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Association of dietary patterns with obesity and metabolically healthy obesity phenotype in Chinese population: a cross-sectional analysis of China Multi-Ethnic Cohort Study

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Abstract

Metabolically healthy obesity (MHO) might be an alternative valuable target in obesity treatment. We aimed to assess whether alternative Mediterranean (aMED) diet and Dietary Approaches to Stop Hypertension (DASH) diet were favourably associated with obesity and MHO phenotype in a Chinese multi-ethnic population. We conducted this cross-sectional analysis using the baseline data of the China Multi-Ethnic Cohort study that enrolled 99 556 participants from seven diverse ethnic groups. Participants with self-reported cardiometabolic diseases were excluded to eliminate possible reverse causality. Marginal structural logistic models were used to estimate the associations, with confounders determined by directed acyclic graph (DAG). Among 65 699 included participants, 11·2 % were with obesity. MHO phenotype was present in 5·7 % of total population and 52·7 % of population with obesity. Compared with the lowest quintile, the highest quintile of DASH diet score had 23 % decreased odds of obesity (OR = 0·77, 95 % CI 0·71, 0·83, $P_{trend} < 0·001$) and 27 % increased odds of MHO (OR = 1·27, 95 % CI 1·10, 1·48, $P_{trend} = 0·001$) in population with obesity. However, aMED diet showed no obvious favourable associations. Further adjusting for BMI did not change the associations between diet scores and MHO. Results were robust to various sensitivity analyses. In conclusion, DASH diet rather than aMED diet is associated with reduced risk of obesity and presents BMI-independent metabolic benefits in this large population-based study. Recommendation for adhering to DASH diet may benefit the prevention of obesity and related metabolic disorders in Chinese population.

Key words: Dietary pattern: Obesity: Metabolically healthy obesity: Metabolic syndrome: Epidemiology

The global obesity prevalence has nearly tripled since 1975[1]. According to Global Burden of Diseases Study 2019, high BMI is among the top five leading risks, accounting for 6·3 % of the global disability-adjusted life-years[2]. In recent years, a novel obesity phenotype with favourable metabolic profiles, referred to as metabolically healthy obesity (MHO), has raised global interest. Many studies have demonstrated that people with MHO have substantially lower risk of cardiometabolic diseases than their metabolically unhealthy obesity (MUO) counterparts; rigorous and stable MHO even have comparable risks with

Abbreviations: aMED, alternative Mediterranean; CMEC, China Multi-Ethnic Cohort; DAG, directed acyclic graph; DASH, Dietary Approaches to Stop Hypertension; MHO, metabolically healthy obesity; MUO, metabolically unhealthy obesity; SES, socio-economic status; WC, waist circumference.

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metabolically healthy normal-weight phenotype[3–6]. Given the unsatisfied effect of weight loss-centred strategies for obesity treatment and substantially improved prognosis of MHO, identification of this phenotype and associated determinants, especially modifiable ones, is important for the targeted management of obesity and related adverse outcomes[7,8].

Dietary factors are a leading modifiable contributor to obesity and cardiometabolic disorders. In particular, dietary pattern has gained great interest because it reflects the holistic effect of diet and facilitates clinical and public dietary recommendations[9,10]. The Mediterranean diet and Dietary Approaches to Stop Hypertension (DASH) diet, as two most well-recognised healthy dietary patterns, have been demonstrated to be related to reduced risk for the metabolic syndrome[11,12]. However, existing empirical studies regarding the associations of Mediterranean or DASH diet with metabolic obesity phenotypes are limited and have produced inconsistent results[13–18]. Most of these studies were conducted in Western countries[13–16], and the results suggest that associations may be heterogeneous across different populations. Up to date, it is unclear whether these healthy dietary patterns are favourably associated with MHO in Chinese population, where the obesity and cardiometabolic disease burden have raised rapidly, and the dietary habits, obesity and metabolic phenotypes distribution differs substantially from Western populations[19,20].

The China Multi-Ethnic Cohort (CMEC) is a large-scale cohort with nearly 0·1 million heterogeneous participants from seven diverse ethnic groups. Exploring the relationship of Mediterranean and DASH diets with obesity and MHO in this population will provide unique evidence and important implications for prevention strategies of obesity and related metabolic disorders in China and may further reveal the age, sex, ethnicity and socio-economic status (SES) disparities of the association.

Therefore, based on baseline data of the CMEC, this study aimed to (1) examine the prevalence of obesity and different metabolic obesity phenotypes in this population; (2) explore whether the Mediterranean and DASH diets are associated with a reduced risk of obesity and (3) further investigate whether those dietary patterns are associated with the favourable MHO phenotype in population with obesity (MHO *v.* MUO).

Materials and methods

Study participants

CMEC started in 2018 and enrolled 99 556 subjects from seven ethnic groups (Tibetan, Yi, Miao, Bai, Bouyei, Dong and Han) in Southwest China. Every eligible participant was required to complete thorough electronic questionnaires, physical measurements and clinical laboratory tests. The survey and collection process were conducted by trained staff with standardised operation procedures. All participants provided written informed consent, and Sichuan University Medical Ethical Review Board and institutional review boards at all CMEC sites approved the study. More detailed information about the study design, sampling methods, baseline measurements and population characteristics has been published elsewhere[21].

For the current analysis, we excluded participants aged < 30 or > 79 years (*n* 1003), without available data to calculate dietary pattern scores (*n* 343) or outcome indicators (*n* 4382), with implausible low or high energy intake (< 3347 [800 kcal] or > 17 572 [4200 kcal] kJ/d for men and < 2510 [600 kcal] or > 14 644 [3500 kcal] kJ/d for women, *n* 2284)[22] and with BMI < 18·5 kg/m^2 (underweight, *n* 3095). In addition, those reported previously physician-diagnosed hypertension, diabetes, hyperlipidaemia, CHD, stroke or cancer were also excluded (*n* 22 750) to minimise possible reverse causality. Finally, 65 699 subjects were eligible and included in this analysis (online Supplementary Appendix Fig. S1).

