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Adherence to diabetes risk reduction diet is associated with metabolic health status in adolescents with overweight or obesity

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Abstract

Background Insufficient evidence exists regarding the relationship between diabetes risk reduction diet (DRRD) and metabolic health status in adolescents. The current study aimed to investigate the relationship between DRRD and metabolic health status in Iranian adolescents with overweight/obesity.

Methods In this cross-sectional study, a multistage cluster random sampling method was used to select 203 overweight/obese adolescents. Dietary intakes were evaluated using a validated 147-item food frequency questionnaire. The following parameters were measured: blood pressure, anthropometric indices, fasting glucose, insulin, and lipid profiles. Participants were classified to metabolically healthy overweight/obese (MHO) or metabolically unhealthy overweight/obese (MUO), based on 2 methods: International Diabetes Federation (IDF) criteria and a combination of IDF and Homeostasis Model Assessment Insulin Resistance (HOMA-IR).

Results Based on IDF criteria, highest vs. lowest adherence to DRRD was associated with a lower odds of having an MUO phenotype in both crude (OR = 0.05; 95%CI: 0.02–0.12) and fully adjusted model (OR = 0.06; 95%CI: 0.02–0.20). Based on IDF/HOMA-IR criteria, similar findings were obtained. This relationship was significant in both genders and was especially significant among adolescents with obesity. In both crude and fully adjusted model, adherence to DRRD was significantly lower the likelihood of having high fasting blood glucose, triglycerides, and HOMA-IR.

Conclusion Adolescents who adhered more strictly to DRRD were less likely to be MUO, and have high fasting blood glucose, triglycerides, and HOMA-IR. Additional large-scale prospective studies are necessary to affirm these results.

Keywords Diabetes risk reduction diet, Metabolic health status, Obesity, Overweight, Adolescents

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Introduction

In the current century, it has been difficult to control the growing rates of overweight and obesity among children and adolescents [1, 2]. Since 1980, there has been an unprecedented rise in the worldwide prevalence of overweight and obesity in children and adolescents; by 2025, these numbers are expected to reach 268 and 145 million, respectively [3, 4]. Obesity may cause type 2 diabetes, hypertension, and dyslipidemia in children, affecting their physical and emotional health [5]. Among those with overweight or obesity, some individuals are considered as metabolically healthy overweight/obese (MHO); these people who have no metabolic abnormalities while they have extra body fat. Whereas metabolically unhealthy overweight/obese (MUO) was defined as simultaneous presence of obesity and metabolic abnormalities [6, 7]. Given an elevated incidence of overweight and obesity among adolescents, along with the consequential difficulties that arise, it is of significant interest to examine the relationship between modifiable risk factors and metabolic health status in this age-group.

Metabolic health status may be influenced by an interplay between hereditary and lifestyle variables, such as physical activity and dietary choices [8]. "Diabetes Risk Reduction Diet" (DRRD) is a dietary index comprising various factors that have potential to impact insulin resistance (IR). Sugar-sweetened beverages (SSBs), coffee, nuts, fruits, red and processed meats, as well as four other dietary components of glycemic index (GI), cereal fiber, ratio of polyunsaturated to saturated fat, and trans-fat are included in the DRRD score [9]. There are some evidences that prevention of metabolic syndrome (MetS) could be developed by lower intake of harmful components of DRRD, such as SSB, trans fatty acids and red and processed meat [10–12]. Other investigations suggested that high consumption of fiber along with low dietary GI, could improve glycemic control and reduce fasting plasma glucose, insulin resistance, and obesity [13].

A few studies have surveyed the relationship between DRRD and cancers such as breast cancer [14], and pancreatic cancer [15, 16]. Another suggested score, named "dietary diabetes risk reduction" (DDRR) is closely like DRRD, differing only in the absence of one component. Some investigations surveyed the association of DDRR and type 2 diabetes [17], and hepatocellular carcinoma [18]. A previous investigation reported that an elevated DDRR score was associated with a 40% significant decrease in the likelihood of diabetes [17]. In Iran, it was reported that those who adhered more closely to the DDRR score had lower rates of MetS [19]. To the best of our knowledge, DRRD as an integrated score was not evaluated in relation to metabolic dysfunctions. Also, there is no information about the connection between DRRD and MHO/MUO among adolescents in Middle Eastern countries such as Iran. Therefore, the purpose of this research was to examine the relationship between adherence to DRRD and MUO profile in a group of adolescents with overweight and obesity in Iran.

