Low Carbohydrate Diet Score and the Risk of Metabolic Syndrome in Chinese Adults

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Research

Keywords: low carbohydrate, high fat, low carbohydrate diet score, metabolic syndrome, Chinese adults

Posted Date: June 1st, 2021

DOI: https://doi.org/10.21203/rs.3.rs-510156/v1

Abstract

Previous studies on estimated associations between low carbohydrate diet (LCD) score and metabolic syndrome (MetS) are inconsistent. We aim to assess the association between LCD score and MetS in a Chinese population.

A multi-stage random sampling method was applied and a total of 1993 participants aged more than 18 years from a cross-sectional study in Nanjing, Jiangsu Province were accessed. Dietary intake was evaluated using a consecutive 3-d, 24-h dietary recall combined with the condiments weighing method.LCD scores, including usual, animal-based, and plant-based LCD scores, were calculated based on energy, carbohydrate, fat, and protein intake by sex.

In multivariate regression analyses adjusted for age, total energy intake and other potential confounders, the usual LCD score significantly increased risk of MetS in men [the highest quartile vs. lowest quartile: odds ratio (OR): 1.75; 95% confidence interval (CI): 1.07–2.87, $P_{\text{for trend}} < 0.05$]. Furthermore, a significant trend was found between plant-based LCD score and the MetS in men ($P_{\text{for trend}} < 0.05$). Among the components of the MetS, higher usual LCD score increased the risk of central obesity, hyperglycemia and hypertriglyceridemia in men, meanwhile animal-based LCD score was positively associated with the risk of central obesity, and plant-based LCD score was positively associated with the risk of hyperglycemia in men.

Our results reveal that low carbohydrate and excessive fat diet (even monounsaturated fatty acids and polyunsaturated fatty acids), may increase the risk of MetS and Chinese male is more sensitive to the transition of dietary composition from high carbohydrate to high fat than Chinese female. Further studies are warranted.

1. Introduction

Metabolic syndrome (MetS) is a multifaceted risk factor, which has been shown to be associated with cardiovascular disease (CVD), type 2 diabetes mellitus and all-cause mortality[1, 2]. In China, as its dramatically increasing prevalence and socioeconomic burden, the MetS has received widespread research attention. In 2000–2001, a cross-sectional study showed that the prevalence of MetS in Chinese adults was 9.8% in men and 17.8% in women [3], which has increased to 33.9% (31.0% in men and 36.8% in women) by 2010[4]. At the same time, the traditional dietary patterns in China characterized with high intake of plant foods, high carbohydrate, and very low fat diet have transited to a Western diet with high animal foods, high edible oil, high fat and less cereals. Chinese population has experienced a transition from malnutrition to over-nutrition due to rapid economic growth [5, 6]. From 1991 to 2011, the percentage of energy intake from fat increased from 10–32% and this percentage rose up to 37% in some megacities. Meanwhile, the percentage of energy intake from carbohydrate dropped significantly from 66–54%, and 47% in megacities[6], which is comparable to the latest national observations in the United States, with 33% of energy from fat and 51% of energy from carbohydrate[7].

In recent years change of dietary patterns, coupled with reduced physical activity, has contributed to the explosive growth of obesity and other chronic diseases in China [8, 9]. Epidemiologic and experimental studies have shown that high fat and relatively low carbohydrate diets may promote weight gain, and increase the risk of type 2 diabetes and cardiometabolic disease [10, 11]. Currently, World Health Organization (WHO) recommends a low-fat diet (< 30% of energy) and limited saturated fat (< 10% of total energy) and encourages substituting saturated fat into unsaturated fat. However, western and some asian countries has recently claimed that reducing carbohydrate intake and increasing fat intake are beneficial to health, such as weight loss and reducing the risk of cardiometabolic diseases[12–14]. Some studies have shown that carbohydrate restriction rather than fat intake reduction should be taken into consideration optimal nutritional approach to decrease the risk of obesity and cardiometabolic disease[15]. These different findings may differ because of ethnicity or dietary factors in different countries. Thus, the association of macronutrient intake with disease in Chinese is of great interest.

Halton et al [16] created the low carbohydrate diet score (LCD score) according to macronutrient of fat, protein and carbohydrate intake, which may be more appropriate to explain the relationship between diet and diseases[17, 18]. However, available researches are sparse on the relationship between LCD score and MetS [19–22]. This study aims to examine LCD scores in relation to the MetS as well as its components among Chinese adults. To our knowledge, this is the first population-based study to examine the relationship between the LCD score and the MetS risk in China.

2. Methods

2.1 Participants

The study was based on the data from the 5th Chinese national nutrition and health survey, which was collected from 2010 to 2013. Detailed methods of the study have been described elsewhere [23].

A total of 2272 eligible participants (1077 men and 1195 women from 1062 households) aged 18 years or older participated in the 3-d, 24-h dietary recalls. We excluded 279 participants without information on laboratory examination or implausible information about energy intake (< 500kcal/day or > 5000 kcal/day). Finally, 1993 adults (907 men and 1086 women) were included in the final analysis. The present study was approved by the Medical Ethics Committee of the Chinese Centre of Disease Control and Prevention, and written consents were obtained from all participants.

