Public Health Nutrition: 24(18), 6299–6308 doi:10.1017/S1368980021003074

The association between low-carbohydrate diet score and metabolic syndrome among Iranian adults

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Submitted 5 December 2020: Final revision received 9 June 2021: Accepted 19 July 2021: First published online 23 July 2021

Abstract

Objective: Assessing the relationship between low-carbohydrate diet (LCD) score and metabolic syndrome (Mets) in Iranian adults.

Design: Cross-sectional study

Setting: Yazd Health Study and Taghzieh Mardom-e-Yazd study.

Participants: Data of 2074 participants were used. Dietary intakes were assessed by a validated semi-quantitative FFQ. LCD score was calculated for each person by summing up the assigned scores to deciles of energy percentages from macronutrients. Mets was evaluated using National Cholesterol Education Program Adult Treatment Panel III. Eventually, association between LCD score and Mets was examined using logistic regression.

Results: Total Mets prevalence was approximately 40·5 %. After adjustment for confounders, subjects in the higher quartile of LCD score had a significant lower chance of Mets than lower quartile among all participants (Q4 *v.* Q1: OR: 0·68, 95 % CI (0·50, 0·92)) and separately in men (Q4 *v.* Q1: OR: 0·54, 95 % CI (0·34, 0·86)) and women (Q2 *v.* Q1: OR: 0·53, 95 % CI (0·34, 0·82)). Furthermore, more LCD adherence in men reduced abdominal obesity by 47 % (Q3 *v.* Q1: OR: 0·53, 95 % CI (0·28, 0·99)). A significant inverse relation was also observed between low HDL cholesterol and LCD score in all participants (Q4 versus Q1 OR: 0·74, 95% CI: 0·56–0·99) and separately in men (Q4 versus Q1 OR: 0·63, 95% CI: 0·40–0·98).

Conclusions: More adherence to LCD might be related to lower chance of Mets and some of its components such as low HDL-cholesterol and abdominal obesity specially in men. Further studies are required to confirm the findings.

Keywords
Low-carbohydrate diet
Metabolic syndrome
Diet
Carbohydrates

Metabolic syndrome (Mets) clusters a number of metabolic complications which is characterised by obesity, hypertension, dyslipidemia, glucose intolerance and insulin resistance[1,2]. The prevalence of Mets in the developed and developing countries is growing. It is reported that Mets is present in 40 % of the adult population in the USA[3] and less than 25 % in European nations[4]. Various modifiable factors such as diet can be effective in preventing and management of Mets[5,6].

Carbohydrate is the main source of energy intake in the middle-eastern region including Iran and is being consumed through foods such as rice, potato and grains. Increasing in carbohydrate consumption is associated with the risks of CVD or other components of Mets by high intakes of energy and glycemic load[4,7]. However, most of these outcomes are controversial, for instance in a study, sugar and sweetened beverage consumption did not have any significant effect on Mets[8]. Therefore, investigating the effect of macronutrients intake within a dietary pattern can help evaluate the association between diet and diseases[9,10].

Dietary pattern assessment takes both the complexity and synergistic effect of the foods and nutrients that make up a diet into account[11–13]. Low-carbohydrate diet (LCD) is a diet with lower intakes of carbohydrate and higher consumption of fat and protein[9,10,14]. Studies suggest that higher carbohydrate intake is followed by lower HDL, hypertriglyceridemia and hyperinsulinemia[4,15,16]. Therefore, LCD may have protective effect against chronic diseases including MetS[7]. Limited

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studies have been conducted assessing the relation between LCD and Mets, or its components and the outcomes are inconsistent[1,7,17–21]. For example, it has been suggested in Shirani *et al.* study that LCD was not significantly associated with Mets in Iranian women[1] which is similar to the results of a recent Korean study that observed no significant relationship between this dietary pattern and Mets[22]. Furthermore, another study among Tehranian adults by Mirmiran *et al.* reported that LCD may in fact be associated with decreased risk of Mets and its components[7]. According to several studies, Iranians traditionally consume high portions of carbohydrate foods, especially refined grains (which have a high glycemic load and increase the energy intake) such as rice and potatoes or foods that consist of a lot of simple sugars; this high-carbohydrate diet could be the possible reason for the incidence or development of many cardiovascular risk factors[7,23–27].