Methods

Study design and participants

The present cross-sectional study was conducted on a group of Iranian adolescents who were to some extent (not completely) representative of the whole population of this age group (12–18 years). The sample size of this study was estimated by the use of the frequency of MUO among Iranian teenagers with overweight and obesity [20, 21]. With taking this parameter into account, along with a power of 80%, type I error of 0.05 (confidence interval (CI) of 0.95), and precision (d) of 7%, the minimum necessary sample size was determined to be 188. Adolescents were randomly recruited through a stratified, multistage cluster sampling approach from students of grade 7 to12 (from middle and high schools). First, 16 public schools were randomly selected from 6 different educational districts of Isfahan. In the next stage, based on the school size, 2–8 classes were randomly selected from each grade. All students from selected classes were invited to participate in this survey. Isfahan is a large city in the center of Iran, and included citizens with various ethnicities, cultures, and socioeconomic statuses. So, a random sample of this population could be to some extent (not completely) representative of Iranian adolescents. Adolescents with overweight or obesity were identified using age and sex-specific percentile curves of body mass index (BMI) [22] and invited to participate in this research. Having type 1 diabetes mellitus, Cushing's syndrome, hypothyroidism, and other genetic or endocrine disorders, weight-loss diets, as well as taking nutritional supplements (e.g., vitamin and mineral supplements), and medications that might affect metabolic markers (such as lipid profile, body weight, blood pressure, or blood glucose) were considered as disqualifying factors. Totally, the current research comprised a total of 203 adolescents (101 boys and 102 girls) who were classified as overweight or obese. The study protocol received approval from the ethical committee of Isfahan University of Medical Sciences (no.63815), and a signed informed permission was collected from each participant and his/her parents. In order to keep away from stigmatization of adolescents with overweight or obesity, we expressed the purpose of the study as evaluating metabolic health status (without mentioning body weight or the terms of "overweight", "obesity", or "fat mass") to adolescents and their parents.

Dietary intake assessment

Data on usual dietary intakes of participants in the previous year were collected using a validated food frequency questionnaire (FFQ) consisting of 147 items [23, 24]. Validation of this FFQ was previously tested among Iranian adolescents [23]. Additionally, confirmed associations between dietary intakes – as determined by this FFQ – and illnesses or disorders in adolescents would be taken into account as a method of validating this questionnaire [25]. Questions about how often and how much of each food item was eaten were asked of respondents. Then, the amount of each food item consumed each day, was converted into gram using standard household measures [26]. Nutritionist IV was then used to calculate the intake of nutrients. This software was based on the USDA food composition database, with some modifications made to accommodate with Iranian food items.

Construction of DRRD score

Construction of DRRD score was done by the prior information about the association between certain dietary items and diabetes, as shown in a previously published document [27]. This technique of scoring takes nine different components into account: cereal fiber, nuts, coffee, whole fruits, ratio of polyunsaturated to saturated fat, GI, trans fats, sugar-sweetened beverage (SSBs)/fruit juices, red and processed meats. We first divided people into quintiles of these components. Participants were given a score based on their quintile of consumption of foods and nutrients that could reduce the risk of developing diabetes in prior research [27]: cereal fiber, nuts, coffee (both caffeinated and decaffeinated), whole fruits (bananas, raisins, cantaloupes, watermelons, prunes, fresh apples/pears, strawberries, oranges/grapefruits, blueberries, peaches/apricots/plums), and ratio of polyunsaturated fat to saturated fat. Those in the lowest quintile received 1 point, whereas those in the top quintile received 5 points. We used the opposite approach for dietary components with adverse associations with diabetes, including GI, trans fats, SSBs/fruit juices (apples, oranges, grapefruits, and other juices), and red and processed meats; individuals in the top quintile were assigned a score of 1, while those in the bottom quintile were assigned a score of 5. The total DRRD score was determined by adding all nine scores of DRRD components. This total score for each adolescent could be between 9 and 45 [27].

Assessment of metabolic health components

Two expert nutritionists took all anthropometric measurements of boys and girls. Weight was measured by the use of a digital scale (Seca Instruments, Germany) accurate to 100 g, while participants wore just light cloths and were barefoot. While the individuals were standing with relaxed shoulders and no shoes on, their height was measured using a stadiometer (accurate to 0.1 cm). BMI was determined by dividing the subject's weight in kilograms by his/her height in square meters. Based on the World Health Organization (WHO) growth curve of age-sex-specific BMI percentiles for adolescents, participants were categorized as overweight (85th ≤ BMI < 95th percentile) or obese (BMI ≥ 95th percentile) [22]. Waist circumference (WC) was measured twice to the closest 0.1 cm using an un-stretchable flexible anthropometric tape immediately after a normal expiration and without applying any pressure to the body surface. Two independent WC readings were averaged to have a mean value. Blood pressure (BP) was also taken twice on the right arm using a mercury sphygmomanometer after a resting period of 15 min. After fasting for 12 h during a night, a blood sample was obtained from each participant for biochemical analysis. Fasting blood glucose (FBG) was measured using the enzymatic calorimetric technique on the day of blood collection. An ELISA kit (Diagnostic Biochem Canada Inc.) was used to measure blood insulin levels. The following formula was used to determine the homeostasis model assessment insulin resistance (HOMA-IR): HOMA-IR = [(fasting insulin (mU/L) × FBG (mmol/L)]/22.5 [28]. Furthermore, commercial kits (Pars Azmoon commercial kits, Tehran, Iran) were used to measure serum triglycerides (TG) and high-density lipoprotein cholesterol (HDL-c).

