

Cross-sectional and longitudinal comparisons of metabolic profiles between vegetarian and non-vegetarian subjects: a matched cohort study

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Abstract

Several previous cross-sectional studies have shown that vegetarians have a better metabolic profile than non-vegetarians, suggesting that a vegetarian dietary pattern may help prevent chronic degenerative diseases. However, longitudinal studies on the impact of vegetarian diets on metabolic traits are scarce. We studied how several sub-types of vegetarian diets affect metabolic traits, including waist circumference, BMI, systolic blood pressure (SBP), diastolic blood pressure, fasting blood glucose, total cholesterol (TC), HDL, LDL, TAG and TC:HDL ratio, through both cross-sectional and longitudinal study designs. The study used the MJ Health Screening database, with data collected from 1994 to 2008 in Taiwan, which included 4415 lacto-ovo-vegetarians, 1855 lacto-vegetarians and 1913 vegans; each vegetarian was matched with five non-vegetarians based on age, sex and study site. In the longitudinal follow-up, each additional year of vegan diet lowered the risk of obesity by 7% (95% CI 0.88, 0.99), whereas each additional year of lacto-vegetarian diet lowered the risk of elevated SBP by 8% (95% CI 0.85, 0.99) and elevated glucose by 7% (95% CI 0.87, 0.99), and each additional year of ovo-lacto-vegetarian diet increased abnormal HDL by 7% (95% CI 1.03, 1.12), compared with non-vegetarians. In the cross-sectional comparisons, all sub-types of vegetarians had lower likelihoods of abnormalities compared with non-vegetarians on all metabolic traits ($P < 0.001$ for all comparisons), except for HDL and TAG. The better metabolic profile in vegetarians is partially attributable to lower BMI. With proper management of TAG and HDL, along with caution about the intake of refined carbohydrates and fructose, a plant-based diet may benefit all aspects of the metabolic profile.

Key words: Vegetarian diets: Longitudinal studies: Metabolic traits

Metabolic abnormalities are key mechanistic steps in the development of coronary heart diseases⁽¹⁾. Previous cross-sectional studies in Western populations have suggested beneficial associations between a vegetarian diet and metabolic health^(2–6), especially in cases where such a dietary pattern has been followed-up for 5 years or longer⁽⁷⁾.

Although several small cross-sectional studies have compared BMI, blood pressure, LDL oxidisability, fasting plasma, TAG, total cholesterol (TC) and LDL-cholesterol levels between Taiwanese vegetarians and matched omnivores^(8,9), examinations of the longitudinal effect of different types of vegetarian diets (e.g. vegan, lacto-ovo and lacto) on metabolic health are scarce. In addition, Western and Taiwanese vegetarian diets differ substantially, with Western vegetarian diets including more nuts, beans, dairy products, eggs and fresh greens, whereas Taiwanese vegetarians tend to eat more rice, cooked vegetables and soya products^(3,4,8). It is unknown whether the

beneficial effect of vegetarian diets observed in Western populations is reproducible in Taiwanese vegetarians.

We conducted a matched cohort study to examine the effects of different types of vegetarian and non-vegetarian diets on metabolic traits in a large Taiwanese cohort. In addition, we compared the subjects' reported food intake from FFQ to provide information for speculation on the potential impact of these diets on metabolic profiles.

Methods

This study used the MJ Health Screening database, for which data were collected from 1994 to 2008 in Taiwan. The MJ Group runs the MJ Health Screening Center chain of private clinics, with health check-up clinics located in Taipei, Taoyuan, Taichung and Kaohsiung. Each clinic provides its members with periodic health examinations, which include anthropometric

Abbreviations: DBP, diastolic blood pressure; FBG, fasting blood glucose; MS, metabolic syndrome; NHRI, National Health Research Institutes; SBP, systolic blood pressure; TC, total cholesterol; WC, waist circumference.

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measures and a check of blood pressure and biochemical markers such as blood glucose and lipids. In addition, at the time of screening, each examinee completes a self-administered questionnaire about his or her socio-demographic and lifestyle characteristics, along with a 23-item FFQ⁽¹⁰⁾. The MJ Health Screening database includes 918 718 check-up records from 473 997 subjects. After excluding subjects whose records contained inconsistencies in age, sex, ID number, examination dates or death dates, along with smokers and those younger than 20 years of age, 315 033 subjects remained (online Supplementary Tables S1 and S2). The remaining group included 4415 lacto-ovo-vegetarians, 1855 lacto-vegetarians and 1913 vegans. In order to control for potential confounding effects, we matched each vegetarian with five non-vegetarians based on age, sex and study site, resulting in a total of 49 098 participants for the final analyses. This study was approved by the institutional ethics committees of the MJ Health Screening Center and the National Health Research Institutes (NHRI).