As a conclusion, considering the growth in Mets prevalence, limited investigations assessing the association between LCD and Mets and inconsistencies in the achieved outcomes, this study aims to investigate the association between LCD and Mets in a sample of adult population in Yazd city, Iran.

Materials and methods

Study population and data collection

We used Yazd Health (YaHS) and Taghzieh Mardom-e-Yazd (TAMIZ) studies data in the current cross-sectional survey. These population-based cohort studies have been conducted in a large sample of adults (20–69 years old) in Yazd city, Iran. Adults (*n* 10 000) from 200 clusters were randomly selected from Yazd population based on residential postal codes via cluster sampling method. Yazd Nutrition Survey (locally known as TAMYZ in Persian) has evaluated dietary and supplements intakes of participants of YaHS by a validated FFQ. More details of these studies have been previously published[28]. Information on socio-demographic characteristics, smoking status, history of chronic disease, biochemical and physical activity evaluations and dietary assessment was collected using a validated questionnaire. Furthermore, anthropometric examinations were performed. In the current study, out of 3443 available cases with data on dietary intakes, biochemical assessment and Mets, some individuals were excluded according to the following exclusion criteria: having under- or over-reporting (total daily energy intake less than 800 or higher than 6500 kcal)[29], pregnancy, following a special diet, having a history of chronic disease such as CVD, diabetes and cancer. Eventually, 2074 participants were entered in the present research. This study was approved by the logical Ethics Committee. Written informed consents were also taken from all subjects.

Dietary assessment

Dietary intakes were evaluated via a validated FFQ consisting of 178 food items which was a modified version of a previously validated 168-item FFQ[28,30]. Ten additional questions relating to the consumption of Yazd-specific food items were added to the original 168-item FFQ[28,30]. Frequency and usual amount of food items intake were answered by participants, and eventually amounts of consumptions were converted to grams based on the guidelines of household scales[31].

Calculation of the low-carbohydrate diet score

For computing LCD score, first the participants were classified based on deciles of percentages of energy from carbohydrates, proteins and fats. For carbohydrate consumption, individuals in the lowest decile received 9 points, adults in the second decile received 8 points, and so on down to the subjects in the highest decile received 0 point. For fats and proteins intake, the assigned points to deciles were reversed so that individuals in the highest decile received 9 points and those in the lowest decile received 0 point. Finally, the assigned points to all macronutrients were summed up and LCD score was obtained. After calculation, LCD score ranged from 0 to 27 and the higher score showed more adherence to LCD dietary pattern (the lower carbohydrate intake and the higher protein and fat intake)[1,9]. Eventually, participants were classified according to quartiles of LCD score.

Metabolic syndrome definition

Mets definition was based on National Cholesterol Education Program Adult Treatment Panel III (NCEP ATP III)[32]. Subjects who had at least three of following criteria were considered as those with Mets: serum TAG ≥150 mg/dl, serum HDL-cholesterol <40 mg/dl for men and HDL-cholesterol < 50 mg/dl for women, fasting blood glucose ≥ 100 mg/dl, blood pressure ≥130/85 mmHg, and waist circumference ≥102 cm for men and >88 cm for women.

Anthropometric measurements

Weight was measured by Omron BF511 portable digital scale with the accuracy of 0·1 kg. Height was measured in a standing position by a tape measure on a straight wall to the nearest centimetre according to the standard method. BMI was also calculated by dividing the body weight (kg) by the square of height (m).

Physical activity assessment

Physical activity was examined via the Persian translated short form of the International Physical Activity Questionnaire (IPAQ). Eventually, the physical activity levels presented as metabolic equivalent (MET)[33,34].

