A vegan diet improves insulin resistance in individuals with obesity: a systematic review and meta-analysis

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Abstract

Background: A vegan diet has benefits on weight reduction and on the parameters of glucose and lipid metabolism. This meta-analysis aimed to investigate the efficacy of plant-based diets on insulin resistance and blood lipids in patients with obesity.

Methods: PubMed, Embase, and the Cochrane Library were searched for available papers published up to March 2021. The primary outcome was insulin resistance which was assessed by Homeostasis Model Assessment Insulin Resistance (HOMA-IR), other metabolic parameters measures including the pre/post-diet changes in triglycerides, HDL-cholesterol, total cholesterol, LDL-cholesterol. All analyses were performed using the random-effects model.

Results: Six studies (seven datasets) were included. Compared with baseline, the plant-based diet improved the HOMA-IR (SMD = 1.64, 95% CI 0.95, 2.33; I² = 91.8%, Pheterogeneity < 0.001), total cholesterol (SMD = 2.51, 95% CI 0.88, 4.13; I² = 98.0%, Pheterogeneity < 0.001), HDL-cholesterol (SMD = 1.55, 95% CI 0.66, 2.44; I² = 92.0%, Pheterogeneity < 0.001), and LDL-cholesterol (SMD = 2.50, 95% CI 1.30, 3.70; I² = 94.4%, Pheterogeneity < 0.001), but not the triglycerides (SMD = −0.62, 95% CI −1.92, 0.68; I² = 97.8%, Pheterogeneity < 0.001). The sensitivity analyses showed that the results were robust.

Conclusions: In obese individuals with insulin resistance, a vegan diet improves insulin resistance and dyslipidemia, except for triglycerides.

Keywords: Obesity, Insulin resistance, Type 2 diabetes mellitus, Vegan diet, Meta-analysis

Background

Obesity is associated with increased morbidity and mortality, including increased risk of cardiovascular events and increased risk of certain cancers [1–4]. An estimated 12% of the world population was obese in 2015 [5]. Once a body mass index (BMI) of 25 kg/m² is reached, any additional increase is associated with an increased risk of all-cause mortality [6]. Conditions such as (but not limited to) type 2 diabetes mellitus (T2DM) [7], hypertriglyceridemia [8–10], nonalcoholic fatty liver disease [11–13], and hypertension [14–16] are associated with overweight. Because each of these conditions is independently associated with increased cardiovascular risk and mortality [7–14, 17], managing body weight has a profound impact on health.

A positive energy balance (increased energy intake and/or decreased energy expenditure in relation to each other) sustained over time will lead to an increase in weight [1]. Even a 5%-15% weight loss may greatly reduce complications in persons with overweight or obesity [1]. Studies have shown that excess weight and its associated comorbidities can be favorably modified.
through lifestyle changes such as adopting a healthy diet and increasing energy expenditure [3, 18–21]. Nevertheless, although marked improvements have been made in initial and long-term weight losses, researchers need to identify more effective strategies to improve long-term maintenance [22].

A vegan diet is a diet that excludes animal products [23, 24], often resulting in hypocaloric diets compared with their meat-containing counterparts. By avoiding meat, vegan diets are often hypocaloric [24]. It has been suggested that persons who follow a vegan diet are more satisfied and are more likely to follow it for a longer period than other weight-loss eating plans [25–27]. Randomized controlled trials (RCTs) [28–30] and a meta-analysis [31] showed the metabolic and weight-control benefits of vegetarian and vegan diets. Consequently, a vegetarian diet has been associated with a lower risk of T2DM [32]. Indeed, the Homeostatic Model Assessment of Insulin Resistance (HOMA-IR) is an index for assessing β-cell function and insulin resistance [33], and vegetarian and vegan diets have been shown to improve the HOMA-IR [34–36]. Furthermore, since non-vegetarian diets are often rich in lipids, two meta-analyses revealed that vegetarian and vegan diets significantly decrease total cholesterol, low-density lipoprotein cholesterol (LDL-C), high-density lipoprotein cholesterol (HDL-C), and non-HDL-C, but without significant changes in triglycerides [37, 38].