Classification of dietary groups

The dietary intakes were assessed through a self-administered FFQ. The FFQ remained the same from 1994 to 2008. The reliability and validity of the MJ Health Screening Center's FFQ have been evaluated previously^(11,12). The Spearman's correlation coefficients for two repeats of the FFQ within 1 year ranged from 0.29 to 0.47 (all $P < 0.0001$) (online Supplementary Table S3). In addition, a summarised dietary quality index – the Overall Dietary Index, Revised, which is based on analysis of data from the FFQ – successfully predicted mortality in a cohort study, indicating the reproducibility of the FFQ^(13,14). The FFQ included twenty-three food items with specified serving sizes. For each item, the participants were asked to select one of the following five frequency categories that best characterised their eating habits over the past year: 'almost never', '1–3 servings/week', '4–6 servings/week', '1 serving/d' or '≥ 2 servings/d'⁽¹⁵⁾. Participants were categorised into the following four diet categories – vegan, lacto-vegetarian, lacto-ovo-vegetarian and omnivore – based on the answers to the following questions: (1) Are you a vegetarian? (2) How much meat (including red meat, poultry and fish) do you eat? (3) How much dairy do you consume? (4) How many eggs do you eat? Participants who answered the first and the second questions inconsistently were excluded. Moreover, participants with multiple visits were excluded from the longitudinal analysis if their answers for these questions were inconsistent during different visits, but were included for cross-sectional comparison using data from the latest visit. A total of 6690 subjects were included in the longitudinal follow-up, with an average follow-up of 2.12 years. The follow-up times for each diet groups are presented in online Supplementary Table S4.

Metabolic traits

The metabolic traits evaluated in this study included waist circumference (WC), BMI, systolic blood pressure (SBP), diastolic blood pressure (DBP), fasting blood glucose (FBG), TAG, TC, HDL, LDL and the TC:HDL ratio. Blood was collected after

overnight fasting on the entry date. FBG, TAG, HDL, TC and LDL were measured using an auto-analyser (Hitachi 7150; Hitachi). The presence of metabolic risk components was determined using the modified National Cholesterol Education Program/Adult Treatment Panel III (NCEP/ATP III) criteria: WC ≥ 90 cm in men or ≥ 80 cm in women, TAG ≥ 1.69 mmol/l or on medication, HDL-cholesterol < 1.03 mmol/l in men or < 1.29 mmol/l in women, blood pressure > 130/85 mmHg or on medication, TC ≥ 5.17 mmol/l or on medication and FBG ≥ 5.56 mmol/l or on medication. The modified ATP III criteria have been shown to be predictive of mortality and CVD in Asians and Taiwanese in previous studies⁽¹⁶⁾. BMI ≥ 27 was also included because it has been shown to be a risk factor for metabolic-related diseases for the Taiwanese population⁽¹⁷⁾.

Statistical analysis

Baseline characteristics were analysed using conditional logistic regression analyses. Generalised estimating equation (GEE) approaches were used to evaluate both the cross-sectional and temporal effects of different types of vegetarian diets relative to the omnivore diet for the dichotomised metabolic traits⁽¹⁸⁾. The 'logit' link was used for dichotomous outcomes, and an exchangeable correlation matrix was assumed in the GEE analyses. Covariates included age, sex, leisure-time physical activity (LTPA), alcohol consumption and education. Age² was also adjusted for in the traits when it was significant. Physical activity was presented as the metabolic equivalent of task (MET), where 1 MET equals 4.19 kJ/kg per h (1 kcal/kg per h) of body weight⁽¹⁹⁾. MET is defined as the ratio of the work metabolic rate to a standard RMR of 4.19 kJ/kg per h (1.0 kcal/kg per h). One MET is considered as the RMR or the energy cost of a person at rest⁽²⁰⁾. The GEE approach accounting for within-subject corrections from repeat measurements is applicable to data under the missing completely at random missing mechanism⁽¹⁸⁾. The non-parametric locally weighted scatterplot smoothing (LOESS) method⁽²¹⁾ was used to depict the patterns of individual quantitative traits over age; participants on medications (or with diseases) related to these traits were excluded. The relative quantity of food intakes of different vegetarian groups compared with non-vegetarians was assessed by linear regression using the GEE approach, while adjusting for the same covariates stated above. The response variable was the food intake at multiple times, and the covariates of interest were the diet groups indicated by three dummy variables. All the statistical analyses were carried out using SAS 9.3.