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Statistical analysis

Statistical analysis was performed by Statistical Package for Social Sciences (SPSS Corp., version 18). Kolmogorov–Smirnov test was used for assessing the normality of data. For the description of data, frequency and percent or median and interquartile range were performed. Comparing categorical and continuous variables were conducted via χ^2 or Kruskal–Wallis tests, respectively, based on the categories of LCD score.

Examination of relationship between adherence to LCD with Mets and its components among all participants and separately in men and women was performed by logistic regression analysis in various models. In the first model, we carried out the adjustments for history of chronic disease (hypercholesterolemia, brain disease, asthma, thyroid disorders, depression, Alzheimer's disease, blood coagulation disorders, arthritis and osteoporosis; yes/no); age (20–29, 30–39, 40–49, 50–59 and 60–69 years); marital status (single, married, widowed or divorced); education level (illiterate, high school, diploma and associated diploma, bachelors, masters and PhD); smoking status (never smoker, current smoker and ex-smoker); total energy intake (continues, kcal/d) and physical activity level (continues, MET/min/week). Further adjustment was conducted for BMI (continues, kg/m^2). *P*-value less than 0·05 was considered as statistical significant level.

Results

As demonstrated in Table 1, the general characteristics of participants across the quartiles of LCD scores are provided. Mets prevalence was estimated as 40·5 % among total population, and the prevalence across the quartiles of LCD was reported in Table 1. Those with higher LCD score were less likely to have Mets and more likely to be more active ($P < 0·05$). No other significant difference has been observed across the quartiles of LCD scores.

Table 2 provides selected food groups and nutrient intake across the quartiles of LCD scores. Participants in the highest quartile of the LCD score had increased intakes of vegetables, legumes, dairy products, red meat, poultry, fish, eggs, nuts and nutrients such as protein and fat in comparison to the lowest quartiles ($P < 0·05$). A significant difference was found across the quartiles of LCD scores for consumption of fruit, whole and refined grains and carbohydrate ($P < 0·05$), while no significant difference was observed in terms of total energy intake.

LCD score and Mets and its components

The OR for developing Mets and its components according to quartiles of the LCD score is presented in Table 3. After adjustment for various confounders such as history of chronic disease, age, marital status, education level, smoking status, total energy intake and physical activity level, it was observed that individuals in the highest quartile of LCD score had 31 % significant lower chances of developing Mets than lowest quartile (OR: 0·69, 95 % CI (0·52, 0·92)). It remained significant even after further adjustment for BMI (OR: 0·68, 95 % CI (0·50, 0·92)). Similarly, the results based on the gender showed a significant decrease in odds of Mets in men in the highest quartiles of LCD score than lowest quartile (OR: 0·57, 95 % CI (0·37, 0·90)) after adjusting for potential confounders. Additional adjustment for BMI remained significant (OR: 0·54, 95 % CI (0·34, 0·86)). Moreover, in women, it was observed that the chance of Mets in the second quartile of LCD score was 41 % lower than those in the first quartile (OR: 0·59, 95 % CI (0·38, 0·90)) after adjustment for confounding variables. This association did not change after additional adjustment for BMI (OR: 0·53, 95 % CI (0·34, 0·86)). No other significant association has been found.

Higher LCD score in the third quartile in men reduced abdominal obesity significantly by 47 % after adjustment for all the confounders including BMI (OR: 0·53, 95 % CI (0·28, 0·99)). Furthermore, significant reduction in low HDL-cholesterol was observed in the highest quartile of LCD adherence compared to the first quartile in all participants (OR: 0·74, 95 % CI (0·56, 0·99)) and in men (OR: 0·63, 95 % CI (0·40, 0·98)) after adjusting for all the potential confounder variables.

Discussion

The present research showed a significant protective association between LCD score and odds of Mets after adjustment for potential confounding variables. Higher LCD score was also associated with lower chance of HDL-cholesterol in all participants and specifically men. Moreover, these health benefit effects were observed for abdominal obesity only in the male population.

