, Lu Y, Haregu T. Lifestyle intervention in reducing insulin resistance and preventing type 2 diabetes in Asia Pacific region: a systematic review and meta-analysis. Curr Diab Rep 2024; 24(9):207-15. Available from: https://doi.org/10.1007/s11892-024-01548-0.
25. Papakonstantinou E, Oikonomou C, Nychas G, Dimitriadis GD. Effects of diet, lifestyle, chrononutrition and alternative dietary interventions on postprandial glycemia and insulin resistance. Nutrients 2022; 14(4):823. Available from: https://doi.org/10.3390/nu14040823.
26. Yaribeygi H, Maleki M, Sathyapalan T, Jamialahmadi T, Sahebkar A. Pathophysiology of physical inactivity-dependent insulin resistance: a theoretical mechanistic review emphasizing clinical evidence. J Diabetes Res 2021; 2021:7796727. Available from: https://doi.org/10.1155/2021/7796727.
27. Rouland A, Thuillier P, Al-Salameh A, Benzerouk F, Bahougne T, Tramunt B, et al. Smoking and diabetes. Ann Endocrinol 2024; 85(6):614-22. Available from: https://doi.org/10.1016/j.ando.2024.08.001.
28. Ulguim FO, Renner JDP, Pohl HH, de Oliveira CF, Bragança GCM. Health workers: cardiovascular risk and occupational stress. Rev Bras Med Trab 2020; 17(1):61-8. Available from: https://doi.org/10.5327/Z1679443520190302.
29. Mestre Font M, Busquets-Cortés C, Ramírez-Manent JI, Tomás-Gil P, Paublini H, López-González ÁA. Influence of sociodemographic variables and healthy habits on the values of insulin resistance indicators in 386,924 Spanish

workers. Nutrients 2023; 15(24):5122. Available from: https://doi.org/10.3390/nu15245122.

