Original Investigation

Vegetarian Diets and Blood Pressure
A Meta-analysis

Yoko Yokoyama, PhD, MPH; Kunihiro Nishimura, MD, PhD, MPH; Neal D. Barnard, MD; Misa Takegami, RN, PhD, MPH; Makoto Watanabe, MD, PhD; Akira Sekikawa, MD, PhD; Tomonori Okamura, MD, PhD; Yoshihiro Miyamoto, MD, PhD

IMPORTANCE Previous studies have suggested an association between vegetarian diets and lower blood pressure (BP), but the relationship is not well established.

OBJECTIVE To conduct a systematic review and meta-analysis of controlled clinical trials and observational studies that have examined the association between vegetarian diets and BP.

DATA SOURCES MEDLINE and Web of Science were searched for articles published in English from 1946 to October 2013 and from 1900 to November 2013, respectively.

STUDY SELECTION All studies met the inclusion criteria of the use of (1) participants older than 20 years, (2) vegetarian diets as an exposure or intervention, (3) mean difference in BP as an outcome, and (4) a controlled trial or observational study design. In addition, none met the exclusion criteria of (1) use of twin participants, (2) use of multiple interventions, (3) reporting only categorical BP data, or (4) reliance on case series or case reports.

DATA EXTRACTION AND SYNTHESIS Data collected included study design, baseline characteristics of the study population, dietary data, and outcomes. The data were pooled using a random-effects model.

MAIN OUTCOMES AND MEASURES Net differences in systolic and diastolic BP associated with the consumption of vegetarian diets were assessed.

RESULTS Of the 258 studies identified, 7 clinical trials and 32 observational studies met the inclusion criteria. In the 7 controlled trials (a total of 311 participants; mean age, 44.5 years), consumption of vegetarian diets was associated with a reduction in mean systolic BP (−4.8 mm Hg; 95% CI, −6.6 to −3.1; $P < .001$; $I^2 = 0$; $P = .45$ for heterogeneity) and diastolic BP (−2.2 mm Hg; 95% CI, −3.5 to −1.0; $P < .001$; $I^2 = 0$; $P = .43$ for heterogeneity) compared with the consumption of omnivorous diets. In the 32 observational studies (a total of 21 604 participants; mean age, 46.6 years), consumption of vegetarian diets was associated with lower mean systolic BP (−6.9 mm Hg; 95% CI, −9.1 to −4.7; $P < .001$; $I^2 = 91.4$; $P < .001$ for heterogeneity) and diastolic BP (−4.7 mm Hg; 95% CI, −6.3 to −3.1; $P < .001$; $I^2 = 92.6$; $P < .001$ for heterogeneity) compared with the consumption of omnivorous diets.

CONCLUSIONS AND RELEVANCE Consumption of vegetarian diets is associated with lower BP. Such diets could be a useful nonpharmacologic means for reducing BP.

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Author Affiliations: Author affiliations are listed at the end of this article.

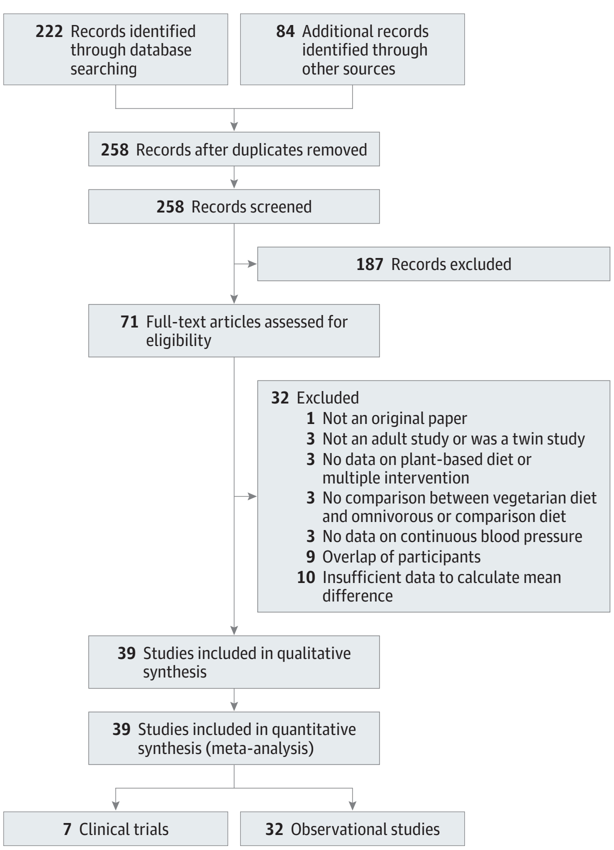
Corresponding Author: Yoko Yokoyama, PhD, MPH, Department of Preventive Medicine and Epidemiologic Informatics, National Cerebral and Cardiovascular Center, 5-7-1 Fujishirodai, Suita-city, Osaka 565-8565, Japan (yyokoyama-kyt @umin.ac.jp).

The relationship between blood pressure (BP) and cardiovascular disease risk is continuous, consistent, and independent of other risk factors.[1] According to Lewington et al,[2] in individuals aged 40 to 70 years, each increment of 20 mm Hg in systolic BP or 10 mm Hg in diastolic BP is associated with more than twice the risk of cardiovascular disease across the BP range from 115/75 to 185/115 mm Hg.

A substantial body of evidence supports the role of modifiable factors, including diet, body weight, physical activity, and alcohol intake, in the risk of developing hypertension.[3] Dietary modifications have been shown[3] to be particularly effective in preventing and managing hypertension.

Vegetarian diets are defined as dietary patterns that exclude or rarely include meats; some vegetarian diets include dairy products, eggs, and fish. All vegetarian diets emphasize foods of plant origin, particularly vegetables, grains, legumes, and fruits. In observational studies,[4,5] consumption of vegetarian diets is associated with a lower prevalence of hypertension. Although some randomized clinical trials[6,7] have found that adoption of a vegetarian diet reduces BP, others[8,9] have not yielded similar results. To our knowledge, the available evidence regarding the association between vegetarian diets and BP has not been subjected to meta-analysis. To clarify the nature of this association and provide a valid estimate of the effect size regarding the effects of consumption of vegetarian diets on BP, both of which could prove useful in formulating dietary guidance, we performed a meta-analysis of studies that had examined associations between vegetarian diets and BP.

