Original papers

Do sociodemographic and health predictors affect the non-insulin-based insulin resistance index? A cross-sectional study

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Conflict of interest
None declared

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Abstract

Background. Insulin resistance (IR) is considered a risk factor for cardiovascular diseases (CVD). Therefore, early diagnosis of IR is clinically significant for primary and secondary CVD prevention initiatives. In addition, non-insulin metabolic indices may be useful for diagnosing IR.

Objectives. The first objective was to estimate the triglyceride and glucose (TyG) index and the metabolic score for insulin resistance (METS-IR) index values in a local community with high social deprivation and increased cardiovascular risk according to the Systematic Coronary Risk Evaluation scale. The second objective was to identify significant sociodemographic and health predictors for the TyG index and METS-IR index.

Materials and methods. This cross-sectional study was conducted in the local community of Janów district in eastern Poland and consisted of 2 stages. The 1st stage involved basic research (n = 4,040), while the 2nd stage involved enhanced diagnostics (n = 2,657). Data from the 2nd stage was used for the analyses. Anthropometric and physiological measurements were taken, blood was drawn for laboratory tests, selected sociodemographic and health variables were evaluated, and the TyG index and METS-IR index were calculated.

Results. The mean TyG index score in the study group was 8.65 (±0.58), and the mean METS-IR index score was 41.45 (±9.02). Both indices were significantly associated with age, male sex, smoking, and systolic blood pressure (SBP) in a multivariable model. In addition, alcohol consumption and body mass index (BMI) were significantly correlated with the TyG index, whereas education was significantly associated with the METS-IR index.

Conclusions. Our results show the association between IR and sociodemographic and health variables in a group with a high social deprivation rate and increased cardiovascular risk. Early detection of cardiometabolic risk is important for both primary and secondary CVD prevention. In primary healthcare, this can be accomplished through surrogate markers of IR.

Keywords: insulin resistance, cardiovascular disease, local community, triglyceride and glucose (TyG), metabolic score for insulin resistance (METS-IR)

Background

As one of the leading causes of morbidity and mortality worldwide, cardiovascular diseases (CVD) have a substantial financial impact on healthcare systems and significantly worse wellbeing.[1] Patients with CVD, especially those with multiple risk factors, continue to have a high risk of cardiovascular complications and recurrence despite the development and implementation of several secondary prevention strategies, such as pharmacotherapy, revascularization and rehabilitation.[2] Therefore, identifying and addressing risk factors in groups at high risk of CVD becomes critical for primary CVD prevention. Glucose and lipid metabolism disorders are a major cause of CVD. Studies indicate that insulin resistance (IR), hyperglycemia and dyslipidemia increase cardiovascular morbidity and mortality.[3] Thus, investigating a correlation between primary CVD prevention and both modifiable and non-modifiable risk factors and glycolipid metabolism may help to reduce the worldwide burden of CVD.

Insulin resistance, defined as decreased insulin responsiveness in tissues, is a crucial mechanism in glycolipid metabolism.[4] Research shows that IR increases the risk of diabetes, hypertension and other illnesses, and may be a primary cause of CVD.[4–6] In addition, IR is the primary risk factor for coronary artery disease (CAD) in young adults and can cause up to 40% of myocardial infarctions.[7] The gold standard for assessing IR is the euglycemic insulin clamp technique,[8] but its use in screening is limited because it is an invasive, expensive and challenging method to use in large cohort studies.[9] Consequently, IR indices, which do not include insulin levels in their calculation algorithm, have been developed. These methods are easier to use and more cost-effective, particularly in primary healthcare and epidemiological studies.

The triglyceride and glucose (TyG) index, which combines serum triglyceride and fasting plasma glucose levels, is a surrogate marker of IR. Wen et al.[10] found that the TyG index is strongly associated with the incidence of prediabetes compared to other IR indices in the Chinese population. Other research suggests it is more accurate than the homeostatic model assessment index (HOMA-IR) in predicting the incidence and prognosis of hypertension, diabetes, stroke, and other CVD.[11–13] It should be noted that IR is not only related to glucose and lipid metabolism but also to nutritional status and fat distribution. Unfortunately, the TyG index does not account for these 2 factors, which is undoubtedly its weakness. Therefore, Bello-Chavolla et al.[14] developed a novel metabolic score for IR (METS-IR) index using biochemical and anthropometric variables easily obtained in primary healthcare, and which demonstrate good diagnostic performance for assessing insulin sensitivity. The METS-IR is also a relevant marker for evaluating cardiometabolic risk in both healthy and at-risk study participants, and may be a useful tool for screening insulin sensitivity.[12] Available data indicate that both the TyG index and METS-IR index are associated with several CVD risk factors, including diabetes, metabolic syndrome, arterial stiffness, CAD, and subsequent cardiovascular events.[11,15,16]