Previous researches on the association of LCD score and the risk of Mets are limited[35–37]. Studies suggest that consumption of diets with high carbohydrate and less fat in patients with non-alcoholic fatty liver disease is associated with higher risk of Mets, obesity and type 2 diabetes in men[36,38,39]. Furthermore, observational studies in Korean[40,41], Japanese[42] and Chinese populations[43] show that high carbohydrate intake is associated with high levels of Mets and type 2 diabetes. In line with our results, a recent study among Iranian adults reported a significant association between LCD and Mets risk[7]. However, in contrast to our study, a study by Eslamian *et al.* did not report any significant relation between LCD score and Mets[44], and also Shirani *et al.* did not find any significant association between scores of LCD and Mets among Iranian women[1].

Our study found a significant inverse relation between LCD and abdominal obesity only in men. Similar to our results, one cross-sectional study by Jafari-Maram *et al.* in Iranian women showed no significant relationship

Table 1 General characteristics of participants according to quartiles of LCD score

	Quartiles of LCD score (total *n* 2074)					
	All (*n*) (*n* 2074)	Q1 (*n* 563)	Q2 (*n* 443)	Q3 (*n* 567)	Q4 (*n* 501)	
	n	%	%	%	%	*P*-value
Age (year)						
20–29	448	26·3 %	20·8 %	29·0 %	23·9 %	0·14
30–39	487	28·1 %	21·6 %	25·9 %	24·4 %	
40–49	521	22·8 %	22·3 %	29·9 %	25·0 %	
50–59	379	32·5 %	18·2 %	25·9 %	23·5 %	
60–69	227	28·2 %	26·4 %	22·9 %	22·5 %	
Gender						
Male	996	28·2 %	20·8 %	27·2 %	23·8 %	0·71
Female	1069	26·1 %	22·1 %	27·3 %	24·5 %	
Education						
Illiterate	415	29·4 %	21·0 %	23·4 %	26·3 %	0·16
Lower than high school diploma	632	27·4 %	21·4 %	29·1 %	22·2 %	
High school diploma or college	653	26·8 %	20·2 %	29·7 %	23·3 %	
University	355	24·2 %	24·2 %	24·2 %	27·3 %	
Smoking status						
Never smoker	1805	26·9 %	21·3 %	27·4 %	24·4 %	0·96
Current smoker	175	28·6 %	21·1 %	26·3 %	24·0 %	
Ex-smoker	37	18·9 %	24·3 %	29·7 %	27·0 %	
Marital status						
Single	224	26·8 %	21·0 %	28·6 %	23·7 %	0·86
Married	1775	27·3 %	21·5 %	26·8 %	24·3 %	
Widowed or divorced	69	24·6 %	17·4 %	34·8 %	23·2 %	
Mets						
Yes	840	29·0 %	20·6 %	28·5 %	21·9 %	*0·04
No	1138	25·2 %	22·4 %	26·2 %	26·2 %	
Abdominal obesity						
Yes	852	29·0 %	21·1 %	27·3 %	22·5 %	0·29
No	1201	25·7 %	21·7 %	27·1 %	25·4 %	
High blood pressure						
Yes	1386	27·3 %	27·8 %	23·4 %	0·46	
No	607	26·0 %	21·6 %	25·9 %	26·5 %	
Hyperglycemia						
Yes	594	28·4 %	18·8 %	26·9 %	25·9 %	0·25
No	1479	26·6 %	22·4 %	27·5 %	23·5 %	
Hypertriglyceridemia						
Yes	1293	27·4 %	20·3 %	28·5 %	23·8 %	0·32
No	781	26·8 %	23·0 %	25·5 %		
Low HDL-cholesterol						
Yes	729	28·0 %	21·4 %	28·3 %	22·4 %	0·52
No	1336	26·6 %	21·5 %	26·7 %	25·1 %	
BMI (kg/m^2)						
Median	26·5	26·7	26·5	26·6	26·1	0·44
IQR	23·5–29·9	23·0–30·0	23·6–30·1	23·3–29·8	23·4–29·4	
Physical activity level (Met/h/week)						
Median	106·1	99·0	102·8	106·1	125·7	*0·04
IQR	35·4–183·1	31·3–166·4	35·4–184·3	41·3–191·1	42·4–192·9	