Figure 1. Study Flow Diagram



Selection of clinical trials and observational studies for meta-analysis of association between vegetarian diets and blood pressure.

Methods

Data Sources and Search Strategy

The electronic search strategy is shown in the Supplement (eTable 1). MEDLINE and Web of Science were searched for articles published in English from January 1, 1946, to November 7, 2013, and from January 1, 1900, to November 7, 2013, respectively, containing 1 or more of the keywords or phrases for vegetarian diets (*plant-based diet* or *diet*, *vegetarian* or *vegetarian diets* or *vegetarianism* or *diets, vegan* or *vegan diets*) and for blood pressure (*blood pressure* or *hypertension*). The reference lists of the retrieved articles were subsequently reviewed for identification of additional articles. If necessary, the relevant authors were contacted by the investigators to acquire missing information (**Figure 1**).

Study Selection

Two reviewers (Y.Y. and M.T.) independently scanned the retrieved abstracts to identify studies that met the following inclusion criteria: (1) use of a sample of participants older than 20 years; (2) an intervention or exposure consisting of a vegetarian diet, defined as a diet generally excluding or rarely including meats; these may include *semivegetarian diets*, defined as rarely including meat; *vegan diets*, defined as omitting all animal products; or *vegetarian diets* that include some animal products as indicated by the terms *lacto* (dairy products), *ovo* (eggs), or *pesco* (fish); (3) collection of sufficient data to allow calculation of mean differences in systolic/diastolic BP between individuals consuming a vegetarian diet and those consuming a referent or control diet; and (4) use of a controlled trial or observational study design. The exclusion criteria were (1) use of a sample consisting of twins; (2) use of multiple interventions (ie, use of lifestyle interventions in addition to dietary interventions); (3) reporting only categorical BP data; or (4) reliance on case series or case reports.

Data Extraction and Quality Assessment

For each study, data regarding systolic and diastolic BP and variance measures; study methodology and sample size; baseline characteristics of the study population, including mean age, sex (proportion of men), BP, antihypertensive medication use, body mass index (BMI) (calculated as weight in kilograms divided by height in meters squared), alcohol intake, and dietary data (including type of diets examined and duration of their consumption); and outcomes, including adjustment factors used for each analytic model, BP measurements, and dietary measurements, were extracted. Mean values for baseline age, proportion of men, systolic and diastolic BP, BMI, and alcohol intake were calculated.

Table 1. Designs and Population Characteristics of Clinical Trials of Vegetarian Diets and BP

Source	Country	Study Design (Duration)	No. of Participants	Mean Age, y	Male Sex, %	Mean BP, mm Hg Systolic	Mean BP, mm Hg Diastolic	Using Medication, %	Mean BMI	Alcohol Intake	Intervention, Food Preparation[a]
Ferdowsian et al,[12] 2010	US	P, O (22 wk)	113	44.4	17.7	117.8	79.7	NR	NR	Participants with active alcohol abuse excluded	Vegan, yes (2/d)
Nicholson et al,[13] 1999	US	P, O (12 wk)[b]	11	54.3	54.5	141.3	84.7	81.8	NR	Individuals using alcohol regularly excluded	Vegan, yes
Sciarrone et al,[14] 1993	Australia	P, O (6 wk)[b]	20	41.0	100	134.2	77.2	None	25.3	Individuals using > 20 g of ethanol/d excluded	Lacto-ovo, yes
Hakala and Karvetti,[15] 1989	Finland	P, O (52 wk)[b]	73	38.0	24.7	129.9	85.0	None	34.4	Veg/Cont, 2%/2% energy	Lacto, no
Kestin et al,[8] 1989	Australia	C, O (6 wk)[b]	17	44.0	100	128.0	79.0	None	25.5	Veg/Cont, 4.2%/4.8% energy	Lacto-ovo, yes (major sources of protein and fat)
Margetts et al,[7] 1986	Australia	C, O (6 wk)[b]	39	49.9	71.8	155.4	99.9	None	27.6	Participants asked to not alter alcohol consumption	Lacto-ovo, yes (meat substitutes)
Rouse et al,[6] 1983	Australia	C, O (6 wk)[b]	38	40.1	50.0	127.7	76.4	None	23.7	Participants asked to not alter alcohol consumption	Lacto-ovo, yes (2/d)

Abbreviations: BP, blood pressure; BMI, body mass index (calculated as weight in kilograms divided by height in meters squared); C, crossover; Cont, control; NR, not reported; O, open label; P, parallel; US, United States; Veg, vegetarian.

[a] Vegan diets, defined as omitting all animal products, or vegetarian diets that include some animal products as indicated by the terms *lacto* (dairy products) and *ovo* (eggs).

[b] Randomized clinical trial.

Data Synthesis and Analysis

Mean differences in systolic and diastolic BP between groups consuming vegetarian or comparison diets were calculated. The pooled SE for the net difference in BP associated with the consumption of a vegetarian diet was obtained or, when not given, estimated using the method of Follmann et al,[10] assuming a correlation of 0.50 between the baseline and final BP values (parallel design) or between the BP values during the intervention and control periods (crossover design). For studies comparing more than 1 exposure group or treatment arm, such as those comparing vegan and lacto-ovo-vegetarian groups, a pooled effect was calculated for each study using a random-effects model and then used to conduct the overall calculation.

Estimates of net change in BP associated with the consumption of vegetarian diets were combined using a random-effects model, which assigns a weight to each study on the basis of an individual study's inverse variance. Overall estimates were derived for controlled trials and observational studies separately, using the study as the unit of analysis. Estimates of BP differences were reported within 95% CIs. Differences were considered significant at 2-sided $P < .05$.

Stratified analyses by mean age, sex, BMI, diet type, sample size, duration of vegetarian diet consumption, antihypertensive medication use, baseline hypertensive status, and location (country) were performed separately for controlled trials and observational studies. As a sensitivity analysis, we conducted a one-study-removed analysis to assess the effect of each study on the combined effect. Calculation of I^2 and meta-regression was performed with subgroups, using the study as the unit of analysis to assess heterogeneity among studies.[11]

Funnel plots were developed and examined to identify publication bias, and the Egger test was performed to assess the relationship between sample size and effect size. The trim-and-fill method was used to adjust for publication bias. The trim-and-fill method determines where missing studies are likely to fall, adds them to the analysis, and then recomputes the combined effect. These analyses were conducted separately for controlled trials and observational studies. All analyses were performed using Comprehensive Meta-analysis, version 2, software (Biostat).