Sociodemographic, environmental and psychosocial factors significantly impact health, contribute to the development of CVD risk factors, and influence CVD morbidity and mortality.[17] Numerous studies have shown a strong association between socioeconomic status (SES), which includes education, income and occupation, and the prevalence of CVD risk factors.[18] De Mestral et al.[19] emphasize the importance of examining how the SES–CVD relationship varies regionally within countries, particularly in middle-income countries where it may be influenced by place of residence (rural vs urban areas). An example is the Janów district in eastern Poland, a local community characterized by low SES and ranked among the 20% most deprived districts in Lublin Province.[20] Comparative analysis of socioeconomic characteristics preceding the study revealed significantly unfavorable differences compared to nationwide indicators: a higher percentage of residents with primary education (23.2% vs 27.55% nationally),[21] a 15.6% unemployment rate among working-age individuals vs the national average of 14%,[22] and 14.6% of the Janów district population receiving social benefits compared to 9.4% across Lublin Province.[23] Low SES is one of several frequently overlooked risk factors for IR. In Europe's multinational, multicultural and socioeconomically diverse regions, a holistic approach that considers both traditional and socioeconomic factors is increasingly important for implementing multidimensional public health programs and integrated social interventions to effectively prevent IR-related diseases. Therefore, understanding the regional relationship between SES and IR is crucial.

Objectives

The 1st objective of the study was to estimate the TyG index and METS-IR index in Janów district, a location characterized by high social deprivation and increased cardiovascular risk according to the Systematic Coronary Risk Evaluation (SCORE) scale. The 2nd objective was to identify significant sociodemographic and health predictors for the TyG index and METS-IR index.

Materials and methods

Study design and participants

The "Take your health to heart" ("Weź sobie zdrowie do serca") prevention and health promotion program was conducted in the Janów district of eastern Poland from June 14 to March 20, 2016. The initiative was funded by the state budget and the Norwegian Financial Mechanism 2009–2014's Operational Program PL 13 – "Reduction of Social

Inequalities in Health." Under the PL 13 Program, funding was provided for health promotion and prevention initiatives in local communities with high standardized mortality ratios (SMRs) between 2009 and 2011 in the following categories: malignant neoplasms, CVD, respiratory diseases, digestive diseases, external causes, and total mortality. Out of 38 districts with the highest standardized cardiovascular mortality ratios in Poland, Janów district was ranked 3rd (SMR = 1.357).[24]

The day before the study, Janów district had a population of 47,500 residents. An epidemiological analysis of CVD incidence among Janów district residents identified a sharp rise in risk between ages 35 and 64. Because the majority of CVD patients are over 65 and healthcare for this group primarily focuses on symptom management, people aged 35–64 were invited to participate in the study, with 18,827 people of this category living in Janów district.

Participants meeting the study criteria were contacted by phone and received invitations from district and municipal authorities, as well as cooperating institutions (religious associations, workplaces, and public utility associations and institutions). The study consisted of 2 stages. Stage 1, the basic study, aimed to identify individuals with a SCORE cardiovascular risk of 5% or higher.[25] After a visit by the patient to the doctor, stage 1 ended with the doctor deciding whether to enroll the patient in an educational program for lifestyle improvement or refer them to stage 2. Inclusion criteria for stage 1 were: 1) age 35–64 years; 2) no history of cardiovascular incidents; 3) no CAD diagnosis; (4) informed consent to participate in the study. Exclusion criteria were: 1) history of cardiovascular incidents (heart attack or stroke); 2) CAD diagnosis; 3) pregnancy; 4) inability to provide informed consent to participate in the study; 5) bedridden status; 6) residing in a nursing home or prison. A total of 4,040 participants, 21.45% of the eligible population, participated in stage 1.