This systematic review and meta-analysis aimed to investigate the efficacy of plant-based diets on the metabolic parameters of patients with obesity and insulin resistance. The results could support the use of such a diet for the management of obesity and T2DM.

Methods

Literature search

This systematic review and meta-analysis was conducted according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines [39]. The search strategy was built using the PICOS principle [40]. PubMed, Embase, and the Cochrane Library were searched for available papers published up to March 2021 using the MeSH terms “Vegan diet”, “Insulin resistance”; and “Overweight”, as well as relevant key words, followed by screening based on the inclusion and exclusion criteria. The exact search processes are shown in Additional file 1: Table S1. For multiple articles reporting the same study population, only the most recent one and meeting the eligibility criteria were included. For articles reporting different study populations, each dataset was considered independently in this meta-analysis.

Eligibility criteria

The eligibility criteria were (1) intervention: plant-based diet, (2) comparison: any non-vegetarian/non-vegan diet (i.e., no diet changes, Mediterranean diet, animal protein, low-fat omnivorous diet, omnivorous, beef/pork, etc.), (3) population: obese/overweight adults, (4) primary outcome: insulin resistance was assessed by Homeostasis Model Assessment Insulin Resistance (HOMA-IR) [41]; other metabolic parameters including triglycerides, HDL-cholesterol, total cholesterol, LDL-cholesterol, and (5) study design: RCT. Reviews, meta-analyses, letters to the editors, commentaries, and case reports were excluded.

Data extraction

Study characteristics (authors, year of publication, country, and study design), patient characteristics (sex, sample size, weight, and BMI), and outcomes measured at baseline and the last assessment in the intervention group (HOMA-IR, triglycerides, HDL-cholesterol, LDL-cholesterol, and total cholesterol) were extracted and reviewed by two different investigators (P.C. and Y.C.) according to a pre-specified protocol. Discrepancies were solved by discussion until a consensus was reached.

Quality of the evidence

The level of evidence of all articles was assessed independently by two authors (P.C. and Y.C.) according to Version 2 of the Cochrane risk-of-bias assessment tool for randomized trials (RoB 2) [42, 43]. Discrepancies in the assessment were resolved through discussion until a consensus was reached.

Statistical analysis

All analyses were performed using STATA SE 14.0 (StataCorp, College Station, Texas, USA). The standardized mean difference (SMD) and 95% confidence intervals (CI) were used to assess the continuous variables. Statistical heterogeneity among studies was calculated using Cochran’s Q-test and the I² index. An I² > 50% and Q-test P < 0.10 indicated high heterogeneity. All analyses were performed using the random-effects model. P-values < 0.05 were considered statistically significant.

Results

Study selection

Figure 1 presents the study selection process. The initial search yielded 241 records. After removing the duplicates, 190 records were screened, and 127 were excluded (review, n = 83; conference abstract, n = 15; note, n = 1; language, n = 3; not accessible, n = 23;
others, \( n = 1 \). Then, 63 abstracts or full-text papers were assessed for eligibility, and 57 were excluded (population, \( n = 10 \); study aim/design, \( n = 27 \); intervention, \( n = 1 \); outcomes, \( n = 14 \); animal study, \( n = 5 \)).

