

Non-pharmacological aspects of blood pressure management: what are the data?

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Hypertension affects 29% of US adults and is a significant risk factor for cardiovascular morbidity and mortality.

Epidemiological data support contribution of several dietary and other lifestyle-related factors to the development of high blood pressure (BP). Several clinical trials investigated the efficacy of non-pharmacological interventions and lifestyle modifications to reduce BP. Best evidence from randomized controlled trials supports BP-lowering effects of weight loss, the Dietary Approaches to Stop Hypertension (DASH) diet, and dietary sodium (Na⁺) reduction in those with prehypertension, with more pronounced effects in those with hypertension. In hypertensive participants, the effects on BP of DASH combined with low Na⁺ alone or with the addition of weight loss were greater than or equal to those of single-drug therapy. Trials where food was provided to participants were more successful in showing a BP-lowering effect. However, clinical studies with long-term follow-up revealed that lifestyle modifications were difficult to maintain. Findings from controlled trials of increased potassium, calcium, or magnesium intake, or reduction in alcohol intake revealed modest BP-lowering effects and are less conclusive. The reported effects of exercise independent of weight loss on BP are inconsistent.

Kidney International (2011) **79**, 1061–1070; doi:10.1038/ki.2011.46; published online 9 March 2011

KEYWORDS: blood pressure; DASH diet; hypertension; lifestyle modification

Hypertension is a disease of epidemic proportions especially in industrialized nations, affecting 29% of US adults alone.¹ It was identified as one of the most significant but modifiable risk factors for not only cardiovascular (CV) disease, stroke, and end-stage kidney disease^{2–6} but also for overall CV death.^{7,8} Despite this, the pathogenesis of primary hypertension is still not completely understood. Epidemiological studies implicated several dietary and other lifestyle-related factors contributing to hypertension development. Extensive published evidence supports the concept that non-pharmacological interventions, more recently referred to as lifestyle modifications, can substantially reduce blood pressure (BP) in both individuals with established hypertension and those with prehypertension. Evidence also indicates that BP reduction decreases risk of poor CV outcomes, even in those with prehypertension.⁹

Large epidemiological studies such as International Cooperative Study on the Relation of Sodium and Potassium to Blood Pressure (INTERSALT) concluded that habitual high sodium (Na⁺) intake, low potassium (K⁺) intake, decreased physical activity, high body mass index, and excess alcohol intake may be critical environmental factors contributing to rising prevalence of hypertension.^{10,11} INTERSALT, a large, cross-sectional epidemiological study done in 52 centers in 32 countries, confirmed that over a wide range of Na⁺ intake, populations with low intake have lower BP than those with high intake.¹⁰ Over the past few thousand years, there was a major increase in Na⁺ content of the human diet as a consequence of salt use in food preservation and preparation. Parallel to this was a significant decrease in dietary K⁺. The resultant dietary K⁺/Na⁺ ratio was reduced by a factor of 100–200, based on the comparison of the modern human diet with that of the Yanomamos, an unacculturated tribe of Amazonian rain forest Indians. Labeled as the ‘no-salt culture,’ they consume very little salt as they live inland and are primarily gardeners and gatherers with a largely vegetarian K⁺-rich diet.¹² In observational studies of Yanomamos, mean Na⁺ excretion was exceptionally low at 0.9 mmol/24 h, urinary K⁺ was 152 mmol/24 h, and mean BP was 96/61 mm Hg.¹² There was no increase in BP with age and hypertension was virtually absent.^{11–14}

Since then, there were several major clinical trials exploring the efficacy of lifestyle modifications to reduce

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Received 2 September 2010; revised 9 December 2010; accepted 5 January 2011; published online 9 March 2011

BP. In this article, evidence supporting the BP-lowering effects of the following non-pharmacological interventions will be reviewed: (1) the Dietary Approaches to Stop Hypertension (DASH) diet; (2) reduced Na⁺ intake; (3) increased K⁺ intake; (4) increased magnesium intake; (5) increased calcium intake; (6) weight loss and increased physical activity; and (7) moderation in alcohol intake. Other non-pharmacological interventions that were tried in smaller clinical trials but revealed small and inconsistent effects will not be reviewed. These include, but are not limited to, increased protein intake, ω-3 fatty acids, onion, garlic, flavanol-rich cocoa, decreased caffeine intake, and device-guided breathing and other biofeedback. Tobacco should be avoided because of increased CV risk, regardless of evidence for BP-lowering effects.