Results

Search Results

The search of the MEDLINE and Web of Science databases led to the retrieval of 258 studies. Of these, 7 clinical trials and 32 observational studies met the inclusion criteria (Figure 1).

Study Characteristics and Quality

Clinical Trials

Seven clinical trials were identified (**Table 1**).[6-8,12-15] The 7 trials included a total of 311 participants (median sample size, 38; range, 11-113), with a mean age of 44.5 years (range, 38.0-54.3 years). All were open (nonmasked) controlled trials conducted for 6 or more weeks (mean, 15.7 weeks). Of these, 6 were randomized clinical trials.[6-8,13-15] As shown in Table 1, several participants in 1 clinical trial[13] used antihypertensive medication. All except 1 study[15] provided foods to the participants. Vegan diets were examined in 2 trials,[12,13] a lacto-vegetarian diet in 1,[15] and lacto-ovo-vegetarian diets in 4.[6-8,14] Four studies[12-15] used parallel designs, and 3 trials[6-8] used crossover designs. All studies[6-8,12-15] reported repeated BP measurements. Adjustments for potential confounders for each trial are shown in the Supplement (eTable 2).

Table 2. Designs and Population Characteristics of Observational Cross-Sectional Studies of Vegetarian Diets and BP

Source	Country	No. of Participants	Mean Age, y	Male Sex, %	Mean BP, mm Hg		Using Antihypertensive Medication, %	Mean BMI	Alcohol Intake (Veg/Cont)	Exposure, Duration of Exposure[a]
					Systolic	Diastolic				
Kim and Bae,[16] 2012	South Korea	107	62.6	0	141.4	85.3	NR	23.8	Mild alcohol drinker, 0%/20.8% (overall, 9.4%)	Lacto-ovo, >20 y
Pettersen et al,[17] 2012	US, Canada	431	62.8	36.7	125.1	74.8	24.8	26.7	Minimal or absent in both groups, 6.75%	Mixed (vegan, lacto-ovo), >1 y
Yang et al,[18] 2012	China	295	33.3	100	120.5	74.7	None	24.0	Regular drinking excluded	Lacto, >5 y
Chen et al,[19] 2011	Taiwan	363	51.9	0	121.4	71.6	None	23.1	NR	Lacto-ovo, >1 y
Fernandes Dourado et al,[20] 2011	Brazil	87	40.0	58.6	120.8	75.9	NR	24.3	0/12.1%	Lacto-ovo, >1 y (mean, 16 y)
Rodenas et al,[21] 2011	Spain	26	68.4	0	135.4	73.4	None	24.2	NR	Mixed (meatless), current
Yang et al,[22] 2011	China	300	33.3	100	120.3	74.4	None	23.9	Excluded	Lacto-ovo, >1 y (mean, 10.4 y)
Lin et al,[23] 2010	Taiwan	204	46.1	0	117.3	75.2	NR	23.4	NR	Vegan, mean, 17.8 y
Pitla and Nagalla,[24] 2009	India	Male, 29; female, 23	46.2; 45.4	100; 0	125.0; 117.8	81.7; 76.1	NR	24.8; 24.9	17%; 0%	Lacto, lifetime
Nakamoto et al,[25] 2008	Japan	Male, 49; female, 73	44.1; 45.4	100; 0	124.9; 113.4	78.6; 68.4	NR	22.5; 21.4	NR	Mixed (lacto-ovo, semi), current
Slavícek et al,[26] 2008	Czech	396	47.4	34.1	125.5	75.8	NR	23.6	NR	Lacto-ovo, >5 y
Fontana et al,[27] 2007	US	42	53.1	61.9	118.0	70.5	None	23.9	NR	Vegan, >2 y (mean, 4.4 y)
Teixeira et al,[28] 2007	Brazil	201	47.0	47.8	122.0	81.0	11.4	25.3	Veg < Cont	Mixed (vegan, lacto, lacto-ovo, pesco), >5 y (mean, 19 y)
Sebeková et al,[29] 2006	Slovakia	136	37.5	36.0	112.3	70.9	None	23.1	NR	Lacto-ovo, >2 y (mean, 10.3 y)
Su et al,[30] 2006	Taiwan	118	58.4	0	127.2	72.0	None	23.3	Regular drinking excluded	Mixed (vegan, lacto), >5 y (mean, 10.4 y)
Goff et al,[31] 2005	UK	46	35.5	46.7	118.7	68.6	NR	23.1	NR	Vegan, >3 y
Appleby et al,[32] 2002	UK	Male, 1557; female, 5702	48.7; 45.9	100; 0	125.5; 119.8	77.2; 73.7	46.3; 58.4[b]	23.9; 23.4	<1 g ethanol/d, 23.0%/11.2%; 23.9%/20.3%	Mixed (vegan, lacto-ovo), current
Lu et al,[33] 2000	Taiwan	Male, 53; female, 56	38.0; 39.2	100; 0	106.1; 99.5	70.0; 64.8	None	21.9; 21.2	Participants using >10 g/d excluded	Mixed (vegan, lacto), >2 y
Famodu et al,[34] 1998	Nigeria	76	48.6	NR	110.1	76.1	NR	28.8	Veg group abstinent	Mixed (vegan, lacto-ovo, semi), current
Harman et al,[35] 1998	New Zealand	Male, 23; female, 24	44.7; 41.0	100; 0	123.5; 115.0	77.4; 72.9	NR	25.2; 24.7	Excluded	Mixed (vegan, lacto), current
Williams,[36] 1997	US	Male, 7253; female, 1989	45.9; 40.3	100; 0	121.7; 112.9	77.1; 71.7	NR	23.8; 21.2	39.1/85.6 mL; 26.3/52.8 mL	Mixed (vegan, lacto), current
Wyatt et al,[37] 1995	Mexico	72	39.0	NR	115.0	78.5	None	24.4	1%/89%	Lacto-ovo, >1 y (mean, 5.1 y)
Melby et al,[38] 1994	US	167	47.5	26.3	119.2	77.7	26.7	28.1	0/2	Mixed (vegetarian, semi), current

(continued)

