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The association between low carbohydrate diet scores and cardiometabolic risk factors in Chinese adults

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Abstract

Epidemiological studies on the association between the low carbohydrate diet (LCD) score and CVD risk factors have limited and inconsistent results. Data are from the baseline survey of Community-based Cohort Study on Nervous System Diseases. A total of 4609 adults aged ≥ 18 years were included in the study. Dietary data were assessed using a validated semi-quantitative FFQ. Multivariable logistic regression analyses were used to estimate relationships of three LCD scores with low HDL-cholesterol, high LDL-cholesterol, hypercholesterolaemia, hypertriacylglycerolaemia, impaired fasting glucose (IFG), high blood pressure and hyperuricaemia after adjusting for potential confounders. A higher LCD score was negatively associated with low HDL-cholesterol (OR: 0·65 (95 % CI 0·50, 0·83), $P = 0·0001$) and IFG (OR: 0·65 (95 % CI 0·51, 0·81), $P = 0·001$) after the final adjustment. However, there are sex differences in this result. Males in the highest quintile of the animal-based or plant-based LCD scores showed a decreased risk of low HDL-cholesterol, and females in the highest quintile of the animal-based or plant-based LCD scores showed a decreased risk of IFG than those in the lowest quintile of the LCD scores. These results suggest that sex differences should be considered when using LCD to treat dyslipidaemia and reduce fasting blood glucose.

Key words: Low carbohydrate diet: Low carbohydrate diet scores: Cardiometabolic risk factors: HDL-cholesterol: Impaired fasting glucose

In 2019, the total number of deaths from CVD in China was 5·09 million, and the age-standardised death rate reached 2·760 per 100 000[1]. CVD remains the top cause of death in China, which poses a strong economic burden[2]. Dyslipidaemia, hypertension and diabetes have long been recognised as risk factors for CVD[3–5]. Diet, as one of the ways to improve CVD risk factors, has been the focus of researchers[6]. In recent years, a growing number of studies have found that limiting carbohydrate intake is associated with lower body weight[7], improved diabetes[8–10] and reduced risk of CVD[11–13]. Therefore, some experts believed that low carbohydrate diet (LCD) could be incorporated into dietary guidelines as a healthy way of diets in the future[14,15].

It is worth noting that the role of the LCD in the treatment of CVD is currently controversial[16–19]. Several studies have suggested that the consumption of unrestricting saturated fat may increase LDL-cholesterol levels, which could increase the risk of cardiovascular mortality[16–19]. However, a review pointed out that the current review focuses only on LDL-cholesterol, a poor indicator of CVD risk, rather than a more reliable CVD risk factor (i.e. diabetes, hypertension, TAG, HDL)[19].

The LCD score was designed by Halton *et al.* to assess dietary carbohydrate intake[20]. Halton *et al.* also created animal-based and plant-based LCD scores. Few studies have examined the relationship between the LCD score and cardiometabolic risk factors in adults, including blood lipid[21–28], fasting blood glucose (FBG)[21–25], blood pressure[21,22,24,25,28] and uric acid[23]. There are several problems with these studies. First, the positive association between the LCD score and HDL-cholesterol has been demonstrated in most studies[22,23,26,28]. However, inconsistent results have been found between other cardiovascular risk factors and the LCD score. Only a few studies have found the negative relationship between the LCD score and FBG[21,24] or blood pressure[21]. Instead, the two other studies found that the LCD score could increase the risk of hypercholesterolaemia[26,27] or hypertriacylglycerolaemia[27]. Inconsistent results may be due to differences in study participants. However, only one study has been conducted in the Chinese population[27].

Abbreviations FBG, fasting blood glucose; IFG, impaired fasting glucose; LCD, low carbohydrate diet; TC, total cholesterol.

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Therefore, more studies are needed to explore the effects of the LCD on cardiovascular risk factors in the Chinese population. Second, sex and dietary source differences may exist in the association of the LCD score with CVD risk factors[22,23,26–28]. Two studies found that animal-based and plant-based LCD scores were significantly positively related to HDL-cholesterol in Japanese populations[23] or Korean females[22]. However, other studies showed more adherence to LCD[28] or animal-based LCD[22] might be associated with the lower risk of low HDL-cholesterol, especially in males. The relationship between animal-based LCD score and hypertriacylglycerolaemia was opposite in Korean[26] and Chinese males[27]. Based on the inconsistency of the above findings, more studies were needed to investigate the effect of sex and different dietary source on the relationship between LCD and cardiovascular risk factors. Finally, no studies have comprehensively explored the relationship between LCD and blood lipid, blood glucose, blood pressure and uric acid.

At the same time, carbohydrate is the main source of energy for Chinese; it is of great public health significance to explore the effects of carbohydrate diet on cardiovascular health of Chinese. The primary aim of the present study was to assess the associations between three LCD scores and cardiometabolic risk factors (blood lipid, FBG, blood pressure and uric acid) among Chinese adults. Second, the association between three LCD scores and cardiometabolic risk factors was assessed after stratification for sex.

Methods

Study population

Detailed methods of the Community-based Cohort Study on Nervous System Diseases have been described in another study[29]. In this study, Hebei, Zhejiang, Shanxi and Hunan provinces were selected as survey sites. Each province randomly selected two cities and two counties. Urban and suburban communities, as well as towns and villages within the county, were randomly selected. This study was reviewed and approved by the Institutional Review Board of the National Institute of Nutrition and Health (No. 2017020, 6 November 2017). Each participant signed an informed consent form before the study.

Participants in this survey were selected only from Hebei province. The baseline survey was conducted in 2018 and 6720 people participated in the survey. There were 5920 people aged 18 and older. For this study, participants with incomplete data on blood sample data (n 906) and incomplete answers to dietary data (n 215) were excluded. Additionally, 190 participants with energy intake < 2092 kJ/d (500 kcal/d) or ≥ 20920 kJ/d (5000 kcal/d) were excluded. Finally, the remaining 4609 participants were included in the study.

Dietary assessment and calculation of the low carbohydrate diet score

Participants' diets were assessed using a validated semi-quantitative FFQ including eighty-one food items. Participants were asked if they had eaten the food item in the previous 12 months, and if so, how often (choosing one of each day, week, month or year) and how much they ate each time. If they had not, zero was recorded. The total amount of one food item equal to the frequency of food intake multiplied by each intake. Finally, the total amount of food item consumed was translated into daily grams. The remaining sixty-five foods were analysed after excluding sixteen nutritional supplements. The validity and reproducibility of the questionnaire were documented in other studies[30,31]. The correlations of nutrient intake between the FFQ and the second FFQ were 0·46–0·71[30] and 0·38–0·52[31], respectively. And the correlations of nutrient intake between the FFQ and the 24-h dietary recalls were 0·25–0·65 and 0·33–0·64[31], respectively. In particular, the correlations of carbohydrate intake between the FFQ and the 24-h dietary recalls in Shanghai men were as high as 0·64[31]. Food nutrient composition based on China Food Composition Book (2009 edition) compiled by National Institute of Nutrition and Food Safety, China CDC. Condiment intake was collected by asking participants how much each condiment was consumed in their households for a month. There are seven condiments including vegetable oil, lard oil, salt, soya sauce, monosodium glutamate, fermented soya paste and sugar. Every condiment intake was computed by the total amount of each condiment by number of family members.