The DASH diet

The DASH Study tested the effects of an overall healthy diet, rather than individual nutrients, on BP in participants with prehypertension or stage I hypertension.¹⁵ This was based on small effects observed on BP reduction in previous trials that modified single nutrients (such as K⁺, magnesium, calcium, fiber, and protein), as well as the generally positive results of vegetarian diets.

A total of 459 adults with BP <160/80–95 mm Hg were randomly assigned for 8 weeks to one of the following: (1) control diet, low in fruits, vegetables, dairy products with a fat content typical of the average US diet, and with K⁺, magnesium, and calcium levels close to the 25th percentile of

the US consumption; (2) fruits-and-vegetables diet, with K⁺ and magnesium at 75th percentile and with high fiber; or (3) combination diet, rich in fruits, vegetables, and low-fat dairy, with reduced saturated fat, total fat, and cholesterol, and K⁺, magnesium, and calcium at the 75th percentile.¹⁵ All the three diets had similar Na⁺ content, 3 g/day. Weight was kept stable.¹⁵

Percent of women and African-American participants, as well as other characteristics of DASH and other major lifestyle modification trials are tabulated in Table 1. Reductions in BP were achieved after 2 weeks in the fruits-and-vegetables and combination diets as compared with the control diet and were sustained for 6 more weeks. There was a gradient reduction in both systolic and diastolic BP across diets, with the combination diet reducing BP more than the fruits-and-vegetables or the control diets (Table 2). Those with hypertension (29%) and minorities (66%) had greater reductions in BP, but there were no significant interactions between minority status and diet or gender and diet.¹⁵

In the Optimal Macronutrient Intake Trial to Prevent Heart Disease (N=164), two reduced carbohydrate versions of DASH (high protein and high unsaturated fat) significantly reduced BP by 3.5/2.4 mm Hg and 2.9/1.9 mm Hg, respectively, in participants with hypertension when compared with a higher carbohydrate DASH diet.¹⁶ A reduced caloric version of DASH reduced BP by 16.1/9.9 mm Hg when compared with control in the Exercise and Nutrition Interventions for Cardiovascular Health Study (Table 1).¹⁷

Table 1 | Major trials of diet, weight, and sodium reduction for BP lowering

Trial	Total, N	Intervention(s) (vs control)	Duration	Women (%)	African-American (%)	Overall BP reduction (mm Hg) compared with control
DASH	459	1. Fruits/vegetables diet 2. Combination/DASH ^a	8 weeks	49	60	2.8/1.1 Fruits/vegetables 5.5/3.0 Combination/DASH
OmniHeart	164	1. High protein (1/2 from plant sources) 2. High unsaturated fat 3. High carbohydrate	6 weeks	45	55	1.4/1.2 High protein vs carbohydrates 1.3/0.8 High unsaturated fat vs carbohydrates
ENCORE	144	1. Usual diet 2. DASH alone 3. Reduced calorie DASH	4 months	67	39	3.4/3.8 Usual diet ^b 11.2/7.5 DASH alone 16.1/9.9 Reduced calorie DASH
DASH-Sodium	412	1. DASH—low Na ⁺ 2. DASH—intermediate Na ⁺ 3. DASH—high Na ⁺	30 days	57	57	2.2/1.1 DASH—low Na ⁺ 5.0/2.5 DASH—intermediate Na ⁺ 5.9/2.9 DASH—high Na ⁺
TOHP I	2182	Three lifestyle changes and four nutritional supplements (see text)	18 months	30	15	2.3/2.9 Weight loss 2/1 Low Na ⁺
TOHP II	2382	1. Weight loss 2. Low Na ⁺ 3. Combination of both	6 and 36 months	34	18	3.7/2.7 Weight loss ^c 2.9/1.6 Low Na ⁺ 4.0/2.8 Combined
DEW-IT	44	Combination of DASH, low Na ⁺ , weight loss	9 weeks	62	62	9.5/5.3 (24 h ambulatory BP)
PREMIER	810	1. Established ^d 2. Established + DASH	6 months	62	34	3.7/1.7 Established 4.3/2.6 Established/DASH

Abbreviations: BP, blood pressure; DASH, Dietary Approaches to Stop Hypertension; DEW-IT, Diet, Exercise and Weight Loss Intervention Trial; ENCORE, Exercise and Nutrition Interventions for Cardiovascular Health; OmniHeart, Optimal Macronutrient Intake Trial to Prevent Heart Disease; TOHP I, Trials of Hypertension Prevention—Phase I; TOHP II, Trials of Hypertension Prevention—Phase II.