Exposure assessment

Dietary intake was assessed using a validated FFQ. The FFQ full text, the collection and processing of diet data and the validation of the FFQ have been reported in detail elsewhere[23]. Briefly, information about the frequency (times per day, week, month or year) and quantity (average grams per time) for each food group during the preceding year was collected with the aid of food moulds. Moreover, we asked about the types, frequency and quantity of alcohol, tea and other beverages at the individual level and the consumption of oil and salt at the family level. Daily consumption of each food group (g/d), total energy and certain nutrient intake were calculated according to the China food exchange lists and the 2018 China food composition tables. Reliability and validity of the FFQ were assessed in subsample population who completed a second FFQ survey or a 3-d non-consecutive 24-h dietary recall survey. In terms of reliability, intraclass correlation coefficients for different food groups ranged from 0·15 to 0·67. In terms of validity, de-attenuated Spearman rank correlation coefficients ranged from 0·10 to 0·66.

A modified DASH index was used to score the participants' adherence to DASH diet[24]. Compared with the reference DASH index, we dropped the sweetened beverages component and nuts component and additionally replaced low-fat dairy component with total dairy products, because of limited information and very low regular consumption proportion for them in our population. Similarly, we adopted alternative Mediterranean diet (aMED) index to represent participants' adherence to Mediterranean diet[22], with further exclusion of nuts due to no available information. The detailed scoring criteria are shown in Table 1.

Outcome definition

Height to the nearest 0·1 cm and weight to the nearest 0·1 kg were measured. Waist circumference (WC) was measured to the nearest 0·1 cm at the midpoint between the lowest rib margin and the iliac crest. BMI was calculated as weight in kilograms divided by height in meters squared (kg/m^2). Systolic and diastolic blood pressures were measured three times after at least 5 min of rest, and the mean values of these measurements were used for analysis. In addition, overnight fasting blood samples were collected, and blood glucose and lipid profiles were tested using an AU5800 automated chemistry analyzer (Beckman Coulter Commercial Enterprise).

Table 1. Scoring criteria for the DASH diet and aMED diet

Dietary pattern	Component	Foods	Scoring criteria
DASH	Whole grain	Oats, sorghum, dried maize, highland barely	Q1 = 1 point
	Fruits	All fresh fruit	Q2 = 2 points
	Vegetables	All fresh vegetables except tubers and legumes	Q3 = 3 points
	Legumes	Soyabeans, black beans, tofu, soyabean milk, dried beans, dried bean curd	Q4 = 4 points
	Dairy products	Fresh milk, yogurt, cheese, milk tea	Q5 = 5 points
	Red and processed meats	Beef, mutton, pork and their products	Reverse scoring:
	Na	Na in salt and preserved vegetables	Q1 = 5 points
			Q2 = 4 points
			Q3 = 3 points
			Q4 = 2 points
			Q5 = 1 points
aMED	Whole grain	Oats, sorghum, dried maize, highland barely	Q1 = 1 point
	Fruits	All fresh fruit	Q2 = 2 points
	Vegetables	All fresh vegetables except tubers and legumes	Q3 = 3 points
	Legumes	Soyabeans, black beans, tofu, soyabean milk, dried beans, dried bean curd	Q4 = 4 points
	Fish	Fish and all kinds of seafood products	Q5 = 5 points
	MUFA:SFA ratio	From all kinds of foods and fats	
	Red and processed meats	Beef, mutton, pork and their products	Reverse scoring:
			Q1 = 5 points
			Q2 = 4 points
			Q3 = 3 points
			Q4 = 2 points
			Q5 = 1 point
	Alcohol	All alcoholic beverages	Moderate alcohol intake criteria*

DASH, Dietary Approaches to Stop Hypertension; aMED, alternative Mediterranean; Q, quintile.

* Alcohol consumption was categorised into five predefined groups: (10,30], (0,10] or (30,40], 0 or (40,45], (45,50] and > 50 g/d for men; (5,15], (0,5] or (15,25], 0 or (25,30], (30,35] and > 35 g/d for women, and then we assigned five points to the first group, four points to the second group, three points to the third group, two points to the fourth group and one point to the fifth group.

Obesity was defined as BMI ≥ 28 kg/m^2 according to Chinese criteria. Metabolic health was defined as the absence of the metabolic syndrome. Thus, based on a harmonised definition for the metabolic syndrome[25], the presence of two or fewer of the following five criteria was considered metabolically healthy: (1) WC ≥ 90 cm for males and ≥ 85 cm for females; (2) TAG ≥ 1·7 mmol/l; (3) HDL-cholesterol < 1·0 mmol/l for males and < 1·3 mmol/l for females; (4) systolic blood pressure ≥ 130 mmHg or diastolic blood pressure ≥ 85 mmHg and (5) fasting blood glucose ≥ 5·6 mmol/l. MHO individuals were therefore those with both metabolically healthy status and obesity.

Covariate measurements

Information about socio-demographic, lifestyle factors, health status, medical history and family history was obtained from the baseline questionnaire. To avoid incomplete adjustment or overadjustment, we firstly determined a pool of potential confounders through a systematic literature review on this study topic and constructed a directed acyclic graph (DAG) for this study according to the procedure of 'Evidence Synthesis for Constructing Directed Acyclic Graphs' method[26]. The minimally sufficient set of confounders based on the constructed DAG was determined (online Supplementary Appendix Text S2), and the subsequent association analysis would adjust for age, sex, ethnic group (Tibetan, Yi, Miao, Bai, Bouyei, Dong or Han), urbanicity (urban or rural), education (no schooling/primary school, middle/high school or college/university), household income (< ¥20 000, ¥20 000–99 999 or ≥ ¥100 000), profession (farmers or non-farmers), marital status (married/cohabiting or other), smoking (current smoker or not), physical activity (metabolic equivalent task, MET h/d), total energy intake (kcal/d), regular intake of soft drinks, dietary supplements (including fish oil/cod liver oil, vitamin D, other vitamins, Ca tablets and other dietary supplements), spicy food and peppery food (yes or no); insomnia symptoms, anxiety symptoms and depression symptoms (presence or absence); menopause status for women (premenopausal, perimenopausal or postmenopausal, men were coded as a distinct category) and family history of cardiometabolic diseases (presence or absence).