2.2 Dietary assessment

Dietary intake was assessed by consecutive 3-d, 24-h dietary recall combined with cooking oil and other condiments weighing method, including two weekdays and one weekend day. Home condiment consumption (including cooking oil, salt, monosodium glutamate, soy sauce and other condiments) in each household was weighed on the same three days. According to the ratio of individual energy intake divided by the energy intake of all family members, the percentage of the oil and condiments of each family member was calculated. The energy and macronutrient intake were calculated using the Chinese Food Composition Table (2nd ed.)[24].

Usual LCD score was calculated with the method developed by Halton et al[16]. Data was presented as percentage of total energy. Participants were divided into 11 strata for carbohydrate, fat, protein by sex. Participants in the highest stratum of fat and protein intake received 10 points, and those in the lowest stratum received 0 points. While for carbohydrate intake, the order of the strata was opposite. The points of each macronutrient were summed to express the overall diet score (range 0–30). Therefore, the higher LCD score, the more likely the participant was to have a low-carbohydrate diet. The animal-based LCD scores were created for animal protein and animal fat, and plant-based LCD scores for plant protein and plant fat [16].

2.3 Measurement of non-dietary variables

The sociodemographic factors and health behaviors of participants were collected via the face to face interview, including site (urban area, rural area), sex, age, educational level (primary school or below, junior or middle school, and high school or more). The health behavioral variables included current drinking habit (a daily alcohol drinking more than 0g for the past one month), current smoking habit (current smoker for the past one month), and physical activity were collected. Physical activity was classified as low (< 600 MET-min/week), moderate (600–2999 MET-min/week), or high (≥ 3000MET-min/week) according to metabolic equivalent of task minutes per week (MET-min/week).

Anthropometric variables including body weight, height, waist circumference (WC) and blood pressure were measured for each participant by trained staffs using standard protocols and calibrated instrument. Body mass index (BMI) was calculated as weight (kg) divided by height square (m^2). Blood pressure was measured twice with a mercury sphygmomanometer and then averaged, after 5 min of rest in the sitting posture. Meanwhile, fasting blood glucose, total cholesterol (TC), triglycerides (TG) and HDL-cholesterol were measured using the Hitachi 7180 auto-analyzer (Hitachi, Tokyo, Japan). And each participant received an 75g oral glucose tolerance test (OGTT), except for those with a known diagnosis of diabetes.

2.4 Definition of metabolic syndrome

Based on the American Heart Association and the National Heart, Lung and Blood Institute scientific statement[25] and criterion of WC for Asians[26], the MetS was defined as the presence of three or more of the following metabolic abnormalities: (1) High blood pressure: SBP/DBP ≥ 130/85mmHg or on antihypertensive drug treatment for a history of hypertension; (2) hyperglycemia, fasting glucose level ≥ 5.56 mmol/l (100 mg/dl) or on drug treatment with elevated blood glucose; (3) central obesity: WC ≥ 90 cm for men and WC ≥ 80 cm for women; (4) hypertriglyceridemia: triglyceride level ≥ 1.7 mmol/l (150 mg/dl) or on drug treatment for this lipid abnormality; and (5) low HDL-cholesterol: HDL-cholesterol < 1.03 mmol/l (40 mg/dl) for men and HDL-cholesterol < 1.3 mmol/l (50 mg/dl) for women or on drug treatment for reduced HDL-cholesterol.

2.5 Statistical analysis

All statistical analyses were stratified by sex and performed using the Statistical Package for Social Sciences software version 17.0.

The subjects were divided into quartiles based on LCD score, and then the prevalence of the MetS and its related components of the quartiles were compared. Across quartiles of three LCD scores, differences among groups of continuous variables were examined by one-way ANOVA, and comparisons between categorical variables were performed with the χ^2 test.

For further analysis, the association between LCD score and the risk of the MetS and its components was assessed using multivariable-adjusted logistic regression models. LCD scores were divided into quartiles, with the lowest (Q1) as the reference group. Odds ratios (ORs) and 95% CI were calculated. Model 1 was adjusted for age, and area of residence. Model 2 was further adjusted for education level, physical activity, smoking and drinking status, BMI (< 22, 22-22.9, 23-24.9, 25-26.9, ≥ 27) and use of anti-diabetic medications, hypolipidemicand anti-hypertension medication and total energy intake. Linear regression analysis was used to test for trend across LCD score quartiles. Statistical significance was considered when $P < 0.05$ (two-sided).

3. Results

3.1 Characteristic of the study subjects

Overall, 1993 individuals were enrolled in the present study (907 men and 1086 women). On average, about 50% of energy intake was from carbohydrate, 14% from protein and 36% from fat in the study population.

General characteristics of the subjects were shown in Table 1 by quartiles of the three types of LCD scores and potential confounding variables for men and women. In both men and women, participants with a higher score of low-carbohydrate diet were more likely urban residents, younger and a higher education levels (except for plant-based LCD score group).