Observational Studies

Thirty-two observational studies were identified (**Table 2**).[16-47] These studies included 21 604 participants (median sample size, 152; range, 20-9242) with a mean age of 46.6 years (range, 28.8-68.4 years). Each of the 32 observational studies used cross-sectional designs. As shown in Table 2, several participants in 5 observational studies[17,28,32,38,40] used antihypertensive medication. Because pooled effects were not reported, male and female subgroups (10 studies)* and racial subgroups (1 study)[40] were included in the subgroup analyses (Table 2). In 22 of these studies, participants had been following vegetarian diets for more than 1 year.† Five studies focused on vegan diets,[23,27,31,39,41] 2 on lacto-vegetarian diets,[18,24] 10 on lacto-ovo-vegetarian diets,‡ and 15 on mixed diet types (vegan, lacto, lacto-ovo, pesco, and/or semivegetarian).§ In 20 studies, diets were assessed by using

*References 24, 25, 32, 33, 35, 36, 41, 44-46

†References 16-20, 22-24, 26-31, 33, 37, 39-43, 45

‡References 16, 19, 20, 22, 26, 29, 37, 43, 44, 47

§References 17, 21, 25, 28, 30, 32-36, 38, 40, 42, 45, 46

Table 2. Designs and Population Characteristics of Observational Cross-Sectional Studies of Vegetarian Diets and BP (continued)

Source	Country	No. of Participants	Mean Age, y	Male Sex, %	Mean BP, mm Hg: Systolic	Mean BP, mm Hg: Diastolic	Using Antihypertensive Medication, %	Mean BMI	Alcohol Intake (Veg/Cont)	Exposure, Duration of Exposure[a]
Orlov et al,[39] 1994	Finland	20	49.2	NR	131.3	78.9	NR	21.4	NR	Vegan, >1 y
Melby et al,[40] 1989	US	Black, 114; white, 264	55.4; 52.5	21.9; 15.9	126.4; 114.8	74.5; 66.9	31.5; 12.7	28.9; 25.7	None; 1/2	Mixed (meatless), 20.6 y; 27.2 y
Sanders and Key,[41] 1987	UK	Male, 22; female, 22	31.5; 26.0	100; 0	115.0; 111.0	70.5; 68.5	None	21.5; 20.6	6/21 g/d; 0/1 g/d	Vegan, >1 y
Wiseman et al,[42] 1987	UK	52	34.4	48.1	113.5	73.1	None	NR	NR	Mixed (vegan, lacto), >3 y (mean, 13.4 y)
Ophir et al,[43] 1983	Israel	196	60.9	51.0	136.4	82.3	NR	NR	Veg group abstinent	Lacto-ovo, >3 y (mean, 19 y)
Rouse et al,[44] 1983	Australia	Male, 80; female, 100	32.8; 33.7	100; 0	117.9; 109.5	69.9; 67.0	None	23.6; 23.8	BP not related to past use of alcohol	Lacto-ovo, current
Burr et al,[45] 1981	UK	Male, 111; female, 189	56.0; 53.6	100; 0	137.5; 140.4	84.6; 84.2	NR	24.0; 23.3	Weekly drinkers, 31%/50%; 23.2%/39.1%	Mixed (meat and fish less than once a month or never), >5 y
Haines et al,[46] 1980	UK	Male, 236; female, 96	48.7; 49.5	100; 0	137.8; 137.7	87.1; 86.2	NR	NR	NR	Mixed (vegan, lacto-ovo), current
Armstrong et al,[47] 1979)	Australia	204	50.6	33.2	145.0	89.9	NR	23.5	NR (partly adjusted)	Lacto-ovo, current

Abbreviations: BP, blood pressure; BMI, body mass index (calculated as weight in kilograms divided by height in meters squared); Cont, control; NR, not reported; UK, United Kingdom; US, United States; Veg, vegetarian.

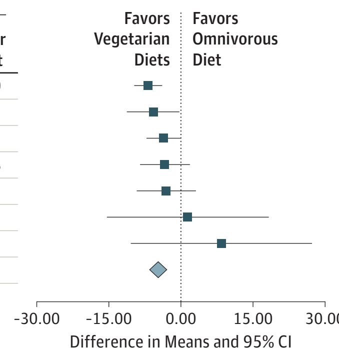
[a] Semivegetarian diets, defined as rarely including meat; vegan diets, defined as omitting all animal products or vegetarian diets that include some animal products as indicated by the terms *lacto* (dairy products), *ovo* (eggs), or *pesco* (fish).

[b] Included nutritional supplements.

Figure 2. Pooled Systolic and Diastolic Blood Pressure (BP) Responses to Vegetarian Diets in Clinical Trials

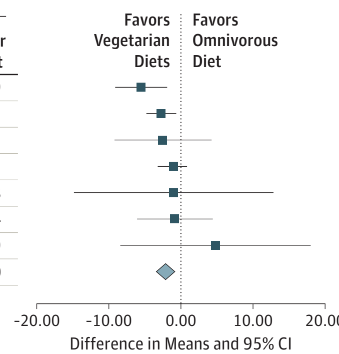
A

Source	Subgroup Within Study	Comparison	Statistics for Each Study: Difference in Mean	Lower Limit	Upper Limit	*P* Value
Rouse et al,[6] 1983	Lacto-ovo	Omnivorous	-6.8	-9.6	-4.0	<.001
Ferdowsian et al,[12] 2010	Vegan	Omnivorous	-5.7	-11.1	-0.3	.04
Margetts et al,[7] 1986	Lacto-ovo	Omnivorous	-3.5	-6.9	-0.1	.047
Hakala and Karvetti,[15] 1989	Lacto	Omnivorous	-3.3	-8.3	1.8	.21
Kestin et al,[8] 1989	Lacto-ovo, men	Omnivorous	-3.0	-9.1	3.1	.34
Sciarrone et al,[14] 1993	Lacto-ovo, men	Omnivorous	1.5	-15.3	18.3	.86
Nicholson et al,[13] 1999	Vegan	Omnivorous	8.5	-10.2	27.2	.37
Total			**-4.8**	**-6.6**	**-3.1**	<.001