Statistical analysis

Age- and sex-adjusted characteristics of the study participants were described as the mean values and standard deviations or percentages across the presence or absence of obesity and across different metabolic phenotypes (MHO and MUO) in population with obesity. Continuous and categorical variables were compared using linear regression analyses and χ^2 tests, respectively. Marginal structural logistic models using the inverse probability of exposure weighting were employed to assess the associations of quintiles of aMED and DASH diet scores with obesity and MHO separately[27]. We constructed the exposure model using quintiles of diet scores as dependent variable and confounders (described in the 'Covariate measurements' section) as independent variables, and we then compared the balances of these confounders across different exposure groups among different candidate weighting methods to determine the

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optimal weighting method[28]. In our final analysis, we used the entropy balancing weighting method due to its preferable performance in balancing confounders[29] (see detailed balancing results in online Supplementary Appendix Text S3). The linear trend of these associations was tested using the median scores of each quintile as continuous variables in models. In addition, we further explored whether the associations of diet scores with MHO phenotype were dependent or independent of BMI by additionally adjusting for BMI when computing the weights.

To facilitate the interpretation and explore the dominant contributors to the observed associations of overall dietary patterns, we further conducted component analysis. First, we included all component scores simultaneously in multivariable logistic regression (adjusting for all identified confounders described in the 'Covariate measurements' section) for each dietary pattern to evaluate the associations of individual components with outcomes. Subsequently, we assessed the contribution of each of the seven or eight components of DASH diet and aMED index to the risk for obesity and MHO, respectively, by dropping one component at a time from the total score[30] (see online Supplementary Appendix Text S4 for more details).

To evaluate disparities in the associations of dietary patterns with obesity and MHO, we performed analysis additionally stratified by sex, age, urbanicity, ethnic group and SES. The heterogeneity among different strata was assessed using the I^2 statistic and Q test ($\alpha = 0{\cdot}1$, and $I^2 > 50\,\%$ was considered significantly heterogeneous). We also performed several sensitivity analyses to examine the robustness of our results: including individuals with self-reported hypertension, diabetes, hyperlipidaemia, CHD, stroke or cancer; using the strict definition of metabolic health (the absence of all abovementioned criteria except for WC); replacing the WC criteria with the waist:hip ratio ($\geq$ 0·90 for men and $\geq$ 0·85 for women) criteria to define metabolic health and additionally adjusting drinking status when estimating the association of DASH diet (without alcohol component) with obesity and MHO. All statistical analyses were performed with the R Project for Statistical Computing version 4.0.2.

Results

Characteristics of participants

Among the 65 699 participating subjects, the mean age was 49·4 (SD10·9) years, and 38·1 % were male. Individuals with obesity accounted for 11·2 % of the total population, and MHO phenotype accounted for 5·7 % of the total population and 52·7 % of population with obesity. The age- and sex-adjusted characteristics of participants with different obesity status and metabolic obesity phenotypes are presented in Table 2. Individuals with obesity were more likely to be male, Tibetans and non-farmers and to have a lower SES (education and household income), unhealthier lifestyles (physical activity, energy intake and soft drink consumption), lower aMED and DASH diet scores and poor physical and biochemical indicators (BMI, WC, blood pressure, blood glucose and lipid profiles) than individuals without obesity. MHO individuals were more likely to be younger, female, Tibetans, rural residents, farmers, non-current smokers or drinkers and to have lower SES, less reported family history of cardiometabolic diseases, lower aMED and higher DASH diet scores, and better physical and biochemical indicators than MUO.

Associations of dietary patterns with obesity and metabolically healthy obesity

Associations of adherence to DASH and aMED diets with obesity and MHO phenotype are shown in Fig. 1. We observed a linearly negative association between quintiles of DASH diet scores and obesity as well as a linearly positive association between DASH index and MHO phenotype in population with obesity. Compared with participants in the lowest quintile, those with the highest quintile of DASH diet scores had a 23 % decrease in the odds of obesity (OR = 0·77, 95 % CI 0·71, 0·83, $P_{\text{trend}} < 0{\cdot}001$). Among individuals with obesity, those in the fifth *v.* the first quintile of DASH diet scores had a 27 % increase in the odds of MHO phenotype (OR = 1·27, 95 % CI 1·10, 1·48, $P_{\text{trend}} = 0{\cdot}001$). However, no linear association of aMED diet scores with obesity or MHO phenotype was observed in this study, only the third and/or fourth quintile showed borderline benefit. Table 3 presents the results of the associations of aMED and DASH diet scores with MHO phenotype after additionally adjusting for BMI. Overall, the estimated OR (95 % CI) of MHO across different quintiles of these two diet scores were almost identical to those in the main analysis.

Regarding component analysis, the discrepant components between the two dietary patterns explained the differences in their overall associations with obesity and MHO (online Supplementary Appendix Tables S1 and S2). Among the three exclusive components of aMED diet, alcohol showed no associations with obesity or MHO; fish were not associated with MHO but positively associated with obesity and MUFA:SFA was detrimental for both obesity and MHO. In contrast, for the two exclusive components of DASH diet, dairy products were beneficial for both obesity and MHO; Na score presented no association with obesity and a positive association with MHO. Table 4 reports the relative contribution of each component to the observed associations of DASH diet with obesity and MHO. In terms of obesity, dairy products, legumes, and red and processed meat components contributed the most, accounting for 63·1, 50·1 and 25·5 % of the overall negative association, respectively. In terms of MHO, Na, dairy products and vegetable components were the dominant contributors, which accounted for 36·3, 32·9 and 32·9 % of the total positive association, respectively.