Assessment of metabolic health status

Several approaches could be applied to define MUO, but no consensus was reached on which approach was more accurate and valid. Therefore, in the current study two more common and accurate approaches were applied to define the outcome of interest. In the first approach, based on modified International Diabetes Federation (IDF) criteria [29], adolescents with two or more of the following abnormalities were classified as MUO individuals: 1) FBG ≥ 100 mg/dL, 2) HDL-c < 40 mg/dL for those under 16 years old, and < 50 mg/dL for girls and < 40 mg/dL for boys with 16 years old or more, 3) triglycerides ≥ 150 mg/dL, 4) SBP ≥ 130 and/or DBP ≥ 85mmHg. Subjects without at least two of the aforementioned risk indicators were classified as MHO. Second approach took IDF requirements as well as IR presence into account. MUO was defined as having HOMA-IR ≥ 90th percentile (or 3.16 unit) and ≥ 2 of the aforementioned risk factors; whereas MHO was defined as individuals with a HOMA-IR < 3.16 [30]. If the association of DRRD and MUO was statistically significant in the second approach which was stricter, the certainty of the obtained associations could be higher.

Assessment of other variables

Physical Activity Questionnaire for Adolescents (PAQ-A), which has been previously validated, was used to determine levels of physical activity that adolescents had [31]. This questionnaire consists of nine questions that cover a wide range of different forms of physical activities. The first eight items of PAQ-A were scored on a scale from 1 to 5, with a score of 1 indicating the least amount of physical activity in the previous week and a score of 5 indicating the most. The last inquiry probed the out-of-the-ordinary activity of participants throughout the previous week. When all questions were answered, the scores were recorded and the adolescents were placed into one of four categories: very active (score ≥ 4), active ($3 \leq$ score < 4), low-active ($3 <$ score ≤ 2), sedentary or inactive (or not having an organized week activity) (score < 2). Since no participants were categorized as very active, we had only 3 categories of physical activity levels (sedentary, low-active, and active). In order to determine socioeconomic status (SES) score of participants, a validated demographic questionnaire was used [32]; the components of this score were: family size (1–4 points), parental occupation (1–5 points), paternal education level (1–6 points), maternal education level (1–6 points), having automobiles in the household (0–2 points), having personal bedrooms for the adolescent (0–1 point), number of computers (0–1 point), and annual vacations of the family (0–2 points). The composite SES score for each subject ranged from 4 to 27 points. Another questionnaire was also used to collect other information on the adolescents, including their age, sex, medical history, medication, and supplement use.

Statistical analysis

Version 20 of SPSS program was used to carry out all statistical analyses (IBM, Chicago, IL). Based on adherence to DRRD, we divided individuals into tertiles. For reporting, mean ± SD or SE was utilized for continuous variables, whereas the number (%) was used for categorical variables. In this study, one-way ANOVA and chi-square were used to compare characteristics of individuals across tertiles of DRRD. Dietary intakes of individuals were assessed using ANCOVA, while controlling was made for age, sex, and energy intake. Odds ratios (ORs) and their associated 95% CIs for MUO in different tertiles of DRRD were estimated in both crude and multivariable models. The initial model took into account factors including age, sex, and energy intake. The second model additionally accounted for socioeconomic status and physical activity. In the third model, we further adjusted BMI. Reference group in each model was the first tertile of DRRD. Tertiles of DRRD were considered as an ordinal variable in logistic regression models when the trend of OR across DRRD categories was evaluated. Furthermore, analyses were stratified according to sex (males vs. females) and BMI ranges (overweight vs. obesity). P-values < 0.05 were regarded as statistically significant.

Results

This study comprised 203 adolescents with an average age of 13.98 ± 1.61 years and an mean weight was 73.48 ± 11.60 kg. The DRRD score varied between 15 and 39 with the median of 27. Table 1 shows general characteristics and cardiometabolic variables of the adolescents in each tertile of DRRDS. Physical activity was higher among individuals in the highest tertile of DRRD compared to the lowest tertile ($P < 0.05$). Those in the top tertile of DRRD also had considerably reduced levels of FBG, insulin, HOMA-IR, and TG ($P < 0.05$). Additionally, their levels of HDL cholesterol were greater ($P < 0.05$). Nevertheless, there were no significant differences in other general or cardiometabolic factors among tertiles of DRRD.