B

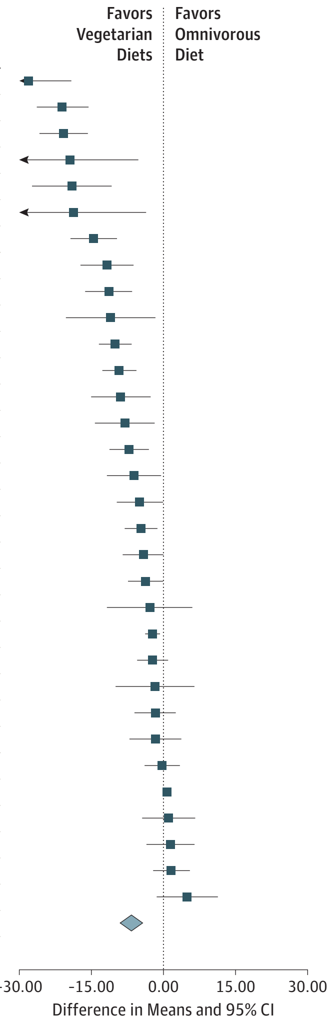
Source	Subgroup Within Study	Comparison	Statistics for Each Study: Difference in Mean	Lower Limit	Upper Limit	*P* Value
Ferdowsian et al,[12] 2010	Vegan	Omnivorous	-5.5	-9.1	-1.9	.003
Rouse et al,[6] 1983	Lacto-ovo	Omnivorous	-2.7	-4.7	-0.7	.008
Hakala and Karvetti,[15] 1989	Lacto	Omnivorous	-2.5	-9.2	4.2	.46
Margetts et al,[7] 1986	Lacto-ovo	Omnivorous	-1.2	-3.1	0.7	.22
Sciarrone et al,[14] 1993	Lacto-ovo, men	Omnivorous	-1.0	-14.8	12.8	.89
Kestin et al,[8] 1989	Lacto-ovo, men	Omnivorous	-0.8	-6.0	4.4	.76
Nicholson et al,[13] 1999	Vegan	Omnivorous	4.8	-8.3	17.9	.47
Total			**-2.2**	**-3.5**	**-1.0**	<.001



Effects on systolic BP (A) and on diastolic BP (B) are depicted as squares; error bars indicate 95% CIs. Meta-analysis yielded pooled estimates of −4.8 mm Hg (95% CI, −6.6 to −3.1) for systolic BP and −2.2 mm Hg (−3.5 to −1.0) for diastolic BP, which are depicted as blue diamonds. Vegan diets were defined as omitting all animal products; vegetarian diets may include some animal products as indicated by the terms *lacto* (dairy products) and *ovo* (eggs).

Figure 3. Pooled Systolic Blood Pressure (BP) Among Vegetarians in Observational Studies

Source	Subgroup Within Study	Comparison	Statistics for Each Study: Difference in Mean	Lower Limit	Upper Limit	*P* Value
Fontana et al,[27] 2007	Vegan	Omnivorous	-28.0	-36.8	-19.2	<.001
Teixeira et al,[28] 2007	Mixed	Omnivorous	-21.0	-26.3	-15.7	<.001
Ophir et al,[43] 1983	Lacto-ovo	Omnivorous	-20.8	-25.8	-15.8	<.001
Rodenas et al,[21] 2011	Mixed, women	Omnivorous	-19.4	-33.6	-5.2	.007
Kim and Bae,[16] 2012	Lacto-ovo, women	Omnivorous	-19.0	-27.3	-10.8	<.001
Orlov et al,[39] 1994	Vegan	Omnivorous	-18.8	-33.9	-3.7	.02
Slavícek et al,[26] 2008	Lacto-ovo	Omnivorous	-14.5	-19.3	-9.7	<.001
Nakamoto et al,[25] 2008	Combined	Omnivorous	-11.7	-17.2	-6.3	<.001
Lu et al,[33] 2000	Combined	Omnivorous	-11.3	-16.2	-6.5	<.001
Goff et al,[31] 2005	Vegan	Omnivorous	-11.0	-20.3	-1.7	.02
Yang et al,[22] 2011	Lacto-ovo, men	Omnivorous	-10.0	-13.3	-6.7	<.001
Yang et al,[18] 2012	Lacto, men	Omnivorous	-9.2	-12.6	-5.7	<.001
Fernandes Dourado et al,[20] 2011	Lacto-ovo	Omnivorous	-8.9	-15.1	-2.7	.005
Haines et al,[46] 1980	Combined	Omnivorous	-8.0	-14.1	-1.9	.01
Wyatt et al,[37] 1995	Lacto-ovo	Omnivorous	-7.1	-11.1	-3.1	.001
Armstrong et al,[47] 1979	Lacto-ovo	Omnivorous	-6.1	-11.7	-0.5	.03
Lin et al,[23] 2010	Vegan, women	Omnivorous	-4.9	-9.6	-0.2	.04
Pettersen et al,[17] 2012	Mixed	Omnivorous	-4.6	-7.9	-1.3	.006
Sebeková et al,[29] 2006	Lacto-ovo	Omnivorous	-4.1	-8.3	0.1	.06
Melby et al,[40] 1989	Combined	Omnivorous	-3.7	-7.2	-0.2	.04
Wiseman et al,[42] 1987	Mixed	Omnivorous	-2.8	-11.6	6.0	.53
Williams et al,[36] 1997	Combined	Omnivorous	-2.2	-3.7	-0.7	.003
Rouse et al,[44] 1983	Combined	Omnivorous	-2.2	-5.3	0.9	.16
Harman et al,[35] 1998	Combined	Omnivorous	-1.7	-9.8	6.4	.68
Melby et al,[38] 1994	Mixed	Omnivorous	-1.7	-5.9	2.6	.44
Pitla and Nagalla,[24] 2009	Combined	Omnivorous	-1.6	-7.0	3.7	.55
Burr et al,[45] 1981	Combined	Omnivorous	-0.2	-3.8	3.4	.90
Appleby et al,[32] 2002	Combined	Omnivorous	0.8	0.1	1.5	.03
Su et al,[30] 2006	Mixed, women	Omnivorous	1.1	-4.4	6.6	.70
Famodu et al,[34] 1998	Mixed	Omnivorous	1.5	-3.3	6.4	.54
Chen et al,[19] 2011	Lacto-ovo, women	Omnivorous	1.7	-2.0	5.4	.38
Sanders and Key,[41] 1987	Combined	Omnivorous	5.0	-1.3	11.3	.12
Total			**-6.9**	**-9.1**	**-4.7**	<.001



Effects on systolic BP are depicted as squares; error bars indicate 95% CIs. Meta-analysis yielded a pooled estimate of −6.9 mm Hg (95% CI, −9.1 to −4.7) for systolic BP, which is depicted as a blue diamond. Arrows indicate that the 95% CI exceeds the left line. Vegan diets were defined as omitting all animal products; vegetarian diets may include some animal products as indicated by the terms *lacto* (dairy products) and *ovo* (eggs).

questionnaires, typically food frequency questionnaires[17,29,32,34,35,38,40] or 24-hour diet recalls.|| Interviews or self-report were used in 7 studies,[18,19,24,28,36,43,47] and weighing methods were used for 1 study[21]; the means of dietary assessment were not reported in 4 studies.[23,26,30,46] Of the 32 observational studies, 12 conducted repeated measurements of BP.# The adjusted factors in each study are shown in the Supplement (eTable 2).