Results

Table 1 shows the baseline characteristics of vegetarians and matched non-vegetarians. Vegetarians had significantly lower abnormal rates for WC (21.7 *v.* 27.7%), BMI (10.9 *v.* 15.4%), SBP (35.3 *v.* 40.2%), DBP (27.3 *v.* 32.0%), FBG (32.0 *v.* 37.6%), TC (29.9 *v.* 50.0%) and LDL (23.4 *v.* 42.3%) levels, along with lower TC:HDL ratios (15.9 *v.* 21.0%) (all $P < 0.0001$), but higher abnormal rates for TAG (24.8 *v.* 23.0%, $P = 0.0003$) and HDL (41.0 *v.* 34.8%, $P < 0.0001$), compared with non-vegetarians.



Table 1. Comparison of baseline characteristics in vegetarians and matched non-vegetarians (Mean values and standard deviations; percentages)

Variables	Vegetarian (n 8183)		Matched non-vegetarian (n 40 915)		P*
	Mean	SD	Mean	SD	
Male (%)		25.0		25.0	1
Age (years)	48.9	14.4	48.9	14.4	0.16
Age (%)					
20–39		29.8		29.8	1
40–54		32.6		32.6	
55–64		22.1		22.1	
65–98		15.5		15.5	
WC (cm)	75.5	9.6	77.1	10.0	<0.0001
WC (male \geq 90, female \geq 80, %)		21.7		27.7	<0.0001
BMI (kg/m ²)	22.8	3.4	23.5	3.6	<0.0001
BMI (\geq 27, %)		10.9		15.4	<0.0001
SBP (mmHg)	122.5	21.9	125.1	22.1	<0.0001
SBP (\geq 130, %)		35.3		40.2	<0.0001
DBP (mmHg)	72.0	12.0	73.9	12.0	<0.0001
DBP (\geq 85, %)		27.3		32.0	<0.0001
FBG (mmol/l)	5.54	1.38	5.66	1.48	<0.0001
FBG (\geq 5.56, %)		32.0		37.6	<0.0001
TAG (mmol/l)	1.37	0.93	1.35	1.00	0.048
TAG (\geq 1.69, %)		24.8		23.0	0.0003
TC (mmol/l)	4.73	0.98	5.23	0.99	<0.0001
TC (\geq 5.17, %)		29.9		50.0	<0.0001
HDL (mmol/l)	1.33	0.37	1.40	0.40	<0.0001
HDL (male < 1.03, female < 1.29, %)		41.0		34.8	<0.0001
LDL (mmol/l)	2.79	0.82	3.24	0.86	<0.0001
LDL (\geq 3.36, %)		23.4		42.3	<0.0001
TC:HDL ratio	3.8	1.2	4.0	1.3	<0.0001
TC:HDL ratio (\geq 5, %)		15.9		21.0	<0.0001
LTPA (MET-h, %)					
Inactive		49.0		49.6	0.28
Low		19.6		19.7	
Median		19.8		19.4	
High		7.9		7.4	
Very high		3.7		3.9	
Alcohol consumption (%)					
Non-drinker		92.3		85.1	<0.0001
Occasional		7.4		13.6	
Regular		0.3		1.3	
Education (%)					
Middle school or below		46.3		44.6	0.0003
High school or junior college		34.7		35.6	
College or higher		19.0		19.8	
Site					
Taipei		43.5		43.5	1
Taoyuan		24.4		24.4	
Taichung		14.1		14.1	
Kaohsiung		18.0		18.0	

WC, waist circumference; SBP, systolic blood pressure; DBP, diastolic blood pressure; FBG, fasting blood glucose; TC, total cholesterol; LTPA, leisure-time physical activity (MET: 1 MET = 4.19 kJ/kg per h (1 kcal/kg per h) of body weight; MET-h, product of intensity (MET) and duration of exercise (h)).

* P-values for matched data were derived from conditional logistic regression.

For LTPA, there was no difference between vegetarians and non-vegetarians ($P=0.28$); however, vegetarians were more likely not to drink alcohol (92.3 *v.* 85.1%, $P<0.0001$) and had a lower educational level (46.3 *v.* 44.6% for middle school or lower education, $P=0.0003$). All significant differences between the dietary patterns have been reported; however, a number of those differences, although significant, was only small in magnitude and could have been caused by the large study sample. Fig. 1 illustrates the metabolic patterns over age by dietary type. Non-vegetarians had higher levels of all metabolic traits than vegetarians, except for TAG. Most metabolic traits increased with age until the age of 60 years, except

for HDL. At approximately the age of 60 years, the trend decreased or stabilised for DBP, TC, LDL and BMI. The differences in BMI, LDL and TC between the omnivores and the vegetarian groups were constantly higher across all ages, whereas SBP, DBP, FBG, TAG, HDL and WC as well as TC:HDL ratios showed interactions with dietary types.