Finally, six articles (seven datasets) and 303 participants were included [44–49] (Table 1). There were six RCTs [44, 45, 47–49] and one pilot study [46]. One study was from Italy [46], and five were from the United States of America [44, 45, 47–49]. The mean participants’ age varied from 44.4 to 58.3 years. The proportion of males varied from 5.3% to 91.1%. The mean participants’ BMI varied from 30.7 to 36.1 kg/m². One study had a high risk

![Fig. 1 Flow diagram of the literature search and filtering results for a systematic review of the effectiveness of a plant diet on obesity](image)

| Study            | Design | Country   | Sample size | Age          | Sex (male), n | Weight, kg | BMI, kg/m²   |
|------------------|--------|-----------|-------------|--------------|---------------|------------|--------------|
| Kahleova 2018 [45] | RCT    | USA       | 38          | 52.6 (14.7)  | 2             | /          | 33.1 (31.8–34.3) |
| Basciani 2020 [46] | Pilot study | Italy     | 16          | /            | /             | 102.1 (12.36) | 36.1 (4.3)   |
| Kahleova 2020 [44] | RCT    | USA       | 122         | 53 (10)      | 17            | 93.6 (13.8) | 33.3 (3.8)   |
| Li 2016 [47]      | RCT    | USA       | 17          | 56 (4)       | 11            | 88.1 (2.9)  | 30.7 (0.6)   |
| Burke 2007a [48]  | RCT    | USA       | 35          | 44.37 (8.4)  | 28            | 97.7 (11.5) | /            |
| Burke 2007b [48]  | RCT    | USA       | 45          | 45.4 (8.5)   | 41            | 93 (16.2)   | /            |
| Barnard 2021 [49] | RCT    | USA       | 30          | 58.3 (8.4)   | 22            | 98.4 (13.2) | 33.7 (3.4)   |
of bias for two items of RoB2 [49], while the remaining studies all had an unclear risk of bias for at least one item [44–48].

**Impact of the vegan diet on metabolic indexes**

The meta-analyses indicated that compared with baseline, the vegan diet improved the HOMA-IR [44–49] (SMD = 1.64, 95% CI 0.95, 2.33; I² = 91.8%, P heterogeneity < 0.001) (Fig. 2), total cholesterol [44–49] (SMD = 2.51, 95% CI: 0.88, 4.13; I² = 98.0%, P heterogeneity < 0.001) (Fig. 3), HDL-cholesterol [44–47, 49] (SMD = 1.55, 95% CI 0.66, 2.44; I² = 92.0%, P heterogeneity < 0.001) (Fig. 4), and LDL-cholesterol [44–47, 49] (SMD = 2.50, 95% CI 1.30, 3.70; I² = 94.4%, P heterogeneity < 0.001) (Fig. 5), but triglycerides showed no significant difference [44–49] (Fig. 6).

**Sensitivity analysis**

The Additional file 1: Figs. S1–S6 show that all analyses were robust. The exclusion of each study, in turn, did not change the results.

**Discussion**

Studies showed that compared with other weight-loss diets, individuals who follow a vegetarian or vegan diet are more satisfied and are more likely to adhere to it [25–27]. RCTs showed the metabolic benefits of a vegetarian or vegan diet [28–30]. This meta-analysis aimed to investigate the efficacy of plant-based diets on the metabolic parameters of patients with obesity and insulin resistance. The results indicate that in obese individuals with insulin resistance, a vegan diet improves...
**Fig. 4** Forest plot illustrating the impact of plant diet on the metabolic parameter of HDL-cholesterol in obese patients

| Study         | SMD (95% CI)       | Weight |
|---------------|--------------------|--------|
| Kahleova 2018 | 1.98 (1.43, 2.53)  | 20.60  |
| Basciani 2020 | 0.29 (-0.50, 0.89) | 19.68  |
| Li 2016       | 2.36 (1.48, 3.25)  | 18.29  |
| Barnard 2020  | 2.64 (1.91, 3.36)  | 19.48  |
| Kahleova 2020 | 0.71 (0.45, 0.97)  | 21.95  |
| Overall, DL ($I^2 = 92.0\%$, $p = 0.000$) | 1.55 (0.66, 2.44) | 100.00 |