Stage 2, involving enhanced diagnostics, was intended for participants scoring 5% or higher on the SCORE scale. This stage was carried out at the Independent Public Complex of Healthcare Facilities in Janów Lubelski. During stage 2, participants underwent a 2nd medical visit, where further testing could be recommended based on enhanced laboratory diagnostics. The aim of this stage included diagnosing the patient, discussing test results with the participant, and referring them for specialized treatment or to a health promotion specialist for better lifestyle management. Of the 3,046 study participants, 168 with diabetes and 221 with a history of cardiovascular events (heart attack or stroke) were excluded. Ultimately, 2,657 respondents were included in the analysis. For the purpose of this study, respondents' results obtained in stage 2 were analyzed.

The study was approved by the Bioethics Committee of the Medical University of Lublin (decision No. KE-0254/112/2014) and conducted in accordance with the Declaration of Helsinki. All participants provided written informed consent.

Anthropometric measurements

Anthropometric measurements of body weight and height were obtained for all respondents. Height was measured using an altimeter to the nearest 0.1 cm, and body weight – without shoes or outer clothing – was measured using a platform scale to the nearest 0.1 kg. Body mass index (BMI) was calculated for each participant by dividing body weight in kilograms (kg) by height in meters squared (kg/m^2).[26]

Blood sampling and laboratory tests

At the blood sample collection point of the Independent Public Complex of Health Care Facility in Janów Lubelski, participants had their blood drawn from the ulnar vein after an overnight fast between 7:00 AM and 9:00 AM. The blood samples were immediately sent to the laboratory for analysis. Serum samples were collected in serum separator tubes (granules) containing a clot activator. Plasma was obtained by centrifugation at 3,000 rpm for 10 min. The serum was used for lipid profile analysis (total cholesterol, triglycerides (TG) and high-density lipoprotein cholesterol (HDL-C)), and serum glucose (FBG) using standard laboratory methods. Cholesterol was calculated using the Friedewald equation when TG levels were <400 mg/dL.[27]

Physiological measurements

Participants' systolic (SBP) and diastolic (DBP) blood pressure were measured twice. Blood pressure was measured on the left arm using a digital blood pressure monitor. The 1st measurement was taken after a rest period of at least 5 min, and the 2nd measurement was taken 15 min after the first. The mean value of these 2 measurements was used for analysis. An additional measurement was taken after another 15 min if the first 2 measurements differed by more than 5 mm Hg. The mean value of these three measurements was then used for data analysis.[28]

TyG index and METS-IR index

The anthropometric measurements and biochemical results were used to calculate the METS-IR index and the TyG index for the respondents. The TyG index was calculated using

$$\mathrm{Ln}\ [\mathrm{TG}\ (\mathrm{mg/dL}) \times \mathrm{FBG}\ (\mathrm{mg/dL})/2],$$[24]

and the METS-IR index was calculated using

$$\mathrm{Ln}\ [2 \times \mathrm{FBG}\ (\mathrm{mg/dL}) + \mathrm{TG}\ (\mathrm{mg/dL})] \times \mathrm{BMI}\ (\mathrm{kg/m^2}) / \mathrm{Ln}\ [\mathrm{HDL\text{-}C}\ (\mathrm{mg/dL})].$$[14,29]

Other variables

A standard questionnaire was used to collect information on age, gender, place of residence, marital status, education, smoking status, frequency of alcohol consumption, and household maintenance.

Two categories of smoking status were identified: non-smoker (those who had never smoked or had stopped smoking at least 1 month before the study) and smoker (those who smoked at least 1 cigarette per day or had smoked a cigarette within the previous month).

Participants were also asked about their alcohol consumption in the year prior to the study. They were also asked how frequently they consumed 1–2 standard doses of alcohol, with 1 dose equivalent to 10 g of pure ethyl alcohol. The respondent could select from the following options: I do not drink alcohol (no alcohol consumption), less than once a month, once a month to once a week, and more than once a week.

Statistical analyses

Numerical variables were presented as mean with standard deviation (SD) and median with interquartile range (Q1–Q3). The distribution of TyG and METS-IR between groups was compared using the Mann–Whitney test or Kruskal–Wallis test. Categorical variables were described by percentages, and the relationship between numerical variables was assessed with Pearson's correlation. In addition, multivariable linear regression with backward elimination ($p < 0.1$) was used to identify significant predictors of TyG and METS-IR. Due to the strong relationship between SBP and DBP, only SBP was included in the multivariable analysis. The results of linear regression were presented as a coefficient (b) with standard error (SE). The coefficient of determination (R^2) was used to describe the goodness-of-fit of the linear regression models. Furthermore, the assumptions of linear regression were checked through plots (linearity (residuals vs fitted), normality of residuals (Q–Q plot), and homogeneity of variance (scale location plot)), whereas the absence of influential observations was confirmed using Cook's distance and the absence of multicollinearity was confirmed with variance inflation factor (VIF). Statistical analyses were performed using IBM SPSS Statistics for Windows, v. 27.0 (IBM Corp., Armonk, USA) and R language (R Core Team (2021); R Foundation for Statistical Computing, Vienna, Austria). P-values < 0.05 were considered statistically significant.