Table 2 presents dietary intakes of participants among tertiles of DRRD. Dietary fiber, nuts, caffeine, and whole fruits were substantially different across DRRD tertiles; those in the third vs. first tertile consumed more fiber, nuts, caffeine, and whole fruits ($P < 0.05$). In contrast, consumption of trans fatty acids, SSBs, GI, red and processed meat was lower among those in the third tertile compared to the first tertile ($P < 0.05$). In terms of other nutrients, there was not a significant difference among DRRD tertiles ($P > 0.05$).

Figure 1 shows the prevalence of MUO phenotype among adolescents in tertiles of DRRD. Those with higher DRRD score were less likely to have MUO according to IDF criteria (T3 vs. T1: 11.1 vs. 73.0%; $P < 0.001$) and IDF combined HOMA-IR criteria (T3 vs. T1: 9.7 vs. 63.5%; $P < 0.001$).

Crude and multivariable-adjusted odds ratios for being MUO in DRRD categories are provided in Table 3. According to IDF criteria, there was a reduced likelihood of MUO in crude model for individuals in the third tertile of DRRD compared to those in the first tertile (OR = 0.05; 95% CI; 0.02, 0.12). After taking possible confounding factors into account, the association was still statistically significant; such that adolescents in the third tertile of DRRD had 94% lower odds of being MUO than those in the first category (OR = 0.06; 95%CI: 0.02, 0.20). When IDF/HOMA-IR criteria was used to define MUO, similar finding was obtained (crude model: OR = 0.06; 95%CI: 0.02, 0.16; fully-adjusted model: OR = 0.08; 95%CI: 0.02, 0.27). Additionally, when we considered DRRD as a continuous variable, we found a significant inverse relationship between each tertile increase in DRRD and likelihood of having MUO according to both IDF criteria

Table 1 General characteristics and cardio-metabolic factors of study participants across tertiles of DRRD score[1]

	Tertiles of DRRD score			
	T1 (*n* = 63) (< 24)	**T2 (*n* = 68) (24–29)**	**T3 (*n* = 72) (> 29)**	***P*-value[2]**
Sex, n (%)				0.33
Boys	27 (42.9)	38 (55.9)	36 (50.0)	
Girls	36 (57.1)	30 (44.1)	36 (50.0)	
Age (year)	14.00 ± 1.61	13.78 ± 1.48	14.15 ± 1.72	0.39
Weight (kg)	75.23 ± 11.03	73.13 ± 10.69	72.29 ± 12.83	0.32
BMI (kg/m^2)	27.71 ± 2.85	27.26 ± 2.51	27.14 ± 4.08	0.57
Waist circumference (cm)	91.78 ± 6.94	90.18 ± 7.22	89.20 ± 9.21	0.17
Physical activity levels, n (%)				< 0.001
Sedentary	47 (74.6)	31 (45.6)	11 (15.3)	
Low-active	15 (23.8)	34 (50.0)	28 (38.9)	
Active	1 (1.6)	3 (4.4)	33 (45.8)	
Socioeconomic status[3], n (%)				0.06
Low	21 (33.3)	23 (33.8)	15 (20.8)	
Medium	32 (50.8)	23 (33.8)	35 (48.6)	
High	10 (15.9)	22 (32.4)	22 (30.6)	
Systolic blood pressure (mmHg)	115.62 ± 10.67	113.56 ± 21.86	109.35 ± 19.69	0.13
Diastolic blood pressure (mmHg)	75.64 ± 6.31	73.52 ± 12.97	71.60 ± 12.92	0.12
Fasting blood glucose level (mg/dL)	103.11 ± 9.21	98.40 ± 6.99	93.53 ± 6.49	< 0.001
Insulin (μUI/mL)	25.80 ± 16.19	19.97 ± 9.25	16.15 ± 10.09	< 0.001
HOMA-IR index	6.56 ± 4.09	4.89 ± 2.48	3.79 ± 2.55	< 0.001
Triglycerides (mg/dL)	156.83 ± 79.66	116.43 ± 57.48	96.65 ± 46.77	< 0.001
HDL cholesterol (mg/dL)	41.83 ± 7.63	44.94 ± 7.28	47.33 ± 7.96	< 0.001

[1] Values are Mean ± SD; unless indicated

[2] P-values were obtained from one-way analysis of variance (ANOVA) and χ2 test for quantitative and categorical variables, respectively

[3] Socioeconomic status (SES) score was evaluated based on parental education level, parental job, number of family members, having car in the family, having computer/laptop, having personal room and having travel by using demographic questionnaire

BMI Body Mass Index, *HOMA-IR* Homeostasis Model Assessment Insulin Resistance, *HDL-c* high-density lipoprotein cholesterol

(fully adjusted model: OR = 0.81; 95%CI: 0.74–0.88) and IDF/HOMA-IR criteria (fully adjusted model: OR = 0.81; 95%CI: 0.74, 0.89).