Stratification and sensitivity analyses

Figure 2 reports the results of stratification analysis on the associations of DASH diet scores with obesity and MHO (results of aMED diet are not shown because of its almost null association in the main analysis). In terms of obesity, the negative association was stronger in younger ($I^2 = 74{\cdot}9\,\%$; $P = 0{\cdot}046$) and higher educated ($I^2 = 70{\cdot}4\,\%$; $P = 0{\cdot}066$) participants. In terms of MHO, the positive association was greater in urban residents

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Table 2. Age- and sex-adjusted characteristics of the study participants
(Mean values and standard deviations for continuous variables; absolute and relative frequencies for categorical variables)

	All participants (*n* 65 699)					Participants with obesity (*n* 7142)				
	Obesity		Non-obesity			MHO		MUO		
Characteristics*	Mean	SD	Mean	SD	*P*†	Mean	SD	Mean	SD	*P*†
n (%)	7342	11·2	58 357	88·8	–	3763	52·7	3379	47·3	–
Age (years)	49·0	10·2	49·4	10·9	<0·001	48·0	10·1	50·1	10·2	<0·001
Female (%)	4291	58·4	36 424	62·4	<0·001	2369	63·0	1781	52·7	<0·001
Urban (%)	2618	35·7	20 826	35·7	0·971	1303	34·6	1318	39·0	<0·001
Ethnic group (%)					<0·001					<0·001
Han in Sichuan Basin	3473	47·3	27 674	47·4		1695	45·0	1753	51·9	
Ethnic minorities in Qinghai-Tibet Plateau	1455	19·8	5243	9·0		991	26·3	324	9·6	
Ethnic minorities in Yunnan-Guizhou Plateau	2414	32·9	25 440	43·6		1076	28·6	1302	38·5	
Education (%)					<0·001					<0·001
No schooling/primary school	4108	56·0	28 341	48·6		2178	57·9	1717	50·8	
Middle/high school	2557	34·8	22 773	39·0		1232	32·7	1289	38·1	
College/university	677	9·2	7243	12·4		352	9·4	374	11·1	
Household income (Yuan/year, %)					<0·001					<0·001
< 20 000	2572	35·0	19 660	33·7		1359	36·1	1099	32·5	
20 000–99 999	3847	52·4	30 353	52·0		1959	52·1	1775	52·5	
≥100 000	923	12·6	8344	14·3		444	11·8	504	14·9	
Farmers (%)	2394	32·6	20 164	34·6	0·001	1311	34·8	1015	30·0	<0·001
Married/cohabiting (%)	6572	89·5	52 581	90·1	0·116	3361	89·3	3039	89·9	0·575
Current smokers (%)	1188	16·2	11 744	20·1	<0·001	612	16·3	683	20·2	<0·001
Current drinkers (%)	838	11·4	7456	12·8	0·001	366	9·7	474	14·0	<0·001
Physical activity (MET h/d)	25·2	18·1	27·6	18·0	<0·001	25·3	17·7	25·6	17·9	0·473
Total energy intake (kcal/d)	1877·4	647·1	1833·8	590·9	<0·001	1916·9	653·0	1861·0	626·6	<0·001
Regular beverage intake (%)	928	12·6	4008	6·9	<0·001	569	15·1	293	8·7	<0·001
Regular spicy food intake (%)	5714	77·8	46 468	79·6	<0·001	2817	74·9	2792	82·6	<0·001
Regular peppery food intake (%)	4807	65·5	39 882	68·3	<0·001	2391	63·6	2352	69·6	<0·001
Dietary supplement intake (%)	822	11·2	9060	15·5	<0·001	401	10·7	366	10·8	0·889
Insomnia symptoms (%)	3050	41·5	24 465	41·9	0·541	1582	42·0	1372	40·6	0·497
Anxiety symptoms (%)	392	5·3	3062	5·2	0·760	204	5·4	178	5·3	0·955
Depressive symptoms (%)	293	4·0	2575	4·4	0·102	143	3·8	147	4·3	0·098
Menopausal status in women (%)					0·045					0·909
Premenopausal	2288	53·4	19 248	52·9		1153	48·8	900	49·7	
Perimenopausal	345	8·1	2615	7·2		198	8·4	159	8·8	
Postmenopausal	1649	38·5	14 538	39·9		1010	42·8	752	41·5	
Family history of cardiometabolic disease (%)	2574	35·1	20 694	35·5	0·505	1257	33·4	1283	38·0	<0·001
aMED diet score	24·3	4·6	24·7	4·3	<0·001	24·0	4·6	24·6	4·5	<0·001
DASH diet score	20·2	4·5	20·7	4·3	<0·001	20·3	4·3	19·8	4·5	<0·001
BMI (kg/m^2)	30·2	2·2	23·3	2·4	<0·001	30·0	2·1	30·3	2·2	<0·001
WC (cm)	94·9	8·3	80·3	8·1	<0·001	93·6	8·6	96·5	7·0	<0·001
SBP (mmHg)	128·9	16·3	121·5	15·2	<0·001	124·2	14·5	134·2	16·3	<0·001
DBP (mmHg)	81·6	10·6	77·3	9·9	<0·001	78·6	9·7	85·5	10·3	<0·001
FBG (mmol/l)	5·4	1·2	5·1	0·9	<0·001	5·0	0·7	5·8	1·5	<0·001
TAG (mmol/l)	2·0	1·7	1·5	1·4	<0·001	1·4	1·0	2·8	2·3	<0·001
HDL-cholesterol (mmol/l)	1·3	0·3	1·5	0·4	<0·001	1·4	0·3	1·2	0·3	<0·001

MHO, metabolically healthy obesity; MET, metabolic equivalent task; MUO, metabolically unhealthy obesity; aMED, alternative Mediterranean; DASH, Dietary Approaches to Stop Hypertension; WC, waist circumference; SBP, systolic blood pressure; DBP, diastolic blood pressure; FBG, fasting blood glucose.
* The reported means and percentages are standardised to the age and sex distribution of the corresponding study population except for N (not adjusted), age (only adjusted sex), sex (only adjusted age) and menopausal status in women (only adjusted age).
† Linear regression analyses and χ^2 tests were used to compare different groups for continuous variables and categorical variables, respectively.

