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Dietary and lifestyle patterns identified through reduced rank regression and their association with insulin-related disorders: a prospective analysis from the Tehran Lipid and Glucose Study

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Abstract

Background Since foods are consumed in combinations that also interact with other lifestyle variables such as body mass index(BMI) and physical activity, it is difficult to separate the role of single foods or a lifestyle variable alone in predicting the risk of chronic diseases such as metabolic disorders. Therefore, a suitable way to examine the combined effect of food consumption and its interaction with other lifestyle variables is to derive dietary patterns and lifestyle patterns using appropriate statistical methods. This study aimed to derive two dietary and lifestyle patterns related to hyperinsulinemia and insulin resistance(IR) using reduced rank regression(RRR) analysis.

Methods The current study was conducted on 1063 individuals aged ≥ 25 years old of the Tehran Lipid and Glucose Study who have complete data on fasting blood sugar, plasma insulin, anthropometric variables, and nutritional intakes. Dietary intakes were collected using a food frequency questionnaire. Dietary and lifestyle patterns were identified via RRR analysis, using 34 food groups, BMI, smoking, and physical activity as predictor variables, and fasting serum insulin and HOMA-IR as response biomarkers.

Results RRR derived a dietary pattern with a higher intake of processed meat, doogh, pickles, lemon juices, fish, and a lower intake of starchy vegetables, garlic and onion, dried fruits, nuts, red meat, dairy products, and coffee as predictive variables for IR and hyperinsulinemia. Also, RRR derived a lifestyle pattern based on the above-mentioned dietary pattern and high BMI as response variables. In the final adjusted model of cross-sectional analysis, the odds of hyperinsulinemia(OR:1.23,95%CI:1.08–1.41,P_{trend}=0.002) and IR(OR:1.52,95%CI:1.25–1.86,P_{trend}<0.001) were

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elevated with increasing each quartile of RRR-derived dietary pattern score. Also, a higher adherence to RRR-derived lifestyle pattern was associated with higher odds of hyperinsulinemia(OR:2.49,95%CI:2.14–2.88,P_{trend}<0.001) and IR(OR:3.20,95%CI:2.50–4.10,P_{trend}<0.001). Moreover, after three years of follow-up, the risk of hyperinsulinemia(OR:1.30, 95%CI:1.08–1.56,P_{trend}=0.006) and IR(OR:1.26,95%CI:1.01–1.58,P_{trend}=0.037) incidence were increased per each quartile increase of the RRR-derived lifestyle pattern.

Conclusions Our findings suggested that a dietary pattern and lifestyle with elevated BMI level, higher consumption of processed meat, doogh, pickles, lemon juices, and fish, and lower consumption of starchy vegetables, garlic and onion, dried fruits, nuts, red meat, dairy products, coffee may be associated with a higher risk of hyperinsulinemia and IR. It is suggested that further studies with a larger sample size and more extended follow-up duration, especially in other populations with different lifestyles and food habits be performed to confirm the findings of the current study.

Keywords Reduced rank regression, Diet, Lifestyle, Hyperinsulinemia, Insulin resistance

Background

Insulin homeostasis-related disorders, such as hyperinsulinemia and insulin resistance (IR), are significant predictors of chronic conditions like type 2 diabetes (T2DM) and metabolic syndrome (MetS) [1]. Their prevalence has increased in the last decade, with IR affecting 16 to 47% of the global population [1]. Lifestyle factors like diet, physical activity, body mass index (BMI), and smoking can contribute to the pathogenesis of these disorders [2–4].

Considering that, most of the meals consumed consist of a wide variety of foods with a mixture of nutrients; therefore, it is preferable to use diets instead of a single food or nutrient to examine the relationship between food and chronic disease such as insulin-related disorders. According to the results of observational studies, higher adherence to a Healthy diet in the style of the Mediterranean diet pattern or DASH diet, characterized by higher consumption of whole grains, fish, fruits, vegetables, nuts, and legumes and lower intake of refined grain, saturated fat, sodium, and simple sugar, can be associated with lower levels of glucose and hemoglobin A1C [5, 6]. In addition to diet, other important factors related to lifestyle, including BMI and PA, significantly impact the development or control of IR and hyperinsulinemia [2–4]. Since diet interacts with other lifestyle variables such as BMI and physical activity in predicting the risk of metabolic disorders, therefore, it is better to measure the combined role of dietary pattern with other lifestyle components as a single variable in predicting insulin disorders.