LCD, low-carbohydrate diet; IQR, interquartile range.
*Comparisons were performed using χ^2 or Kruskal–Wallis tests for categorical and continues variables, respectively.
$P < 0·05$ was considered as a significance level.
Data were presented as *n* (%) for categorical variables or median and IQR for continues variables.

between LCD and obesity[9]. However, contrary to our finding, a meta-analysis reported that carbohydrate intake did not have any effect on the risk of obesity[45]. Mixed results regarding the association between LCD and obesity are also reported[46–49] A limited number of studies have assessed the effects of LCD on abdominal fat loss and, therefore, the improvement in cardiovascular factors in both obese and none obese individuals[50]. As suggested by Brinkworth *et al.*, LCD can decrease abdominal fat mass by approximately 30 %[51].

This study found a significant relationship between LCD score and OR of low HDL-cholesterol in all the participants and in men. Just like what has been mentioned above, previous investigations have shown controversial results. Several studies reported that despite a low-fat intake, a high-carbohydrate diet can positively associate with a low HDL-cholesterol level and an increased risk of Mets[20,41]. These findings similar to our results are also in accordance with previous Randomized clinical trial that indicated an improvement in levels of HDL-cholesterol after the

Table 2 Dietary intakes of participants according to quartiles of LCD score

	Quartiles of LCD score										
	All (*n* 2074)		Q1 (*n* 563)		Q2 (*n* 443)		Q3 (*n* 567)		Q4 (*n* 501)		
*Dietary intakes	Median	IQR	Median	IQR	Median	IQR	Median	IQR	Median	IQR	***P*-value
Total energy (kcal/d)	2479·5	1868·3–3613·4	2412·8	1865·6–3744·0	2294·4	1800·1–3595·0	2431·8	1862·1–3514·1	2810·9	2037·2–3695·6	0·07
Carbohydrates (g/d)	337·6	257·7–496·2	380·4	289·5–634·1	331·5	260·3–541·6	330·1	250·3–463·7	304·6	219·0–403·4	***P* < 0·001
Proteins (g/d)	98·7	73·9–136·9	82·1	65·5–113·8	90·7	70·9–123·0	101·9	79·6–134·9	129·8	93·3–180·5	***P* < 0·001
Fats (g/d)	89·0	61·1–145·7	65·8	52·7–113·8	74·0	58·8–140·3	93·9	67·5–146·3	120·5	83·6–167·7	***P* < 0·001
Whole grains (g/d)	60·1	25·2–93·4	82·7	26·9–122·2	74·4	30·2–95·7	56·6	23·0–92·3	44·2	20·4–87·1	***P* < 0·001
Refined grains (g/d)	180·1	114·2–289·2	241·1	128·3–307·1	166·3	99·0–289·0	174·5	116·7–277·2	167·5	104·6–273·9	***P* < 0·001
Vegetables (g/d)	210·8	146·5–340·6	193·8	133·3–322·7	196·0	142·2–317·0	230·1	155·2–339·0	239·2	154·5–383·3	***P* < 0·001
Fruits (g/d)	420·4	272·7–705·6	496·7	315·7–833·4	413·9	293·3–667·6	401·9	255·6–654·6	373·7	226·3–655·2	***P* < 0·001
Legumes (g/d)	32·5	22·2–51·7	27·3	20·0–46·1	33·2	23·2–53·7	33·7	23·1–52·0	34·6	24·4–53·4	***P* < 0·001
Dairy products (g/d)	191·2	126·0–302·1	175·8	110·1–265·2	193·9	120·8–294·2	194·2	132·0–312·7	216·8	146·8–346·9	***P* < 0·001
Red meat (g/d)	39·0	20·2–66·6	31·0	14·1–54·5	35·3	17·7–61·0	41·6	23·3–69·9	61·0	34·7–97·0	***P* < 0·001
Poultry (g/d)	27·3	14·7–19·9	23·7	11·1–39·2	27·3	14·7–51·0	39·2	15·4–74·8	62·9	27·3–146·0	***P* < 0·001
Fish (g/d)	9·4	3·5–19·9	5·6	2·4–14·3	7·0	3·6–15·2	10·6	3·7–28·6	10·0	3·5–24·1	***P* < 0·001
Eggs (g/d)	17·2	8·0–51·5	17·2	4·0–25·7	17·2	4·0–51·5	25·7	8·6- 51·5	25·7	8·0–51·5	***P* < 0·001
Nuts (g/d)	12·1	6·4–26·2	10·8	5·5–18·8	12·7	99·0–289·0	13·0	7·3–29·2	11·7	6·2–32·5	***P* < 0·001