Supplemental Table 1 displays multivariate adjusted odds ratio and 95% confidence interval for MUO phenotype across tertiles of DRRD, stratified by BMI levels. According to IDF definition, there was a significant negative relationship between DRRD score and MUO in both overweight (OR = 0.03; 95%CI: 0.01, 0.22) and obese category (OR = 0.14; 95%CI: 0.04, 0.54), after accounting for possible confounding factors. Based on IDF/HOMA-IR criteria, similar results were obtained in adolescents with obesity, but the association in adolescents with overweight was marginally significant (OR = 0.15; 95%CI: 0.02, 1.08). Supplemental Table 2 shows the results of stratified analysis by sex. Girls in the highest vs. lowest tertile of DRRD had lower likelihood of having MUO phenotype, defined by IDF (OR = 0.05, 95%CI: 0.01, 0.25) or IDF-HOMA-IR (OR = 0.07, 95%CI: 0.01, 0.44). Similar relationships were seen in boys (IDF definition: OR = 0.05, 95%CI: 0.01, 0.33; IDF/HOMA-IR definition: OR = 0.07, 95%CI: 0.01, 0.41).

Table 4 provides crude and multivariate-adjusted ORs and 95% CIs for metabolic health components across DRRD tertiles. In fully adjusted model, individuals in the highest vs. lowest tertile of DRRD had decreased odds of hypertriglyceridemia (OR = 0.14; 95%CI: 0.05, 0.43), high HOMA-IR (OR = 0.20; 95%CI: 0.06, 0.67), and high fasting blood glucose (OR = 0.07; 95% CI: 0.03, 0.19).

Discussion

In current cross-sectional investigation, adolescents in both sexes with a higher DRRD score had lower likelihood of having MUO phenotype when we considered two defining approaches. The relationship between these variables was independent from confounders. This relationship was more pronounced among adolescents who were obese compared to those who were overweight. In

Table 2 Dietary intakes of study participants across tertiles of DRRD score[1]

	Tertiles of DRRD score			
	T1 (*n* = 63) (< 24)	**T2 (*n* = 68) (24–29)**	**T3 (*n* = 72) (> 29)**	***P*-value[2]**
Nutrients				
Energy, kcal	2927.13 ± 68.70	2882.67 ± 66.15	2844.77 ± 64.22	0.68
Protein (g/d)	99.87 ± 3.33	102.83 ± 3.21	106.28 ± 3.11	0.37
Carbohydrate (g/d)	433.04 ± 11.01	423.05 ± 10.60	407.59 ± 10.29	0.23
Fat (g/d)	99.10 ± 2.96	91.59 ± 2.85	92.87 ± 2.77	0.95
Fiber (g/d)	15.42 ± 0.49	19.77 ± 0.47	22.67 ± 0.46	< 0.001
Food items				
Cereal fiber (g/d)	5.36 ± 0.18	5.26 ± 0.17	5.37 ± 0.17	0.89
Nuts (g/d)	6.00 ± 1.24	11.55 ± 1.19	18.18 ± 1.16	< 0.001
Caffeine (mg/d)	2.51 ± 4.65	21.76 ± 4.48	22.43 ± 4.35	0.01
Whole fruits (g/d)	190.78 ± 16.14	329.95 ± 15.53	353.00 ± 15.09	< 0.001
PUFA to SFA ratio	1.03 ± 0.04	1.10 ± 0.04	1.12 ± 0.04	0.27
Glycemic index (GI)	65.62 ± 0.34	63.34 ± 0.33	61.24 ± 0.32	< 0.001
Trans fatty acids (g/d)	8.45 ± 0.37	6.30 ± 0.36	3.34 ± 0.35	< 0.001
SSB/fruit juices (g/d)	113.52 ± 6.46	76.94 ± 6.21	42.25 ± 6.04	< 0.001
Red and processed meats (g/d)	32.61 ± 1.88	30.69 ± 1.81	16.82 ± 1.76	< 0.001

[1] Values are Mean ± SE. Energy intake was adjusted for age and sex; all other values were adjusted for age, sex and energy intake

[2] P-values were obtained from ANCOVA test

PUFA to SFA Ratio of polyunsaturated fatty acid to saturated fatty acid, *GI* Glycemic index, *SSB* Sugar-sweetened beverages

case of metabolic components, a greater DRRD category was significantly associated with reduced odds of elevated blood glucose levels, triglycerides, and HOMA-IR.

Individuals diagnosed with MUO have an increased susceptibility to develop chronic disorders, including cardiovascular diseases [33]. While all individuals with an MHO phenotype do not have normal clinical outcomes, it is beneficial to avoid transitioning to MUO or even keeping MHO status throughout adolescence and adulthood [34, 35]. Therefore, it is important to therapeutically advise adolescents to adhere more strictly to DRRD in order to avoid metabolic complications associated with obesity.