Two main approaches have been used for analyzing dietary and lifestyle patterns in epidemiological studies: the a priori method, which forms a pattern using existing knowledge, and the posteriori approach, which derives patterns based on correlations between different items using statistical methods [7]. However, these methods may not match the current knowledge of the outcome, which is the main limitation of using the latter [7]. To overcome these limitations, a new method called reduced rank regression (RRR) was introduced by Hoffmann et al. [8], which uses nutrients or biomarkers associated with a specific outcome to identify patterns. Also, in contrast with principal components analysis that provides a linear combination (factor) of dietary intake data that maximally explains the variation in food consumption, the RRR approach identifies factors from dietary intake data that maximize the explained variation in the intermediate indices that are supposed to be associated with a specific health outcome [8, 9]. Indeed, RRR is a posteriori method, using present knowledge to identify a pattern that explains higher variation in biomarker levels [10]. By combining the two previous approaches, RRR has taken advantage of both and removed their limitations.

Although, to the best of our knowledge, no study has examined the association of dietary and lifestyle patterns derived from the RRR approach with the risk of IR and hyperinsulinemia, limited studies have explored the relationship between dietary patterns derived from RRR methods and other insulin-related disorders risk, such as T2DM [11, 12] and MetS [13]. It suggested that a diet rich in poultry, coffee, whole grains, condiments, and potatoes was associated with higher odds of T2DM [12]. However, Jacobs et al. showed that a diet rich in whole grains, yellow and green vegetables, fruit, and dairy products and poor in processed and red meat, sweetened beverages, and white rice was related to a lower risk of T2D [11]. Furthermore, An unhealthy diet characterized by a lower intake of vegetables, bread, millet, mushrooms, and fruit and a higher in pickles, rice, beef, and red meat can be positively related to the risk of MetS [13].

In this study, fasting serum insulin (FSI) level and HOMA-IR were considered as response biomarkers. Previous studies have shown that HOMA-IR offers acceptable performance compared to the hyperinsulinemic-euglycemic clamp technique as the “golden standard” for measuring IR [14]. Given this fact and the limited data on extracting dietary and lifestyle patterns against these two biomarkers using the RRR method and also the lack of evidence on investigating their relationship with the insulin-related disorders risk, in this study, we aimed to use the RRR method to identify dietary and lifestyle patterns related to IR and hyperinsulinemia in Tehranian adults.

Methods

Study population

This work is performed among participants of the Tehran Lipid and Glucose Study (TLGS), a population-based prospective study that was initiated in 1999 to determine non-communicable disease risk factors (NCDs) among a representative urban population in Tehran, including 15,005 participants aged ≥ 3 years old. The TLGS data were collected at 3-year intervals. Details of TLGS have already been reported [15].

In the third survey of the TLGS (2006–08), out of 12,523 participants, 3,568 were randomly selected for dietary assessment. For the present study, 1286 participants from both sexes, aged ≥ 25 years old who have complete fasting blood sugar (FBS), insulin, anthropometric, and nutritional data were selected. We excluded people who met at least one of these criteria: history of heart attack, stroke, or cancer ($n = 18$), diabetics ($n = 105$), people with daily energy intake outside the range of 800–4200 kcal per day in men and 500–3500 kcal per day in women ($n = 80$) and pregnant or lactating women ($n = 23$). Some individuals were in more than one group. Ultimately, 1,063 participants remained for the cross-sectional analysis. The dietary and lifestyle patterns were derived using the data from these 1,063 participants. For the prospective analysis (follow-up of individuals from survey 3 to survey 4 of TLGS), in addition to subjects excluded for the above-mentioned criteria, we exclude the participants with hyperinsulinemia ($n = 322$) and IR ($n = 124$) from the baseline. Therefore, the final analyses were conducted to explore the relationship between the RRR-derived dietary and lifestyle patterns with hyperinsulinemia and IR in 741 and 939 participants, respectively.

Dietary intake assessment

The participant's nutritional information in the current study was obtained by experienced and trained interviewers, through a valid and reproducible semi-quantitative food frequency questionnaire (FFQ) with 168 food items [16, 17]. Individuals were asked to report the frequency of their consumption for each questionnaire item over the past year by day, week, month, or year. The United States Department of Agriculture (USDA) food composition table was utilized to determine the amount of energy and nutrients received. Also, the Iranian food composition table was utilized for local foods that are specific to Iran and are not available in the USDA composition table. For compound foods (such as pizza), the nutrients were calculated based on the total nutrients of the food constituents.