(I^2 = 87·3 %; P = 0·005) and increased with the rising education levels (I^2 = 87·3 %; P = 0·005).

In the sensitivity analysis, the association of DASH diet and MHO was moderately attenuated when including individuals with self-reported cardiometabolic diseases or cancer (online Supplementary Appendix Fig. S4), indicating the existence of reverse causality. When we used the strict definition of metabolic health or replaced the WC criteria with waist:hip ratio criteria, the estimated results were very similar (online Supplementary Appendix Fig. S5 and S6). Moreover, further adjusting for drinking status in models of DASH diet resulted in almost identical results as in the main analysis (online Supplementary Appendix Fig. S7).

Discussion

Summary of main results

Our findings show that in this multi-ethnic Chinese population, the highest adherence to DASH diet was associated with 23 % lower odds of obesity and 27 % higher odds of MHO in population with obesity, with no obvious benefits found for aMED diet.

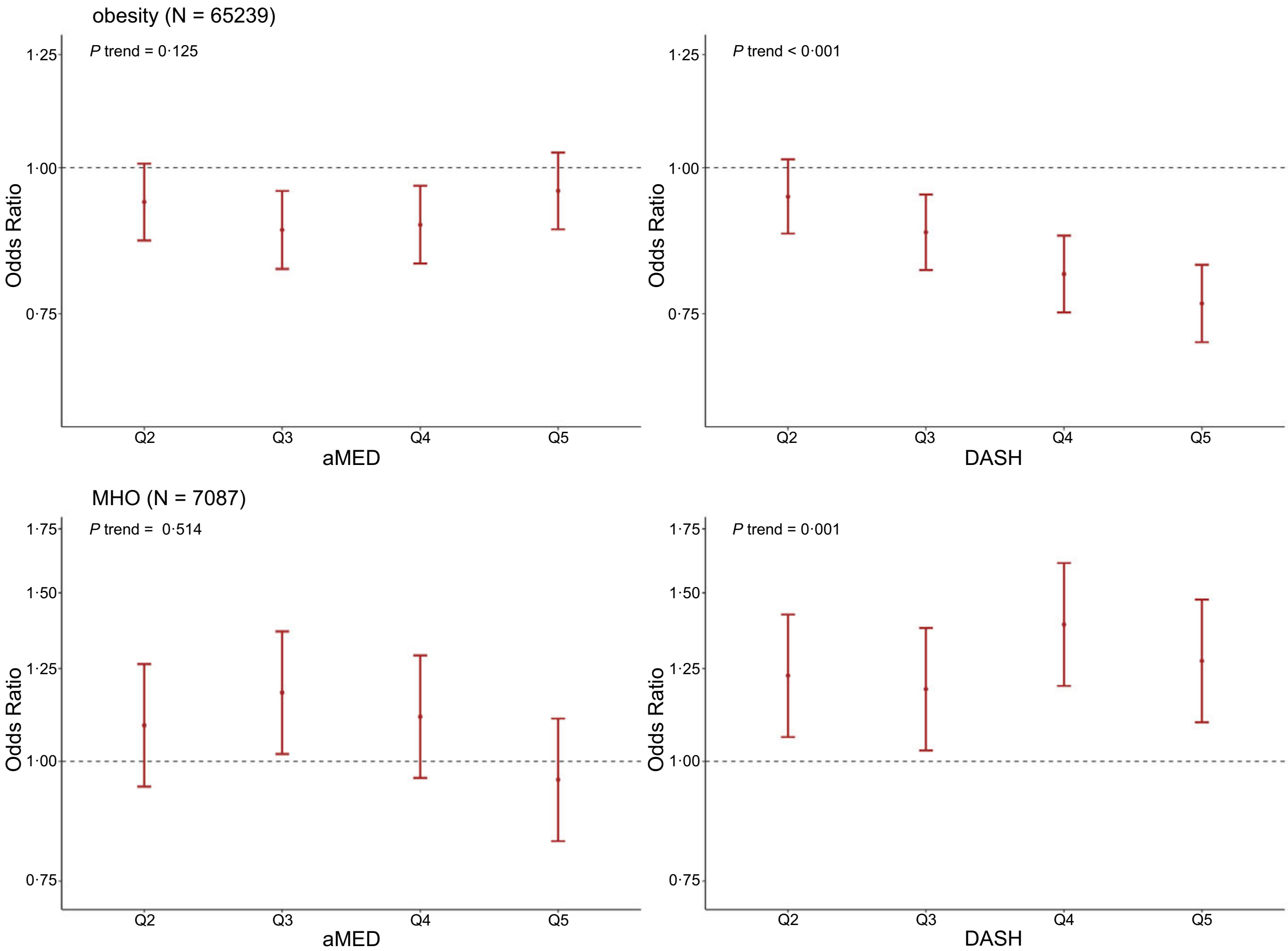

Fig. 1. Association of aMED and DASH diet scores with obesity and MHO phenotype. All models adjusted for age, sex, ethnic group, urbanicity, education, household income, profession, marital status, smoking, physical activity, total energy intake, regular intake of soft drinks, dietary supplements, spicy food and peppery food, insomnia symptoms, anxiety symptoms, depression symptoms, menopause status and family history of cardiometabolic diseases using logistic regression with inverse probability of exposure weighting (IPEW). Q2–Q5 represent the second to fifth quintiles of diet scores. The filled red dots represent estimated OR and the vertical red lines represent 95 % CI. aMED, alternative Mediterranean; DASH, Dietary Approaches to Stop Hypertension; MHO, metabolically healthy obesity.