Pooled Effects of Vegetarian Diets on BP

In the clinical trials, consumption of vegetarian diets was associated with a mean reduction in systolic BP (−4.8 mm Hg; 95% CI, −6.6 to −3.1; $P < .001$; $I^2 = 0$; $P = .45$ for heterogeneity) and diastolic BP (−2.2 mm Hg; 95% CI, −3.5 to −1.0; $P < .001$; $I^2 = 0$; $P = .43$ for heterogeneity) compared with the consumption of omnivorous diets (**Figure 2**).

In the observational studies, consumption of vegetarian diets was associated with lower mean systolic BP (−6.9 mm Hg; 95% CI, −9.1 to −4.7; $P < .001$; $I^2 = 91.4$; $P < .001$ for heterogeneity) and diastolic BP (−4.7 mm Hg; 95% CI, −6.3 to −3.1; $P < .001$; $I^2 = 92.6$; $P < .001$ for heterogeneity) compared with consumption of omnivorous diets (**Figure 3** and **Figure 4**).

Meta-regression

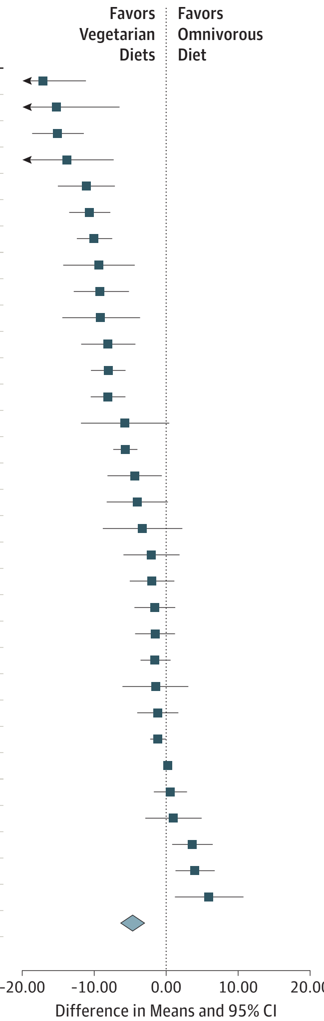
In the meta-regression investigating the sources of heterogeneity in the observational trials, the potential sources were sex (proportion of men) (β coefficient, −0.03; $P < .001$), baseline systolic BP (−0.13; $P = .003$), baseline diastolic BP (−0.30; $P < .001$), sample size (0.001; $P < .001$), and BMI (−0.46; $P = .02$).

|| References 16, 20, 22, 25, 27, 31, 33, 37, 39, 41, 42, 44, 45

#References 16-18, 24, 27, 28, 31, 34, 35, 38, 40, 44

Figure 4. Pooled Diastolic Blood Pressure (BP) Among Vegetarians in Observational Studies

Source	Subgroup Within Study	Comparison	Statistics for Each Study: Difference in Mean	Lower Limit	Upper Limit	P Value
Fontana et al,[27] 2007	Vegan	Omnivorous	-17.0	-22.8	-11.2	<.001
Orlov et al,[39] 1994	Vegan	Omnivorous	-15.2	-23.9	-6.5	.001
Teixeira et al,[28] 2007	Mixed	Omnivorous	-15.0	-18.5	-11.5	<.001
Rodenas et al,[21] 2011	Mixed, women	Omnivorous	-13.7	-20.1	-7.3	<.001
Nakamoto et al,[25] 2008	Combined	Omnivorous	-11.0	-14.9	-7.1	<.001
Ophir et al,[43] 1983	Lacto-ovo	Omnivorous	-10.6	-13.4	-7.8	<.001
Slavícek et al,[26] 2008	Lacto-ovo	Omnivorous	-9.9	-12.3	-7.5	<.001
Kim and Bae,[16] 2012	Lacto-ovo, women	Omnivorous	-9.3	-14.3	-4.3	<.001
Wiseman et al,[42] 1987	Mixed	Omnivorous	-9.0	-12.8	-5.2	<.001
Wyatt et al,[37] 1995	Lacto-ovo	Omnivorous	-9.0	-14.3	-3.7	.001
Haines et al,[46] 1980	Combined	Omnivorous	-8.0	-11.7	-4.3	<.001
Yang et al,[22] 2011	Lacto-ovo, men	Omnivorous	-8.0	-10.3	-5.7	<.001
Yang et al,[18] 2012	Lacto, men	Omnivorous	-8.0	-10.3	-5.6	<.001
Harman et al,[35] 1998	Combined	Omnivorous	-5.7	-11.7	0.4	.07
Pettersen et al,[17] 2012	Mixed	Omnivorous	-5.6	-7.2	-4.0	<.001
Lu et al,[33] 2000	Combined	Omnivorous	-4.3	-8.0	-0.6	.02
Fernandes Dourado et al,[20] 2011	Lacto-ovo	Omnivorous	-4.0	-8.1	0.2	.06
Goff et al,[31] 2005	Vegan	Omnivorous	-3.2	-8.7	2.3	.25
Armstrong et al,[47] 1979	Lacto-ovo	Omnivorous	-2.0	-5.9	1.9	.31
Su et al,[30] 2006	Mixed, women	Omnivorous	-1.9	-4.9	1.1	.22
Sebeková et al,[29] 2006	Lacto-ovo	Omnivorous	-1.5	-4.2	1.2	.28
Rouse et al,[44] 1983	Combined	Omnivorous	-1.5	-4.2	1.2	.28
Melby et al,[40] 1989	Combined	Omnivorous	-1.4	-3.4	0.6	.16
Pitla and Nagalla,[24] 2009	Combined	Omnivorous	-1.4	-5.9	3.1	.54
Melby et al,[38] 1994	Mixed	Omnivorous	-1.1	-3.9	1.7	.45
Williams et al,[36] 1997	Combined	Omnivorous	-1.1	-2.1	-0.1	.03
Appleby et al,[32] 2002	Combined	Omnivorous	0.3	-0.3	0.9	.36
Chen et al,[19] 2011	Lacto-ovo, women	Omnivorous	0.7	-1.6	2.9	.56
Burr et al,[45] 1981	Combined	Omnivorous	1.1	-2.8	5.0	.58
Lin et al,[23] 2010	Vegan, women	Omnivorous	3.7	0.9	6.5	.009
Famodu et al,[34] 1998	Mixed	Omnivorous	4.1	1.4	6.8	.003
Sanders and Key,[41] 1987	Combined	Omnivorous	6.0	1.3	10.7	.01
Total			**-4.7**	**-6.3**	**-3.1**	<.001