Assessment of demographic and anthropometric characteristics and physical activity (PA)

Information on age, sex, medical history, medication use, and smoking habits was collected by a trained interviewer using a pre-tested questionnaire. Weight, height, and BMI were measured using standard methods detailed in previous studies [18]. A modifiable Physical Activity Questionnaire (MAQ) that has been previously updated and validated among the Iranian population was used to record PA data [19]. Collected data were reported as metabolic equivalent per hour in Week (MET-h/week).

Biochemical assessment

Blood samples were collected from all subjects after 12 to 14 h of overnight fasting between 7:00 and 9:00 in the morning and immediately centrifuged for 30–45 min. All samples were analyzed in the TLGS research laboratory using Selectra 2 automatic analyzer (Vital Scientific, Spankeren, Netherlands). Glucose was measured by the enzymatic calorimetry method with glucose oxidase technology and using glucose kits (Pars Azmoun Company, Iran). Both Inter- and intra-assay coefficients of variation for glucose were 2.2%. Insulin was measured by electrochemiluminescence immunoassay (ECLIA) using Roche diagnostic kits and Roche / Hitachi Cobas e-411 analyzer (Gmbh, Manhim, Germany). Inter- and intra-assay coefficient variations for insulin were 1.2 and 3.5, respectively.

Outcome ascertainment

Insulin resistance (IR) determined by the homeostatic model assessment for insulin resistance (HOMA-IR) according to the following formula [20].

HOMA-IR = [FBS (mmol / L) × Insulin (μU / mL) / 22.5] (HOMA-IR ≥ 3.2 were determined as IR criteria).

Hyperinsulinemia FSI concentrations higher than 9.16 and 11.13 were considered hyperinsulinemic states in men and women, respectively [20].

Reduced rank regression (RRR)

Dietary and lifestyle patterns in the present study were determined using the RRR method described by Hoffman et al. [8]. In RRR, the dietary data is used to create a set of dietary pattern variables, called "reduced rank predictors", which are linear combinations of the original food variables. These predictors are created by identifying the patterns of food intake that are most strongly associated with the outcome based on prior knowledge, such as scientific evidence or previous studies. The RRR method then uses these reduced rank predictors as independent variables in a regression model, with the outcome as the dependent variable. The resulting regression coefficients for each predictor indicate the strength of the association between that predictor and the outcome.

Dietary and lifestyle patterns analysis

In this study, FSI level and HOMA-IR were considered as response biomarkers. Previous studies have shown that HOMA-IR offers acceptable performance compared to the hyperinsulinemic-euglycemic clamp technique as the "golden standard" for measuring IR [14]. According to the existing research background, all food groups and subgroups that were previously shown to be associated with insulin-related disorders such as IR, hyperinsulinemia, diabetes, and metabolic syndrome (especially in Iranian studies) were extracted. The intakes of these food groups were calculated as a portion per 1000 kcal intake.

The food items that were considered in our analysis to derive the dietary pattern were included red meat, processed meat, chicken, fish, eggs, organ meats, low-fat dairy, high-fat dairy, doogh, refined grains, whole grains, legumes, nuts, dried fruits, fruit juices and other fruits, lemon juice, starchy vegetables, tomatoes, pickles, leafy vegetables, garlic and onions, other vegetables, French fries, solid animal oil, liquid oil, butter, mayonnaise, olives, sweet snacks, industrialized beverages, tea, salt, and coffee. In the next step, in addition to the food components mentioned above, BMI, physical activity, and smoking as components related to lifestyle were included in the analysis.

FSI and HOMA-IR values were converted to Z-score before analysis. A dominant dietary pattern was derived via RRR analysis. The dietary patterns extracted by RRR are similar to the scores obtained from the factor analysis (FA). Each participant receives a score that represents the sum of the food intake and lifestyle variables that are weighted with the factor loadings and shows how well their intake or lifestyle corresponds to the extracted pattern [21]. Dietary factor loadings represent the strength of the relationship between a specific food or nutrient and a dietary pattern. A high factor loading indicates that a specific food or nutrient has a strong association with a dietary pattern, while a low factor loading indicates a weak relationship. Finally, foods and lifestyle-related factors with absolute factor loadings > 0.2 were used to form the dietary and lifestyle patterns.