Table 3. OR of MHO associated with quintiles of aMED and DASH diet scores after adjusting for BMI*
(Odds ratios and 95 % confidence intervals)

	OR (95 % CI) for MHO			
	aMED diet		DASH diet	
Quintiles of diet score	OR	95 % CI	OR	95 % CI
Q1	1·00 (ref)		1·00 (ref)	
Q2	1·08	0·93, 1·25	1·22	1·06, 1·42
Q3	1·15	0·99, 1·33	1·18	1·02, 1·37
Q4	1·09	0·94, 1·27	1·38	1·19, 1·60
Q5	0·95	0·82, 1·10	1·27	1·09, 1·47

MHO, metabolically healthy obesity; aMED, alternative Mediterranean; DASH, Dietary Approaches to Stop Hypertension; Q, quintiles.
* BMI was further included in the exposure models (rather than the outcome models) to compute the weights.

The favourable effect of DASH diet on metabolic health for population with obesity was independent of BMI. The benefits of DASH diet on obesity or metabolic health were greater in urban residents and younger and higher educated participants.

The prevalence, characteristics and mechanism of metabolically healthy obesity

In recent decades, interest has focused on MHO phenotype, including the definition, prevalence, characteristics, mechanism, prognosis and medical implications of this new concept. In terms of prevalence, existing studies have reported results with very large variability, ranging from 6 to 75 %[31]. Differences in the definition of MHO used, study design and sample size of the research, age, sex, ethnicity and other characteristics of the included population are likely responsible for the huge disparity[7]. In terms of characteristics, MHO seems to be more common in females[31], younger individuals[31], Asian populations[31], more physically active individuals[32] and subjects with better nutritional status[8], which were almost consistent with our findings. In mechanism, MHO may attribute to better body fat distribution (lower ectopic fat and higher leg fat deposition), preserved insulin sensitivity, normal adipose tissue function, lower levels of inflammatory and greater cardiorespiratory fitness compared with MUO[33]. In our study, 52·7 % of subjects

Table 4. OR of obesity and MHO associated with overall DASH diet score and subtracted DASH diet scores for each component
(Odds ratios and 95 % confidence intervals)

	Obesity				MHO			
Dietary score	OR	95 % CI*,†	*P*	Reduction in apparent effect (%)‡,§	OR	95 % CI*,†	*P*	Reduction in apparent effect (%)‡,§
DASH overall	0·843	0·807, 0·882	<0·001	0·0	1·163	1·066, 1·269	0·001	0·0
DASH minus whole grain	0·851	0·815, 0·889	<0·001	5·0	1·145	1·051, 1·249	0·002	10·9
DASH minus fruit	0·827	0·792, 0·864	<0·001	–10·4	1·166	1·070, 1·269	<0·001	–1·6
DASH minus vegetables	0·803	0·771, 0·837	<0·001	–25·7	1·109	1·024, 1·202	0·011	32·9
DASH minus legumes	0·922	0·883, 0·962	<0·001	50·1	1·190	1·094, 1·295	<0·001	–16·7
DASH minus red and processed meats	0·883	0·848, 0·920	<0·001	25·5	1·170	1·080, 1·267	<0·001	–4·0
DASH minus dairy products	0·942	0·902, 0·985	0·008	63·1	1·110	1·018, 1·209	0·018	32·9
DASH minus Na	0·842	0·808, 0·878	<0·001	–0·6	1·104	1·017, 1·198	0·017	36·3

MHO, metabolically healthy obesity; DASH, Dietary Approaches to Stop Hypertension.
* We assumed a linear relationship between dietary scores and outcomes, with OR representing the risk change per 25 % score range increment.
† The models of seven DASH minus component scores were further adjusted for the corresponding subtracted component score in addition to confounders in the main analysis, and the estimated coefficients of these logistic regressions were multiplied by 25/29 to correct for different score ranges.
‡ Reduction in apparent effect (%) = $(OR_{DASH\ overall} - OR_{DASH\ minus\ component})/(OR_{DASH\ overall} - 1) \times 100$ %.
§ The reduction in apparent effect can be negative when the effect of the corresponding subtracted component score was unexpectedly detrimental in this study. Similarly, the sum of those positive percentages of the reduction in apparent effect can exceed 100 %.