The present study indicates that a higher DRRD score was associated with a decreased likelihood of MUO in Iranian teenagers. There are few prior studies examining the relationship between metabolic health status and DRRD. A prospective, population-based cohort study done on adults in Tehran, Iran indicated that a higher level of DDRR score was associated with a reduced risk of developing MetS and some components of MetS (central obesity and high BP) [19]. Also, according to a cross-sectional study on Tehranian women with overweight and obesity, higher DDRR score was linked to lower levels of insulin, liver enzymes, and lipid profiles [36]. Rhee et al. have also reported that a higher score of DDRR score was associated with a decrease in likelihood of developing type 2 diabetes in females [17]. Nevertheless, a cross-sectional study on 6,964 American women with obesity found no significant differences in food consumption between MHO and MUO individuals [37]. Previous investigations reported that high fiber content, along with low dietary GI in DDRR, might reduce likelihood of developing MetS by improving many metabolic factors such as glycemic control, IR, dyslipidemia, obesity, and BP [38]. Reducing nutrient absorption rate, suppressing appetite, regulating energy homeostasis, improving gut microbiota and glucose homeostasis, modulating inflammatory cytokines and endothelial dysfunction, and regulating hormones might be all potential mechanisms through which dietary fiber affects MetS components [38, 39]. Caffeine, the main component in coffee, could lower blood triglyceride levels and likelihood of developing type 2 diabetes by raising thermogenesis and metabolic rate, promoting fat oxidation and release of free fatty acids (FFAs) from peripheral tissues, and mobilizing glycogen in muscles [40]. Additionally, nuts are essential in regulating MetS components by enhancing endothelial function, reducing oxidative stress, and inflammation [41]. Several research studies found that a diet rich in nuts reduced systolic and

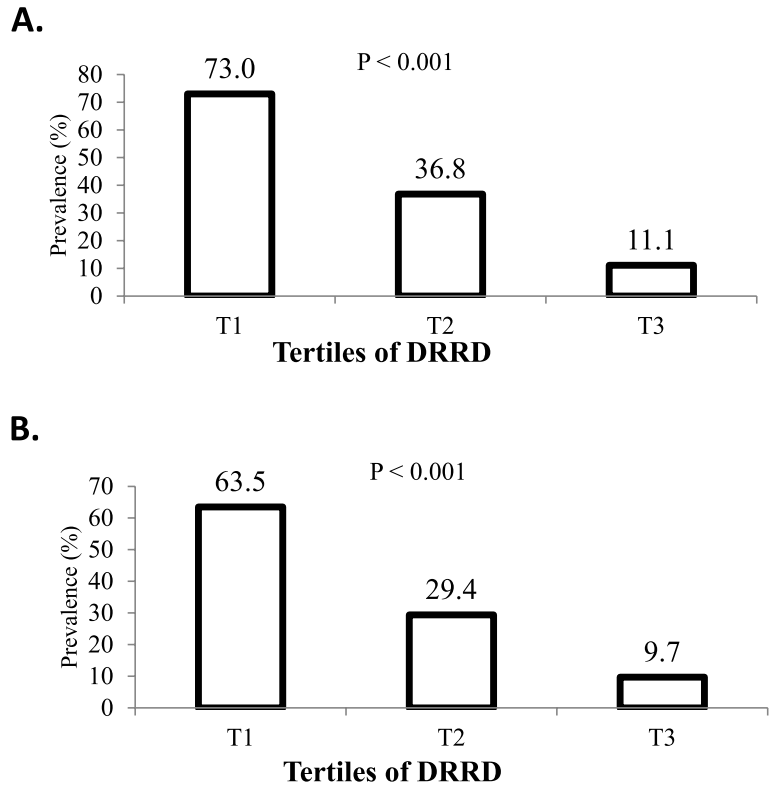

Fig. 1 Prevalence of MUO across tertiles of DRRD score in the study population. **A**. MUO based on IDF definition among tertiles of DRRD score. **B**. MUO based on IDF/HOMA-IR definition among tertiles of DRRD score. *P*-values were obtained from χ2 test; and $P < 0.05$ indicated prevalence of MUO was statistically significant across tertiles of DRRD

Table 3 Multivariate adjusted odds ratios (ORs) and 95% confidence intervals (CIs) for MUO phenotype across tertiles of DRRD score[1]