Table 1 Factor loadings* explained variation of dietary and lifestyle pattern components related to insulin concentration and HOMA-IR extracted using RRR among the participants of the third survey of TLGS (2006–2008)

	Factor loadings	
	Dietary pattern	**Lifestyle pattern**
Positive association		
Body mass index		0.54
Processed meat	0.20	-
Fish	0.39	0.20
Doogh	0.43	0.21
Lemon juices	0.55	0.31
Pickles	0.21	0.20
Negative association		
Starchy vegetables	-0.26	-0.31
Garlic and onion	-0.39	-0.38
Dried fruits	-0.22	-
Nuts	-0.24	-0.43
Red meat	-0.28	-0.20
High-fat dairy	-0.20	-0.31
Low-fat dairy	-	-0.25
Coffee	-0.55	-0.65
Explained variation in predictors	0.028	0.029
Explained variation in responses		
Fasting insulin	0.062	0.247
HOMA-IR	0.058	0.245
Cumulative average	0.060	0.246

*Food groups with factor loadings <|0.20| not shown

Doogh: a dairy-derived beverage made from yogurt, which has a relatively high salt content

Factor loadings represent the strength of the relationship between a specific food or nutrient and a dietary pattern. A high factor loading indicates that a specific food or nutrient has a strong association with a dietary pattern, while a low factor loading indicates a weak relationship

Abbreviations: HOMA-IR: homeostatic model assessment for insulin resistance

Statistical analysis

Statistical analysis of data was performed using Stata software (version 14.2). The data normality was assessed by histogram chart and Kolmogorov-Smirnov test. Demographic variables were presented as mean ± standard deviation (SD) or median (IQR) for quantitative variables and as percentages for qualitative variables. Participants were categorized into quartiles according to the extracted diet and lifestyle patterns. Chi-square and linear regression tests were utilized to evaluate the P for trend of baseline characteristics and dietary intakes of individuals across quartiles of lifestyle patterns. Multivariable logistic regression analysis was utilized to assess the relationship between the derived dietary and lifestyle patterns and odds of hyperinsulinemia and IR, adjusting for age, sex, PA, smoking status, and energy intake. BMI was adjusted only for extracted dietary patterns. Odds ratio (OR) with 95% confidence interval (95% CI) was reported, and $P < 0.05$ was defined as statistically significant differences.

Results

The mean ± SD age and BMI of all eligible participants were 43.0 ± 12.2 and 27.4 ± 4.8, respectively. Table 1 displays the factor loadings and explains the variation of dietary and lifestyle pattern components. The dietary pattern included processed meat, fish, doogh, lemon juices, pickles, and leafy vegetables that had a positive association with FSI concentration and HOMA-IR value. Also, starchy vegetables, garlic and onion, dried fruits, nuts, red meat, high-fat dairy, and coffee were the other components of the RRR-extracted dietary pattern which had a negative association with the value of the above-mentioned biomarker. The extracted lifestyle pattern had seven components, including BMI, fish, doogh, lemon juice, pickles, and leafy vegetables, positively correlated with FSI concentration and HOMA-IR values, and six components, including starchy vegetables, garlic and onion, nuts, red meat, high-fat dairy, and coffee, negatively correlated with above-mentioned biomarkers. The variation in food groups explained by dietary and lifestyle patterns were 0.028 and 0.029, respectively. Explained variation in fasting insulin, HOMA-IR, and their cumulative average was 0.062, 0.058, and 0.060 for dietary patterns, and 0.247, 0.245, and 0.246 for lifestyle patterns, respectively.

Baseline characteristics of TLGS participants across quartiles of lifestyle patterns are presented in Table 2. Individuals in the top quartile of extracted lifestyle patterns significantly were more likely to be male and have higher weight and BMI compared to those in the lowest one. Also, the mean fasting serum insulin, FBS, and HOMA-IR were increased across quartiles of RRR-extracted lifestyle pattern. Moreover, participants in the fourth quartile of the lifestyle pattern had higher intake of carbohydrates and lower intake of fat compared to those in the lowest quartile. The trend of changes in other baseline characteristics of participants was not statistically significant according to the quartiles of the lifestyle pattern.