Effects on diastolic BP are depicted as squares; error bars indicate 95% CIs. Meta-analysis yielded a pooled estimate of −4.7 mm Hg (95% CI, −6.3 to −3.1) for diastolic BP, which is depicted as a blue diamond. Arrows indicate that the 95% CI exceeds the left line. Vegan diets were defined as omitting all animal products; vegetarian diets may include some animal products as indicated by the terms *lacto* (dairy products) and *ovo* (eggs).

These factors were not significant in the meta-regression of clinical trials (data not shown). These results suggest that the association between vegetarian diets and lower BP in adults is stronger among men and those with higher baseline BP and BMI. The association is also stronger in studies with smaller sample sizes.

Subgroup Analysis

Pooled changes in BP associated with consumption of vegetarian diets in planned strata are summarized in the Supplement (eTables 3 and 4). In the clinical trials, no heterogeneity was found in any subgroup and the estimated effect sizes were very similar.

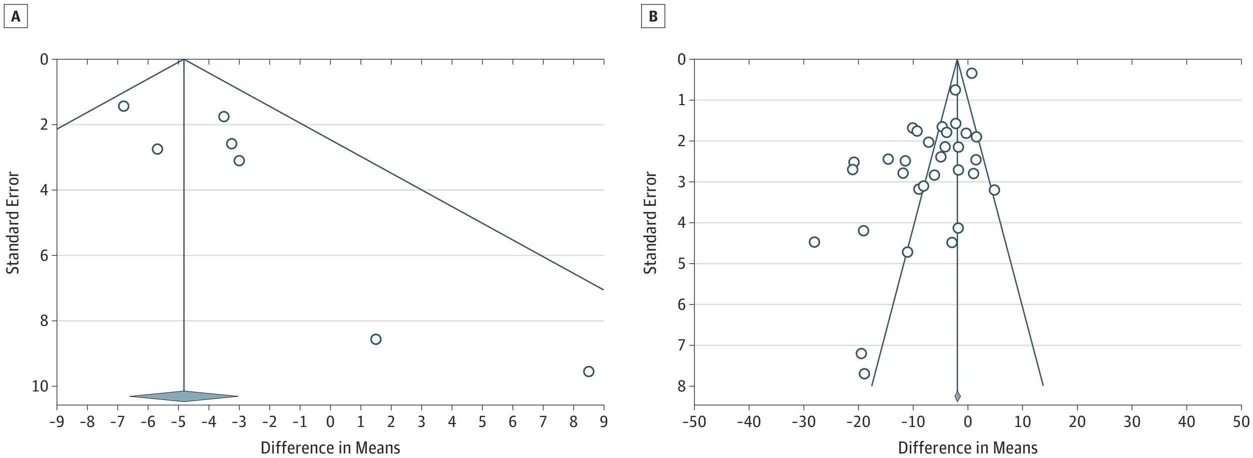
For observational studies, subgrouping reduced heterogeneity in most cases, and vegetarian diets were associated with lower BP regardless of subgroup, although effect sizes were attenuated in some groups. Lower systolic BP values were reported in the predominantly (50%-99%) male subgroups compared with the 100% female subgroups. Lower systolic and diastolic BP were found in both BMI subgroups (<25 and ≥25), sample size subgroups (<100 and ≥100), and baseline BP subgroups (normal, prehypertension, and stage 1 hypertension).

In the one-study-removed analysis, results were largely unchanged, with BP differences between the vegetarian and comparison groups ranging from −5.3 to −3.5 mm Hg for systolic BP and −2.9 to −1.8 mm Hg for diastolic BP in clinical trials (all results, $P < .05$) and from −7.2 to −6.3 mm Hg for systolic BP and −5.0 to −4.3 mm Hg for diastolic BP for observational studies (all results, $P < .001$).

Publication Bias

For clinical trials, visual examination of the funnel plot revealed that smaller trials that reported small reductions in systolic BP were possibly overrepresented (**Figure 5**A). In the

Figure 5. Funnel Plot of Comparison of Weight and Differences in Mean Systolic Blood Pressure (BP) Associated With Consumption of Vegetarian Diets



Funnel plot of study weights against change in systolic blood pressure (BP) in clinical trials (A) and observational studies (B). Blood pressure results in individual studies are depicted as circles scattered around the pooled BP estimate. A trim-and-fill method indicated that 3 clinical trials and no observational studies might have been missing owing to publication bias. After adjustment for putative missing data, the overall differences for systolic BP increased to −5.2 mm Hg (95% CI, −6.9 to −3.5) in clinical trials.

absence of publication bias, study results would be symmetrically represented about the mean effect size; our findings suggest that a few studies were missing in the bottom left side. This visual impression was confirmed by the Egger test ($P = .04$). The results of use of the trim-and-fill method suggest that 3 trials might have been missing such that their addition would change the overall effect on systolic BP to −5.2 mm Hg (95% CI, −6.9 to −3.5).

For observational studies, visual examination of the funnel plot revealed that larger trials that reported generous reductions in systolic BP were possibly overrepresented. Our findings suggest that a few studies were missing in the middle right side (Figure 5B). This visual impression was confirmed by the Egger test ($P < .001$). The results of the trim-and-fill method suggest that no study was missing.