Results

General characteristics of participants

Table 1 shows the characteristics of the study group (n = 2,657). The mean age of the study group was 52.7 (±7.99) years. The majority of participants were women (58.4%, n = 1,553), residing in rural areas (66.7%, n = 1,772), with vocational education (38.1%, n = 1,012), and married (88.1%, n = 2,343). The mean TyG index score in the study group was 8.65 (±0.58) and the mean METS-IR index score was 41.45 (±9.02).

Relationship between sociodemographic and health variables and levels of the TyG index and METS-IR index

Table 2 shows the relationship between selected sociodemographic and health variables and the TyG index and METS-IR index levels. The TyG index level was positively associated with age ($r = 0.114$, $p < 0.001$), BMI ($r = 0.331$, $p < 0.001$) and blood pressure: SBP ($r = 0.221$, $p < 0.001$), DBP ($r = 0.222$, $p < 0.001$). In addition, a significant increase in the TyG index was observed

Table 1. Baseline demographics and clinical characteristics

Variable		Study group
Demographic and social data		
Age [years][b]		52.7 ±7.99
Sex[a]	female	1,553 (58.4)
	male	1,104 (41.6)
Place of residence[a]	rural	1,772 (66.7)
	urban	885 (33.3)
Education[a]	primary	292 (11)
	vocational	1,012 (38.1)
	secondary	868 (32.7)
	university	485 (18.3)
Marital status	married	2,343 (88.1)
	single	185 (7)
	widow/widower	129 (4.9)
Living alone	no	2,530 (95.2)
	yes	127 (4.8)
Health data		
Smoking status[a]	smoker	413 (15.5)
	former-smoker	558 (21)
	never-smoker	1,686 (63.5)
Alcohol consumption[a]	no or less than once a month	2,374 (89.3)
	between once a month and once a week	157 (5.9)
	more than once a week	126 (4.7)
Clinical data		
BMI [kg/m^2][b]		28.9 ±4.84
Total cholesterol [mg/dL][b]		223.6 ±54.03
LDL-C [mg/dL][b]		128.3 ±59.8
HDL-C [mg/dL][b]		60.7 ±21.17
Triglyceride [mg/dL][c]		114.7 (80.4–165.5)
Glucose [mg/dL][c]		94 (87–106)
Blood pressure	SBP [mm Hg][b]	140 ±19.08
	DBP [mm Hg][b]	85.7 ±11.39
TyG[b]		8.65 ±0.58
METS-IR[b]		41.45 ±9.02

Data are presented as: [a]n (%); [b]mean ±SD; [c]median (Q1–Q3); BMI – body mass index; LDL-C – low-density lipoprotein; HDL-C – high-density lipoprotein; SBP – systolic blood pressure; DBP – diastolic blood pressure; TyG – triglyceride-glucose index; METS-IR – metabolic score for insulin resistance index; SD – standard deviation.

in men, participants with primary and vocational education compared to those with higher education ($p \leq 0.01$), as well as in smokers or former smokers compared to never-smokers ($p < 0.001$). Similarly, higher values of the TyG index were associated with more frequent alcohol consumption ($p < 0.001$).

The METS-IR index level was positively associated with age ($r = 0.158$, $p < 0.001$) and blood pressure: SBP ($r = 0.256$, $p < 0.001$), DBP ($r = 0.234$, $p < 0.001$). Men had significantly higher values of the METS-IR index, and as educational level increased, the value of this index decreased. Former smokers had significantly higher values of the METS-IR index compared to smokers or never-smokers ($p < 0.01$, for comparisons). In addition, respondents who reported consuming 1–2 standard doses of alcohol between once a week or once a month had higher METS-IR values compared to those who reported consuming this amount of alcohol less frequently or not at all ($p = 0.008$).