With adjustment for age, sex, physical activities, alcohol consumption and education, vegetarians had significantly lower abnormalities in WC, BMI, SBP, DBP, FBG, TC and LDL as well as in TC:HDL ratios, with OR ranging from 0.37 to 0.90, but higher abnormality in HDL (OR ranged from 1.17 to 1.52), when compared with non-vegetarians cross-sectionally (Table 2). The

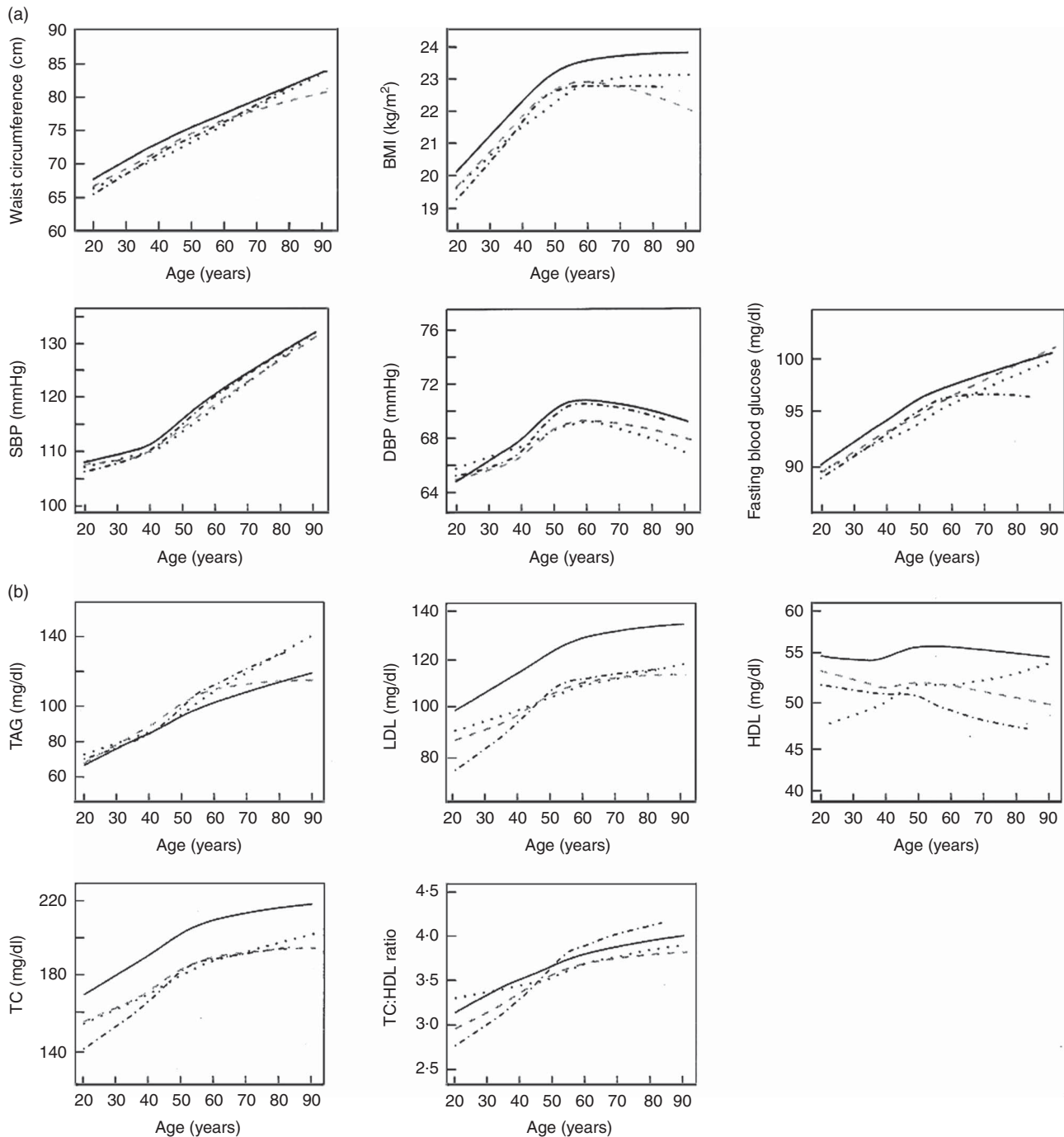


Fig. 1. (a) Patterns of waist circumference, BMI, systolic blood pressure (SBP), diastolic blood pressure (DBP), and fasting blood glucose over age by dietary type. (b) The patterns of TAG, LDL, HDL, total cholesterol (TC) and TC:HDL ratios over age by dietary type. — · — ·, Vegan; · · · ·, lacto; - - - -, ovo-lacto; ———, omnivore. To convert fasting blood glucose from mg/dl to mmol/l, multiply by 0.0555. To convert TAG from mg/dl to mmol/l, multiply by 0.0113. To convert LDL, HDL and total cholesterol from mg/dl to mmol/l, multiply by 0.0259.

