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Blood Pressure Regulation and Vegetarian Diets

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Hypertension affects approximately 50 million individuals in the United States and approximately 1 billion worldwide. Although heredity plays a role in blood pressure variability, diet and lifestyle exert considerable influence in blood pressure regulation. This report reviews the evidence of the relationship between a vegetarian diet and blood pressure regulation and presents data as to the putative mechanisms of action.

Key words: blood pressure, diet, vegetarian

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Introduction

Hypertension affects approximately 50 million individuals in the United States and approximately 1 billion worldwide.[1] As blood pressure (BP) rises, the risk of coronary heart disease, congestive heart failure, stroke, and renal disease rises directly.[1] The risk of cardiovascular disease (CVD) doubles with each 20 mm Hg increment in systolic BP (SBP) over 115 mm Hg or each 10 mm Hg increment in diastolic BP (DBP) over 75 mm Hg.[2]

Heredity accounts for approximately 20% to 40% of BP variability in the general population.[3] Lifestyle factors, particularly diet, also play a major role in BP regulation. Epidemiological data suggest that plant-based dietary patterns are associated with a significantly lower prevalence of hypertension and a correspondingly lower risk of CVD and stroke.[4] In addition, randomized, controlled studies indicate that plant-based diets, particularly vegetarian regimens, are associated with BP reductions in both normotensive and hypertensive individuals.[5-8] This report reviews the evidence on the relationship between vegetarian diets and BP regulation and presents data as to the putative mechanisms of action.

A MEDLINE (National Library of Medicine, Bethesda, MD) search was conducted for studies published on the relationship between vegetarian diets and blood pressure in adults using the key words vegetarian, vegan, lacto-ovo-vegetarian, omnivore, dietary patterns, dietary intake plus blood pressure or hypertension, limiting the search to human studies (excluding infants) published in the English language for the period catalogued since 1966.

Observational Studies

Individuals from cultures where diets are predominately plant-based (e.g., rural Asia, Africa, New Guinea, and the Pacific Islands) historically have lower BP compared with omnivores living in industrialized societies.[9,10] When these individuals migrate to industrialized societies, BP and the prevalence of hypertension increase.[11]

However, even within industrialized societies, lifestyle influences BP. Studies in Australia and the United States show that BP levels tend to be lower in individuals following self-selected vegetarian diets compared with non-vegetarians.[12-14] In an attempt to control for lifestyle confounders, several researchers have compared BP levels of populations with similar lifestyles but different dietary practices. The BP levels of strictly vegetarian Trappist monks were found to be lower than those of Benedictine monks, who consume a western diet.[15] In a cross-sectional analysis, Sacks[12] compared the mean BP of a group of persons consuming a largely vegetarian macrobiotic diet to that of persons consuming a general western diet. Systolic BP was found to be significantly lower in males consuming a macrobiotic diet.

Some of the best-controlled observational data on the effects of vegetarian diets on BP come from studies of Seventh-Day Adventists, for whom religious tenets call for a vegetarian diet as well as proscription of alcohol, nicotine, and caffeine and other stimulants. About 50% of Adventists follow a lacto-ovo-vegetarian diet defined as including dairy products and eggs but no other animal-based products. Anholm[16] compared BP levels of lacto-ovo-vegetarian Adventists and age- and sex-matched Mormons, who have a similar lifestyle but

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eat an omnivorous diet. The results indicated that BP levels of Adventists were significantly lower than those of Mormons, and that the differences increased with age. Similarly, Rouse et al.[14] compared lacto-ovo-vegetarian Adventists with non-vegetarian Adventists and Mormons. The prevalence of mild hypertension was 1% to 2% in the vegetarians compared with 8.5% in the Adventist omnivores and 10% in the Mormons. Differences of 5 to 6 mm Hg SBP ($P < 0.01$) and 3 to 4 mm Hg DBP ($P < 0.05$) persisted between the vegetarians and omnivores after adjustment for the lower body weight of the vegetarians.

In a later study, cross-sectional data from a cohort of 34,192 California Adventists showed that vegetarian Adventists have approximately half the prevalence of hypertension as non-vegetarian Adventists.[17] When hypertensives were defined as those taking antihypertensive medication, a nearly 3-fold difference in hypertension prevalence was seen between the two groups.[18] Adjusting for body weight reduced the magnitude of the effect somewhat, suggesting that a vegetarian diet may work in part by promoting a lower body mass.