	Tertiles of DRRD score				Per 1 tertile increase in DRRD score
	T1 (*n* = 67) (score < 24)	T2 (*n* = 68) (24–29)	T3 (*n* = 68) (> 29)	P-trend[2]	
MUO phenotype based on IDF criteria					
Cases (n)	46	25	8		
Crude	1 (Ref.)	0.22 (0.10, 0.45)	0.05 (0.02, 0.12)	< 0.001	0.79 (0.73, 0.85)
Model 1	1 (Ref.)	0.21 (0.10, 0.46)	0.04 (0.01, 0.11)	< 0.001	0.78 (0.72, 0.84)
Model 2	1 (Ref.)	0.26 (0.12, 0.59)	0.08 (0.03, 0.22)	< 0.001	0.82 (0.75, 0.89)
Model 3	1 (Ref.)	0.26 (0.11, 0.58)	0.06 (0.02, 0.20)	< 0.001	0.81 (0.74, 0.88)
MUO phenotype based on HOMA-IR criteria					
Cases (n)	40	20	7		
Crude	1 (Ref.)	0.24 (0.12, 0.50)	0.06 (0.02, 0.16)	< 0.001	0.80 (0.74, 0.86)
Model 1	1 (Ref.)	0.22 (0.10, 0.48)	0.05 (0.02, 0.15)	< 0.001	0.79 (0.73, 0.86)
Model 2	1 (Ref.)	0.27 (0.12, 0.62)	0.11 (0.03, 0.32)	< 0.001	0.83 (0.76, 0.90)
Model 3	1 (Ref.)	0.26 (0.11, 0.60)	0.08 (0.02, 0.27)	< 0.001	0.81 (0.74, 0.89)

[1] All values are odds ratios and 95% confidence intervals. Model 1: Adjusted for age, sex, and energy intake. Model 2: Additionally adjusted for physical activity and socioeconomic status (evaluated based on parental education level, parental job, number of family members, having car in the family, having computer/laptop, having personal room and having travel by using demographic questionnaire). Model 3: Additionally adjusted for body mass index (BMI)

[2] Obtained by the use of tertiles of DRRD score as an ordinal variable in the model

Table 4 Multivariable adjusted odds ratios (ORs) and 95% confidence intervals (CIs) for metabolic components across tertiles of DRRD score[1]

	Tertiles of DRRD score			
	T1 (score < 24)	T2 (24–29)	T3 (> 29)	P-trend
High blood pressure				
(Participants/Cases)	63/9	68/13	72/7	
Crude model	1 (Ref.)	1.42 (0.56–3.59)	0.65 (0.23–1.85)	0.42
Fully-adjusted model[2]	1 (Ref.)	1.71 (0.63–4.64)	0.64 (0.17–2.39)	0.69
High fasting blood glucose				
(Participants/Cases)	63/44	68/31	72/9	
Crude model	1 (Ref.)	0.36 (0.18–0.74)	0.06 (0.03–0.15)	< 0.001
Fully-adjusted model[2]	1 (Ref.)	0.34 (0.16–0.74)	0.07 (0.03–0.19)	< 0.001
High triglyceride				
(Participants/Cases)	63/28	68/17	72/7	
Crude model	1 (Ref.)	0.42 (0.20–0.87)	0.14 (0.05–0.34)	< 0.001
Fully-adjusted model[2]	1 (Ref.)	0.36 (0.15–0.82)	0.14 (0.05–0.43)	< 0.001
Low HDL-c				
(Participants/Cases)	63/40	68/20	72/16	
Crude model	1 (Ref.)	0.24 (0.12–0.50)	0.16 (0.08–0.35)	< 0.001
Fully-adjusted model[2]	1 (Ref.)	0.28 (0.12–0.66)	0.41 (0.16–1.08)	0.03
High HOMA-IR				
(Participants/Cases)	63/57	68/57	72/32	
Crude model	1 (Ref.)	0.55 (0.19–1.58)	0.08 (0.03–0.22)	< 0.001
Fully-adjusted model[2]	1 (Ref.)	0.75 (0.22–2.57)	0.20 (0.06–0.67)	0.01

[1] All values are odds ratios and 95% confidence intervals

[2] Fully-adjusted model: Adjusted for age, sex, total energy intake, physical activity, socioeconomic status and body mass index (BMI)

HOMA-IR Homeostasis Model Assessment Insulin Resistance, *HDL-c* high-density lipoprotein cholesterol

diastolic BP in healthy persons and those at risk of cardiovascular diseases [42]. However, other investigations found that nut intake had no impact on BP [43–45]. Greatest amount of fruit has reduced developing MetS, as well [46]. On the other hand, reducing the intake of detrimental components of DRRD, including red and processed meat, SSBs, and trans fatty acids, is crucial for preventing MetS [10–12]. Red and processed meats contain saturated fatty acids, heme–iron, and nitrites and nitrates, which could potentially raise risk of metabolic disorders such as type 2 diabetes by promoting weight gain, hyperinsulinemia, IR, elevated blood glucose levels, increased inflammation and oxidative stress, and higher production of nitrosamines [11, 47]. Additionally, a high consumption of trans fatty acids might lead to MetS by having a negative impact on circulating lipid levels, causing endothelial dysfunction, systemic inflammation, and increasing visceral adiposity, body weight, and IR [10]. Excessive consumption of SSBs might result in weight gain, positive energy balance, and raising risk of MetS [12]. Possible explanations for discrepancies between findings of aforementioned studies include variations in study design, populations examined, assessment instruments, and confounding factors.