The calculation method of LCD was proposed by Halton *et al.*[20]. Fat, protein and carbohydrate intakes, expressed as percentage of energy, were divided into eleven strata. For protein and fat, the higher the stratum, the higher the score (0–10). For carbohydrates, the opposite is true (10–0). The final three macronutrient scores were added together for a total score of 0–30, with higher scores representing participants intaking more protein and fat and less carbohydrates. In the study, two other LCD scores (animal-based LCD score and plant-based LCD score) were also calculated. Animal-based LCD score was calculated from the percentage of energy of carbohydrate, animal fat and animal protein. Plant-based LCD score was calculated from the percentage of energy of carbohydrate, plant fat and plant protein, please refer to Table 1 for details.

Biochemical measurements

The participants' blood was collected without breakfast. Blood samples were immediately sent to the First People's Hospital of Hebei Province for testing. HDL-cholesterol, LDL-cholesterol, total cholesterol (TC), TAG, FBG and uric acid were measured on an AU5800 instrument (Beckman Coulter, Inc.). According to the Chinese guideline for the management of dyslipidaemia[32], high LDL-cholesterol was defined as LDL-cholesterol ≥ 160 mg/dl; low HDL-cholesterol was defined as HDL-cholesterol < 40 mg/dl; hypercholesterolaemia was defined as TC ≥ 240 mg/dl and hypertriacylglycerolaemia was defined as TAG ≥ 200 mg/dl. Impaired fasting glucose (IFG) was defined as FBG ≥ 5·6 mmol/l according to the American Diabetes Association criteria[33]. According to the guidelines[34], hyperuricaemia was defined as uric acid ≥ 7 mg/dl in men and ≥ 6 mg/dl in women.

Blood pressure was measured three times using an automated electronic sphygmomanometer (HBP-1300; Omron Corporation). The average of the three measurements was used as the final analysis. Of the 547 participants, only one blood

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Table 1. Energy percentage of macronutrients used in calculating the low carbohydrate diet (LCD) scores, animal-based LCD scores and plant-based LCD scores of Chinese adults, Community-based Cohort Study on Nervous System Diseases[a]

	Carbohydrate intake		Total protein intake		Total fat intake		Animal-based protein		Animal-based fat		Plant-based protein		Plant-based fat	
Points	Median of energy %	Minimum–maximum	Median of energy%	Minimum–maximum	Median of energy %	Minimum–maximum	Median of energy %	Minimum–maximum	Median of energy %	Minimum–maximum	Median of energy %	Minimum–maximum	Median of energy %	Minimum–maximum
0	76·43	73·71–88·79	11·68	5·99–12·43	11·03	3·14–12·58	1·59	0·00–2·17	2·37	0·00–3·18	7·45	3·52–8·21	5·00	1·44–6·14
1	71·24	69·31–73·70	12·97	12·44–13·52	14·38	12·62–15·92	2·55	2·18–2·85	3·8	3·19–4·53	8·75	8·22–9·08	6·98	6·15–7·59
2	67·22	65·82–69·29	13·98	13·53–14·44	17·18	15·93–18·19	3·17	2·86–3·45	5·19	4·54–5·80	9·35	9·09–9·59	8·02	7·60–8·54
3	64·44	63·37–65·80	14·91	14·45–15·37	18·98	18·20–19·71	3·78	3·46–4·13	6·45	5·81–7·08	9·87	9·60–10·08	9·10	8·55–9·56
4	62·36	61·35–63·36	15·77	15·38–16·22	20·53	19·72–21·18	4·43	4·14–4·75	7·67	7·09–8·29	10·32	10·09–10·59	10·08	9·57–10·59
5	60·42	59·57–61·34	16·67	16·23–17·07	21·87	21·19–22·53	5·08	4·76–5·44	8·86	8·31–9·46	10·88	10·60–11·12	11·09	10·60–11·55
6	58·61	57·61–59·56	17·50	17·08–18·01	23·21	22·55–23·82	5·76	5·45–6·12	10·06	9·47–10·77	11·43	11·13–11·77	12·02	11·56–12·46
7	56·55	55·49–57·60	18·61	18·02–19·27	24·60	23·83–25·40	6·54	6·13–7·02	11·60	10·78–12·49	12·12	11·78–12·51	12·97	12·47–13·49
8	54·03	52·39–55·48	19·98	19·28–20·84	26·48	25·41–27·56	7·52	7·03–8·22	13·54	12·5–14·77	12·97	12·52–13·50	14·05	13·50–14·77
9	50·48	47·60–52·38	21·88	20·85–23·40	29·09	27·59–31·24	9·09	8·23–10·25	16·35	14·78–18·40	14·27	13·51–15·57	15·50	14·78–16·75
10	43·49	16·75–47·58	26·06	23·42–56·84	34·92	31·25–74·44	12·23	10·26–31·04	22·94	18·41–69·39	17·72	15·58–46·93	18·96	16·76–37·54

[a] Energy from diet carbohydrate, total protein, total fat, animal protein, animal fat, plant protein and plant fat is shown according the score assigned to the eleven groups after ranking the participants' macronutrient intake, respectively.

pressure measurement was included in the analysis. High blood pressure was defined as systolic blood pressure ≥ 130 mm Hg and/or diastolic blood pressure ≥ 85 mm Hg[35].

Assessment of other variables

Height was measured during the baseline period using a stable stadiometer (Seca) with a 0·1 cm precision. Weight was measured using an electronic scale. BMI was calculated by dividing body weight in kilograms by height in meters. Weight status was divided by four groups based on BMI: underweight (<18·5 kg/m^2), normal weight (≥ 18·5 and <24 kg/m^2), overweight (≥ 24 and <28 kg/m^2) and obesity (≥ 28 kg/m^2) according to the Guidelines for the Prevention and Control of Overweight and Obesity in Chinese Adults (2003).

Other covariates were obtained by questionnaire, including sex, age, the area of residence, monthly income per family, education (primary school or below, junior high, and senior high school and above), smoking (current/previous smoking and non-smoking), alcohol consumption (yes and no) in the past year (2017), physical activity, hypertension and diabetes. The area of residence was classified as rural or urban based on where they currently live. Monthly income per family was collected by asking each family about their per capita monthly income. Participants could choose from three levels (<1000, 1000–3999, ≥ 4000). Anyone who had consumed alcohol in the past year is considered 'yes'. Physical activity was expressed in metabolic equivalent hours per day (Met-h/day). According to the Compendium of Physical Activities[36], MET per hour for every sport were: 10·0 for martial arts, 7·0 for running or swimming, 4·5 for gymnastics, dancing or acrobatics, 3·5 for walking, 7·0 for playing football, basketball or tennis, 3·75 for playing badminton or volleyball and 4·0 for playing table tennis or tai chi. The history of the disease was determined by asking participants whether their doctor had given them a diagnosis of the disease.