proportions of abnormal TAG appeared to be higher in lacto-ovo-vegetarians compared with non-vegetarians (OR 1.15; 95% CI 1.06, 1.24), whereas no significant difference was seen for vegans (OR 1.11; 95% CI 0.99, 1.24) or lacto-vegetarians (OR 1.07; 95% CI 0.95, 1.19). Although vegetarians were more likely to have abnormal HDL levels, lacto and lacto-ovo-vegetarians had better TC:HDL ratios compared with non-vegetarians (lacto

vegetarians: OR 0.79; 95% CI 0.69, 0.90; lacto-ovo-vegetarians: OR 0.58; 95% CI 0.52, 0.64). With additional adjustment for BMI (Table 3), the beneficial effects for blood pressure and blood glucose were partly attenuated, whereas the effect on lipids remained consistent.

The 1-year temporal effects of a vegetarian diet generally showed beneficial trends for metabolic traits (Table 2), even after

Table 2. Longitudinal dietary effects on metabolic traits without adjusting for BMI (Odds ratios and 95 % confidence intervals)

Abnormality of metabolic variable	Baseline assessment								Temporal effect					
	Omnivore		Vegan v. omnivore		Lacto v. omnivore		Ovo-lacto v. omnivore		Vegan v. omnivore		Lacto v. omnivore		Ovo-lacto v. omnivore	
	OR	95 % CI	OR	95 % CI	OR	95 % CI	OR	95 % CI	OR	95 % CI	OR	95 % CI	OR	95 % CI
WC ($\geq 90/80$ cm)†	1.01	1.00, 1.02	0.69	0.61, 0.78	0.62	0.55, 0.70	0.68	0.62, 0.74	0.98	0.89, 1.09	0.98	0.90, 1.06	0.98	0.93, 1.03
BMI (≥ 27 kg/m ²)*	1.03	1.02, 1.03	0.68	0.59, 0.78	0.60	0.52, 0.71	0.69	0.62, 0.76	0.93	0.88, 0.99	0.96	0.89, 1.03	0.96	0.91, 1.00
SBP (≥ 130 mmHg)†	1.04	1.03, 1.05	0.81	0.73, 0.90	0.71	0.63, 0.79	0.76	0.70, 0.82	1.00	0.91, 1.09	0.92	0.85, 0.99	0.98	0.93, 1.03
DBP (≥ 85 mmHg)*	1.03	1.03, 1.04	0.81	0.73, 0.91	0.69	0.62, 0.78	0.76	0.70, 0.82	1.03	0.94, 1.13	0.97	0.89, 1.06	0.99	0.94, 1.04
FBG (≥ 5.56 mmol/l)†	1.09	1.08, 1.09	0.82	0.74, 0.91	0.73	0.65, 0.81	0.77	0.72, 0.83	1.01	0.93, 1.10	0.93	0.87, 0.99	0.98	0.94, 1.02
TAG (≥ 1.69 mmol/l)†	1.02	1.01, 1.02	1.11	0.99, 1.24	1.07	0.95, 1.19	1.15	1.06, 1.24	0.98	0.90, 1.08	1.01	0.94, 1.09	1.03	0.99, 1.08
TC (≥ 5.17 mmol/l)†	1.02	1.01, 1.02	0.40	0.36, 0.45	0.40	0.36, 0.45	0.39	0.37, 0.42	0.96	0.89, 1.05	1.04	0.97, 1.12	0.99	0.94, 1.03
HDL ($< 1.03/1.29$ mmol/l)†	0.92	0.92, 0.93	1.52	1.39, 1.68	1.42	1.29, 1.57	1.17	1.10, 1.25	1.03	0.94, 1.12	0.98	0.90, 1.08	1.07	1.03, 1.12
LDL (≥ 3.36 mmol/l)†	0.98	0.98, 0.99	0.45	0.40, 0.50	0.43	0.39, 0.48	0.37	0.34, 0.40	0.91	0.81, 1.03	1.01	0.93, 1.09	1.01	0.95, 1.06
TC:HDL ratio (≥ 5)†	0.93	0.92, 0.94	0.90	0.80, 1.02	0.79	0.69, 0.90	0.58	0.52, 0.64	0.94	0.79, 1.12	0.98	0.83, 1.15	1.07	1.00, 1.15

WC, waist circumference; SBP, systolic blood pressure; DBP, diastolic blood pressure; FBG, fasting blood glucose; TC, total cholesterol; LTPA, leisure-time physical activity.

* Adjusted for age, age², sex, education, LTPA, alcohol consumption and study site.