Table 3 shows the OR and 95% CI for the risk of hyperinsulinemia and IR per each quartile increase in the derived dietary and lifestyle patterns among study participants based on cross-sectional analysis. In survey three of TLGS, a higher adherence to RRR-derived dietary and lifestyle patterns was directly related to the odds of hyperinsulinemia and IR in crude models. After adjusting for possible confounding variables including age, sex, PA, smoking status, energy intake, and BMI, the odds of hyperinsulinemia (OR: 1.23, 95% CI: 1.08–1.41, P_{trend}= 0.002) and IR (OR: 1.52, 95% CI: 1.25–1.86, P_{trend} = < 0.001) were elevated with increasing each quartile in adherence to the RRR-derived dietary pattern. Also, in the final model, adjusted for age, sex, PA, smoking status, and energy intake, a higher score of the RRR-derived lifestyle pattern was associated with increased odds of hyperinsulinemia by about 2.5 times (OR: 2.49, 95% CI: 2.14–2.88, P_{trend} = < 0.001) and IR by more than 3 times (OR: 3.20, 95% CI: 2.50–4.10, P_{trend} = < 0.001) per each quartile.

The relationship of the derived dietary and lifestyle patterns with the odds of insulin-related disorders was also determined based on prospective design investigation after a 3-year follow-up. Table 4 presents the OR and 95% CI for the risk of hyperinsulinemia and IR incidence per each quartile increase in the RRR-derived dietary and lifestyle patterns in participants after three years of follow-up. After adjustment for confounding variables, increasing each quartile in adherence to the RRR-derived lifestyle pattern was associated with increased

Table 2 Baseline characteristics of participants of TLGS across quartiles of lifestyle pattern related to insulin and HOMA-IR extracted using reduced rank regression among the participants of the third survey of TLGS (2006–2008)*

Variables	Total population (*n* = 1063)	Quartiles of lifestyle pattern				*P*-trend†
		Q1(*n* = 266)	Q2(*n* = 266)	Q3(*n* = 266)	Q4(*n* = 265)	
Age, (year)	43.1 ± 12.3	44.2 ± 12.7	42.1 ± 12.0	43.3 ± 12.3	42.5 ± 12.2	0.053
Men, (%)	44.8	44.5	45.8	51.1	38.3	0.029
Weight (kg)	73.5 ± 14.0	70.8 ± 12.2	72.3 ± 13.7	73.4 ± 14.1	76.8 ± 15.2	< 0.001
Body mass index, kg/m^2	27.4 ± 4.9	26.7 ± 4.5	27.0 ± 4.8	27.6 ± 5.0	28.3 ± 5.2	< 0.001
Current smokers, (%)	13.5	15.8	14.4	12.1	11.7	0.468
Physical activity (MET-h/wk)	26.2 (10.9–55.2)	25.8 (10.7–54.2)	25.4 (9.9–51.7)	24.3 (11.4–63.4)	27.8 (10.7–54.5)	0.102
Fasting insulin(mU/mL)	8.9 ± 5.0	7.4 ± 3.5	8.4 ± 4.5	9.4 ± 5.2	10.5 ± 6.1	< 0.001
Fasting blood sugar (mg/dl)	87.2 ± 8.8	86.6 ± 8.7	87.0 ± 8.5	87.3 ± 9.2	88.0 ± 9.0	< 0.001
HOMA-IR	1.9 ± 1.2	1.60 ± 0.80	1.84 ± 1.08	2.07 ± 1.32	2.30 ± 1.38	< 0.001
Dietary intakes						
Energy intake, Kcal	2218 ± 681	2246 ± 644	2227 ± 652	2208 ± 674	2192 ± 753	0.158
Carbohydrate (% of energy)	57.9 ± 7.3	55.5 ± 7.3	57.5 ± 6.9	58.7 ± 7.2	59.8 ± 7.1	0.003
Protein (% of energy)	13.6 ± 2.4	13.7 ± 2.5	13.5 ± 2.1	13.8 ± 2.4	13.4 ± 2.4	0.339
Fat (% of energy)	31.1 ± 7.1	33.5 ± 7.0	31.8 ± 6.6	30.1 ± 6.8	29.2 ± 7.3	0.002

*Data are presented as the mean ± SD or as the median (interquartile range) for continuous variables and as percentages for categorical variables

†Chi-square and linear regression were used to test the trend of qualitative and quantitative variables across quartiles of the RRR-derived lifestyle pattern

Abbreviations: HOMA-IR: homeostatic model assessment for insulin resistance

Table 3 The odds ratio and 95% confidence interval for the risk of hyperinsulinemia and insulin resistance per each quartile increase in RRR-derived dietary and lifestyle patterns in study participants based on the third survey of TLGS (2006–2008)