*NOTE: Weights are from random-effects model*

**Fig. 5** Forest plot illustrating the impact of plant diet on the metabolic parameter of LDL-cholesterol in obese patients

| Study         | SMD (95% CI)       | Weight |
|---------------|--------------------|--------|
| Kahleova 2018 | 1.65 (1.13, 2.17)  | 20.72  |
| Basciani 2020 | 1.04 (0.30, 1.78)  | 19.93  |
| Li 2016       | 3.62 (2.51, 4.73)  | 18.19  |
| Barnard 2020  | 2.26 (1.60, 2.96)  | 20.16  |
| Kahleova 2020 | 3.97 (3.53, 4.40)  | 20.98  |
| Overall, DL ($I^2 = 94.4\%$, $p = 0.000$) | 2.50 (1.30, 3.70) | 100.00 |

*NOTE: Weights are from random-effects model*

**Fig. 6** Forest plot illustrating the impact of plant diet on the metabolic parameter of triglycerides in obese patients

| Study         | SMD (95% CI)       | Weight |
|---------------|--------------------|--------|
| Kahleova 2018 | -1.09 (-1.57, -0.60)| 14.37  |
| Basciani 2020 | 0.55 (-0.15, 1.26) | 14.05  |
| Li 2016       | 0.84 (0.14, 1.54)  | 14.05  |
| Burke 2007a   | 0.03 (-0.44, 0.50) | 14.38  |
| Burke 2007b   | 0.16 (-0.26, 0.57) | 14.44  |
| Barnard 2020  | -0.86 (-1.41, -0.31)| 14.28  |
| Kahleova 2020 | -3.94 (-4.37, -3.50)| 14.42  |
| Overall, DL ($I^2 = 97.8\%$, $p = 0.000$) | -0.62 (-1.92, 0.68) | 100.00 |

*NOTE: Weights are from random-effects model*
insulin resistance and dyslipidemia, except for triglycerides. Whether these changes result in changes in morbidity and mortality remains to be examined.

The present meta-analysis showed that a vegan diet improved the HOMA-IR in obese individuals with insulin resistance. It is supported by a previous meta-analysis that showed that a vegetarian diet could prevent the development of T2DM [32]. Such a relationship is independent of BMI [50–52]. Vegans also have low levels of intramyocellular lipids related to improved insulin sensitivity [53]. In addition, low consumption of saturated lipids [54, 55] and low liver fat content [56] participate in a better β-cell function. The effect of vegetarian and vegan diets on insulin resistance has been documented by other studies [36, 57–60].

The present meta-analysis showed that the vegan diet improved the blood cholesterol parameters but not the triglycerides. Similar results were reported by a previous meta-analysis [37]. Still, other studies reported conflicting results. Some studies showed that a vegetarian diet improved cholesterol and triglycerides [61, 62], while others reported changes in cholesterol but not HDL-C and triglycerides [63, 64]. A meta-analysis showed that vegetarian diets improved HDL-C [65], and another showed improvement in triglycerides [66]. Still, the changes could depend upon obesity and leptin levels [67, 68], which could explain the conflicting results, at least in part. Nevertheless, all studies agree that a vegetarian or vegan diet induces some beneficial changes in blood lipids.

Substantial heterogeneity was observed in all analyses. Even if all studies examined a vegan diet, there were some differences among the studies, including the exact composition of the diet and the caloric target. Of note, the definition of a vegetarian diet varies in the literature, but the definition of a vegan diet is the same [69–72]. The proportion of males varied from 5 to 91%, and it is well known that obesity, glucose metabolism, and blood lipids display differences between men and women [73]. Future studies should examine the sex differences or be specific to one sex. In addition, the methods to compensate for nutrient deficiencies varied among studies and can influence the results of glucose and lipid metabolism.

Of course, a meta-analysis is always limited by the limitations of each included study, and caution must be applied while extrapolating our results. As for any diet study, the self-reporting of dietary intake has well-known limitations. It is impossible to eliminate uncertainty regarding participants’ adherence. Nevertheless, the studies showed that the reported diet changes were accompanied by changes in weight and plasma lipid levels, suggesting reasonable adherence.

Conclusions
In conclusion, in obese individuals with insulin resistance, a vegan diet improves insulin resistance and dyslipidemia, except for triglycerides.