Statistical analyses

The Mantel–Haenszel χ^2 statistical test for nominal variables and the 'contrast' option for linear regression analysis were used to assess whether there were significant differences in variables across quintiles of three LCD scores. Trend *P* values were obtained. All results for the continuous variables are presented as the mean values with their standard error, and the results for the categorical variables are presented as *n* (%). Multivariable logistic regression analyses were used to estimate OR with 95 % CI for the association between quintiles of three LCD scores and CVD indicators (including low HDL-cholesterol, high LDL-cholesterol, hypercholesterolaemia, hypertriacylglycerolaemia, IFG, high blood pressure and hyperuricaemia). Based on previous studies[25–27], model 1 adjusted for age, sex, area of residence, monthly income per family, weight status, smoking, alcohol, education level, physical activity, history of diabetes and hypertension. In addition, model 2 adjusted for model 1 covariates + salt, soya sauce, monosodium glutamate and sugar, as condiment intakes were associated with an increased risk of CVD[37–39]. Tests for linear trend for OR were performed using the median value for each quintile as a

Table 2. General characteristics of Chinese adults according to the quintiles of the low carbohydrate diet (LCD) scores, Community-based Cohort Study on Nervous System Diseases (Numbers and percentages; mean values with their standard errors)[a, b]

	Total LCD score							Animal-based LCD score							Plant-based LCD score						
	Q1		Q3		Q5			Q1		Q3		Q5			Q1		Q3		Q5		
	n	%	*n*	%	*n*	%	*P*	*n*	%	*n*	%	*n*	%	*P*	*n*	%	*n*	%	*n*	%	*P*
n	1024		888		827			999		851		882			1038		870		791		
LCD score (median)	3		16		26			3		16		27			6		16		24		
LCD range (min–max)	0–7		14–18		26–30			0–6		14–18		24–30			0–9		15–17		22–30		
Sex																					
Male	440	42·23	379	42·68	319	38·57	0·008	428	42·84	344	40·42	360	40·82	0·047	429	41·33	351	40·34	319	40·33	0·563
Female	602	57·77	509	57·32	508	61·43		571	57·16	507	59·58	522	59·18		609	58·67	519	59·66	472	59·67	
Age (years)																					
Mean	57·63		58·72		57·06		0·184	57·88		58·64		57·58		0·362	57·37		59·69		58·97		0·111
SE	0·47		0·52		0·58			0·48		0·53		0·57			0·49		0·53		0·54		
Age group (years)																					
18–29	56	5·37	51	5·74	75	9·07	0·368	58	5·81	44	5·17	81	9·18	0·310	70	6·74	57	6·55	48	6·07	0·033
30–39	125	12·00	100	11·26	96	11·61		108	10·81	94	11·05	98	11·11		114	10·98	77	8·85	72	9·10	
40–49	81	7·77	55	6·19	67	8·10		77	7·71	65	7·64	73	8·28		90	8·67	60	6·90	54	6·83	
50–59	227	21·79	169	19·03	132	15·96		216	21·62	181	21·27	126	14·29		214	20·62	146	16·78	163	20·61	
60–69	330	31·67	282	31·76	256	30·96		318	31·83	242	28·44	265	30·05		326	31·41	281	32·30	248	31·35	
≥ 70	223	21·40	231	26·01	201	24·30		222	22·22	225	26·44	239	27·10		224	21·58	249	28·62	206	26·04	
Area of residence																					
Rural	938	90·02	670	75·45	429	51·87	<0·0001	923	92·39	631	74·15	474	53·74	<0·0001	799	76·97	702	80·69	503	63·59	<0·0001
Urban	104	9·98	218	24·55	398	48·13		76	7·61	220	25·85	408	46·26		239	23·03	168	19·31	288	36·41	
Monthly income per family																					
< 1000	252	25·69	190	22·62	105	13·91	<0·0001	255	26·81	191	23·46	144	17·78	<0·0001	194	20·29	252	30·69	115	15·35	<0·0001
1000–3999	652	66·46	513	61·07	456	60·40		634	66·67	485	59·58	470	58·02		638	66·74	469	57·13	464	61·95	
≥ 4000	77	7·85	137	16·31	194	25·70		62	6·52	138	16·95	196	24·20		124	12·97	100	12·18	170	22·70	
Weight status																					
Underweight	37	3·55	24	2·71	28	3·40	0·050	37	3·70	28	3·31	31	3·52	0·486	48	4·63	30	3·45	22	2·78	0·004
Normal	411	39·44	340	38·42	302	36·65		366	36·64	326	38·49	331	37·61		392	37·8	359	41·26	284	35·95	
Overweight	405	38·87	337	38·08	303	36·77		395	39·54	327	38·61	314	35·68		408	39·34	308	35·4	308	38·99	
Obese	189	18·14	184	20·79	191	23·18		201	20·12	166	19·60	204	23·18		189	18·23	173	19·89	176	22·28	
Smoking status																					
Current/previous	870	84·47	744	84·16	691	83·66	0·506	825	83·76	699	82·53	724	82·27	0·990	883	85·89	714	82·26	649	82·15	0·003
Yes	160	15·53	140	15·84	135	16·34		160	16·24	148	17·47	156	17·73		145	14·11	154	17·74	141	17·85	
Alcohol consumption																					
No	897	87·00	716	81·18	662	80·15	0·0001	854	86·61	678	80·43	708	80·82	0·001	883	85·89	713	82·43	628	79·59	0·0001
Yes	134	13·00	166	18·82	164	19·85		132	13·39	165	19·57	168	19·18		145	14·11	152	17·57	161	20·41	
Physical activity (MET-h/day)																					
Mean	1·91		2·66		3·35		0·008	1·86		2·89		2·89		0·008	2·79		2·41		2·41		0·765
SE	0·31		0·61		0·36			0·33		0·49		0·32			0·54		0·50		0·14		
Education level																					
Primary school or below	517	49·66	435	49·15	303	36·64	<0·0001	518	51·96	404	47·64	326	37·00	<0·0001	445	42·87	453	52·19	338	42·73	0·175
Junior high	382	36·70	296	33·45	296	35·79		364	36·51	289	34·08	333	37·80		394	37·96	285	32·83	289	36·54	
Senior high school and above	142	13·64	154	17·40	228	27·57		115	11·53	155	18·28	222	25·20		199	19·17	130	14·98	164	20·73	
Diabetes																					
0	786	78·05	633	72·18	622	75·58	0·324	732	75·93	601	71·46	676	77·26	0·174	820	81·92	628	72·85	556	70·65	<0·0001
1	221	21·95	244	27·82	201	24·42		232	24·07	240	28·54	199	22·74		181	18·08	234	27·15	231	29·35	

Table 2. (*Continued*)