Multivariable association between Tyg index, METS-IR index, and socioeconomic and health factors

Table 3 shows the significant predictors of the TyG index and METS-IR obtained by linear regression. Age, male

Table 2. Relation between selected sociodemographic and health variables and the TyG index and METS-IR index levels

Variable		TyG	p-value	METS-IR	p-value
Demographic and social data					
Sex	female (n = 1,553)	8.54 ±0.52 8.52 (8.16–8.90)	<0.001[a]	40.45 ±9.06 39.42 (33.49–43.12)	<0.001[a]
	male (n = 1,104)	8.8 ±0.64 8.8 (8.34–9.20)		42.87 ±8.79 42.46 (36.46–47.99)	
Place of residence	rural (n = 1,772)	8.65 ±0.6 8.60 (2.88–9.04)	0.675[a]	41.84 ±9.05 41.30 (35.26–47.41)	<0.001[a]
	urban (n = 885)	8.65 ±0.56 8.64 (8.25–9.00)		40.67 ±8.92 39.50 (24.36–45.85)	
Education	primary (n = 292)	8.72 ±0.58 8.75 (8.29–9.07)	0.01[b]	43.5 ±9.06 43.08 (37.28–49.36)	<0.001[b]
	vocational (n = 1,012)	8.68 ±0.6 8.84 (8.24–9.06)		41.82 ±8.88 41.33 (35.29–47.14)	
	secondary (n = 868)	8.64 ±0.57 8.60 (8.23–9.01)		41.52 ±9.13 40.98 (34.92–47.11)	
	university (n = 485)	8.57 ±0.56 8.53 (8.19–8.93)		39.32 ±8.71 38.04 (32.85–44.52)	
Marital status	married (n = 243)	8.65 ±0.58 8.62 (8.24–9.03)	0.182[b]	41.55 ±8.92 41.00 (35.15–47.03)	0.100[b]
	single (n = 185)	8.69 ±0.68 8.66 (8.17–9.11)		40.56 ±10.51 39.53 (31.95–48.50)	
	widow/widower (n = 129)	8.56 ±0.47 8.53 (8.23–8.82)		40.96 ±8.53 39.86 (34.99–46.01)	
Living alone	no (n = 2,530)	8.65 ±0.58 8.62 (8.23–9.02)	0.589[a]	41.42 ±8.97 40.71 (34.93–46.92)	0.409[a]
	yes (n = 127)	8.68 ±0.61 8.63 (8.23–9.06)		42.16 ±10.04 41.60 (34.58– 48.63)	
Health data					
Smoking status	smoker (n = 413)	8.8 ±0.66 8.76 (8.30–9.17)	<0.001[b]	40.81 ±10.2 40.27 (32.97–47.08)	0.001[b]
	former-smoker (n = 558)	8.73 ±0.59 8.73 (8.31–9.1)		42.59 ±8.78 41.77 (36.31–47.93)	
	never-smoker (n = 1,686)	8.59 ±0.55 8.55 (8.19–8.95)		41.23 ±8.76 40.43 (34.94–46.76)	
Alcohol consumption	no or less than once a month (n = 2,374)	8.62 ±0.57 8.58 (8.21–8.99)	<0.001[b]	41.33 ±9.05 40.46 (34.82–46.89)	0.008[b]
	between once a month and once a week (n = 157)	8.89 ±0.63 8.84 (4.46–9.24)		43.37 ±9.00 43.54 (37.25–49.01)	
	more than once a week (n = 126)	8.91 ±0.64 8.89 (8.36–9.40)		41.37 ±8.21 41.79 (34.94–46.72)	

TyG – triglyceride-glucose index; METS-IR – metabolic score for insulin resistance index; BMI – body mass index; data are presented as mean with standard deviation (SD) and median with interquartile range (Q1–Q3). Statistical significance tested with: [a] Mann-Whitney test, [b] Kruskal-Wallis test.

gender, smoking status, and SBP were significantly associated with both TyG and METS-IR. Age and SBP showed a positive relationship with surrogate markers of IR. Moreover, men had higher mean values of both the TyG index and METS-IR index compared to women. Former smokers and never-smokers had lower TyG index values compared to current smokers. However, for METS-IR, participants who were former smokers had higher values than current smokers.