In industrialized nations, BP tends to increase with advancing age.[1] To determine the effects of long-term consumption of a vegetarian diet on this relationship, Melby[19] measured BP in Adventists over the age of 60 years who had followed a meatless regimen for at least 3 years and compared them with non-vegetarian Adventists. Vegetarian Adventists had significantly lower SBP than non-vegetarian Adventists. The investigators suggested that this result might have been due to the lower body mass of vegetarians. However, other studies have found that lower BP levels in Adventists who follow a vegetarian diet are independent of body mass index (BMI).[13,14] Ophir[20] found significantly lower BP in every decade of age in a group of adult Israeli vegetarians (range 126 ± 16.3 mm Hg) compared with a group of matched non-vegetarians (range 146.8 ± 19 mm Hg) In addition, when stratified analyses adjusted for body weight, the difference in BP remained significant, supporting the results seen in studies in the Adventist population.

In the United States, blacks exhibit a steeper increase in BP with advancing age compared with whites, leading to a significantly higher prevalence of hypertension.[1] To examine the possible interactions of race, diet, and BP, Melby[21] measured the BP of white and black Adventist vegetarians. Black vegetarians showed significantly lower SBP than black non-vegetarians after adjusting for BMI and waist/hip ratio. The reported difference between the two groups may have been underestimated, since a significant proportion of the non-vegetarians had their high BP attenuated through the use of hypertensive medication. In a later study,[22] Melby compared the prevalence of hypertension among white Adventist omnivores and vegetarians with the prevalence in black Adventist omnivores and vegetarians. In that study, regardless of BMI, waist circumference, waist/hip ratio, and dietary preferences, older black adults exhibited higher SBP (range 121.8 ± 2.5 to 139.0 ± 3.0 mm Hg) and DBP (range 67.3 ± 1.3 to 76.1 ± 1.9 mm Hg) than their white counterparts. However, black vegetarians exhibited a lower prevalence of hypertension (approximately 40%) than did black omnivores (approximately 60%) ($P < 0.001$). In a similar study comparing prevalence of hypertension among Adventist black vegetarians, semi-vegetarians (eating one to three servings of meat/week), and non-vegetarians, only 16% of the vegetarians were confirmed to be hypertensive compared with 35.7% of the semi-vegetarians and 31.1% of the non-vegetarians[23] (DBP range 116.6 ± 2.5 mm Hg for black SDA vegetarians to 120.2 ± 2.7 mm Hg for black SDA non-vegetarians; SBP range 77.2 ± 1.4 mm Hg for black SDA vegetarians to 78.5 ± 4.6 mm Hg for black SDA non-vegetarians).

When Adventist vegetarians and non-vegetarians in New Zealand were compared, BMI did not differ between groups.[24] However, DBP was significantly lower in vegetarian males compared with non-vegetarian males No difference in BP was found between vegetarian and non-vegetarian females. However, collectively, the vegetarian groups had BP levels below the New Zealand average.

Haines et al.[25] compared BP levels in a cohort of vegetarians with that in non-vegetarians who participated in the Northwick Park Heart Study, a prospective study of hemostatic variables in the pathogenesis of clinical ischemic heart disease. Results indicated that DBP was significantly lower in both male and female vegetarians compared with controls. Consumption of a vegetarian diet was associated with a reduced risk of ischemic heart disease.

These observational studies (Table 1) show that the SBP of vegetarians is 3 to 14 mm Hg lower and the DBP is 5 to 6 mm Hg lower than that of non-vegetarians. The prevalence of hypertension ranges from 2% to 40% in vegetarians compared with 8% to 60% in non-vegetarians.

Randomized Controlled Trials

Rouse et al.[5] introduced a lacto-ovo-vegetarian diet to normotensive meat eaters in a 6-week, crossover-design trial. After adjusting for age, obesity, heart rate, weight change, and initial BP, a significant diet-related decrease of 5 to 6 mm Hg SBP and 2 to 3 mm Hg DBP was observed. These changes were independent of dietary sodium. In a similar study in individuals with untreated mild hypertension, Margetts et al.[7,26] also observed a

Table 1. Observational Studies on the Difference in Systolic Blood Pressure (SBP) and Diastolic Blood Pressure (DBP) in Vegetarians Compared with Non-Vegetarians