† Adjusted for age, sex, education, LTPA, alcohol consumption and study site.

Table 3. Longitudinal dietary effects on metabolic traits with adjustment for BMI (Odds ratios and 95 % confidence intervals)

Abnormality of metabolic variable	Baseline assessment								Temporal effect					
	Omnivore		Vegan v. omnivore		Lacto v. omnivore		Ovo-lacto v. omnivore		Vegan v. omnivore		Lacto v. omnivore		Ovo-lacto v. omnivore	
	OR	95 % CI	OR	95 % CI	OR	95 % CI	OR	95 % CI	OR	95 % CI	OR	95 % CI	OR	95 % CI
WC ($\geq 90/80$ cm)†	0.99	0.98, 1.00	1.04	0.87, 1.24	0.84	0.71, 1.01	0.86	0.76, 0.97	1.06	0.90, 1.25	0.94	0.82, 1.07	0.99	0.92, 1.07
SBP (≥ 130 mmHg)†	1.04	1.03, 1.04	0.90	0.80, 1.00	0.79	0.70, 0.89	0.84	0.77, 0.91	1.01	0.93, 1.11	0.92	0.85, 1.01	0.98	0.93, 1.03
DBP (≥ 85 mmHg)*	1.03	1.02, 1.04	0.90	0.81, 1.02	0.77	0.68, 0.87	0.83	0.76, 0.90	1.05	0.96, 1.15	0.98	0.90, 1.08	0.99	0.94, 1.04
FBG (≥ 5.56 mmol/l)†	1.08	1.08, 1.09	0.89	0.80, 0.99	0.79	0.71, 0.88	0.83	0.77, 0.89	1.02	0.93, 1.12	0.94	0.87, 1.01	0.98	0.94, 1.03
TAG (≥ 1.69 mmol/l)†	1.01	1.00, 1.02	1.29	1.15, 1.45	1.26	1.12, 1.42	1.33	1.22, 1.44	1.00	0.91, 1.10	1.02	0.95, 1.11	1.04	0.99, 1.09
TC (≥ 5.17 mmol/l)†	1.01	1.01, 1.02	0.42	0.38, 0.46	0.43	0.38, 0.47	0.41	0.38, 0.44	0.97	0.89, 1.06	1.05	0.98, 1.13	0.99	0.94, 1.03
HDL ($< 1.03/1.29$ mmol/l)†	0.91	0.91, 0.92	1.72	1.56, 1.89	1.63	1.47, 1.80	1.30	1.21, 1.39	1.04	0.95, 1.14	0.99	0.90, 1.10	1.08	1.03, 1.12
LDL (≥ 3.36 mmol/l)†	0.98	0.97, 0.99	0.47	0.42, 0.52	0.46	0.41, 0.51	0.38	0.35, 0.41	0.92	0.82, 1.04	1.01	0.93, 1.10	1.01	0.95, 1.06
TC:HDL ratio (≥ 5)†	0.92	0.91, 0.93	1.01	0.89, 1.15	0.90	0.79, 1.03	0.63	0.57, 0.70	0.96	0.80, 1.16	0.98	0.82, 1.18	1.08	1.00, 1.16

WC, waist circumference; SBP, systolic blood pressure; DBP, diastolic blood pressure; FBG, fasting blood glucose; TC, total cholesterol; LTPA, leisure-time physical activity.

* Adjusted for age, age², sex, BMI, education, LTPA, alcohol consumption and study site.

† Adjusted for age, sex, BMI, education, LTPA, alcohol consumption and study site.

Table 4. Food intake frequency for different types of vegetarians compared with non-vegetarians (Estimates and 95 % confidence intervals)

Food category	Vegan		Lacto		Ovo-lacto	
	Estimate*	95 % CI	Estimate*	95 % CI	Estimate*	95 % CI
Rice and noodles	-0.27	-0.56, 0.022	-0.21	-0.50, 0.072	1.00	0.82, 1.18
Whole grains	0.76	0.59, 0.92	0.85	0.69, 1.00	0.71	0.61, 0.81
Sweet breads	-0.68	-0.77, -0.59	-0.15	-0.25, -0.041	-0.098	-0.16, -0.034
Beans	1.04	0.87, 1.20	1.50	1.33, 1.67	1.66	1.56, 1.76
Light-green vegetables	0.75	0.59, 0.91	0.89	0.74, 1.05	0.75	0.66, 0.84
Dark-green vegetables	0.66	0.51, 0.82	0.81	0.66, 0.96	0.71	0.63, 0.80
Root vegetables	0.20	0.10, 0.31	0.40	0.30, 0.51	0.50	0.44, 0.56
Fried rice and noodle products	-0.087	-0.16, -0.014	0.016	-0.069, 0.10	0.16	0.10, 0.21
Stir-fried rice or noodles	-0.28	-0.41, -0.15	0.058	-0.10, 0.22	-0.0075	-0.17, 0.16
Fried vegetables	-1.99	-2.66, -1.33	0.14	-0.57, 0.85	-0.30	-0.70, 0.10
Fried food	-0.80	-0.87, -0.73	-0.61	-0.69, -0.53	-0.49	-0.55, -0.44
Fruit	-0.14	-0.26, -0.012	0.087	-0.039, 0.21	-0.21	-0.28, -0.13
Jam and honey	-0.11	-0.15, -0.069	0.13	-0.069, 0.19	0.10	0.063, 0.14
Sugar drinks	-0.71	-0.84, -0.58	-0.51	-0.64, -0.38	-0.31	-0.40, -0.22
Pickled vegetables	-0.36	-0.42, -0.30	-0.28	-0.34, -0.21	-0.23	-0.27, -0.19
Instant noodles	-0.070	-0.10, -0.038	0.014	-0.029, 0.056	0.040	0.012, 0.067