	Total LCD score							Animal-based LCD score							Plant-based LCD score						
	Q1		Q3		Q5			Q1		Q3		Q5			Q1		Q3		Q5		
	n	%	*n*	%	*n*	%	*P*	*n*	%	*n*	%	*n*	%	*P*	*n*	%	*n*	%	*n*	%	*P*
Hypertension																					
0	961	95·15	823	93·84	759	92·11	0·008	911	94·21	781	92·87	800	91·32	0·013	952	94·73	803	93·16	719	91·36	0·004
1	49	4·85	54	6·16	65	7·89		56	5·79	60	7·13	76	8·68		53	5·27	59	6·84	68	8·64	
	Mean	SE	Mean	SE	Mean	SE		Mean	SE	Mean	SE	Mean	SE		Mean	SE	Mean	SE	Mean	SE	
CVD indicators																					
HDL-cholesterol (mg/dl)	48·76	0·41	50·58	0·47	50·51	0·49	0·024	48·98	0·43	50·15	0·48	49·82	0·45	0·088	49·02	0·41	51·42	0·49	50·07	0·49	0·069
LDL-cholesterol (mg/dl)	107·08	1·00	110·61	1·09	112·16	1·20	0·001	106·67	1·04	110·43	1·13	112·52	1·19	0·001	109·34	1·04	109·73	1·13	110·23	1·18	0·131
TC (mg/dl)	178·08	1·10	179·54	1·22	183·42	1·32	0·001	177·37	1·14	179·73	1·22	183·3	1·32	0·002	179·92	1·16	179·14	1·23	180·78	1·30	0·262
TAG (mg/dl)	151·04	4·22	144·76	4·23	151·71	4·06	0·859	151·89	4·41	147·74	4·15	151·5	3·86	0·781	146·53	3·66	140·94	3·48	153·1	4·35	0·587
Uric acid (mg/dl)	5·17	0·05	5·26	0·05	5·35	0·05	0·014	5·18	0·05	5·27	0·05	5·37	0·05	0·063	5·25	0·05	5·16	0·05	5·43	0·05	<0·0001
FBG (mg/dl)	105·48	0·91	104·21	0·98	105·17	1·08	0·785	105·00	0·98	105·76	1·06	106·34	1·08	0·513	105·93	0·98	103·7	0·89	107·28	1·30	0·119
SBP (mmHg)	133·95	0·56	133·22	0·66	132·13	0·71	0·098	134·4	0·59	133·42	0·67	132·20	0·66	0·010	133·33	0·57	133·07	0·65	134·9	0·73	0·026
DBP (mmHg)	82·99	0·34	82·4	0·37	81·12	0·39	0·001	83·57	0·35	82·40	0·36	81·00	0·38	<0·0001	81·92	0·34	82·44	0·38	82·82	0·41	0·017

[a] TC, total cholesterol; FBG, fasting blood glucose; SBP, systolic blood pressure; DBP, diastolic blood pressure; Q, quintile.
[b] The numbers of missing values were 7, 22, 32, 53, 7, 68 and 72 for weight status, smoke, alcohol consumption, smoking status, physical activity, education level, diabetes and hypertension, respectively. *P* values were calculated by the Mantel–Haenszel χ^2 statistical test for nominal variables and the 'contrast' option for linear regression analysis.

continuous variable. All statistical analyses were performed using R software (Version 4.0.5). All *P* values were two tailed. $P<0·05$ was considered significant.

Results

The general characteristics of the study population according to the LCD score quintiles are shown in Table 2. In all LCD scores, participants with a higher LCD score tended to live in urban, have a higher household income level, consume alcohol, history of hypertension and lower mean diastolic blood pressure than those with a lower score (all $P<0·05$). In animal-based LCD score, participants with a higher LCD score tended to be female, have a higher physical level and a higher education level, have higher LDL-cholesterol and TC and have a lower systolic blood pressure than those with a lower score (all $P<0·05$). Moreover, participants with a higher plant-based LCD score tended to be older, obese, smoking, history of diabetes and have higher systolic blood pressure and uric acid than those with a lower score (all $P<0·05$).

Macronutrient intake and seasoner intakes according to the three LCD scores are shown in Table 3. In the three LCD scores, participants with a higher LCD score had higher protein and fat intakes instead of lower carbohydrate intake compared with those with a lower score (all $P<0·0001$).

In animal-based LCD score, participants with a higher LCD score had higher lard oil, monosodium glutamate and fermented soya paste intake, and lower vegetable oil and salt than those with a lower score (all $P<0·05$). In plant-based LCD score, participants with a higher LCD score had higher fermented soya paste and sugar, and had lower vegetable oil intake than those with a lower score (all $P<0·0001$). Refer to online Supplementary Table S1 for additional food intake and energy percentage according to the LCD score quintiles.

Carbohydrate and fat intake levels according to the quintiles of the three LCD scores are shown in Fig. 1. According to the acceptable macronutrient distribution range (AMDR) carbohydrate and fat recommendations, 12·8 % of participants intake was below the recommended levels of carbohydrates and 11·5 % of participants intake was above the recommended levels of fat. As quantiles of the three LCD scores increased, more participants had lower carbohydrate intake and higher fat intake (all $P<0·0001$).

Multivariate-adjusted OR for CVD indicators across quintiles of three LCD scores are presented in Table 4. Adjusted OR of low HDL-cholesterol for comparisons of Q5 with Q1 were 0·65 (95 % CI 0·50, 0·83) for the total LCD score ($P_{\text{for trend}}=0·0001$), 0·72 (95 % CI 0·56, 0·91) for animal-based LCD score ($P_{\text{for trend}}=0·001$) and 0·73 (95 % CI 0·57, 0·93) for plant-based LCD score ($P_{\text{for trend}}=0·01$). Adjusted OR of IFG for comparisons of Q5 with Q1 were 0·65 (95 % CI 0·51, 0·81) for the total LCD score ($P_{\text{for trend}}=0·001$) and 0·74 (95 % CI 0·59, 0·92) for plant-based LCD score ($P_{\text{for trend}}=0·005$). No significance was found between IFG and animal-based LCD score for comparisons of Q5 with Q1 ($P_{\text{for trend}}=0·070$). Three LCD scores were not related to high LDL-cholesterol, hypercholesterolaemia, hypertriacylglycerolaemia, high blood pressure and hyperuricaemia ($P_{\text{for trend}}>0·05$).

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Table 3. Macronutrient and condiment intake according to the low carbohydrate diet (LCD) scores, Community-based Cohort Study on Nervous System Diseases (Mean values with their standard errors) [a]