Reference	Population	Δ SBP	Δ DBP
		mm Hg	
Sacks et al.[12]	Macrobiotic dieters (age 16–19, n = 140; age 30–39, n = 20; age 40+, n = 3): compared with non-macrobiotic dieters		
	• Age 16–19 (n = 29)	−8.21	−9.55
	• Age 30–39 (n = 7)	−13.06	0.0
	• Age 40+ (n = 3)	+3.53	−3.82
Armstrong et al.[13]	SDA vegetarians (103 M, 187 F) compared with non-vegetarians		
	• 177 M	−8.9*	−9.1*
	• 241 F	−11.5*	−7.9*
	(all subjects age 30–79)		
Rouse et al.[14]	SDA lacto-ovo-vegetarians (47 M, 51 F)		
	• Compared with SDA non-vegetarians (43 M, 49 F)	−7.9† (M) −1.4 (F)	−5.0 (M) 0.0 (F)
	• Compared with Mormon non-vegetarians (59 M, 54 F)	−8.2† (M) −8.6† (F)	−6.2‡ (M) −7.9† (F)
	(all subjects age 25–40)		
Groen et al.[15]	Strict vegetarian Trappist monks (n = 181 M) compared with non-vegetarian Benedictine monks (n = 168 M)	−11	−2
Melby et al.[19]	Long-term (for ≥3 yrs before study) vegetarians (n = 61) compared with non-vegetarians (n = 29)	−13.9†	2.5
	(all subjects age ≥60)		
Ophir et al.[20]	Vegetarians (for avg. of 19 yrs before study) age 25–84 (avg. age 62) compared with non-vegetarians (50 M, 48 F)	−20.8‡	−10.3‡
Melby et al.[21]	Black SDA vegetarians (for avg. of 20.6 yrs before study) (n = 55)		
	• Compared with black SDA non-vegetarians (n = 59)	−6.9‡	ND
	• Compared with white SDA vegetarians (for avg. of 27.2 yrs before study) (n = 164)	−15.0‡	ND
	• Compared with white SDA non-vegetarians (n = 100)	−14.7‡	ND
	(all subjects age 52–57)		
Melby et al.[22]	Black SDA vegetarians (for avg. of 3.2 yrs before study) (n = 27)		
	• Compared with black SDA non-vegetarians (n = 37)	ND	ND
	• Compared with white SDA vegetarians (for avg. of 1.9 yrs before study) (n = 85)	ND	ND
	• Compared with white SDA non-vegetarians (n = 54)	ND	ND
	(all subjects age 65 to 69)		
Melby et al.[23]	Black SDA vegetarians (n = 66)		
	• Compared with black SDA semi-vegetarians (1–3 servings meat/wk) (n = 56)	ND	ND
	• Compared with black SDA non-vegetarians (n = 45)	ND	ND
	(all subjects avg. age 47)		
Harmon et al.[24]	Non-vegetarians (n = 23) compared with vegetarians (n = 24) (all subjects age 20–65)	−86 (M) −4.5 (F)	−7.8‡ (M) −3.7 (F)
Haines et al.[25]	Vegetarians (n = 50) compared with non-vegetarians (n = 282) (all subjects age 40–51)	−11† (M) −5 (F)	−9* (M) −7‡ (F)

SDA = Seventh-Day Adventist; ND = no difference. * $P < 0.001$; † $P < 0.01$; ‡ $P < 0.05$.

significant decrease of 5 mm Hg in SBP but no change in DBP during the vegetarian periods. Lindahl et al.[80] placed 26 hypertensive patients on a vegan diet for one year. They observed a significant reduction in both SBP and DBP in these patients compared with controls despite the fact that 20 out of the 26 participants had terminated hypertensive medication by the end of the year (average SBP = 142 ± 20.4 mm Hg; average DBP = 83 ± 9.6 mm Hg). In these and other studies,[6,27] a low sodium intake appeared not to be associated with the BP-lowering effect of the vegetarian diet. Also, as in most clinical studies, adjustment for body weight may have led to an underestimation of the effect of a vegetarian diet on BP, because weight loss is one of the mechanisms by which a vegetarian diet may influence BP.

In summary, observational studies[12-14,16] (Table 2) show that vegetarians have lower BP than the general population. Randomized clinical trials have shown that BP is lowered when animal products are replaced with vegetable products in both normotensive and hypertensive individuals.[5,7,26] The beneficial expected consequences of a reduction in BP include a reduction in major coronary events.[29] Vegetarians have been shown to have a lower incidence of coronary heart disease[30] and ischemic heart disease and a reduced risk of ischemic heart disease-related death[31,32] compared with non-vegetarians.

Potential Mechanisms

To understand how a vegetarian diet lowers BP, researchers have focused on the possible BP-lowering mechanisms of changes in body weight and intake of specific food groups and individual nutrients.