Supplementary Information
The online version contains supplementary material available at https://doi.org/10.1186/s13098-022-00879-w.

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Author contributions
PC contributed to design, and critically revised the manuscript for important intellectual content; YZ contributed to acquisition, analysis, and interpretation of data; YC contributed to conception, and drafted the manuscript. All authors read and approved the final manuscript.

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Availability of data and materials
The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations
Ethics approval and consent to participate
Not applicable.

Consent for publication
Not applicable.

Competing interests
The authors declare that they have no competing interests.

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References
1. Kushner RF, Ryan DH. Assessment and lifestyle management of patients with obesity: clinical recommendations from systematic reviews. JAMA. 2014;312:943–52.
2. Jensen MD, Ryan DH, Apovian CM, Ard JD, Comuzzie AG, Donato KA, et al. 2013 AHA/ACC/TOS guideline for the management of overweight and obesity in adults: a report of the American College of Cardiology/American Heart Association Task Force on Practice Guidelines and The Obesity Society. Circulation. 2014;129:S102–38.
3. Garvey WT, Mechanick JI, Brett EM, Garber AJ, Hurley DL, Jastrzeboff AM, et al. Association of Clinical Endocrinologists and American College of Endocrinology Comprehensive Clinical Practice Guidelines for Medical Care of Patients with Obesity. Endocr Pract. 2016;22(Suppl 3):1–203.

4. Heymsfield SB, Wadden TA. Mechanisms, pathophysiology, and management of obesity. N Engl J Med. 2017;376:254–66.

5. Collaborators GBDO, Afshin A, Forouzanfar MH, Reitsma MB, Sur P, Estep K, et al. Health effects of overweight and obesity in 195 countries over 25 years. N Engl J Med. 2017;377:13–27.

6. Bhasharan K, Dos-Santos-Silva I, Leon DA, Douglas JL, Sreetha L. Association of BMI with overall and cause-specific mortality: a population-based cohort study of 3.6 million adults in the UK. Lancet Diabetes Endocrinol. 2018;6:944–53.

7. Chatterjee S, Khunti K, Davies MJ. Type 2 diabetes. Lancet. 2017;389:2239–51.

8. Berglund L, Brunzell JD, Goldberg AC, Goldberg U, Sacks F, Murad MH, et al. Evaluation and treatment of hypertriglyceridemia: an Endocrine Society clinical practice guideline. J Clin Endocrinol Metab. 2012;97:2969–89.

9. Miller M, Stone NJ, Ballantyne C, Bittner V, Criqui MH, Ginsberg HN, et al. Triglycerides and cardiovascular disease: a scientific statement from the American Heart Association. Circulation. 2011;123:2292–333.

10. Mach F, Baigent C, Carapito AL, Koskins KC, Casula M, Badimon L, et al. 2019 ESC/EAS Guidelines for the management of dyslipidaemias: lipid modification to reduce cardiovascular risk. Eur Heart J. 2020;41:111–88.

11. Chalasani N, Younossi Z, Lavine JE, Diehl AM, Brunt EM, Cusi K, et al. The diagnosis and management of non-alcoholic fatty liver disease: practice guideline by the American Gastroenterological Association, American Association for the Study of Liver Diseases, and American College of Gastroenterology. Gastroenterology. 2012;142:1592–609.

12. European Association for the Study of the Liver, European Association for the Study of O. EASL-EASD-EASO Clinical Practice Guidelines for the management of non-alcoholic fatty liver disease. J Hepatol. 2016;64:1388–402.

13. Chalasani N, Younossi Z, Lavine JE, Charlton M, Cusi K, Rinella M, et al. The diagnosis and management of nonalcoholic fatty liver disease: Practice guidance from the American Association for the Study of Liver Diseases. Hepatology. 2018;67:328–57.