	Total LCD score							Animal-based LCD score							Plant-based LCD score						
	Q1		Q3		Q5			Q1		Q3		Q5			Q1		Q3		Q5		
	Mean	SE	Mean	SE	Mean	SE	*P*	Mean	SE	Mean	SE	Mean	SE	*P*	Mean	SE	Mean	SE	Mean	SE	*P*
n	1024		888		827			1038		870		791			999		851		882		
Total energy (kcal/d)	1305·86	18·44	1411·95	17·52	1388·42	19·83	<0·0001	1316·78	19·74	1370·69	18·4	1549·87	18·83	<0·0001	1337·7	18·75	1475·13	19·33	1342·89	20·24	0·705
Carbohydrate (g/d)	237·62	3·45	211·62	2·59	165·33	2·42	<0·0001	230·88	3·56	206·37	2·80	201·12	2·56	<0·0001	238·79	3·39	218·8	2·79	162·12	2·44	<0·0001
Protein (g/d)	43·14	0·63	61·83	0·88	77·84	1·19	<0·0001	46·69	0·75	57·55	0·77	80·08	1·16	<0·0001	46·01	0·76	65·24	1·08	72·37	1·20	<0·0001
Fat (g/d)	20·32	0·32	35·35	0·52	46·19	0·78	<0·0001	22·94	0·47	35·00	0·74	47·23	0·73	<0·0001	22·06	0·37	37·67	0·62	44·99	0·90	<0·0001
Total energy from carbohydrates (%)	72·85	0·12	60·03	0·05	47·59	0·19	<0·0001	70·36	0·22	60·33	0·22	51·79	0·22	<0·0001	71·82	0·16	59·64	0·14	48·65	0·23	<0·0001
Total energy from protein (%)	13·16	0·04	17·54	0·10	22·60	0·14	<0·0001	14·16	0·09	17·00	0·11	20·83	0·16	<0·0001	13·58	0·07	17·61	0·12	21·8	0·16	<0·0001
Animal based	3·05	0·05	5·63	0·08	9·62	0·14	<0·0001	4·92	0·10	5·54	0·10	6·12	0·09	<0·0001	2·47	0·03	5·44	0·05	10·39	0·12	<0·0001
Plant based	10·03	0·05	11·72	0·10	12·71	0·14	<0·0001	9·06	0·04	11·32	0·07	14·57	0·13	<0·0001	11·02	0·07	11·96	0·13	11·22	0·14	0·132
Total energy from fat (%)	13·99	0·10	22·42	0·12	29·81	0·18	<0·0001	15·49	0·16	22·67	0·21	27·38	0·20	<0·0001	14·61	0·12	22·75	0·15	29·55	0·23	<0·0001
Animal based	4·52	0·08	9·81	0·12	16·46	0·22	<0·0001	7·52	0·16	9·93	0·21	10·78	0·17	<0·0001	3·51	0·04	9·63	0·09	18·55	0·23	<0·0001
Plant based	9·13	0·09	11·80	0·13	12·25	0·20	<0·0001	7·28	0·06	11·98	0·09	15·93	0·16	<0·0001	10·67	0·11	12·16	0·14	10·10	0·15	0·004
Vegetable oil (g/d)	29·6	0·53	25·32	0·54	24·05	0·51	<0·0001	28·22	0·58	26·67	0·52	25·15	0·55	<0·0001	28·25	0·51	25·24	0·55	24·44	0·54	<0·0001
Lard oil (g/d)	0·41	0·10	0·32	0·06	0·75	0·10	0·0002	0·46	0·07	0·34	0·09	0·38	0·05	0·296	0·32	0·08	0·28	0·07	0·81	0·10	<0·0001
Salt (g/d)	4·91	0·09	5·33	0·12	4·75	0·09	0·015	4·74	0·09	5·23	0·10	4·76	0·09	0·815	4·93	0·09	5·17	0·11	4·79	0·10	0·028
Soya sauce (g/d)	2·86	0·10	3·34	0·09	2·98	0·10	0·481	2·74	0·09	3·33	0·10	2·94	0·09	0·055	2·92	0·10	3·23	0·10	2·94	0·10	0·105
Monosodium glutamate (g/d)	0·38	0·03	0·40	0·02	0·48	0·03	0·001	0·46	0·03	0·32	0·02	0·47	0·03	0·067	0·39	0·03	0·40	0·03	0·46	0·03	0·008
Fermented soya paste (g/d)	0·38	0·04	0·89	0·05	1·11	0·07	<0·0001	0·43	0·03	0·74	0·05	1·15	0·07	<0·0001	0·54	0·05	0·89	0·05	0·91	0·07	<0·0001
Sugar (g/d)	0·69	0·04	0·94	0·06	1·14	0·06	<0·0001	0·75	0·04	0·69	0·05	1·38	0·07	<0·0001	0·79	0·05	0·88	0·05	0·90	0·05	0·103

[a] *P* values were calculated by the ‘contrast’ option for linear regression analysis.

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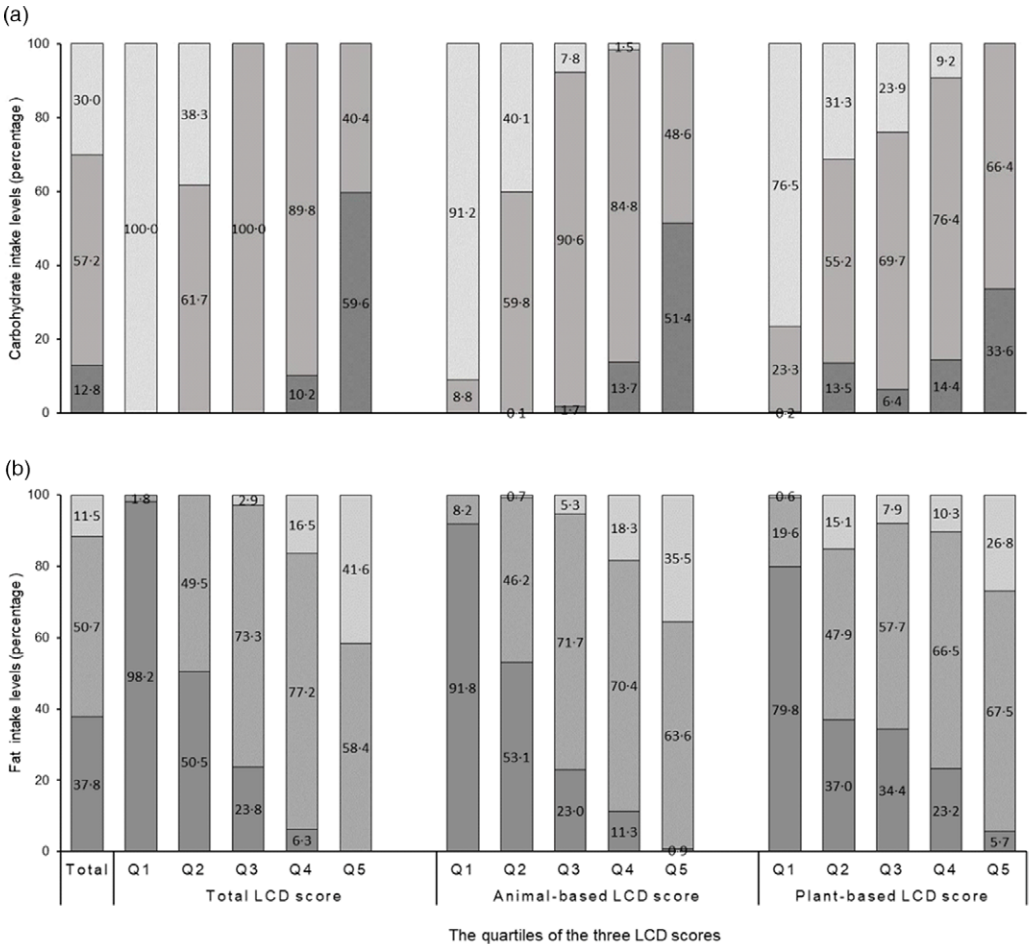

Fig. 1. Carbohydrate and fat intakes levels among Chinese adults according to the quintiles (Q) of the low-carbohydrate diet (LCD) scores. Values are presented as *n* (%). (a) Classification of the dietary carbohydrate level based on acceptable macronutrient distribution range (AMDR) Chinese Dietary Reference Intakes (CDRI) Handbook (2013). (b) Classification of the dietary fat level based on AMDR CDRI Handbook (2013). (a) ■, low (< 50%); ■, moderate; □, high (> 65%). (b) ■, low (< 20%); ■, moderate; □, high (> 30%).

After stratification for sex, males in the highest quintile of the animal-based or plant-based LCD scores showed a decreased risk of low HDL-cholesterol (animal-based LCD score: OR: 0·60 (95 % CI 0·42, 0·87), $P = 0·002$; plant-based LCD score: OR: 0·58 (95 % CI 0·40, 0·83), $P = 0·001$), and females in the highest quintile of the animal-based or plant-based LCD scores showed a decreased risk of IFG than those in the lowest quintile of the LCD score (animal-based LCD score: OR: 0·69 (95 % CI 0·51, 0·94), $P = 0·021$; plant-based LCD score: OR: 0·71 (95 % CI 0·53, 0·96), $P = 0·012$) (Table 5). Refer to online Supplementary Table S2 for the risk of CVD indicators according to the quintiles of the total LCD score after stratification for sex.