Body Weight

Self-reported data from the Continuing Survey of Food Intake by Individuals (CSFII) 1994–1996,[33] along with other observational data,[14,17,34,35] indicate that vegetarians are leaner and have a lower body weight than non-vegetarians. Lower body weight is associated strongly with lower BP.[13,14,17] Clinical studies report that in overweight people with high-normal BP, weight loss of 4.5 kg short-term (6 months) and 2 kg long-term (36 months) results in a statistically significant reduction in SBP and DBP compared with controls (3.7/2.7 mm Hg at 6 months, $P < 0.001$; 1.3/0.9 mm Hg at 36 months, $P < 0.001$).[36] These findings were confirmed after 18 months, when body weight decreased by 2.4 kg, and a corresponding significant net reduction in SBP was associated with the weight loss (5.8 mm Hg, $P = <0.001$) and net reduction in DPB (3.2 mm Hg, $P = <0.005$).[37] After 7 years of follow-up, the incidence of hypertension was 18.9% in the weight loss group and 40.5% in the control group. Consumption of a vegetarian diet contributes to reduction in body weight in overweight individuals and to the maintenance of a low body weight, with corresponding reductions in BP and in the risk of hypertension. However, reduced body weight is not the only mechanism by which vegetarian diets influence BP, as indicated by the studies cited above showing lower BP after adjustment for body weight.

Dietary Fat

Data from the CSFII 1994–1996[38] and other reports[39-42] show that vegetarian diets are significantly lower than non-vegetarian diets in total fat and saturated fat as a percentage of total energy and have a higher polyunsaturated to saturated fat ratio (approximately 1.0 vs. 0.6,

Table 2. Randomized, Controlled Studies on the Difference in Systolic Blood Pressure (SBP) and Diastolic Blood Pressure (DBP) in Patients Placed on an Ovo-Lacto-Vegetarian Diet

Reference	Design	Δ SBP	Δ DBP
		mm Hg	
Margetts et al.[7,26]	Randomized crossover; age range 39–61; 25% female, 75% male		
	• Group I: Ovo-lacto-vegetarian diet 1st 6 weeks	−5*	ND
	• Group II: Ovo-lacto-vegetarian diet 2nd 6 weeks	−5*	ND
	• Control	ND	ND
Rouse et al.[5]	Randomized crossover; age range 29–50; 50% female, 50% male		
	• Group I: Ovo-lacto-vegetarian diet 1st 6 weeks	−6.8 ± 8.8 to −8.9 ± 6.0	−2.6 ± 6.8 to −2.7 ± 6.3
	• Group II: Ovo-lacto-vegetarian diet 2nd 6 weeks	−6.8 ± 8.8 to −8.9 ± 6.0	−2.6 ± 6.8 to −2.7 ± 6.3
	• Control	ND	ND
Lindahl et al.[80]	Hypertensive patients (n = 26) age 40–69 on vegan diet for 1 yr	−9 ± 5.3†	−5 ± 5.3*

ND = No difference; *$P < 0.05$; †$P < 0.01$.

respectively). It is possible that total dietary fat, the polyunsaturated to saturated fat ratio, and/or their interaction contribute to the BP-lowering effect of a vegetarian diet. Iacono[43,44] reported that the SBP and DBP of individuals consuming a diet low in total fat (23%–25% energy from fat) and a polyunsaturated to saturated fat ratio of 1.0 to 1.2 decreased significantly in both short- and long-term studies compared with controls. The decrease in BP was greater among hypertensive than among normotensive subjects. In later studies, these researchers showed that a reduction in total fat intake (from 38% to 24% of total calories), with modest changes in the dietary polyunsaturated to saturated fat ratio, resulted in a significant decrease in SBP and DBP.[45] Margetts et al.[46] reported no change in BP in normotensives consuming a vegetarian diet when total dietary fat was maintained but the polyunsaturated to saturated fat ratio was increased. Changes in fat intake may modulate BP through their effect on blood viscosity. In blood rheology studies, Ernst[78] observed that vegetarians had lower plasma viscosity along with significantly lower BP than controls.

Fiber

Several studies show that fiber intake among vegetarians is significantly greater than among non-vegetarians as a result of their intake of fruits, vegetables, legumes, nuts, and whole-grain breads and cereals.[38,40,41] Dietary fiber reduces energy density[48] and influences satiety and body weight[49] and thus may have an effect on BP mediated by its effect on weight. Although a recent meta-analysis[47] of observational studies has shown an inverse association between the consumption of dietary fiber and both BP and risk of hypertension, clinical studies have not been able to demonstrate a significant effect of dietary fiber on BP.[50-53]