LCD, low-carbohydrate diet; IQR, interquartile range.
*Data were presented as median and IQR.
**Comparisons were performed using Kruskal–Wallis test.
$P < 0·05$ was considered as a significance level.

Table 3 Multivariable-adjusted OR for metabolic syndrome and its components across quartiles low-carbohydrate diet (LCD) score

	Quartiles of LCD score						
	Q1 (*n* 563)	Q2 (*n* 443)		Q3 (*n* 567)		Q4 (*n* 501)	
	OR (95 % CI)	OR	95 % CI	OR	95 % CI	OR	95 % CI
Metabolic syndrome							
Model 1							
All	Reference	0·81	0·61–1·09	0·95	0·72–1·26	*0·69	0·52–0·92
Men	Reference	0·94	0·60–1·46	0·84	0·56–1·27	*0·57	0·37–0·90
Women	Reference	*0·59	0·38–0·90	0·96	0·64–1·46	0·69	0·46–1·05
Model 2							
All	Reference	0·74	0·54–1·01	0·90	0·67–1·21	*0·68	0·50–0·92
Men	Reference	0·91	0·57–1·45	0·80	0·52–1·24	*0·54	0·34–0·86
Women	Reference	*0·53	0·34–0·82	0·94	0·62–1·44	0·74	0·48–1·12
Abdominal obesity							
Model 1							
All	Reference	0·94	0·70–1·27	0·98	0·74–1·30	0·83	0·62–1·12
Men	Reference	0·69	0·42–1.	0·72	0·45–1·15	0·82	0·51–1·32
Women	Reference	0·92	0·59–1·42	1·07	0·71–1·62	0·70	0·46–1·06
Model 2							
All	Reference	0·80	0·55–1·17	0·89	0·611·23	0·82	0·57–1·17
Men	Reference	0·61	0·31–1·20	*0·53	0·28–0·99	0·73	0·39–1·38
Women	Reference	0·79	0·46–1·33	1·07	0·65–1·77	0·79	0·48–1·29
High blood pressure							
Model 1							
All	Reference	0·96	0·70–1·32	1·14	0·85–1·54	0·80	0·59–1·09
Men	Reference	1·18	0·70–1·99	0·99	0·62–1·59	0·78	0·49–1·26
Women	Reference	0·80	0·52–1·23	1·28	0·84–1·94	0·86	0·57–1·29
Model 2							
All	Reference	0·92	0·66–1·27	1·12	0·83–1·53	0·82	0·60–1·11
Men	Reference	1·11	0·64–1·87	0·94	0·58–1·54	0·75	0·46–1·23
Women	Reference	0·77	0·50–1·20	1·29	0·85–1·97	0·91	0·60–1·39
Hyperglycemia							
Model 1							
All	Reference	0·84	0·61–1·16	0·86	0·63–1·16	1·11	0·78–1·43
Men	Reference	0·82	0·51–1·32	0·83	0·53–1·28	0·96	0·61–1·49
Women	Reference	0·85	0·54–1·34	0·91	0·59–1·40	1·14	0·74–1·76
Model 2							
All	Reference	0·82	0·59–1·14	0·86	0·63–1·16	1·09	0·80–1·49
Men	Reference	0·82	0·50–1·34	0·85	0·55–1·33	0·98	0·63–1·54
Women	Reference	0·82	0·52–1·30	0·89	0·57–1·38	1·19	0·77–1·84
Hypertriglyceridemia							
Model 1							
All	Reference	0·94	0·70–1·26	1·03	0·78–1·37	0·95	0·71–1·26
Men	Reference	1·06	0·70–1·61	0·96	0·65–1·41	0·81	0·54–1·20
Women	Reference	0·77	0·50–1·19	1·06	0·69–1·61	1·04	0·68–1·60
Model 2							
All	Reference	0·99	0·74–1·35	1·06	0·80–1·41	0·94	0·70–1·25
Men	Reference	1·10	0·72–1·70	0·98	0·66–1·47	0·82	0·55–1·24
Women	Reference	0·82	0·52–1·28	1·06	0·69–1·64	0·99	0·64–1·53
Low HDL-cholesterol							
Model 1							
All	Reference	0·86	0·64–1·15	0·91	0·69–1·19	*0·75	0·57–0·99
Men	Reference	0·82	0·53–1·29	1·01	0·67–1·52	0·64	0·41–1·01
Women	Reference	0·84	0·56–1·24	0·83	0·57–1·21	0·80	0·55–1·17
Model 2							
All	Reference	0·82	0·62–1·10	0·89	0·68–1·17	*0·74	0·56–0·99
Men	Reference	0·78	0·49–1·22	0·97	0·64–1·47	*0·63	0·40–0·98
Women	Reference	0·81	0·54–1·20	0·83	0·57–1·21	0·81	0·55–1·20