Table 1
Characteristics of participants by quartiles of usual, animal-based, and plant-based LCD score(Mean values and standard deviations and percentages)

	Usual LCD			Animal-based LCD			Plant-based LCD		
	Q 1(low)	Q 4(high)	$P_{\text{for trend}}$	Q 1(low)	Q 4(high)	$P_{\text{for trend}}$	Q 1(low)	Q 4(high)	$P_{\text{for trend}}$
Men (907)	(n = 248)	(n = 213)		(n = 227)	(n = 207)		(n = 247)	(n = 174)	
Age (years)	59.7±12.8	55.1±14.0	< 0.001	60.7±13	54.1±14	< 0.001	56.5±14	58.8±13.5	0.066
BMI (kg/m^2)	24.0±3.2	24.5±2.9	0.062	24.1±3.2	24.6±2.9	0.078	24±3.2	24.3±3.1	0.224
Urban (%)	53.6	80.8	< 0.001	55.1	78.7	< 0.001	57.9	75.9	< 0.001
Education (%)			< 0.001			< 0.001			0.575
Primary school or below	27.0	19.2		30.4	17.9		24.7	25.9	
Junior school	40.3	28.6		42.3	27.1		35.2	36.2	
High school/university	32.7	52.1		27.3	55.1		40.1	37.9	
Current smoking (%)	52.4	56.8	0.360	55.9	58.5	0.681	55.5	56.3	0.923
Current drinking (%)	54.0	53.1	0.692	52.9	55.6	0.540	51.8	48.3	0.568
Physical activity (%)			0.449			0.707			0.670
Low	17.4	10.8		19.0	10.6		14.2	14.9	
Moderate	32.4	49.3		30.5	49.3		40.2	44.3	
High	50.2	39.9		50.4	40.1		45.5	40.8	
Antihypertensive drug use (%)	25.4	26.8	0.675	26.9	27.5	0.997	23.9	25.3	0.693
Hypoglycemic drug use (%)	6.0	7.5	0.402	5.3	4.8	0.858	5.3	10.3	0.023
Lipid-lowering drug use (%)	2.4	4.7	0.218	1.8	4.8	0.058	2.0	3.4	0.347
Women (1086)	(n = 314)	(n = 262)		(n = 301)	(n = 207)		(n = 300)	(n = 225)	
Age (years)	57.0±13.2	53.4±14.3	< 0.001	57.4±13	52±15.3	< 0.001	55.1±14	55.7±13.2	0.549
BMI (kg/m^2)	24.0±3.2	24.5±2.9	0.882	24.5±3.5	23.9±3.5	0.24	24.3±3.2	24.9±3.5	0.021
Urban (%)	51.9	86.3	< 0.001	52.0	85.4	< 0.001	64.3	79.6	< 0.001
Education (%)			< 0.001			< 0.001			0.015
Primary school or below	51.6	22.9		52.0	21.7		42.7	32.4	
Junior school	30.6	34.0		29.8	31.9		29.7	34.7	
High school/university	17.8	43.1		18.2	46.5		27.7	32.9	
Current smoking (%)	1.6	4.2	0.252	2.3	3.5	0.300	2.3	3.1	0.541
Current drinking (%)	7.3	10.3	0.193	9.3	9.1	0.932	7.7	8.4	0.860
Physical activity (%)			0.625			0.184			0.045
Low	16.0	11.1		13.3	13.4		18.0	8.9	
Moderate	13.4	23.0		12.6	26.5		14.3	17.4	
High	70.6	65.9		74.1	60.1		67.7	73.7	
Antihypertensive drug use (%)	28.7	22.5	0.095	29.8	20.1	0.006	25.7	25.3	0.877
Hypoglycemic drug use (%)	8.3	8.8	0.800	8.6	5.9	0.254	8.0	9.8	0.209
Lipid-lowering drug use (%)	4.1	4.6	0.640	4.6	5.1	0.960	4.7	5.3	0.623

3.2 Associations of LCD scores with nutrients and food items

Nutritional variables of participants by quartiles of the three types of LCD score in men and women were shown in Table 2. Men and women who adhered to a higher score of low-carbohydrate diet consumed less cereal and cereal product and more red meat(except plant-based LCD score group), more vegetable oil with a lower dietary glycemic load, and a higher dietary fat including saturated fatty acids (SPA), monounsaturated fatty acids (MUFA), and polyunsaturated fatty acids (PUFA). Mean intakes of vegetables were higher in higher usual LCD score group in both sexes ($P_{\text{for trend}}$<0.01).No significant difference was found in fruits consumption across quartiles of the three types of LCD scores.

Table 2
Nutrient characteristics of participants by quartiles of the three types of LCD score (Mean values and standard deviations)