Fruits and Vegetables

Because vegetarian diets are generally high in fruits and vegetables and are associated with BP-lowering effects, the DASH (Dietary Approaches to Stop Hypertension) trial examined whether a dietary pattern high in fruits and vegetables would be associated with a lower BP while remaining palatable to the general population.[54-57] In an 8-week trial, a diet rich in fruits and vegetables, low in meat, and including low-fat dairy products, with reduced saturated and total fat was found to lower SBP in both hypertensive and non-hypertensive individuals.[54-57] Fruit and vegetable intake was responsible for about one-half the BP reduction of the DASH diet.[54] Fruits and vegetables are rich sources of minerals, fiber, and other nutrients. Vegetarian diets, generally higher in fruits and vegetables, are correspondingly rich sources of potassium, magnesium, other minerals, antioxidants, and fiber.

Potassium

Vegetarians have a greater potassium intake compared with omnivores, also due to their greater fruit and vegetable consumption.[38-42] Observational studies have demonstrated an inverse relationship between potassium intake and BP in free-living populations.[20,27,58,59] Results of two meta-analyses of 52 randomized, clinical trials indicated that potassium intake significantly lowered SBP and DBP in hypertensive and normotensive individuals.[60,61]

Magnesium

Dietary sources of magnesium include fruits, vegetables, nuts, cereals, and dairy products, foods that are typically consumed in vegetarian diets.[38,40-42] Accordingly, the magnesium intake of vegetarians is significantly higher than that of non-vegetarians.[38,42] In a 4-year prospective study, Witteman et al.[62] reported that magnesium intake from a variety of plant foods was independently associated with a lower risk of hypertension. Data from the Honolulu Heart Study showed that a low magnesium intake was the dietary factor most strongly associated with high BP.[63] The effect of magnesium is less impressive in trials using supplements. The results from randomized, controlled trials suggested that magnesium, when given in the form of a supplement, did not have a significant effect on BP, although there was a downward trend in SBP and DBP levels in some[64,65,67] but not all[66] trials. Results of other trials in mild to moderate hypertensives failed to show an effect of magnesium on BP.[68] The mechanism by which magnesium may affect BP is uncertain, nor is it clear that the BP-lowering effect of magnesium-rich diets is not due to an aspect of these diets other than their magnesium content.

Sodium

Population data comparing the 24-hour sodium and potassium excretion levels of vegetarians and omnivores show no differences in sodium excretion.[20,69] This observation was confirmed in clinical trials in both normotensive[5] and hypertensive individuals[7] in which BP changes were unrelated to sodium intake or excretion. Dietary sodium, therefore, does not account for BP differences between vegetarians and non-vegetarians.

Antioxidants

Fruits and vegetables are rich sources of antioxidants. Not surprisingly, the intake of vitamin C[38,41,42] and vitamin E[41] is significantly greater in vegetarians than in non-vegetarians. When persons with habitually low intakes of fruits and vegetables increased their consumption of these foods for 8 weeks, plasma vitamin C, α-carotene, and β-carotene increased in parallel with increased dietary intake.[70] John et al.[28] reported that when subjects increased their intake of fruits and vege-

tables for 6 months, plasma vitamin C, α-carotene, β-carotene, lycopene, and β-cryptoxanthin levels increased. In this study, increased intake of fruits and vegetables was associated with decreases in SBP and DBP in both normotensives and hypertensives. A proposed mechanism by which antioxidants may modulate BP is through their regulation of nitric oxide synthase.[71] Reduced generation of nitric oxide is believed to be responsible for the impaired endothelial vasodilator response commonly found in essential hypertension. Because nitric oxide can be inactivated in vivo by the superoxide anion, the ability of dietary antioxidants to remove excess superoxide may be expected to potentiate the action of nitric oxide and reduce BP.[71,72]

Soy

Some soy foods may have a BP-lowering effect in hypertensive[73,74] and normotensive[75,76] individuals. It is uncertain if this effect can be explained by the presence of isoflavones and/or the amino acid content of soy protein.[73,77]

Conclusion

Abundant evidence supports the BP-lowering effect of a vegetarian diet. Vegetarian diets are high in fruits, vegetables, legumes, and nuts. As a result, they have a relatively high polyunsaturated to saturated fat ratio, are relatively low in total fat, and have a high potassium, magnesium, and fiber content. The protective effect of these foods likely is mediated by their tendency to reduce body weight and modulate blood viscosity, along with the BP-lowering properties of individual nutrients. This effect appears to be independent of BMI, sodium intake, and other lifestyle factors such as exercise and alcohol consumption. The benefits of a well-balanced vegetarian diet, both for maintaining a healthy BP and lowering BP in hypertensives, deserve further consideration.

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