In addition, participants who reported being non-drinkers or consuming alcohol less than once a month had lower TyG index values compared to those who drank alcohol more than once a week. There was also a positive association between BMI and the TyG index. Finally, participants with a university education had lower METS-IR values compared to those with only a primary education level. Based on plots, Cook's distance, and the VIF index, there were no violations of the assumptions of the linear regression model (Supplementary Fig. 1, Supplementary Fig. 2 and Supplementary Table 1).

Discussion

The TyG index and METS-IR index were found to be dependent on sociodemographic and health factors in the local community under study, which is characterized by high social deprivation and increased cardiovascular risk as measured using the SCORE scale. According to our results, the mean TyG index value among residents of the Janów district in eastern Poland was 8.65 (±0.58), whereas the mean METS-IR index value was 41.45 (±9.02). A similar TyG index value was obtained by Mirr et al.[30] in a group without diabetes and increased fasting glycemia, whereas the METS-IR index in their study group was lower (38.2 ±8.6) than in our study. Li et al.[31] described slightly different mean TyG index and METS-IR index values in a study conducted in rural areas of China, which were 6.91 and 40.18, respectively. Variations in surrogate markers of IR between our results and earlier studies can be explained by the distinctive characteristics of the Polish population, particularly the high cardiovascular risk determined with SCORE in our study group. This is supported by the findings of Wang et al.,[32] who observed that an increase in the METS-IR index level was independently associated with a higher prevalence of coronary artery calcification (CAC). Insulin resistance is strongly related to lifestyle factors such as smoking, alcohol consumption, a high-calorie diet, and physical inactivity. In turn, lifestyle and health-related attitudes are determined by and are related to social, economic and demographic factors. Consequently, the search for associations between IR and sociodemographic variables may contribute to better disease prevention planning, particularly for CVD.

Insulin resistance and aging are closely associated due to factors such as loss of lean body mass, increase in visceral adipose tissue and decline in sex hormone levels.[33]

Table 3. Significant predictors of the TyG index and METS-IS index levels

Variable		b	SE	p-value	R^2
TyG					
Demographic and social data	age	0.003	0.001	0.01	0.19
Sex (reference category: female)	male	0.17	0.023	<0.001	
Health and clinical data					
Smoking status (reference category: smoker)	former-smoker	–0.12	0.034	<0.001	
	never-smoker	–0.210	0.03	<0.001	
Alcohol consumption (reference category: more than once a week)	between once a month and once a week	–0.025	0.063	0.70	
	no or less than once a month	–0.16	0.05	0.002	
SBP		0.003	0.009	<0.001	
BMI		0.037	0.002	<0.001	
METS-IR					
Demographic and social data	age	0.102	0.022	<0.001	0.10
Sex (reference category: female)	male	1.488	0.365	<0.001	
Education (reference category: primary)	vocational	–0.929	0.585	0.11	
	secondary	–0.728	0.595	0.22	
	university	–1.877	0.674	0.005	
Health and clinical data					
Smoking status (reference category: smoker)	former-smoker	1.708	0.563	0.003	
	never-smoker	0.625	0.486	0.199	
SBP		0.099	0.009	<0.001	

TyG – triglyceride-glucose index; METS-IR – metabolic score for insulin resistance index; SBP – systolic blood pressure; BMI – body mass index; b – regression coefficients; SE – standard error; R^2 – coefficient of determination.

Higher METS-IR index values in older adults were observed in the SouthKorean population studied by Wang et al.,[32] whereas higher TyG index values were observed in the American population study by Sun et al.[34]

In our sample, men had significantly higher IR values than women. This is consistent with findings from a Chinese cohort[35] and a Japanese cohort,[36] where women showed lower TyG index values and METS-IR index values, respectively. The protective role of estrogen in the development of IR may account for these differences in surrogate markers of IR between men and women.[37] However, it must be noted that Nakagomi et al.[38] hypothesized that changes in sex hormone levels and body composition related to menopause may diminish the predictive ability of female sex, making it similar to that of male sex, but this hypothesis needs confirmation.