	Usual LCD			**Animal-based LCD**			**Plant-based LCD**		
	Q 1(low)	Q 4(high)	P for trend	Q 1(low)	Q 4(high)	P for trend	Q 1(low)	Q 4(high)	P for trend
Men (907)	n = 248	n = 213		n = 227	n = 207		n = 247	n = 174	
Energy (kcal)	1879.5±617.2	1842.4±510.4	0.765	1854.1±635.2	1841.4±508.8	0.610	1923.6±583	2077.4±635.2	0.053
Total carb (%kcal)	61.7±5.9	38.8±4.9	< 0.001	60.5±7.3	40.1±5.9	< 0.001	57.6±9.5	40.3±7.2	< 0.001
Protein (%kcal)	12.3±2.2	15.7±2.7	< 0.001	12.2±2.9	15.9±2.9	< 0.001	14±2.8	13.5±3.7	0.043
Animal protein (%kcal)	4±2.1	9.2±2.8	< 0.001	3.2±1.6	9.7±2.7	< 0.001	6.6±3.3	5.6±2.5	< 0.001
Plant protein (%kcal)	8.3±1.6	6.6±1.7	< 0.001	9±2.7	6.3±1.5	< 0.001	7.4±1.7	7.9±3	0.022
Fat (%kcal)	26.1±5.8	45±5.8	< 0.001	27.7±7.4	43±6.7	< 0.001	28.4±8	45.6±8.3	< 0.001
Animal fat (%kcal)	10.1±5.6	21.4±7.3	< 0.001	7.5±3.9	24.1±5.8	0.064	17±8.4	12.7±5.7	< 0.001
Plant fat (%kcal)	16±7.1	23.6±9.3	< 0.001	20.2±8.3	18.9±8.1	< 0.001	11.4±4.6	32.9±9.3	< 0.001
SPA (%kcal)	5.8±1.6	10.6±1.9	< 0.001	5.5±1.4	10.8±1.8	< 0.001	7.4±2.7	8.9±1.8	< 0.001
MUFA (%kcal)	10.2±3.3	16.7±4	< 0.001	10.7±4	16±3.9	< 0.001	11±3.6	16.9±5.2	< 0.001
PUFA (%kcal)	6.9±3.2	11.8±4.7	< 0.001	8.2±4.1	10.2±4	< 0.001	5.9±2.2	14.8±5.7	< 0.001
GL	213.9±78.8	116.8±31.9	< 0.001	201.7±75.3	122.3±38.9	< 0.001	201.2±80.4	137.1±38.8	< 0.001
Cereal and cereal Products (g/d)	316.4±114.1	174.4±49.6	< 0.001	299.4±109.3	182±58.8	< 0.001	297.1±117.2	206.2±58.2	< 0.001
Vegetables (g/d)	246.8±137.5	279.8±134	0.006	263.4±160.5	288.1±142.7	0.074	260.4±145.2	285.2±166.4	0.134
Fruits (g/d)	44.1±106.9	39.6±66.4	0.354	40.2±99.5	36.9±64	0.967	47.2±101.2	37.3±74.4	0.111
Red meat (g/d)	46.6±40.7	104.1±58.8	< 0.001	35.1±32.1	117.8±55.5	< 0.001	85.6±59.3	71.3±47.7	< 0.001
Vegetable oil (g/d)	24.5±15.3	38.6±23.1	< 0.001	31.8±32.1	31.5±20.8	0.392	18.2±12.4	62.6±39.5	< 0.001
Women (1086)	(n = 314)	(n = 262)		(n = 301)	(n = 207)		(n = 300)	(n = 225)	
Energy (kcal)	1649.8±490.2	1675.4±533	0.283	1657.8±508.5	1621.2±474.4	0.117	1641.8±514.3	1819.7±593.1	< 0.001
Total carb (%kcal)	62±5.5	39.3±4.5	< 0.001	60.2±7.2	41.2±5.8	< 0.001	58±8.9	41±7	< 0.001
Protein (%kcal)	12.4±2.2	16±3.1	< 0.001	12.1±2.3	16.4±3	< 0.001	14.4±2.9	13.8±3.4	0.035
Animal protein (%kcal)	4.1±2.2	9.1±3	< 0.001	3.4±1.7	9.9±2.8	< 0.001	6.9±3.4	5.8±2.5	< 0.001
Plant protein (%kcal)	8.4±1.6	6.9±2.3	< 0.001	8.7±2	6.5±1.5	< 0.001	7.4±1.6	8±2.7	0.01
Fat (%kcal)	26.4±6	45.6±6	< 0.001	28.5±7.7	43.2±7	< 0.001	28.4±7.7	46±8.3	< 0.001
Animal fat (%kcal)	9.7±5.6	21.3±7.6	< 0.001	7.4±3.9	24.4±6	0.021	16.9±8.5	13.3±6.1	< 0.001
Plant fat (%kcal)	16.7±7.5	24.3±9.7	< 0.001	21.1±8.6	18.8±8.9	< 0.001	11.5±4.9	32.7±9.6	< 0.001
SPA (%kcal)	5.7±1.6	10.6±1.9	< 0.001	5.6±1.5	11±1.8	< 0.001	7.4±2.7	9.2±2	< 0.001
MUFA (%kcal)	10.4±3.5	16.6±3.9	< 0.001	11.3±4.4	15.9±3.7	< 0.001	10.8±3.6	16.7±5	< 0.001

Abbreviations:

SPA, saturated fatty acids; MUFA, monounsaturated fatty acids; PUFA, polyunsaturated fatty acids; GL, glycemic load.

	Usual LCD			Animal-based LCD			Plant-based LCD		
PUFA(%kcal)	7.1±3.3	12.3±5	< 0.001	8.4±4	10.3±4.4	< 0.001	6.2±2.5	14.8±5.7	< 0.001
GL	184.2±59.1	104.8±35.6	< 0.001	177.5±60.5	108.5±41.2	< 0.001	168.4±63.8	119.8±38.7	< 0.001
Cereal and cereal Products (g/d)	269±84	153.5±53.6	< 0.001	259.4±86.1	159.5±62.8	< 0.001	247.5±90.9	176.7±56	< 0.001
Vegetables (g/d)	228.8±122	267.6±145.3	0.001	233.7±126.5	266.5±150	0.002	241.2±130.8	261.3±142.1	0.077
Fruits (g/d)	50.2±92.1	50.9±82.6	0.949	52.2±87.2	48.7±75.3	0.756	55.7±98.5	49.7±81.9	0.843
Red meat (g/d)	38.6±34	90.4±53.4	< 0.001	29.8±27.1	103.7±51.8	< 0.001	69.8±53.3	60.6±41.6	0.015

Abbreviations:

SPA, saturated fatty acids; MUFA, monounsaturated fatty acids; PUFA, polyunsaturated fatty acids; GL, glycemic load.