	OR (95% CI)	*P*-value
Hyperinsulinemia (*n* = **1063**)		
Dietary pattern		
Crude model	1.39 (1.23–1.57)	< 0.001
Model 1*	1.36 (1.20–1.54)	< 0.001
Model 2†	1.36 (1.20–1.53)	< 0.001
Model 3‡	1.23 (1.08–1.41)	0.002
Lifestyle pattern		
Crude model	2.32 (2.02–2.80)	< 0.001
Model 1*	2.48 (2.14–2.88)	< 0.001
Model 2¶	2.49 (2.14–2.88)	< 0.001
Insulin Resistance (*n* = **1063**)		
Dietary pattern		
Crude model	1.70 (1.41–2.04)	< 0.001
Model 1*	1.68 (1.39–2.02)	< 0.001
Model 2†	1.68 (1.39–2.02)	< 0.001
Model 3‡	1.52 (1.25–1.86)	< 0.001
Lifestyle pattern		
Crude model	3.09 (2.43–3.94)	< 0.001
Model 1*	3.20 (2.50–4.10)	< 0.001
Model 2¶	3.20 (2.50–4.10)	< 0.001

Logistic regression models were used to obtain the odds ratio and 95% confidence interval for hyperinsulinemia and insulin resistance per each quartile increase in dietary and lifestyle patterns

*Adjusted for age and sex

†Adjusted for model 1 and physical activity, smoking (yes or no), and daily intake of energy‡Adjusted for model 2 and body mass index¶Adjusted for model 1 and daily intake of energy

Table 4 The odds ratio and 95% confidence interval for the risk of incidence of hyperinsulinemia and insulin resistance per each quartile increase in RRR-derived dietary and lifestyle patterns after three years of follow-up

	OR (95% CI)	*P*-value
Hyperinsulinemia (*n* = **741**)		
Dietary pattern		
Crude model	0.95 (0.80–1.13)	0.556
Model 1*	0.90 (0.75–1.07)	0.217
Model 2†	0.89 (0.75–1.07)	0.213
Model 3‡	0.87 (0.73–1.04)	0.129
Lifestyle pattern		
Crude model	1.26 (1.06–1.51)	0.010
Model 1*	1.29 (1.08–1.55)	0.006
Model 2¶	1.30 (1.08–1.56)	0.006
Insulin Resistance (*n* = **939**)		
Dietary pattern		
Crud model	1.16 (0.95–1.41)	0.138
Model 1*	1.16 (0.95–1.41)	0.144
Model 2†	1.14 (0.94–1.39)	0.191
Model 3‡	1.12 (0.91–1.36)	0.287
Lifestyle pattern		
Crud model	1.27 (1.02–1.58)	0.033
Model 1*	1.26 (1.02–1.58)	0.036
Model 2¶	1.26 (1.01–1.58)	0.037

Logistic regression models were used to obtain the odds ratio and 95% confidence interval for hyperinsulinemia and insulin resistance per each quartile increase in dietary and lifestyle patterns after three years of follow-up

*Adjusted for age and sex

†Adjusted for model 1 and physical activity, smoking (yes or no), and daily intake of energy‡Adjusted for model 2 and body mass index¶Adjusted for model 1 and daily intake of energy

risk of hyperinsulinemia (OR: 1.30, 95% CI: 1.08–1.56, P_{trend}=0.006) and IR (OR: 1.26, 95% CI: 1.01–1.58, P_{trend}= 0.037) incidence, However, no significant relationship was identified between the RRR-extracted dietary pattern and above-mentioned outcomes in participants after 3-year follow up.

Discussion

In the present study, we identified dietary pattern using the RRR method that was characterized by a higher intake of processed meat, doogh, pickles, lemon juices, Fish, and a lower intake of starchy vegetables, garlic and onion, dried fruits, nuts, red meat, dairy products, and coffee as predictive variables for IR and hyperinsulinemia. Also, a lifestyle pattern was derived from the RRR method that was defined by higher BMI level and the above-mentioned dietary characteristics. In the cross-sectional analysis, adherence to higher scores of the dietary and lifestyle patterns defined above was positively related to the risk of hyperinsulinemia and IR. Furthermore, in a prospective analysis, after three years of follow-up, a higher score of the above-mentioned RRR-derived lifestyle pattern was related to an increase in the risk of IR and hyperinsulinemia.