Discussion

This study found that Chinese adults who adhered to LCD obtained 47·6 % of energy from carbohydrate and 29·8 % of energy from fat. This was similar to the results of another study among Chinese adults[27]. Tan *et al.* found that Chinese adults in the highest quartile of the LCD score obtained 53·3–53·8 % of energy from carbohydrate and 28·7–29·3 % of energy from fat[27]. However, this is close to the energy intake from carbohydrate (54·7 %) and fat (28·3 %) in the lowest decile of the LCD score in the USA[40]. American adults who adhered to LCD obtained 29·6 % of energy from carbohydrate and 46·1 % of energy from fat[40]. Similarly, normal carbohydrate intake (≥ 45 %) is 52·6 % of total energy in the UK[41]. Current studies restrict carbohydrate energy to less than 45 % of total energy as the LCD[42,43]. However, only a small part of the participants were able to meet this standard without intervention due to Chinese eating habits.

The study showed all LCD scores were positively associated with HDL-cholesterol after multivariable logistic regression analyses. Similar results have been found in other two studies[22,23]. Ha *et al.* found animal-based and plant-based LCD scores significantly decreased the risk of reduced HDL-cholesterol in females[22]. The INTERMAP study also found that all three LCD scores were significantly positively related to HDL-cholesterol (all $P < 0·001$) in a Japanese population[23]. The beneficial effects of LCD on HDL-cholesterol have been demonstrated in several systematic reviews[44–47]. The benefit of LCD on HDL-cholesterol may be due to an increase in fatty acids intake[48]. And this study found that the intake of fatty acids increased HDL-cholesterol levels independent of the

Table 4. Risk of CVD indicators according to the quintiles of the low carbohydrate diet (LCD) scores, Community-based Cohort Study on Nervous System Diseases (Odds ratios and 95 % confidence intervals)[a, b]

Total LCD score

	Q1	Q2 OR	Q2 95 % CI	Q3 OR	Q3 95 % CI	Q4 OR	Q4 95 % CI	Q5 OR	Q5 95 % CI	P_{trend}
Low HDL-cholesterol										
Model 1	1·00	0·88	0·70, 1·09	0·79	0·63, 0·99	0·69	0·55, 0·87	0·65	0·51, 0·83	0·0001
Model 2	1·00	0·86	0·69, 1·08	0·79	0·63, 1·00	0·68	0·54, 0·86	0·65	0·50, 0·83	0·0001
High LDL-cholesterol										
Model 1	1·00	1·70	1·14, 2·54	1·35	0·90, 2·05	1·36	0·91, 2·06	1·39	0·91, 2·14	0·351
Model 2	1·00	1·69	1·13, 2·55	1·29	0·85, 1·97	1·32	0·88, 2·01	1·37	0·89, 2·12	0·425
Hypercholesterolaemia										
Model 1	1·00	1·19	0·78, 1·81	1·06	0·69, 1·63	1·00	0·65, 1·53	1·08	0·70, 1·68	0·983
Model 2	1·00	1·20	0·78, 1·86	1·03	0·67, 1·6	0·97	0·63, 1·50	1·07	0·69, 1·66	0·863
Hypertriacylglycerolaemia										
Model 1	1·00	0·90	0·70, 1·15	0·82	0·64, 1·06	0·87	0·67, 1·11	0·94	0·72, 1·22	0·590
Model 2	1·00	0·90	0·70, 1·16	0·83	0·64, 1·07	0·86	0·67, 1·11	0·94	0·72, 1·23	0·594
IFG										
Model 1	1·00	0·73	0·59, 0·89	0·68	0·55, 0·83	0·75	0·61, 0·92	0·67	0·54, 0·84	0·003
Model 2	1·00	0·72	0·59, 0·89	0·67	0·54, 0·82	0·73	0·59, 0·90	0·65	0·51, 0·81	0·001
High blood pressure										
Model 1	1·00	0·80	0·65, 0·99	0·73	0·59, 0·91	0·84	0·68, 1·05	0·80	0·63, 1·00	0·124
Model 2	1·00	0·85	0·68, 1·06	0·76	0·61, 0·95	0·87	0·70, 1·08	0·81	0·64, 1·03	0·140
Hyperuricaemia										
Model 1	1·00	0·97	0·75, 1·26	0·89	0·69, 1·15	1·05	0·82, 1·36	1·02	0·78, 1·34	0·669
Model 2	1·00	1·00	0·77, 1·30	0·91	0·70, 1·19	1·04	0·81, 1·35	1·02	0·78, 1·33	0·797

Animal-based LCD score

	Q1	Q2 OR	Q2 95 % CI	Q3 OR	Q3 95 % CI	Q4 OR	Q4 95 % CI	Q5 OR	Q5 95 % CI	P_{trend}
Low HDL-cholesterol										
Model 1	1·00	0·90	0·72, 1·12	0·85	0·67, 1·07	0·66	0·52, 0·84	0·71	0·56, 0·90	0·0004
Model 2	1·00	0·89	0·72, 1·12	0·84	0·67, 1·07	0·65	0·51, 0·84	0·72	0·56, 0·91	0·001
High LDL-cholesterol										
Model 1	1·00	1·24	0·84, 1·83	1·17	0·78, 1·76	1·17	0·78, 1·77	1·27	0·85, 1·91	0·358
Model 2	1·00	1·23	0·83, 1·83	1·14	0·75, 1·72	1·13	0·75, 1·71	1·26	0·84, 1·91	0·421
Hypercholesterolaemia										
Model 1	1·00	1·12	0·74, 1·70	0·92	0·59, 1·42	0·85	0·54, 1·33	1·12	0·73, 1·72	0·915
Model 2	1·00	1·13	0·74, 1·72	0·92	0·59, 1·44	0·81	0·51, 1·28	1·11	0·72, 1·72	0·814
Hypertriacylglycerolaemia										
Model 1	1·00	0·99	0·78, 1·27	0·93	0·72, 1·20	0·9	0·69, 1·17	0·96	0·74, 1·25	0·552
Model 2	1·00	1·00	0·78, 1·27	0·94	0·72, 1·21	0·9	0·69, 1·17	0·97	0·74, 1·26	0·602
IFG										
Model 1	1·00	0·92	0·75, 1·13	0·84	0·68, 1·03	0·83	0·67, 1·03	0·86	0·69, 1·07	0·106
Model 2	1·00	0·90	0·74, 1·11	0·82	0·66, 1·01	0·80	0·64, 1·00	0·84	0·67, 1·05	0·070
High blood pressure										
Model 1	1·00	0·97	0·79, 1·20	0·80	0·64, 0·99	0·91	0·73, 1·14	0·87	0·70, 1·09	0·206
Model 2	1·00	1·02	0·82, 1·26	0·82	0·66, 1·03	0·94	0·75, 1·18	0·89	0·71, 1·12	0·254
Hyperuricaemia										
Model 1	1·00	1·05	0·82, 1·35	0·91	0·70, 1·19	0·96	0·73, 1·25	1·08	0·83, 1·41	0·829
Model 2	1·00	1·06	0·83, 1·37	0·92	0·71, 1·21	0·95	0·72, 1·24	1·09	0·83, 1·42	0·859