3.3 Association of LCD scores with the metabolic syndrome and its components

Figure 1 and Fig. 2 show the associations of three LCD scores with the prevalence rate of the metabolic syndrome and its components in men and women, respectively. In men, the prevalence rate of the MetS and hyperglycaemia was positively associated with the three LCD scores quartiles after adjusting age (all $P_{\text{for trend}} < 0.05$), and the prevalence rates of the central obesity increased with quartiles of both the usual and animal-based LCD score groups ($P_{\text{for trend}}<0.05$). In women, only quartiles of the plant-based LCD score was positively correlated with hyperglycaemia ($P_{\text{for trend}} < 0.05$). In addition, a direct positive relationship was shown between the mean of the three of LCD score and the number of MetS components in men (all $P_{\text{for trend}} < 0.05$), but not in women (Fig. 3).

In men, the multivariable-adjusted ORs and 95%CIs of the MetS and its components according to the three LCD scores were shown in Table 3. Compared with subjects in the lowest quartile of usual LCD score, multivariable-adjusted ORs (95% CI) for the MetS in Q2, Q3, Q4 were 1.97 (1.21–3.19), 1.88 (1.17–3.03) and 1.75 (1.07–2.87), respectively ($P_{\text{for trend}} < 0.05$). A significant trend was found between plant-based LCD score and the MetS ($P_{\text{for trend}}<0.05$) in model 2. Furthermore, the LCD scores were associated with individual components of the MetS, especially hyperglycemia, central obesity and hypertriglyceridemia. The odds ratios for central obesity were significantly increased with all the three LCD scores in model 2 (all $P_{\text{for trend}}<0.05$), and the subjects in the highest quartiles had 55%-118% increased odds for having central obesity compared with the lowest quartile. The positive association between hyperglycaemia and groups of usual and plant-based LCD score was observed (all $P_{\text{for trend}}<0.05$), but not in animal-based LCD score group. The risk of hypertriglyceridemia was significantly increased with the higher usual LCD score grouponly ($P_{\text{for trend}}<0.05$). The subjects in the highest quartiles had 73% increased odds for hypertriglyceridemia compared with those in the lowest quartile. The above multivariable logistic regression results were for men and no significant association between LCD scores and the MetS and its components in women was found (data not shown).

Table 3

Multivariable-adjusted odds ratio and 95% confidence intervals of metabolic syndrome according to quartiles of three LCD scores in me

	Usual LCD					Animal-based LCD					Plant-based LCD		
	Q 1	Q2	Q 3	Q 4	$P_{\text{for trend}}$	Q 1	Q2	Q 3	Q 4	$P_{\text{for trend}}$	Q 1	Q2	Q 3
Metabolic syndrome													
model 1*	1	1.85(1.22–2.81)	1.96(1.30–2.93)	1.65(1.08–2.54)	0.021	1	1.34(0.89–2.01)	1.50(1.00-2.26)	1.38(0.90–2.11)	0.117	1	1.31(0.88–1.95)	1.5 2.2
model 2§	1	1.97(1.21–3.19)	1.88(1.17–3.03)	1.75(1.07–2.87)	0.045	1	1.26(0.78–2.03)	1.4(0.87–2.25)	1.38(0.83–2.27)	0.186	1	1.15(0.73–1.82)	1.4 2.2
High blood pressure													
model 1	1	1.17(0.78–1.75)	0.98(0.66–1.44)	1.02(0.68–1.54)	0.866	1	0.96(0.64–1.42)	0.88(0.59–1.32)	0.92(0.61–1.41)	0.627	1	1.58(1.07–2.32)	1.1 1.6
model 2	1	1.2(0.78–1.83)	0.99(0.65–1.5)	1.03(0.67–1.59)	0.896	1	0.94(0.62–1.44)	0.84(0.55–1.28)	0.89(0.57–1.4)	0.507	1	1.47(0.98–2.21)	1.0 1.6
Hyperglycaemia													
model 1	1	1.43(0.97–2.12)	1.49(1.02–2.19)	1.55(1.03–2.31)	0.033	1	1.11(0.75–1.64)	1.53(1.04–2.25)	1.28(0.85–1.93)	0.096	1	1.12(0.77–1.64)	1.4 2.1
model 2	1	1.38(0.92–2.07)	1.52(1.02–2.26)	1.53(1.01–2.32)	0.037	1	1.11(0.75–1.66)	1.52(1.02–2.27)	1.25(0.82–1.92)	0.131	1	1.07(0.73–1.58)	1.4 2.1
Central obesity													
model 1	1	1.54(1.03–2.29)	1.88(1.28–2.77)	1.57(1.04–2.36)	0.015	1	1.35(0.91–2.01)	1.68(1.13–2.49)	1.42(0.93–2.15)	0.054	1	1.23(0.84–1.81)	1.5 2.1
model 2	1	1.82(1.02–32.33)	2.18(1.24–3.84)	2.18(1.21–3.94)	0.007	1	1.57(0.88–2.79)	2.00(1.13–3.56)	1.83(1.00-3.34)	0.035	1	0.87(0.51–1.5)	1.5 2.7
Hypertriglyceridemia													
model 1	1	1.61(1.08–2.42)	1.51(1.01–2.24)	1.67(1.10–2.51)	0.027	1	0.96(0.65–1.44)	1.35(0.91-2.00)	1.21(0.80–1.83)	0.159	1	1.57(1.07–2.31)	1.6 2.3
model 2	1	1.60(1.05–2.44)	1.45(0.95–2.2)	1.73(1.13–2.66)	0.027	1	0.95(0.62–1.45)	1.32(0.87-2.00)	1.22(0.79–1.89)	0.17	1	1.43(0.96–2.14)	1.5 2.2
Low HDL cholesterol													
model 1	1	1.88(1.07–3.28)	1.51(0.86–2.64)	1.17(0.64–2.13)	0.867	1	1.03(0.6–1.74)	0.80(0.46–1.39)	0.89(0.51–1.57)	0.504	1	1.56(0.91–2.66)	1.2 2.1
model 2	1	1.64(0.92–2.93)	1.25(0.7–2.24)	1.07(0.58–1.98)	0.852	1	0.88(0.5–1.53)	0.71(0.4–1.25)	0.84(0.47–1.52)	0.433	1	1.43(0.82–2.49)	1.2 2.1