Model 1: Adjusted for history of chronic disease, age, marital status, education level, smoking status, total energy intake and physical activity level (MET/min/week).
Model 2: Model 1 + BMI.
*$P < 0{\cdot}05$ was considered as a significance level.

administration a LCD[15,52]. Additionally, the recent Japanese[53] and Korean studies[22] have found that higher LCD scores had positive effects on HDL-cholesterol and dyslipidemia level, regardless of the food source. However, in contrast to our findings, in some studies that were conducted among Iranian adults, no significant association was reported between HDL-cholesterol and LCD score[1,7].

In the light of what has been mentioned above, multiple systematic review studies have shown that LCD score is negatively related to hypertension and low HDL-cholesterol[54,55].

Even though we did not observe any significant association between hypertension or any of the other components of Mets with LCD score in the present study which might be due to different study design (randomised clinical trial *v.* cross-sectional study), carbohydrate proportion and population characteristics, most of the studies included in these systematic reviews were conducted in Western countries in which a LCD is defined differently[15,52].

In Iranian population, consuming a large portion of food with carbohydrate base such as grains, rice and potatoes accompanied by food containing simple sugar is very common which contribute to the incident or development of the cardiovascular risk factors[23–27]. In this study, LCD is defined as a relatively lower percentage of carbohydrate intake, accompanied by higher percentage of protein and fat intake, in which each macronutrient may affect the risk of Mets differently[33,34]. Subjects with high scores of LCD consume more food groups such as vegetables, legumes, dairy products, red and white meat (poultry and fish), and eggs and generally have higher intakes of protein and fat. This could be another possible explanation for the null association outcomes, since the high protein portion which consists of healthy foods such as poultry and fish inversely associates with Mets. On the other hand, the high amount of red and processed meat consumption has direct effects on the incident and development of Mets[37,56,57] and this can lead to neutral results. Therefore, our results are similar to Mediterranean dietary pattern which is rich in vegetables, fish, nuts and legumes and is indicated to reduce the risk of Mets[58]. In contrast, Western dietary pattern is characterised by the high consumption of carbohydrate such as sweet beverage and sugar that is majorly associated with greater odds of increased Mets components[59]. Moreover, the present study reports that participants in high quartiles of LCD score consume less amount of carbohydrate (which consist of whole and refined grains and fruit) in general. This outcome is similar to the findings of multiple studies that suggest individuals with lower intake of simple sugars such as fructose are less susceptible to cardiometabolic disorders including dyslipidemia, insulin resistance, high BP and obesity[60,61]. We also observed that higher scores of LCD were associated with increased intakes of dairy products as well which has further been suggested to be associated with lower risk of Mets[62]. Overall, it seems that participants with higher scores of LCD are less prone to various chronic diseases such as Mets.