* Servings/week, adjusted for age, sex, education, leisure-time physical activity, alcohol consumption and study site.

adjusting for the baseline metabolic profile. However, perhaps due to the limited sample size of individuals with multiple follow-up visits, only three differences in the temporal dietary effects were observed. First, each additional year of vegan diet lowered the risk of obesity by 7% (95% CI 0.88, 0.99). Second, each additional year of lacto-vegetarian diet lowered the risk of elevated SBP by 8% (95% CI 0.85, 0.99) and lowered the risk of elevated glucose by 7% (95% CI 0.87, 0.99). Finally, each additional year of ovo-lacto-vegetarian diet increased abnormal HDL by 7% (95% CI 1.03, 1.12) compared with a non-vegetarian diet. Nevertheless, overall TC:HDL ratios in ovo-lacto-vegetarians remained lower than that in non-vegetarians because they had the lowest baseline-level values.

With additional adjustment for BMI (Table 3), the abnormal rates of TAG at baseline became significantly higher in vegans and lacto-vegetarians compared with non-vegetarians, with OR of 1.29; 95% CI 1.15, 1.45 and OR of 1.26; 95% CI 1.12, 1.42, respectively. Although lacto-ovo-vegetarians appeared to have an increased 1-year temporal risk for a high TC:HDL ratio compared with non-vegetarians (OR 1.08; 95% CI 1.00, 1.16), this is largely due to their lower baseline TC:HDL ratio; the lacto-ovo-vegetarians actually had a lower overall average TC:HDL ratio compared with non-vegetarians.

Furthermore, we examined the intake of twenty plant-based foods (servings/week) for the four dietary groups at baseline (Table 4). Vegans had the lowest intake of fried foods, fried rice and noodle products, fried vegetables, jam and honey, instant noodles and pickled vegetables. Lacto-vegetarians had the highest intake of whole grains, light-green and dark-green vegetables and fruits. Ovo-lacto-vegetarians had the highest intake of beans and root vegetables. Non-vegetarians had the highest intake of (sweet) bread, fried vegetables, fried food, sugary drinks and pickled vegetables.

The summary of abnormality rates for individual metabolic traits at each visit are displayed in the supplemental materials (online Supplementary Tables S5 and S6). Visit frequencies, by

diet and the number of participants and missing observations for each abnormal metabolic trait, are listed in online Supplementary Table S7 and S8. The numbers of subjects included in the analyses for Tables 2–4 are displayed in online Supplementary Tables S9–S11, respectively.

Discussion

Overall, we observed lower values for WC, BMI, SBP, DBP, FBG, TC, HDL and LDL, along with lower TC:HDL ratios, in vegetarians compared with non-vegetarians, which replicated the findings of previous Taiwanese studies^(9,22,23). Except for HDL and TAG values in lacto-ovo-vegetarians, the vegetarian diets showed significant beneficial effects on metabolic traits, which may be partly due to the lower BMI of vegetarians.

Similar to previous Taiwanese studies, our cross-sectional analysis indicates that vegetarians consistently showed a better lipid profile, except for TAG and HDL, although longitudinal follow-up showed no significant associations, suggesting potential reverse causation in which individuals with poor health conditions switched to a vegetarian diet in order to improve their health. Previous studies have found that higher TAG levels may be caused by high consumption of refined carbohydrates, fructose or fat⁽²⁴⁾; however, generally, vegetarians in our study, consumed lower amounts of sugary drinks, sweet bread and fried food and, except for lacto-ovo-vegetarians, higher amounts of vegetables and whole grains (healthier type of carbohydrates). Lacto-ovo-vegetarians appeared to eat more carbohydrates and fructose, which could be one of the main causes for TAG elevation in this group. The dietary choices of vegetarians indicate that they may be more health conscious; such behaviours may have been motivated, in part, by the need to improve health in the presence of existing chronic degenerative conditions. Whether the lower HDL in vegetarians can be regarded as a risk factor may require further

study, as vegetarians generally had better TC:HDL ratios. In addition, previous studies have found that low HDL due to reduced fat intake was not associated with poor cardiovascular health^(25,26).