*Model 1 was adjusted for age(continuous), and area of residence (urban, rural).

§Model 2 was adjusted for age(continuous), area of residence (urban, rural), education level (primary school or below, junior school, high school/university), p medial, high), smoking and drinking status, BMI (< 22, 22-22.9, 23-24.9, 25-26.9, ≥ 27), use of anti-diabetic medications, hypolipidemic and anti-hypertension intake.

4. Discussion

In this study, with mean carbohydrate intake relatively low accompanied by a higher fat intake (50% and 36% of total energy, respectively), the usual LCD score was positively associated with the risk of MetS in men. A significant trend was found between plant-based LCD score and the MetS ($P_{\text{for trend}}$<0.05) in men. However, no association between any kind of LCD score and the MetS was found in women. In addition, a direct positively relationship was identified between the mean values of the three LCD scores and the number of MetS components in men, but not in women. It suggests that the usual LCD score may be an independent risk factor for the MetS in men but not in women. Furthermore, the LCD scores were associated with individual components of the MetS in men, especially for central obesity, hyperglycemia and hypertriglyceridemia.

The underlying mechanism of this gender difference was unclear, and possibly it is related to the differences in lifestyle and dietary characteristics between men and women [27–29]. Besides, different food choices in men and women may exist. In Chinese men, there was the existence of an “alcohol” or “animal and fried food” dietary pattern, characterized by animal foods (eg, meat, poultry, fish), fried dough and alcohol[28, 29], which was the main source of total fat, especially saturated fat[30]. Our study showed that intake of alcohol consumption and red meat was higher in men than that in women, despite fat intake was similar. For example, in Q1 of the usual LCD, the drinking rate of men and women was 54% and 7.3% respectively, and the average intake of red meat was 46.6 g and 38.6 g respectively. For Q4, the drinking rate of men and women was 53.1% and 10.3%, and average red meat intake was 104.1 g and 90.4 g, respectively. High alcohol consumption has been confirmed to be positively associated with the risk of MetS and its components[31, 32]. And red meat consumption was related to insulin resistance, lipid peroxidation and metabolic syndrome reported in Brazilian middle-aged men[33].

Epidemiologic researches linking LCD score and the risk for MetS were limited and controversial[19–22]. A cohort study in Tehran showed LCD may be associated with a decreased risk of MetS and its components in adults[19], but not in children and adolescents[20]. And other studies also displayed null association between LCD score and MetS[20, 22]. Our study showed that the high usual LCD score was significantly positively associated with the risk of MetS and its components in men, such as hyperglycaemia, hypertriglyceridemia, central obesity. One of the possible explanations for this controversy in the present study might be related to the composition of LCD, such as the quantity and quality of macronutrients. Low-carbohydrate diets usually have a relatively lower percentage of carbohydrate intake from total energy and a higher percentage of fat intake from total energy. In this study, the average carbohydrate intake and fat intake of the highest quartile groups of the LCD score were 39–40% and 43–46% of total energy in men, respectively, which were different from that in Tehranian adults (53.5% for carbohydrate and 35.2% for fat, respectively) and the Korean adults (46–48% for carbohydrate and 32–33% for fat, respectively). Our study showed that high fat intake of total energy was slightly higher than the recommended levels of China and WHO.

High fat intake has been shown to be positively associated with metabolic syndrome risk[34–36],although the 2015–2020 Dietary Guidelines for Americans emphasize the types of fat rather than total fat intake[37]. In our investigation fat intake of total energy was over 40% in men in the highest quartile groups of the LCD score accompanied with higher consumptions of different types of fats (SFA, MUFA and PUFA). The main types of fat in Chinese diet are MUFA and PUFA, because vegetable cooking oil consumption is the main source of fat for people. However, high LCD score including a high plant-based LCD score were associated with the high incidence of type 2 diabetes in Chinese adults[11]. In the present study similar results were found that a high plant-based LCD score increased the risk of metabolic diseases, such as hyperglycaemia, central obesity and MetS in men, which was inconsistent with the results of western countries[13, 17, 18]. In our study, the vegetable cooking oil is the main source of fat in a high plant-based LCD score, and the vegetable cooking oil intake was up to 63g in men with the highest quartile of the plant-based LCD score, which was two folds as much the recommended maximum intake level (recommended intake is 25-30g). Previous reports showed individuals with a higher total fat intake(> 37E%) did not have beneficial impact from MUFA[38], and only in subjects with a lower total fat intake (< 35E%) was found that the association of changes in estimated desaturase activities with changes in insulin sensitivity[39]. The present study showed that excessive fat intake, even MUFA and PUFA, may be dangerous, and the overall dietary feature should be considered whether it is an animal-based diet or a plant-based diet.