With what has been mentioned above, it is reported that Mets is highly carbohydrate-intolerant[63]. Over consumption of carbohydrate is related to high plasma levels of glucose and insulin which is followed by insulin resistance and symptoms of Mets. Since dietary carbohydrate not only serves as a source of energy but also serves as a control element whether directly through glucose or fructose or indirectly as an insulin signalling agent, its decrease can ameliorate markers of Mets more efficiently than a low-fat diet[64]. Low-fat and high-carbohydrate diet are reported to exacerbate Mets[65]. Dietary fat has also a passive role in insulin resistance that contributes to down-regulation due to hyperinsulinemia[66]. Low intake of dietary carbohydrates resulted in decreased carbohydrates-induced insulin and causes the impaired regulation goback to normal levels[64]. Furthermore, LCD diet may be generally associated with lower fructose intake. Fructose consumption has a major role in epidemics of obesity, Mets and type 2 diabetes and is known to be the cause of hypertension, de novo lipogenesis, hepatic insulin resistance and adiposity[67–70]. Additionally, it is worth mentioning that high-carbohydrate diets and consumptions of foods with high glycemic index, especially fructose, can conduct rapid stimulation of lipogenesis, TAG accumulation, adipocyte hypertrophy and macrophage accumulation in adipose tissues that is associated with obesity[18,71]. High blood glucose, a result of high glycemic index foods consumption, is followed by an enhanced need to insulin secretion and consequently impairment in beta cells function and glucose metabolism which accompanied by counter-regulatory insulin secretion and then a number of metabolic disorders and chronic diseases such as Mets[70].

Several key strengths are needed to be taken into consideration. To the best of our knowledge, this is the first study that evaluated the association between LCD and Mets in a larger sample of Iranian adults with various confounders being controlled in different models. In the present study, a validated FFQ was also used which was based on a list of food items and list of specific foods that are commonly consumed in the study population. Moreover, dietary assessments were achieved by professional interviewers. Our study has several limitations: (i) the cross-sectional design does not show a causal relationship between LCD and Mets; therefore, more prospective studies are needed to be done to truly examine the effect of LCD on Mets in the Iranian population. Moreover, the subjects with Mets may have modified their diet towards improvement for reduction of disease complications due to cross-sectional nature of the study. However, we excluded the individuals with chronic disease history to decrease this issue; (ii) despite controlling for various confounders in our analyses, other confounding factors due to unknown or unmeasured confounders cannot be ignored; (iii) since dietary assessments in this study were based on FFQ, misclassification of study participants might be occurred; (iv) although socio-demographic characteristics of the population including age, gender, education, marital status and smoking status were evaluated, we did not assess economic status; and (v) it should be considered that the study participants were selected from municipal areas of Yazd city. Thus, the findings generalisation may be done with caution.

In conclusion, our findings suggest that adherence to LCD may be associated with lower chances of Mets and some of its component such as HDL-cholesterol levels and abdominal obesity in men. Further large-scale researches, especially cohort studies, are highly recommended to clarify the nature of the observed associations.

Acknowledgements

Acknowledgements: The authors thank Nutrition and Food Security Research Center, Shahid Sadoughi University of Medical Sciences, Yazd, Iran, to support this study. *Financial support:* This study supported by Nutrition and Food Security Research Center, Shahid Sadoughi University of Medical Sciences, Yazd, Iran (Number: 7943). *Conflict of interest:* The authors declare that they have no conflict of interest. *Authorship:* M.H., A.N. and M.M. designed the study. Z.S.S. and E.L. conducted the statistical analysis. Z.S.S. and E.L. wrote the draft of manuscript. M.H., A.N. and M.M. critically revised the manuscript and confirmed the final version of it to submit. All authors read the final version of the manuscript and approved it. *Ethics of human subject participation:* The research was approved by the Ethics Committee of Shahid Sadoughi University of Medical Sciences, Yazd, Iran (Ethical approval code: IR.SSU.SPH.REC.1399.159, Date: 16 September 2020). Written informed consents were also obtained from all subjects.

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