So far, several studies have shown that dietary patterns identified by the RRR method, related to the HOMA-IR index level, can predict the risk of T2DM [11, 12, 21, 22] and MetS [13]. Osei et al. showed that a dietary pattern derived from the RRR method, characterized by higher consumption of poultry, coffee and tea, whole grain, condiments, and potatoes was related to higher odds of T2DM [12]. However, another study suggested that a dietary pattern rich in whole grains, yellow and green vegetables, fruit, and dairy products and poor in processed and red meat, sweetened beverages, and white rice was associated with a lower risk of T2D [11]. Furthermore, The unhealthy dietary pattern with lower consumption of vegetables, bread, millet, mushrooms, and fruit and higher in pickles, rice, beef, and red meat may be directly linked to the risk of MetS [13]. A study on Urban Ghanaian Population suggested that the RRR method-identified dietary pattern, characterized by a higher intakes of plantain, cassava, and garden egg, and a low consumption of rice, juice, vegetable oil, eggs, chocolate drink, sweets, and red meat may increases the risk of T2DM [22]; the findings of this study, in line with our results, showed that the red meat is inversely correlated with mentioned biomarkers. Besides, McNaughton et al. demonstrated that a dietary pattern related to the HOMA-IR level may increase the risk of T2DM [21].

In the previous studies, PCA and FA were mostly used to extract dietary patterns in populations and examine their link with the risk of various outcomes [23, 24]. Indeed, in these approaches, the extracted patterns have been determined based on the correlation between food intakes, however, the derived patterns or some of their components in above mentioned approaches may not match the current knowledge related to the certain outcome [7], so these dietary patterns are not specified to a particular outcome. Also, according to PCA or factor analysis methods, the degree of correlation and specificity of extracted dietary patterns with the outcome is unclear and immeasurable. However, the RRR method identifies an outcome-specific dietary pattern and therefore the limitations of previous studies have been addressed by applying a new method of food pattern extraction [10]. In the present study, we extracted dietary patterns using the RRR method by considering the food groups that correlated with FSI or HOMA-IR levels. The extracted dietary pattern in our study is characterized by higher consumption of several food items including processed meat, fish, doogh, lemon juices, pickles, and leafy vegetables that have a positive association with FSI concentration and HOMA-IR value. Also, our derived dietary pattern included other components including starchy vegetables, garlic and onion, dried fruits, nuts, red meat, high-fat dairy, and coffee with a negative association with FSI concentration and HOMA-IR value.

Generally, the patterns derived in this study are consistent with present knowledge [25–28]. consistent with the findings of previous studies, in this work, the intake of processed meat is directly related to FSI and HOMA-IR levels [29]. In contrast, the intake of starchy vegetables, garlic, onions, nuts, and coffee is inversely related to the biomarkers mentioned earlier. However, some of the observed results need further explanation. In examining the association of diet with the risk of metabolic diseases, in addition to the type and amount of food components consumed, how they are prepared and cooked, as well as the effect of a food component on increasing the intake of other food components is also important. According to dietary habits in the Iranian population, fish is mostly prepared through frying, which can increase the intake of saturated fatty acids and weaken the beneficial properties of this valuable food item. Red meat, on the other hand, is mostly eaten in unprocessed form in our population. There is evidence that the consumption of unprocessed red meat has no effect on glycemic indices and inflammatory biomarkers in the blood [30], it seems that the most harmful effects attributed to red meat in some previous studies are mainly related to its processed form [30]. Also, in Iranian food culture red meat has been consumed along with legumes and vegetables, which may modulate its potential adverse effects according to previous studies [31]. Doogh is a dairy-derived drink made from yogurt, relatively high in salt. The extracted patterns in this study showed that increased consumption of doogh is directly related to FSI and HOMA-IR levels, which some reasons can explain these results. First, the high salt content of doogh in Iranian food habits may have detrimental metabolic effects [32]. Second, higher consumption of doogh indirectly indicates higher intakes of high-carbohydrate and high-caloric foods because, in the Iranian population, it is usually consumed with such foods. The last reason also applies to pickles and lemon juice.