In our study, lower education levels were associated with higher levels of METS-IR index and TyG index in univariate models, although this relationship was observed only for METS-IR in the multivariable analysis. Similar results to ours were obtained by Bukhari[39] and Almubark et al.[40] The correlation between education and IR and diabetes risk was also validated in an extensive European study.[41]

Both the TyG index and METS-IR index were found to be related to smoking. Former smokers and never-smokers had lower TyG index values than smokers, and former smokers had higher METS-IR index values than smokers. Similar results were obtained by Ferreira et al.[42] and Li et al.[43] Experimental research indicates that smoking can induce and worsen IR through mechanisms involving catecholamines and other anti-insulin hormones, thus disrupting glucose and lipid metabolism and exacerbating vascular endothelial cell dysfunction.[44] Smokers also exhibit relatively low insulin sensitivity compared to non-smokers. It should be noted that insulin sensitivity improves within 1–2 weeks after quitting smoking, although it never returns to normal values.[45] Observations were similar regarding alcohol consumption. Surrogate markers of IR were higher in those who drank alcohol more frequently, although this trend was seen only for the TyG index in the multivariable analysis. The relationship between IR and alcohol consumption was also observed by Bermudez et al.[46] However, in a meta-analysis of 47 studies, Bendsen et al.[47] found that beer intake >500 mL/day is positively associated with abdominal obesity, which plays a key role in the development of IR.

A significant correlation has been observed in certain prospective and cross-sectional studies between the TyG index and BMI[48] and the METS-IR index and the TyG index and the risk of hypertension.[49,50] Our study revealed the same relationship. The mechanism explaining the correlation between surrogate markers of IR and hypertension could be attributed to overstimulation of the sympathetic nervous system, which increases cardiac output and peripheral vascular resistance, thereby raising blood pressure.[51] In addition, IR stimulates the activity of the renin–angiotensin–aldosterone system by increasing tubular Na^+ reabsorption,[52] which can cause a rapid rise in blood pressure. In contrast, a higher BMI indicates the presence of excess body fat and is associated with elevated levels of free fatty acids and inflammatory mediators such as interleukin 6 (IL-6) and tumor necrosis factor alpha (TNF-α), which are closely related to IR because they impair lipid homeostasis and lead to inflammation.[53]

Limitations

The study had several limitations. First, the cross-sectional study design did not allow us to address the causality of the observed relationships. Second, because the respondents had an increased cardiovascular risk, presumably due to risk factors such as poor diet and lack of physical activity being more prevalent in our study group, the TyG index and METS-IR index values may be overestimated compared to the general population. Third, we used surrogate markers of IR instead of including HOMA-IR, which has been more widely used in previous studies. However, previous studies comparing multiple indices to assess IR levels have found similar effects when using HOMA-IR, TyG, and METS-IR indices.[14,54] Lastly, because every study participant was Polish, it is unclear whether our findings apply to other ethnic groups. Future research examining the relationship between SES and IR should use a nationally representative sample and clarify the mechanisms linking low SES to IR when behavioral-health variables are considered. Nonetheless, our research undoubtedly contributes to understanding the relationship between sociodemographic and health factors and IR in a local community with increased cardiovascular risk and high deprivation. These findings may be useful in the development of primary and secondary CVD prevention strategies.

From a practical standpoint, this work has implications for healthcare professionals and future researchers. The study results may be of key importance for healthcare professionals such as physicians, nurses, dieticians, and others working with low-income, undereducated or at-risk patients for diabetes and CVD. Healthcare workers, particularly those in primary care, can monitor patients undergoing treatment or seeking to adopt a healthier lifestyle over time by using surrogate IR markers to quickly and affordably determine the patient's risk of IR. Such assessments should be routine, especially in communities with low SES. If significant screening deviations occur, the patient may be referred for more expensive, in-depth diagnostic procedures.

Conclusions

The study results show a significant relationship between surrogate markers of IR and sociodemographic and health-related variables. The TyG index and METS-IR index values were found to increase with age and SBP. In addition, these indices showed higher values in men, people with lower education levels, current or former smokers, and those who consume alcohol more frequently. Furthermore, the TyG index was positively associated with BMI. Low-cost surrogate markers of IR, such as the TyG index or METS-IR index, may find use in primary healthcare for assessing IR, potentially facilitating early prevention of CVD.

Supplementary data

The Supplementary materials are available at https://doi.org/10.5281/zenodo.12664545. The package includes the following files:

Supplementary Table 1. The values of VIF for independent predictors for TyG and METS-IR.

Supplementary Fig. 1. Testing the assumption of multivariable linear model for independent predictors for TyG index.

Supplementary Fig. 2. Testing the assumption of multivariable linear model for independent predictors for METS-IR index.

Data availability

The datasets generated and/or analyzed during the current study are available from the corresponding author on reasonable request.

Consent for publication

All authors have read and approved the published version of the manuscript.

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