30. Bhandari P. Prevalence of cardiovascular risk factors among Asian migrant workers in South Korea. PLoS One 2023; 18(7):e0288375. Available from: https://doi.org/10.1371/journal.pone.0288375.
31. Yang BY, Guo Y, Markevych I, Qian ZM, Bloom MS, Heinrich J, et al. Association of long-term exposure to ambient air pollutants with risk factors for cardiovascular disease in China. JAMA Netw Open 2019; 2(3):e190318. Available from: https://doi.org/10.1001/jamanetworkopen.2019.0318.
32. Zhou H, Liang X, Zhang X, Wu J, Jiang Y, Guo B, et al. Associations of long-term exposure to fine particulate constituents with cardiovascular diseases and underlying metabolic mediations: a prospective population-based cohort in Southwest China. J Am Heart Assoc 2024; 13(10):e033455. Available from: https://doi.org/10.1161/JAHA.123.033455.
33. Manzanero RZ, López-González AA, Tomás-Gil P, Paublini H, Martínez-Jover A, Ramírez-Manent JI. Estimation of cardiometabolic risk in 25,030 Spanish kitchen workers. Acad J Health Sci 2023; 38 (6):101-10. Available from: https://doi.org/10.3306/AJHS.2023.38.06.101.
34. Manzanero RZ, López-González AA, Tomás-Gil P, Paublini H, Martínez-Jover A, Ramírez-Manent JI. Cardiometabolic risk assessment in 28,300 Spanish waiters. Acad J Health Sci 2023; 39(2):16-24. Available from: https://doi.org/10.3306/AJHS.2024.39.02.16.
35. Gado M, Tsaousidou E, Bornstein SR, Perakakis N. Sex-based differences in insulin resistance. J Endocrinol 2024; 261(1):e230245. Available from: https://doi.org/10.1530/JOE-23-0245.
36. Broussard JL, Perreault L, Macias E, Newsom SA, Harrison K, Bui HH, et al. Sex differences in insulin sensitivity are related to muscle tissue acylcarnitine but not subcellular lipid distribution. Obesity 2021; 29(3):550-61. Available from: https://doi.org/10.1002/oby.23106.
37. De Paoli M, Zakharia A, Werstuck GH. The role of estrogen in insulin resistance: a review of clinical and preclinical data. Am J Pathol 2021; 191(9):1490-8. Available from: https://doi.org/10.1016/j.ajpath.2021.05.011.
38. Wang Y, Cao P, Liu F, Chen Y, Xie J, Bai B, et al. Gender differences in unhealthy lifestyle behaviors among adults with diabetes in the United States between 1999 and 2018. Int J Environ Res Public Health 2022; 19(24):16412. Available from: https://doi.org/10.3390/ijerph192416412.
39. Mestre-Font M, Busquets-Cortés C, Ramírez-Manent JI, Tomás-Gil P, Paublini H, López-González AA. Influence of sociodemographic variables and healthy habits on the values of type 2 diabetes risk scales. Acad J Health Sci 2024; 39(2):99-106. Available from: https://doi.org/10.3306/AJHS.2024.39.02.99.
40. Dayi T, Ozgoren M. Effects of the Mediterranean diet on the components of metabolic syndrome. J Prev Med Hyg 2022; 63(3):E56-E64. Available from: https://doi.org/10.15167/2421-4248/jpmh2022.63.2S3.2747.
41. Tosoratto J, Tárraga López PJ, López-González AA, Busquets-Cortes C, Obrador de Hevia J, Ramírez-Manent JI. Associations between shift work and insulin resistance markers in 53,053 Spanish workers. J Clin Med 2025; 14(13):4604.
42. Kaplan AK, Sezgin Y. Evaluation of the relationship between smoking and insulin resistance: a case-control study. Cureus 2023; 15(3):e36684. Available from: https://doi.org/10.7759/cureus.36684.
43. Memme JM, Erlich AT, Phukan G, Hood DA. Exercise and mitochondrial health. J Physiol 2021; 599(3):803-17. Available from: https://doi.org/10.1113/JP278853.
44. Perego S, Sansoni V, Ziemann E, Lombardi G. Another weapon against cancer and metastasis: physical-activity-dependent effects on adiposity and adipokines. Int J Mol Sci 2021; 22(4):2005. Available from: https://doi.org/10.3390/ijms22042005.
45. Ramdas Nayak VK, Satheesh P, Shenoy MT, Kalra S. Triglyceride Glucose (TyG) index: a surrogate biomarker of insulin resistance. J Pak Med Assoc 2022; 72(5):986-8. Available from: https://doi.org/10.47391/JPMA.22-63.
46. Bello-Chavolla OY, Almeda-Valdes P, Gomez-Velasco D, Viveros-Ruiz T, Cruz-Bautista I, Romo-Romo A, et al. METS-IR, a novel score to evaluate insulin sensitivity, is predictive of visceral adiposity and incident type 2 diabetes. Eur J Endocrinol 2018; 178(5):533-44. Available from: https://doi.org/10.1530/EJE-17-0883.
47. Pilar Fernández-Figares Vicioso M, Riutord Sbert P, López-González ÁA, Ramírez-Manent JI, Del Barrio Fernández JL, Herrero MTV. Risk of insulin resistance: comparison of the commerce vs. industry sector and associated variables. Diseases 2025; 13(5):150. Available from: https://doi.org/10.3390/diseases13050150.
48. Montemayor S, Mascaró CM, Ugarriza L, Casares M, Llompart I, Abete I, et al. Adherence to Mediterranean diet and NAFLD in patients with metabolic syndrome: the FLIPAN study. Nutrients 2022; 14(15):3186. Available from: https://doi.org/10.3390/nu14153186.
49. Franco E, Urosa J, Barakat R, Refoyo I. Physical activity and adherence to the Mediterranean diet among Spanish employees in a health-promotion program before and during the COVID-19 oandemic: the sanitas-healthy cities challenge. Int J Environ Res Public Health 2021; 18(5):2735. Available from: https://doi.org/10.3390/ijerph18052735.
50. Tramunt B, Smati S, Grandgeorge N, Lenfant F, Arnal JF, Montagner A, et al. Sex differences in metabolic regulation and diabetes susceptibility. Diabetologia. 2020; 63(3):453-61. Available from: https://doi.org/10.1007/s00125-019-05040-3.
51. Vicente-Herrero MT, Egea-Sancho M, Ramírez-lñiguez MV, López González ÁA. Relación de los índices de adiposidad visceral (VAI) y disfuncional (DAI) con riesgo de enfermedad de hígado graso no alcohólico. Acad J Health Sci 2024; 39(2):130-6. Available from: https://doi.org/10.3306/AJHS.2024.39.02.130.
52. He J, Zhu Z, Bundy JD, Dorans KS, Chen J, Hamm LL. Trends in cardiovascular risk factors in US adults by race and ethnicity and socioeconomic status, 1999-2018. JAMA 2021; 326(13):1286-98. Available from: https://doi.org/10.1001/jama.2021.15187.
53. Zhang YB, Chen C, Pan XF, Guo J, Li Y, Franco OH, et al. Associations of healthy lifestyle and socioeconomic status with mortality and incident cardiovascular disease: two prospective cohort studies. BMJ 2021;373:n604. Available from: https://doi.org/10.1136/bmj.n604.

54. Lynch J, Jin L, Richardson A, Conklin DJ. Tobacco smoke and endothelial dysfunction: role of aldehydes? Curr Hypertens Rep 2020; 22(9):73. Available from: https://doi.org/10.1007/s11906-020-01085-7.

55. Guasch-Ferré M, Willett WC. The Mediterranean diet and health: a comprehensive overview. J Intern Med 2021; 290(3):549-66. Available from: https://doi.org/10.1111/joim.13333.

56. Costa JSR, Fonseca GFAC, Ottone NCDS, Silva PA, Antonaccio RF, Silva G, et al. Strength training improves insulin resistance and differently affects mitochondria in skeletal muscle and visceral adipose tissue in high-fat fed mice. Life Sci 2021; 278:119639. Available from: https://doi.org/10.1016/j.lfs.2021.119639.

57. Gado M, Tsaousidou E, Bornstein SR, Perakakis N. Sex-based differences in insulin resistance. J Endocrinol 2024; 261(1):e230245. Available from: https://doi.org/10.1530/JOE-23-0245.