Plant-based LCD score

	Q1	Q2 OR	Q2 95 % CI	Q3 OR	Q3 95 % CI	Q4 OR	Q4 95 % CI	Q5 OR	Q5 95 % CI	P_{trend}
Low HDL-cholesterol										
Model 1	1·00	0·92	0·74, 1·14	0·83	0·66, 1·04	0·68	0·54, 0·86	0·74	0·59, 0·94	0·001
Model 2	1·00	0·91	0·73, 1·14	0·82	0·65, 1·03	0·67	0·53, 0·85	0·73	0·57, 0·93	0·001
High LDL-cholesterol										
Model 1	1·00	1·40	0·97, 2·05	1·02	0·68, 1·54	1·52	1·05, 2·21	0·87	0·57, 1·33	0·681
Model 2	1·00	1·46	1·00, 2·17	1·07	0·70, 1·62	1·52	1·04, 2·24	0·86	0·56, 1·33	0·583
Hypercholesterolaemia										
Model 1	1·00	0·84	0·56, 1·25	0·74	0·48, 1·12	1·08	0·74, 1·58	0·59	0·38, 0·91	0·103
Model 2	1·00	0·87	0·58, 1·32	0·77	0·50, 1·18	1·09	0·74, 1·61	0·58	0·37, 0·90	0·080
hypertriacylglycerolaemia										
Model 1	1·00	1·09	0·85, 1·39	0·82	0·63, 1·06	0·82	0·64, 1·06	1·01	0·78, 1·31	0·388
Model 2	1·00	1·09	0·85, 1·39	0·81	0·62, 1·06	0·82	0·63, 1·05	1·00	0·77, 1·30	0·348
IFG										
Model 1	1·00	0·91	0·74, 1·12	0·80	0·65, 0·99	0·85	0·69, 1·04	0·78	0·63, 0·97	0·021
Model 2	1·00	0·92	0·75, 1·13	0·80	0·65, 1·00	0·83	0·67, 1·03	0·74	0·59, 0·92	0·005
High blood pressure										
Model 1	1·00	0·82	0·66, 1·01	0·82	0·66, 1·02	0·78	0·63, 0·96	0·94	0·75, 1·17	0·459
Model 2	1·00	0·88	0·71, 1·09	0·87	0·70, 1·08	0·81	0·66, 1·01	0·96	0·76, 1·20	0·519
Hyperuricaemia										
Model 1	1·00	0·90	0·70, 1·17	0·91	0·70, 1·18	1·03	0·81, 1·32	1·13	0·87, 1·46	0·194
Model 2	1·00	0·95	0·73, 1·23	0·93	0·71, 1·22	1·04	0·81, 1·34	1·10	0·85, 1·43	0·338

[a] IFG, impaired fasting glucose; Q, quintile.
[b] Values are presented as OR (95 % CI). Tests for linear trend for ORs were performed using the median value for each quintile as a continuous variable. $P < 0.05$ was considered significant. Model 1 adjusted for age, sex, area of residence, monthly income per family, weight status, smoking, alcohol, education level, physical activity, history of diabetes and hypertension. Model 2 adjusted for model 1 + salt, soya sauce, monosodium glutamate and sugar.

Table 5. Risk of CVD indicators according to the quintiles of the low carbohydrate diet (LCD) scores after stratification for sex
(Odds ratios and 95 % confidence intervals)[a, b]

	Animal-based LCD score										Plant-based LCD score									
		Q2		Q3		Q4		Q5				Q2		Q3		Q4		Q5		
	Q1	OR	95 % CI	OR	95 % CI	OR	95 % CI	OR	95 % CI	P_{trend}	Q1	OR	95 % CI	OR	95 % CI	OR	95 % CI	OR	95 % CI	P_{trend}
Male (*n* 1926)																				
Low HDL-cholesterol	1·00	0·81	0·59, 1·11	0·79	0·56, 1·11	0·59	0·41, 0·85	0·60	0·42, 0·87	0·002	1·00	0·83	0·60, 1·16	0·64	0·45, 0·91	0·61	0·43, 0·84	0·58	0·40, 0·83	0·001
High LDL-cholesterol	1·00	1·28	0·68, 2·48	1·17	0·57, 2·39	1·30	0·65, 2·64	0·56	0·23, 1·26	0·211	1·00	0·78	0·38, 1·59	0·98	0·48, 1·97	1·26	0·68, 2·37	0·55	0·24, 1·22	0·429
Hypercholesterolaemia	1·00	1·04	0·47, 2·36	0·89	0·36, 2·15	0·74	0·28, 1·86	0·75	0·29, 1·87	0·387	1·00	0·58	0·23, 1·38	0·84	0·34, 1·96	1·08	0·52, 2·27	0·28	0·08, 0·79	0·119
Hypertriacylglycerolaemia	1·00	0·79	0·53, 1·17	0·93	0·61, 1·40	0·78	0·51, 1·20	0·96	0·63, 1·46	0·857	1·00	1·49	0·99, 2·24	0·97	0·62, 1·51	1·12	0·74, 1·68	1·18	0·76, 1·83	0·934
IFG	1·00	1·06	0·79, 1·43	0·95	0·69, 1·31	0·90	0·65, 1·26	1·04	0·74, 1·45	0·816	1·00	0·86	0·63, 1·18	0·86	0·62, 1·19	0·88	0·65, 1·20	0·75	0·53, 1·05	0·143
High blood pressure	1·00	1·10	0·80, 1·52	0·90	0·64, 1·26	1·10	0·77, 1·58	0·87	0·61, 1·24	0·507	1·00	0·96	0·69, 1·34	0·98	0·70, 1·38	0·96	0·69, 1·33	1·14	0·80, 1·65	0·516
Hyperuricaemia	1·00	1·06	0·73, 1·55	1·07	0·72, 1·59	0·87	0·57, 1·31	1·09	0·73, 1·64	0·953	1·00	1·18	0·80, 1·72	0·74	0·48, 1·13	0·97	0·67, 1·42	1·01	0·67, 1·51	0·699
Female (*n* 2683)																				
Low HDL-cholesterol	1·00	0·97	0·71, 1·33	0·92	0·66, 1·26	0·72	0·51, 1·00	0·83	0·59, 1·15	0·076	1·00	1·02	0·74, 1·39	1·05	0·76, 1·45	0·76	0·55, 1·06	0·92	0·66, 1·28	0·231
High LDL-cholesterol	1·00	1·20	0·72, 2·00	1·19	0·71, 2·01	1·08	0·64, 1·83	1·70	1·04, 2·82	0·093	1·00	1·95	1·22, 3·18	1·16	0·68, 1·96	1·68	1·03, 2·76	1·08	0·64, 1·83	0·999
Hypercholesterolaemia	1·00	1·17	0·71, 1·92	0·97	0·58, 1·63	0·86	0·51, 1·46	1·31	0·80, 2·18	0·677	1·00	0·97	0·61, 1·56	0·79	0·47, 1·3	1·12	0·71, 1·79	0·72	0·43, 1·18	0·355
Hypertriacylglycerolaemia	1·00	1·17	0·84, 1·62	0·95	0·68, 1·34	0·99	0·71, 1·4	0·99	0·70, 1·41	0·664	1·00	0·89	0·65, 1·23	0·74	0·53, 1·04	0·67	0·48, 0·94	0·96	0·69, 1·33	0·324
IFG	1·00	0·77	0·58, 1·03	0·71	0·53, 0·95	0·71	0·53, 0·96	0·69	0·51, 0·94	0·021	1·00	0·96	0·72, 1·27	0·74	0·55, 0·99	0·79	0·59, 1·06	0·71	0·53, 0·96	0·012
High blood pressure	1·00	0·98	0·73, 1·31	0·78	0·58, 1·05	0·86	0·64, 1·16	0·92	0·68, 1·26	0·424	1·00	0·82	0·62, 1·09	0·79	0·59, 1·06	0·74	0·55, 0·99	0·87	0·65, 1·17	0·268
Hyperuricaemia	1·00	1·07	0·75, 1·53	0·83	0·57, 1·20	1·03	0·72, 1·48	1·10	0·77, 1·58	0·713	1·00	0·75	0·52, 1·09	1·03	0·72, 1·47	1·07	0·75, 1·52	1·16	0·82, 1·65	0·110