Several studies in Western countries have found that vegetarian diets play a favourable role in lowering the risk of metabolic syndrome (MS)^(2,27–29). However, similar to the results of Shang *et al.*⁽¹⁵⁾, in the present study, the prevalence of MS, defined by modified ATP III criteria for Asians⁽¹⁵⁾, did not differ between vegetarians and non-vegetarians, except for lacto-vegetarians (OR 0.87; 95 % CI 0.76, 0.99). When the International Diabetes Federation's criteria for MS (which requires elevated WC plus two additional risk factors) was used, all types of vegetarians showed a significantly lower MS prevalence compared with non-vegetarians (OR 0.76; 95 % CI 0.65, 0.89; OR 0.67; 95 % CI 0.57, 0.78; OR 0.78; 95 % CI 0.70, 0.87 for vegans, lacto-vegetarians and lacto-ovo-vegetarians, respectively), with adjustment for age, alcohol consumption, LTPA and education. This indicates that the beneficial effects of a vegetarian diet may be mainly mediated through lower likelihood of obesity and abdominal obesity. Recently, the Adventist Health Study 2 also found that a vegetarian dietary pattern is associated with a more favourable MS profile⁽²⁾ and greater longevity⁽³⁰⁾. The slight discrepancy in our findings may result partially from differences between Taiwanese and Western diets in food intakes and cooking styles, and differences between the two populations in the prevalence of obesity and abdominal obesity.

Our finding on blood pressure is consistent with both the EPIC-Oxford study and the Adventist Health Study 2, which found that vegetarians, particularly vegans, had a lower age-adjusted prevalence of hypertension and lower blood pressure compared with non-vegetarians; these differences were largely attributable to the lower BMI of the vegetarians⁽³¹⁾. In addition, we found that 1 additional year of exposure to lacto-vegetarian diet (instead of a non-vegetarian diet) is associated with reduced chance of elevated blood pressure. Lacto-vegetarians had the highest intake of whole grains, fruits and vegetables – foods that are high in K – which are known to reduce blood pressure.

The EPIC-Oxford study showed that vegetarians had a significantly lower risk of hospitalisation or death due to IHD compared with non-vegetarians⁽³¹⁾. The Adventist Health Study 2 also found that vegetarians had lower cardiovascular mortality than non-vegetarians⁽³²⁾. Whether this MJ Health Screening cohort replicates these findings deserves further investigation.

The limitations of this study are that the participants came back irregularly and were re-evaluated at unequal time intervals. Of the participants, 63.2% had only one visit recorded. Sensitivity analysis on those with only one visit and those with multiple visits showed no significant differences in the baseline associations of the separate subsets. An assumption of constant diet patterns was made when the dietary types were confirmed by the FFQ and when the answers to the specific dietary questions remained consistent over multiple visits. A longer duration (≥ 2 decades) of very low meat intake has been shown to be associated with an increase in life expectancy of 3–6 years⁽³⁰⁾. In this study, access to complete

dietary duration information was not feasible, and longer dietary effects will be assessable with a longer follow-up period. As the MJ Health Screening Center requires an annual fee, its enrollees tend to be better off than the general population. Overall, they represent a group that has a higher socioeconomic status and is more health conscious than the general population. However, the participants of the MJ Health Screening Center are comparable with subjects attending other health-examination clinics^(11,12). Their diets may represent those of the middle-to-upper class in society⁽³³⁾. However, some of the statistically significant findings may appear by chance due to multiple testing for multiple traits. Even with such limitations, this study remains one of the largest Taiwanese samples of vegetarians and omnivores to examine the longitudinal effects of vegetarian diets in Taiwan. These findings were mostly consistent with previous studies on Taiwanese vegetarians^(22,23). Lacto-ovo-vegetarians, who are the majority of Taiwanese vegetarians, did not appear to have a more advantageous metabolic profile than the other two types of vegetarians. On the contrary, based on the FFQ, vegans appeared to have a healthier food profile than the others. These observations suggest that, with a cautious management of carbohydrate and fructose intake⁽³⁴⁾, plant-based diets can benefit all aspects of the metabolic profile.

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There are no conflicts of interest to declare.

Supplementary material

For supplementary material/s referred to in this article, please visit <http://dx.doi.org/doi:10.1017/S0007114515002937>

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