14. James PA, Opali S, Carter BL, Cushman WC, Dennison-Himmelfarb C, Handler J, et al. 2014 evidence-based guideline for the management of high blood pressure in adults: report from the panel members appointed to the Eighth Joint National Committee (JNC 8). JAMA. 2014;311:507–20.

15. Rabi DM, Baigent C, Carpano AL, Koskins KC, Casula M, Badimon L, et al. 2019 ESC/EAS Guidelines for the prevention, diagnosis, risk assessment, and treatment of hypertension in adults and children. Can J Cardiol. 2020;36:596–624.

16. Williams B, Mancia G, Spiering W, Agabiti Roe E, Azizi M, Burnier M, et al. 2018 Hypertension Canada’s 2020 comprehensive guidelines for the prevention, diagnosis, risk assessment, and treatment of hypertension in adults and children. Can J Cardiol. 2020;36:596–624.

17. Williams B, Mancia G, Spiering W, Agabiti Roe E, Azizi M, Burnier M, et al. 2018 Hypertension Canada’s 2020 comprehensive guidelines for the prevention, diagnosis, risk assessment, and treatment of hypertension in adults and children. Can J Cardiol. 2020;36:596–624.

18. Williams B, Mancia G, Spiering W, Agabiti Roe E, Azizi M, Burnier M, et al. 2018 Hypertension Canada’s 2020 comprehensive guidelines for the prevention, diagnosis, risk assessment, and treatment of hypertension in adults and children. Can J Cardiol. 2020;36:596–624.

19. American Heart Association Nutrition Committee, Lichtenstein AH, Appel LJ, Brands M, Carnethon M, Daniels S, et al. Diet and lifestyle recommendations revision a scientific statement from the American Heart Association Nutrition Committee. Circulation. 2006;114:82–96.

20. Knowler WC, Barrett-Connor E, Fowler SE, Hamman RF, Lachin JM, Walker EA, et al. Reduction in the incidence of type 2 diabetes with lifestyle intervention or metformin. N Engl J Med. 2002;346:393–403.

21. Locke A, Schneiderhan J, Zick SM. Diets for health: goals and guidelines. Am Fam Physician. 2018;97:721–8.

22. Wing RR. Behavioral interventions for obesity: recognizing our progress and future challenges. Obes Res. 2003;11(Suppl):S5–65.

23. Tuso PJ, Ismail NH, Ha BR, Bartolotta C. Nutritional update for physicians: plant-based diets. Perm J. 2013;17:761–6.
47. Li J, Armstrong CL, Campbell WW. Effects of dietary protein source and quantity during weight loss on appetite, energy expenditure, and cardiometabolic responses. Nutrients. 2016;8:63.

48. Burke LE, Hudson AG, Warziski MT, Styn MA, Music E, Elci OU, et al. Effects of a vegetarian diet and treatment preference on biochemical and dietary interventions in overweight and obese adults: a randomized clinical trial. Am J Clin Nutr. 2007;86:588–96.

49. Barnard ND, Alwarth J, Rembert E, Brandon L, Nguyen M, Goergen A, et al. A Mediterranean diet and low-fat vegan diet to improve body weight and cardiometabolic risk factors: a randomized, cross-over Trial. J Am Coll Nutr. 2021;41:1–13.

50. Tonstad S, Butler T, Yan R, Fraser GE. Type of vegetarian diet, body weight, and prevalence of type 2 diabetes. Diabetes Care. 2009;32:791–6.

51. Tonstad S, Stewart K, Oda K, Batech M, Herring RP, Fraser GE. Vegetarian diets and incidence of diabetes in the Adventist Health Study-2. Nutr Metab Cardiovasc Dis. 2013;23:292–9.

52. Vang A, Singh PN, Lee JW, Haddad EH, Brinegar CH. Meats, processed meats, obesity, weight gain and occurrence of diabetes among adults: findings from Adventist Health Studies. Ann Nutr Metab. 2008;52:96–104.