[a] IFG, impaired fasting glucose; Q, quintile.
[b] Values are presented as OR (95 % CI). Tests for linear trend for ORs were performed using the median value for each quintile as a continuous variable. $P < 0.05$ was considered significant. Model adjusted for age, area of residence, monthly income per family, weight status, smoking, alcohol, education level, physical activity, history of diabetes and hypertension, salt, soya sauce, monosodium glutamate and sugar.

type of fatty acids. This speculation was also reflected in other studies[26,48].

Surprisingly, this study found that LCD increased HDL-cholesterol levels only in males. This finding was similar to another study in an Iranian population[28]. A randomised controlled study also demonstrated that HDL-cholesterol levels increased significantly with carbohydrate restriction in men but not in women[49]. This result contradicts a current view. The view suggests that hormone-dependent differences between men and women cause women to have higher HDL-cholesterol levels than men[50]. In addition, high-fat diets also lead to higher levels of HDL-cholesterol in women than in men[50]. Therefore, LCD should be more able to elevate HDL-cholesterol levels in women than in men. However, this study found that it would be inappropriate to use only hormone-dependent differences to explain sex differences in the relationship between LCD and HDL-cholesterol levels. The specific mechanism needs to be explored in the future.

The study showed that substituting animal protein and fat for carbohydrates could not lead to an increase in LDL-cholesterol, hypercholesterolaemia and hypertriacylglycerolaemia. This result has been confirmed in most studies[22,24,25]. The three studies did not find a significant association between the LCD scores and low LDL-cholesterol, hypercholesterolaemia or hypertriacylglycerolaemia. Only one study found that a higher animal-based LCD score was significantly associated with higher odds of hypercholesterolaemia and hypertriacylglycerolaemia in males[27]. This study explains that higher consumption of an animal-based diet leads to higher TC levels. A prospective study also shown that animal protein substitution of carbohydrates was positively associated with LDL-cholesterol or TC[51]. However, the notion that animal-based LCD may have a deleterious effect on blood lipids remains speculative. More studies are needed in the future to carefully explore whether replacing LCD with more animal protein and fat increases the risk of dyslipidaemia.

Plant-based LCD score but not animal-based LCD score was negatively associated with IFG after the multivariate analysis in this study. The likely reason was that participants with high plant-based LCD scores consumed more legumes and nuts. A prospective study shown that replacing similar bread or rice with half a daily serving of beans may reduce the incidence of diabetes[52]. A systematic review showed that nuts (walnuts, almonds and hazelnuts) reduced FBG and glycated Hb levels by varying degrees[53]. After sex stratification, the association between LCD scores and IFG was found only in women. Shirani *et al.* also found that LCD score was associated with low FBG in Iranian women but did not study in men[24]. Ha *et al.* showed that both males and females who adhered to the LCD had no association with FBG[22]. There is no study to explore the sex difference of LCD on IFG, and the specific mechanism needs to be solved in future studies.

The study found all LCD scores were not significantly associated with blood pressure, similar to previous findings[22,24,25]. There were no association between total LCD score with high blood pressure. At the same time, meta-analysis did not find a significant difference between LCD and isoenergetic balanced or higher carbohydrate diets for either systolic blood pressure or diastolic blood pressure[54,55]. Even if LCD showed a short-term advantage in lowering systolic or diastolic blood pressure compared with the high carbohydrate diet, the effect disappeared after a year[56,57]. Only a cohort study shown that total LCD score was a faint association with blood pressure in Tehranian adults ($P = 0{\cdot}048$)[21]. The study also found all LCD scores were not significantly associated with hyperuricaemia. Similar results were also found in the study by Nakamura *et al.*[23]. However, there was a randomised controlled trial showing that a 24-month non-energy-restricted LCD improved uric acid levels[58]. The study restricted carbohydrates to 20–120 g/d, compared with 165 g in the highest quintile of the LCD score in this study. It is very difficult for Chinese people to meet this requirement in real life without any intervention.

This study has several strengths. First, this was the study to use the LCD scores to study multiple cardiometabolic risk factors among Chinese adults. Second, few studies had considered the effect of condiment intake on the results. Condiment was adjusted as confounding factors in this study.

This study has several limitations. First, this was a cross-sectional study, and the causal relationship between three LCD scores and cardiometabolic risk could not be established. Further large prospective studies are required to examine the effect of three LCD scores on cardiometabolic risk factors in the Chinese population. Second, this study used a semi-quantitative FFQ which may have a large recall bias. This study found that FFQ underestimated energy intake (1306–1531 kcal/d). Part of the reason may be that the total energy intake of the elderly in China is low, and 44·5 % of the participants in this study were elderly. A study showed that mean total energy intake was 1463 kcal/d among older Chinese adults in 2009[59]. A 3-d 24-h dietary recalls should be applied to assess dietary intake in future studies. Third, the questionnaire on condiments was based on the household consumption divided by the number of family members. This calculation method cannot accurately reflect the actual situation of personal condiment intake. Fourth, the participants in this study only included the population in northern China. However, there is a big difference in eating habits in the north and south of China. A study has shown that people in southern China consume more grains, beans, milk and eggs, and less fish and seafood than people in the north[60]. Therefore, it is difficult to extend the results of this study to the general Chinese population. Finally, blood lipids, blood pressure and uric acid are good predictors of CVD in this study. However, other risk factors (i.e. small, dense LDL, lipoprotein-a and inflammatory biomarkers) are more closely linked to CVD outcomes[19], which should be used to explore the relationship with three LCD scores.

Conclusions

This study found that the LCD score was negatively associated with low HDL-cholesterol and IFG. Males in the highest quintile of the animal-based or plant-based LCD scores showed a decreased risk of low HDL-cholesterol, and females in the highest quintile of the animal-based or plant-based LCD scores showed a decreased risk of IFG than those in the lowest quintile of the LCD score. These results suggest that sex differences should be considered when using LCD to treat dyslipidaemia

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and reduce FBG. Further studies were needed to explore the specific mechanisms of the sex difference.

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All authors declare that they have no conflict of interest.

Supplementary material

For supplementary material referred to in this article, please visit https://doi.org/10.1017/S0007114522001076

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