In our study, in the cross-sectional phase, we observed that the participants with greater adherence to dietary and lifestyle patterns, extracted based on a positive association with FSI concentration and HOMA-IR, had significantly higher odds of hyperinsulinemia and IR. Also, after about three years of follow-up, the results showed that higher adherence to a lifestyle pattern is significantly associated with an increased risk of hyperinsulinemia and IR incidence. In contrast, such an association was no longer observed in the dietary pattern. This is not a surprising finding because, firstly, FSI and HOMA-IR index as response biomarkers for hyperinsulinemia and IR are mainly influenced by the unmodifiable endogenous factors such as regulatory and hormonal mechanisms [33] and the contribution of nutrition alone in the pathogenesis of metabolic disorders are small and not predictive of the risk of hyperinsulinemia and IR in the relatively short-term follow-up period of our study. Secondly, Dietary intakes in our study population are very close and the dietary pattern alone cannot adequately cover changes in biomarker levels. However, the lifestyle pattern by combining diet with BMI, which is an important and determining factor in the metabolic status of the body, including insulin homeostasis [34], explained larger variation in the FSI concentration, HOMA-IR, and their cumulative average than the dietary pattern (more than four times). This can explain why the lifestyle pattern, despite the dietary pattern, was able to predict the risk of hyperinsulinemia and IR incidence after three years of follow-up. Similarly, in our previous study, we examined the relationship between empirical dietary (EDIH) and lifestyle (ELIH) indices for hyperinsulinemia with the risk of insulin-related disorders, previously [18]. In line with the present study, we found that a higher score of the lifestyle index is associated with an increased risk of IR, hyperinsulinemia, and insulin insensitivity, while, the relationship between diet index and these disorders was not statistically significant.

Our study had some strengths. For the first time, this study derived two dietary and lifestyle patterns related to FSI and HOMA-IR in the Iranian population using the RRR method and investigated their relationship with the risk of hyperinsulinemia and IR both cross-sectionally and prospectively. This study also had some limitations. The FFQ questionnaire has some inevitable errors, such as recall bias, and like the other epidemiologic studies, we were not able to remove them, quietly. However, we served a reliable and valid questionnaire and the face-to-face manner of interview for data collection to reduce the errors. Since alcoholic drinks such as wine and beer are not common or may be unreported in the Iranian population due to religious considerations and legal restrictions; therefore we could not measure individuals' information for alcohol drinking, which could be considered as a response variable for IR in RRR analysis in the present study. The lack of data made us unable to examine sleep quality as a possible predictor in the framework of lifestyle for IR risk. In addition, although we examined the relationship between the identified pattern and the odds of insulin homeostasis-related disorders according to different statistical models by adjusting the effect of potential confounders, the possibility of unmeasured or unknown intervening variables in the statistical analysis is not ruled out. Also, the follow-up period in this study was relatively short; however, the number of incidents in this study was acceptable.

Conclusions

In the current study, two dietary and lifestyle patterns related to FSI concentration and HOMA-IR index were identified in the Iranian population using the RRR method. Our findings showed that adherence to a dietary pattern and lifestyle with a higher BMI level, higher intake of processed meat, doogh, pickles, lemon juices, fish, and a lower intake of starchy vegetables, garlic and onion, dried fruits, nuts, red meat, dairy products, coffee can be related to an increment risk of hyperinsulinemia and IR. It is recommended that further studies with a larger sample size and more extended follow-up duration, especially in different populations, be performed to confirm the results of this study.

Abbreviations

BMI	Body mass index
CI	Confidence interval
EDIH	Empirical dietary index for HI
ELIH	Empirical lifestyle index for HI
FA	Factor analysis
FBS	Fasting blood sugar
FFQ	Food Frequency Questionnaire
FSI	Fasting serum insulin
HbA1c	Hemoglobin A1c
HOMA-IR	Homeostatic model assessment for insulin resistance
IQR	Interquartile range
IR	Insulin resistance
MAQ	Modifiable Activity Questionnaire
MetS	Metabolic syndrome
NCDs	Non-communicable disease risk factors
PA	Physical activity
PCA	Principal component analysis
RRR	Reduced rank regression
SD	Standard deviation
T2D	Type 2 diabetes
TLGS	Tehran lipid and glucose study

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Author contributions

EM and FT: conceptualized and designed the study. FT, EM, MN, and HF: drafted the initial manuscript; HF and FT: analyzed and interpreted the data; MKJ: contributed to the revision of the manuscript; PM and FA: supervised the project; all authors read and approved the final version of the manuscript.

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Data availability

The data utilized for this work will be available by the corresponding author at reasonable demand.

Declarations

Ethics approval and consent to participate

All participants filled out a written informed consent. This study was conducted in conformance with good clinical practice standards and was performed according to the Declaration of Helsinki 1975, as subsequent amendments. Also, this study was approved by the ethics research committee of the Research Institute for Endocrine Sciences, Shahid Beheshti University of Medical Sciences, Tehran, Iran.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

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