Our study indicated that relationship between higher DRRD and MUO was more pronounced in adolescents with obesity compared to overweight. There is a hypothesis that suggests persons with obesity might have a greater potential to improve metabolic risk variables compared to individuals with overweight, due to more severe metabolic conditions. Therefore, it is likely that the protective impact of following a DRRD would be stronger among individuals with obesity. Further research is required to approve this hypothesis.

The current study was one of the first examinations of relationship between DRRD score and metabolic health status in adolescents with overweight or obese. However, it contained a number of limitations. The sample size for this study was somewhat small, despite the fact that we obtained significant results with this sample size and this investigation included a reasonably representative sample of adolescents with overweight or obesity. So, due to investigating a relatively small sample of adolescents with

overweight or obesity from a large city of Iran and probably underrepresenting adolescents of rural areas, generalizing current findings to all Iranian adolescents and especially to children from other nations should be done cautiously. Due to cross-sectional nature of the research, we could not establish any causal relationship between exposure and endpoints; additional prospective cohort studies are required to prove a causal relationship. Some individuals might be inaccurately reported their food consumption, even though we applied a validated FFQ to gather dietary information. Although the applied FFQ was filled out by the interviewer (using interviewer-administered method) to somewhat reduce recall bias, this kind of bias was inevitable in case of FFQ and was a limitation of current investigation. In addition, although the components of DRRD were relatively aligned with dietary intakes of Iranians, validation of the applied FFQ for DRRD in Iranian adolescents was not performed. While adjustments were made for several socio-demographic and other factors, data on puberty stage, sleep quality or duration, and body composition were not collected due to low financial budget allocated to this study and low cooperation of participants in case of having long questionnaires.

In this cross-sectional study, adolescents of both sexes with higher DRRD score were less likely to be MUO (based on two defining approaches). This relationship was stronger in individuals with obesity than overweight. A higher DRRD score was also associated with lower odds of increased blood glucose, triglycerides, and HOMA-IR, in adolescents with overweight or obesity. Therefore, more adherences to DRRD could enhance metabolic health status of adolescents. Policy makers should provide better access to protective components of DRRD in order to facilitate more adherences of adolescents to DRRD and improve their health status.

Abbreviations

ANOVA	Analysis of variance
DRRD	Diabetes risk reduction diet
DDRR	Dietary diabetes risk reduction
BP	Blood pressure
CKD	Chronic kidney disease
FFQ	Food frequency questionnaire
OR	Odds ratio
95% CI	95% Confidence interval
BMI	Body mass index
MHO	Metabolically healthy overweight/obese
MUO	Metabolically unhealthy overweight/obese
IDF	International Diabetes Federation
HOMA-IR	Homeostasis Model Assessment Insulin Resistance
IR	Insulin resistance
PAQ-A	Physical Activity Questionnaire for Adolescents
MetS	Metabolic syndrome
SES	Socioeconomic status
SFA	Saturated fatty acids
SSBs	Sugar-sweetened beverages
WHO	World Health Organization
WC	Waist circumference
SBP	Systolic blood pressure
DBP	Diastolic blood pressure
TG	Triglycerides
HDL-c	High density lipoprotein cholesterol
LDL-c	Low density lipoprotein cholesterol
FFA	Free fatty acid
FBG	Fasting blood glucose
FPG	Fasting plasma glucose
ANCOVA	Analysis of covariance
SPSS	Statistical package for the social sciences
SD	Standard deviation
SE	Standard error

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s12937-025-01111-x.

Supplementary Material 1

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None.

Authors' contributions
Authors' contributions and Consent for publication: AG: Conceptualization, methodology, formal analysis, funding acquisition, writing-original draft. ZM: Investigation, writing-original draft. S.M: Investigation. A.A: Investigation and data curation. M.A: Investigation and data curation. P.S: Conceptualization, methodology, supervision, resource, formal analysis, funding acquisition, writing-editing and reviewing. All authors agreed on all aspects of the work and publication.

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Data availability
Data availability: The datasets applied and analyzed during the current study could be available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate
The study was performed according to the declaration of Helsinki and the STROBE checklist. All study participants signed an informed written consent. The local Ethics Committee of Isfahan University of Medical Sciences approved the study protocol.

Competing interests
The authors declare no competing interests.

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