To our knowledge, this is the first epidemiology study examining the association between LCD score and the MetS in Chinese adults who undergoing nutrition transition. As a cross-sectional study of the relatively large sample, this study used the 3 consecutive days of dietary recollection combined with condiments weighing method to evaluate LCD score according to food source and explore the relationship between LCD score and the MetS, adjusting for various potential confounders such as age, sex, smoking, drinking, BMI, physical activity, drug use and total energy intake in the multiple regression models. The overall results are relatively reliable.

The study has several limitations. First, causal relationship can not be identified due to the cross-sectional nature of our data. Second, the observation from our study may not be generalizable to all Chinese populations because of the survey location, which is only one Chinese megacity. Other limitations may include measurement bias and residual confounding, as all other observational studies.

5. Conclusions

In conclusion, low carbohydrate and excessive fat diets, which are far different from the traditional Chinese diet, may increase the risk of MetS and some of its components in male in our study. Prospective studies are needed to explore the effect of low carbohydrate diet on metabolic diseases in Chinese populations in future.

Declarations

Acknowledgments

We thank all participants and investigators to the present study from local Centres of Disease Control and Prevention, including Nanjing, Gulou, Qinhuai, primary Baixia, Yuhuatai, Pukou and Lishui, for their support in the survey implement. Thanks for the expert advice of the English proofreading from Dr. Hui Xia and Prof. Guiju Sun.

Author Contributions

Conceptualization, Baofu Guo, Guoxiang Xie and Nan Zhou; Data curation, Baofu Guo and Xiaocheng Li; Formal analysis, Baofu Guo, Xiaocheng Li and Fangyan Zhu; Investigation, Baofu Guo, Xiaocheng Li, Di Jin, Yanli Wang, Yun Jiang, Baichun Zhu and Liankai Ma; Methodology, Baofu Guo, Xiaocheng Li and Hui Zuo; Project administration, Baofu Guo and Di Jin; Writing – original draft, Baofu Guo; Writing – review & editing, Hui Zuo and Nan Zhou.

Funding

This research was funded by Nanjing Municipal Medical Science and Technology Development Foundation, grants number YKK17194 and 201108006.

Availability of data and materials

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

Ethics approval and consent to participate

This report was approved by the Medical Ethics Committee of the Chinese Centre of Disease Control and Prevention.

Consent for publication

Not applicable.

Conflicts of Interest

The authors declare no conflict of interest.

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Figures

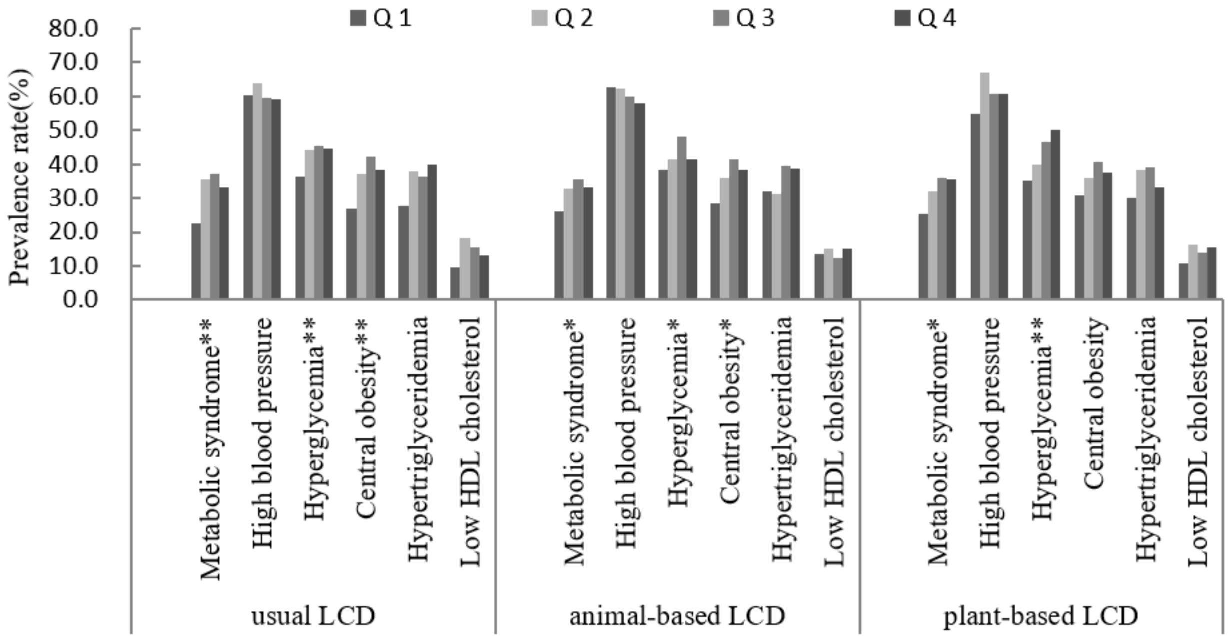

Figure 1

Prevalence rates of the metabolic syndrome and its components in different LCD score quartiles adjusting for age in men. (*P for trend<0.05, **P for trend<0.01)