53. Goff LM, Bell JD, So PW, Dornhorst A, Frost GS. Veganism and its relationship with insulin resistance and intramyocellular lipid. Eur J Clin Nutr. 2005;59:291–8.

54. Acosta-Montano P, Garcia-Gonzalez V. Effects of dietary fatty acids in pancreatic beta cell metabolism, implications in homeostasis. Nutrients. 2018;10:393.

55. Zheng X, Ho QWC, Chua M, Stelmashenko O, Yeo XY, Muralidharan S, et al. Destabilization of beta Cell FIT2 by saturated fatty acids alter lipid droplet numbers and contribute to ER stress and diabetes. Proc Natl Acad Sci U S A. 2022;119:e2113074119.

56. Tushuizen ME, Bunck MC, Pouwels PJ, Bontepe S, van Waesbergehe JH, Schindhelm RK, et al. Pancreatic fat content and beta-cell function in men with and without type 2 diabetes. Diabetes Care. 2007;30:2916–21.

57. Oliff MD, Wattick RA. Vegetarian diets and the risk of diabetes. Curr Diab Rep. 2018;18:101.

58. Turner-McGinley GM, Barnard ND, Scialli AR. A two-year randomized weight loss trial comparing a vegan diet to a more moderate low-fat diet. Obesity. 2007;15:2276–81.

59. Chiu THT, Pan WH, Lin MN, Lin CL. Vegetarian diet, change in dietary patterns, and diabetes risk: a prospective study. Nutr Diabetes. 2018;8:12.

60. Pathak M. Diabetes mellitus type 2 and functional foods of plant origin. Recent Pat Biotechnol. 2014;8:160–4.

61. Li D, Sinclair A, Mann N, Turner A, Ball M, Kelly F, et al. The association of diet and thrombotic risk factors in healthy male vegetarians and meat-eaters. Eur J Clin Nutr. 1999;53:612–9.

62. De Base SG, Fernandes SF, Gianini RJ, Duarte JL. Vegetarian diet and cholesterol and triglycerides levels. Arq Bras Cardiol. 2007;88:35–9.

63. Robinson F, Hackett AF, Billington D, Stratton G. Changing from a mixed diet to self-selected vegetarian diet—influence on blood lipids. J Hum Nutr Diet. 2002;15:323–9.

64. Papadaki A, Vardavas C, Hatzis C, Kafatos A. Calcium, nutrient and food intake of Greek Orthodox Christian monks during a fasting and non-fasting week. Public Health Nutr. 2008;11:1022–9.

65. Zhang Z, Ma G, Chen S, Li Z, Xia E, Sun Y, et al. Comparison of plasma triacylglycerol levels in vegetarians and omnivores: a meta-analysis. Nutrients. 2013;5:426–30.

66. Miettinen TA. Cholesterol production in obesity. Circulation. 1971;44:842–50.

67. VanPatten S, Rangiamani N, Shefer S, Nguyen LB, Rossetti L, Cohen DE. Impaired biliary lipid secretion in obese Zucker rats: lepton promotes hepatic cholesterol clearance. Am J Physiol Gastrointest Liver Physiol. 2001;281:G393-404.

68. Agrawal S, Millett CJ, Dhillon PK, Subramanian SV, Ebrahim S. Type of vegetarian diet, obesity and diabetes in adult Indian population. Nutr J. 2014;13:89.

69. Chiu TH, Huang HY, Chiu YF, Pan WH, Kao HY, Chiu JP, et al. Taiwanese vegetarians and omnivores: dietary composition, prevalence of diabetes and IFG. PLoS ONE. 2014;9:e88547.

70. Jaacks LM, Kapoor D, Singh K, Narayan KM, Ali MK, Kadir MM, et al. Vegetarianism and cardiometabolic disease risk factors: differences between South Asian and US adults. Nutrition. 2016;32:975–84.

71. Varlamov O, Bethea CL, Roberts CT Jr. Sex-specific differences in lipid and glucose metabolism. Front Endocrinol. 2014;5:241.

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