Discussion

This meta-analysis of 7 controlled trials and 32 observational studies indicates that consumption of vegetarian diets is associated with lower BP compared with consumption of omnivorous diets. The meta-analysis indicates an overall difference in systolic BP of −4.8 mm Hg in controlled trials and −6.9 mm Hg in observational studies. For diastolic BP, the differences were −2.2 mm Hg in controlled trials and −4.7 mm Hg in observational studies. These effect sizes are similar to those observed with commonly recommended lifestyle modifications, such as adoption of a low-sodium diet[48] or a weight reduction of 5 kg,[49] and are approximately half the magnitude of those observed with pharmaceutical therapy, such as administration of angiotensin-converting enzyme inhibitors to individuals with hypertension.[50] According to Whelton et al,[51] a reduction in systolic BP of 5 mm Hg would be expected to result in a 7%, 9%, and 14% overall reduction in mortality due to all causes, coronary heart disease, and stroke, respectively.

The findings of the present study are consistent with those of a previous review of observational studies.[5] They also accord with those of the Dietary Approaches to Stop Hypertension study,[52,53] which was based on the observation that consumption of vegetarian diets was associated with a reduced risk of hypertension and found that a diet rich in vegetables and fruits, along with other dietary changes, reduced systolic BP and diastolic BP.

Specific diet and lifestyle factors are known to influence BP. Obesity, excessive sodium intake, and excessive alcohol use are associated with increased BP and risk of hypertension; potassium intake and physical activity are associated with lower BP.[54,55] In addition, intake of unsaturated fat, protein, magnesium, and dietary fiber may be associated with differences in BP.[5] The details provided in the studies included in the present review were insufficient to justify subgroup analyses that might have investigated the influence of these factors on the observed BP differences. Nonetheless, the following factors merit consideration as possible explanations for the observed associations. First, compared with omnivores, vegetarians typically have lower BMIs and a lower risk of obesity, which is mainly attributable to the lower energy density of the diet that results from higher fiber content and lower fat content.[56] Weight differences do not fully explain the observed BP differences, however, because studies controlling for body weight have demonstrated a BP-lowering effect of vegetarian diets.[6] Second, potassium is abundant in vegetarian diets.[57] Meta-analyses[58,59] of randomized clinical trials have reported that potassium supplementation decreases BP. It is hypothesized that a high potassium intake increases vasodilation and glomerular filtration rate while decreasing renin level, renal sodium reabsorption, reactive oxygen species production, and platelet aggregation.[60] Third, some reports[61] have suggested that vegetarian diets may be lower in sodium; however, others[57] have shown no clear differences in sodium intake between nonvegetarians and vegetarians. Fourth, some studies[32,36,37,41] have reported that alcohol consumption is lower in vegetarian populations compared with the general population. However, of the 7 clinical trials included in our study, 5 were limited to participants with no more than modest alcohol consumption; their results are unlikely to be substantially affected by alcohol intake. Vegetarian diets are often proportionately lower in saturated fatty acids and richer in polyunsaturated fatty acids compared with omnivorous diets; both of these dietary characteristics are associated with lower BP.[5,62,63] Consumption of vegetarian diets has also been associated with reduced blood viscosity, which may affect BP.[64] The consumption of vegetable protein has been shown to be inversely associated to BP.[65]

The present meta-analysis has several strengths. First, the available clinical trials and observational studies provided a reasonably large overall sample size that fosters confidence in the findings as well as permitting subgroup analyses in specific population groups. Second, its focus on dietary patterns rather than on the use of dietary supplements or artificial dietary manipulations makes the findings easily applicable to general or clinical populations.

This review also has several limitations. First, although no heterogeneity existed among the controlled trials, heterogeneity was high among the observational studies. Meta-regression and subgroup analyses showed that sex, baseline BP, sample size, and BMI may be key reasons for this heterogeneity. Nonetheless, lower BP was evident in all subgroups, although the differences were not significant for some subgroups. Second, this meta-analysis carried forward design limitations of the included studies. Most notable in this regard are small sample sizes and the fact that all observational studies used cross-sectional rather than prospective designs; however, the latter limitation is partially compensated for by the inclusion of several randomized clinical trials. Third, some of the observational studies did not adjust for lifestyle factors, such as alcohol intake or physical activity level. Finally, foods that make up vegetarian diets and the nutrient composition of the diets differ from person to person and from country to country. Further studies are needed to explore the relationships between specific foods and nutrients and BP. Nevertheless, the results of the meta-analysis of the controlled trials suggest a robust relationship between consumption of vegetarian diets and lower BP.

Conclusions

Consumption of vegetarian diets is associated with lower BP. Further studies are required to clarify which types of vegetarian diets are most strongly associated with lower BP. Research into the implementation of such diets, either as public health initiatives aiming at prevention of hypertension or in clinical settings, would also be of great potential value.

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Author Affiliations: Department of Preventive Medicine and Epidemiologic Informatics, National Cerebral and Cardiovascular Center, Osaka, Japan (Yokoyama, Takegami, Miyamoto); Japan Society for the Promotion of Science, Tokyo, Japan (Yokoyama); Physicians Committee for Responsible Medicine, Washington, DC (Yokoyama, Barnard); Division of Evidence-Based Medicine and Risk Analysis, Preventive Medicine and Epidemiology, National Cerebral and Cardiovascular Center, Osaka, Japan (Nishimura); Department of Nephrology, School of Medicine, Fujita Health University, Aichi, Japan (Nishimura); Department of Medicine, George Washington University School of Medicine and Health Sciences, Washington, DC (Barnard); Department of Healthcare Epidemiology, Kyoto University School of Medicine and Public Health, Kyoto, Japan (Takegami); Department of Preventive Cardiology, National Cerebral and Cardiovascular Center, Osaka, Japan (Watanabe, Miyamoto); Department of Epidemiology, University of Pittsburgh, Pittsburgh, Pennsylvania (Sekikawa); Department of Preventive Medicine and Public Health, School of Medicine, Keio University, Tokyo, Japan (Okamura).

Author Contributions: Dr Yokoyama had full access to all the data in the study and takes responsibility for the integrity of the data and the accuracy of the data analysis.

Study concept and design: Yokoyama, Nishimura, Barnard, Okamura, Miyamoto.
Acquisition of data: Yokoyama.
Analysis and interpretation of data: Yokoyama, Nishimura, Barnard, Takegami, Watanabe, Sekikawa.
Drafting of the manuscript: Yokoyama, Nishimura, Barnard, Miyamoto.
Critical revision of the manuscript for important intellectual content: All authors.
Statistical analysis: Yokoyama, Nishimura.
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