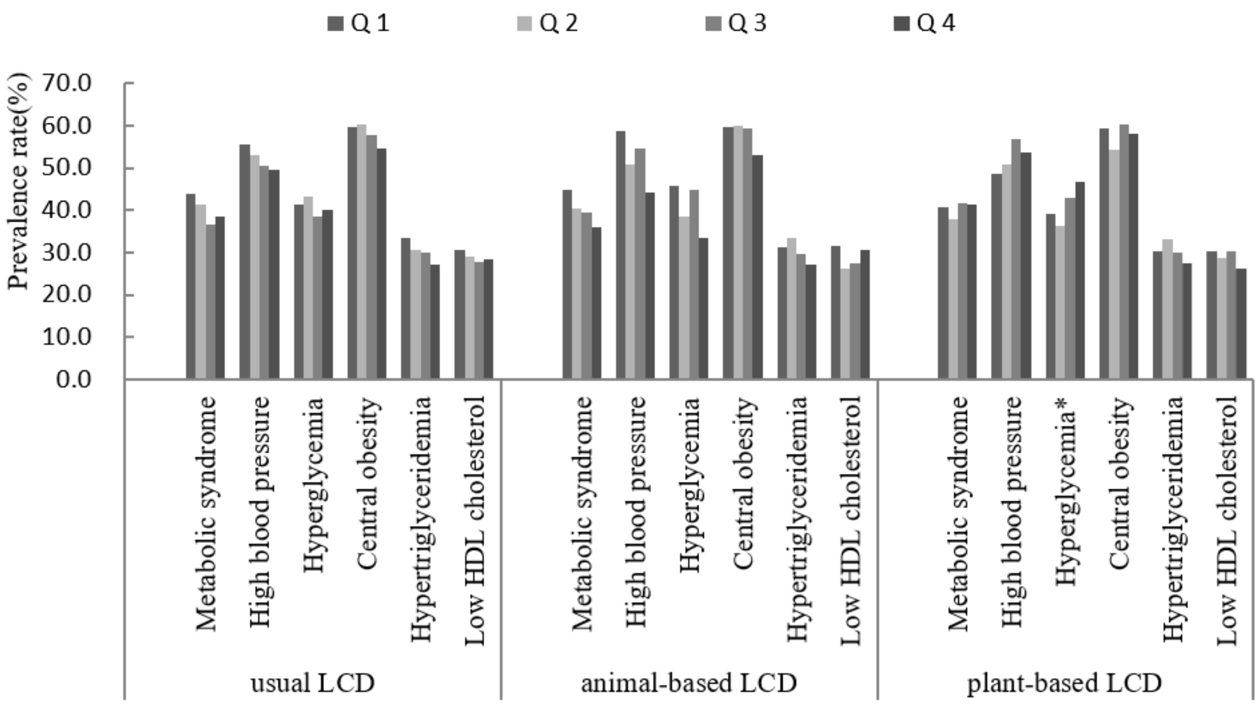

Figure 2

Prevalence rates of the metabolic syndrome and its components in different LCD score quartiles adjusting for age in women. (*P for trend<0.05, **P for trend<0.01)

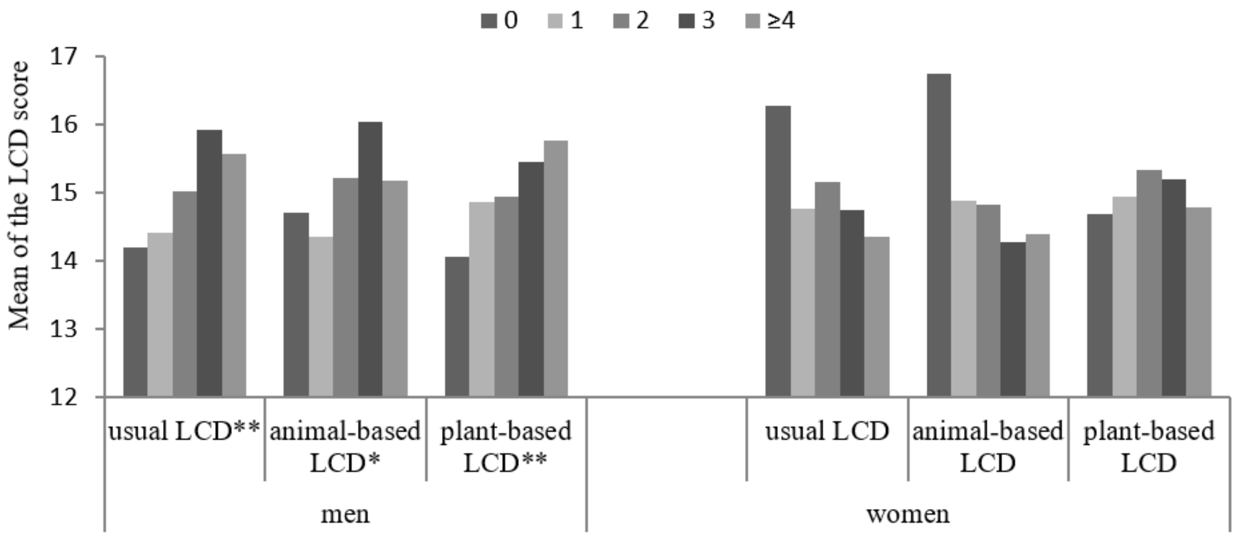

Figure 3

Mean of the three of LCD score in the different number of the metabolic syndrome components adjusting for age (*P for trend<0.05, **P for trend<0.01).