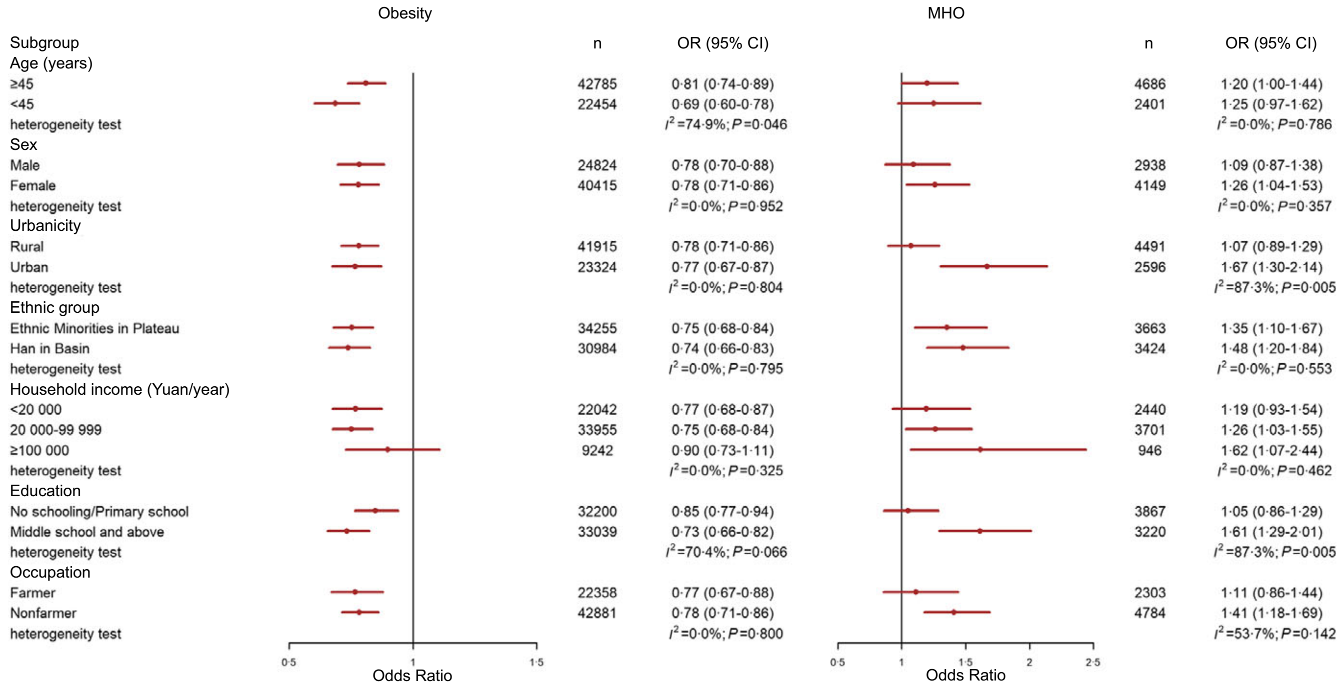

Fig. 2. Stratified analysis for associations of DASH diet scores with obesity and MHO according to predefined demographic and socio-economic factors by comparing the highest with the lowest quintiles. All models adjusted for age, sex, ethnic group, urbanicity, education, household income, profession, marital status, smoking, physical activity, total energy intake, regular intake of soft drinks, dietary supplements, spicy food and peppery food, insomnia symptoms, anxiety symptoms, depression symptoms, menopause status and family history of cardiometabolic diseases using logistic regression with inverse probability of exposure weighting (IPEW), with exclusion of the corresponding stratification factor as appropriate. I^2 statistic and Q test were used to assess heterogeneity among different strata of each stratification factor. The filled red dots represent estimated OR and the horizontal red lines represent 95 % CI. DASH, Dietary Approaches to Stop Hypertension; MHO, metabolically healthy obesity.

with obesity were ascertained to have MHO, which was relatively high among existing reports. The large proportion of female participants and exclusion of self-reported cardiometabolic diseases may largely explain the disparity. In addition, given the multi-ethnic nature of our study participants, genetic factors which are related to biological mechanisms of MHO may differ across diverse ethnic populations and thus contribute to the observed difference[34,35].

Regarding obesity and metabolically healthy obesity, Dietary Approaches to Stop Hypertension diet is a superior dietary recommendation

In this study, we observed significant and robust beneficial effects of DASH diet, which was consistent with previous evidence[18,36], but no obvious favourable findings for aMED diet. As shown in the component analysis, unexpected

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detrimental or null associations of the three exclusive components of aMED diet with outcomes were responsible for the overall null association. MUFA:SFA ratio and fish components represent the recommendation for consumption of healthy olive oil and marine fish, which are rich in MUFA[37,38], but this recommendation may be difficult to follow in non-Mediterranean regions and populations such as ours. The lack of such a superior source of MUFA and the high-temperature and deep cooking style in these populations may eliminate or even reverse the protective effect. In addition, moderate alcohol consumption is recommended in aMED diets, but the benefits of the recommendation were controversial or conditional. A rigorous Mendelian randomisation study based on the largest cohort in China demonstrated that alcohol intake uniformly increases cardiovascular risk without a protective effect of moderate consumption[39]. Frequent consumption of beer or strong spirits rather than grape wine may partially explain the inconsistent results.

In contrast, the results of two exclusive components of DASH diet were as expected. Dairy products showed consistent and substantial benefits on both obesity and metabolic health, which was in line with previous studies, especially in populations with generally low consumption of dairy products[40,41]. The Na component score showed no association with obesity but a positive association with MHO because Na mainly influences blood pressure, which is an important component of metabolic health. Moreover, as a holistic dietary pattern, DASH diet is characterised by a low fat, cholesterol and Na content, but high fibre, K, Mg, Ca and antioxidants content, all of which are demonstrated to be beneficial to components of the metabolic syndrome through different mechanisms including improving β-cells function, insulin sensitivity and gut microbiota and reducing adiposity accumulation, systemic inflammation and oxidative stress[42]. Therefore, regarding improvement on obesity per se or metabolic health for population with obesity, DASH diet may represent a more relevant and valuable dietary recommendation in Chinese population than aMED diet. In addition, it is worth noting that the dominant contributors to the benefits of DASH diet were not identical for different outcomes, which implies that under the overall guidance of DASH diet, recommendations could be flexibly focus more on certain components according to different levels of obesity prevention and control goals in practice.

Metabolic health is achievable without weight loss

The concept of MHO is attractive, given the limited success of current weight loss-centred and 'one size fits all' approaches to prevent and control obesity. An increasing number of studies point out that management of obesity does not necessarily consider weight loss to be the most important goal, and maintaining favourable cardiometabolic health and ultimately improving adverse health outcomes may be an easier and wiser strategy[4,5]. Our results presented BMI-independent metabolic benefits of DASH diet for population with obesity, which implied that cardiometabolic health may be improved by adopting healthy dietary patterns even without weight loss. There are many previous studies confirming the same viewpoint, including the OmniHeart trial[43], PREDIMED trial[44,45], trials conducted by the DASH Collaborative Research Group[46] and so on[47–49], which consistently demonstrate that following several healthy diets, albeit without changes in weight or BMI, can substantially improve BP, lipid profiles, WC, insulin resistance and even cardiovascular events. Of course, we cannot deny that weight loss is an ideal and essential goal in obesity treatment because obesity has many adverse health effects other than cardiometabolic risk, such as respiratory and sleep disorders, musculoskeletal system diseases and certain cancers[8]; furthermore, MHO may not be an absolutely benign and stable status (many MHO individuals may transit to MUO years later)[5,7]. Fortunately, healthy diets and many other lifestyle recommendations (such as maintaining physical activity) also have beneficial effects on weight loss[50,51]; targeting the more achievable goal of metabolic health can encourage and facilitate adherence to such healthy behaviours and ultimately improve the long-term and overall health status.

The beneficial effect of diet is stronger in populations with higher socio-economic status and in more developed regions

Another interesting finding in the present study was that the benefits of DASH diet on obesity or metabolic health were significantly stronger in urban residents and individuals with higher education levels. In fact, after carefully observing the results, we found a consistent, although non-significant, tendency of strengthened associations with increasing individual SES levels and regional development levels. The disparity in the availability and affordability of high-quality food is one potential explanation for the observed heterogeneous associations. That is, given the same overall dietary pattern (food type and quantity) guidance, there are substantial variability and flexibility in the choice and quality of specific food items, which may in turn modify the magnitude and even the direction of the health effects of diets. Therefore, to further strengthen and broaden the beneficial effect of healthy dietary patterns, improving the diet quality as well as the availability and affordability of such high-quality food for the whole population through multilevel and multicomponent cooperation and efforts is crucial and warranted.

The generalisability of the study

In terms of internal generalisability, the sampling strategy of the CMEC was carefully designed, which was a multistage stratified cluster sampling method with full consideration of representation for geography feature, ethnic structure, urbanicity status and demographic characteristics (such as sex ratio and age ratio)[21]. However, as a labour exporting area, the demographic characteristics of residents in southwest China might be very different from what are expected (e.g. much more man go out to work; thus, the female:male ratio is high). In addition, the CMEC is a volunteer-based study, although the sampling and recruiting process are carefully designed, the response rates are various among population with different characteristics (e.g. women are more willing to participant in the survey, especially in rural and less-developed areas). Therefore, some characteristics of our participants seem to be unrepresentative for the general population (such as the sex ratio); however, we have carefully adjusted such confounding variables in the primary statistical analysis to obtain a valid average treatment effect estimation and conducted several stratification analyses to explore the potential heterogeneity which showed overall homogeneous results.

In terms of external generalisability, the dietary patterns and other characteristics of the CMEC population might be different from that of other countries and regions, and we calculated the DASH and MED diet scores according to population-specific quintiles rather than specific amounts recommended in original DASH and MED diets. Therefore, the estimation results in the present study might not be directly comparable with those from other studies and extrapolated to other populations. However, the findings and conclusions of this study may be generalisable, which are shared by many other studies as we discussed above.

Strengths and limitations

To our knowledge, the present study is the first large-scale study to investigate the associations of well-known healthy dietary patterns with obesity and metabolic obesity phenotypes in Chinese multi-ethnic populations. The strengths of our study include a heterogeneous and unique population, rigorous and standardised data collection methods ensuring high-quality data, large sample size and number of cases and careful adjustment for potential confounders according to an evidence-based DAG and causal inference methods. Nevertheless, there are several limitations worthy of consideration. First, the cross-sectional nature of this study limited the determination of a causal relationship, although we adopted the DAG and inverse probability of exposure weighting approach and tried to minimise reverse causality by excluding participants with any self-reported cardiometabolic disease. Second, the dietary data were collected using an FFQ with only thirteen food groups, which was less accurate than an FFQ with specific food items or other methods, such as 24-h dietary recall. However, such a method is more feasible in large-scale epidemiology studies (especially in this less-developed ethnic minority region where many participants are illiterate, and speaking different languages) and may not lead to serious misclassification in assessing adherence to prior dietary patterns, whose components are also food types and almost covered by the FFQ used. Of course, such a method may result in underreporting and underestimating energy intake. Third, there exists inherent memory error in self-reporting of food and beverage consumption, physical activity and diseases history, etc., and insufficient measurements for some outcome indicators which may introduce bias to some extent. Fourth, although we adjusted for confounders based on a DAG, we cannot exclude the possibility of residual confounding due to measurement errors and unmeasured variables. Finally, given the transient nature of MHO, the determination of metabolic status merely on the basis of one time point measurement is not an optimal strategy and may result in misclassification.

Conclusions

In conclusion, higher adherence to DASH diet rather than aMED diet was favourably associated with obesity and MHO in this study, suggesting that DASH diet may be a superior dietary recommendation regarding the prevention of obesity and related metabolic disorders in Chinese population. The observed BMI-independent metabolic benefits of such a healthy dietary pattern imply that metabolic health may be improved even without weight loss, which may provide encouragement and positive reinforcement for individuals with obesity towards long-term adherence and thorough health benefits. Prospective and interventional studies are needed to confirm the findings and to further explore the effect of healthy dietary patterns on the transition and maintenance of MHO phenotype.

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D. T., X. X. and X. Z. designed the study. X. Z. was the principal investigator and J. Y. and F. H. the co-principal investigators of the CMEC study. D. T. and X. X. wrote the analysis plan and draft the manuscript. All other authors contributed to the acquisition and analysis of data, and interpretation of results. All authors made important contributions to editing and critically revising the manuscript for important intellectual content. All authors have approved the final version to be published. X. Z. is the guarantor of this work, has full access to all of the data and takes responsibility for the integrity of the data.

The authors declare no conflict of interest.

Supplementary material

For supplementary material referred to in this article, please visit https://doi.org/10.1017/S0007114521005158.

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