^aCombination or DASH diet was rich in fruits, vegetables, and low-fat dairy, with reduced saturated fat, total fat, and cholesterol; potassium, magnesium, and calcium at levels close to the US 75th percentile.

^bReduction in BP in each group compared with preintervention values.

^cRefers to BP reductions for 6 months.

^dEstablished refers to a behavioral intervention that implemented established lifestyle recommendations.

Table 2 | Mean reductions in BP from baseline in the DASH Trial^{a15}

Group	Combination minus control (97.5% CI), P-value		Combination minus fruits/vegetables (97.5% CI), P-value		Fruits/vegetables minus control (97.5% CI), P-value	
<i>Systolic BP (mm Hg)</i>						
All	-5.5 (-7.4, -3.7)	<0.001	-2.7 (-4.6, -0.9)	0.001	-2.8 (-4.7, -0.9)	<0.001
<140/90	-3.5 (-5.3, -1.6)	<0.001	-2.7 (-4.5, -0.8)	0.001	-0.8 (-2.7, 1.1)	NS
≥140/90	-11.4 (-15.9, -6.9)	<0.001	-4.1 (-8.6, 0.3)	NS	-7.2 (-11.4, -3.0)	<0.001
Minority	-6.8 (-9.2, -4.4)	<0.001	-3.2 (-5.6, -0.8)	0.003	-3.6 (-6.1, -1.2)	0.001
Non-minority	-3.0 (-5.9, -0.1)	0.02	-1.9 (-4.8, 1.0)	NS	-1.1 (-3.9, 1.7)	NS
<i>Diastolic BP (mm Hg)</i>						
All	-3.0 (-4.3, -1.6)	<0.001	-1.9 (-3.3, -0.6)	0.002	-1.1 (-2.4, 0.3)	NS
<140/90	-2.1 (-3.6, -0.5)	0.003	-1.8 (-3.4, -0.3)	0.009	-0.3 (-1.9, 1.3)	NS
≥140/90	-5.5 (-8.2, -2.7)	<0.001	-2.6 (-5.4, 0.1)	NS	-2.8 (-5.4, -0.3)	0.01
Minority	-3.5 (-5.2, -1.8)	<0.001	-2.1 (-3.8, -0.4)	0.007	-1.4 (-3.2, 0.3)	NS
Non-minority	-2.0 (-4.2, 0.2)	0.04	-1.6 (-3.8, 0.5)	NS	-0.4 (-2.5, 1.7)	NS

Abbreviations: BP, blood pressure; CI, confidence interval; DASH, Dietary Approaches to Stop Hypertension; NS, not significant.

^aAdapted from Appel et al.¹⁵

Dietary Na⁺ restriction

There are several clinical trials of dietary Na⁺ reduction, the largest being the Trials of Hypertension Prevention—Phase I (TOHP I) and the DASH–Sodium Trial (Table 1). The former was a large multicenter, randomized trial in prehypertensives of seven non-pharmacological interventions in the context of usual living patterns. In Phase I, 6 of 10 sites tested an intervention to reduce dietary Na⁺ intake to 80 mmol/24 h (1800 mg/24 h), with a total of 417 control and 327 active group participants.¹⁸ The intervention arm received nutrition and behavior change counseling with the goal of reducing Na⁺ intake to 60 mmol/day (1400 mg). The control arm received no intervention.

At 18 months, net decrease from baseline in urinary Na⁺ was 44 mmol/24 h. White women had the highest proportion of decreased urinary Na⁺ to target and African-Americans had four times the odds of failing to achieve the target. Net decrease in BP associated with treatment was 2/1 mm Hg ($P < 0.01$). There was a larger systolic BP effect in women than men (-4.4 versus -1.2 mm Hg, $P = 0.02$). Overall adjusted decrease in BP was 1.4/0.9 mm Hg for a decrease of 100 mmol/24 h in urinary Na⁺.²⁰ In an observational 10- to 15-year follow-up of TOHP, dietary salt reduction was shown to significantly decrease long-term risk of CV events by 25%.⁹

In the DASH–Sodium Trial, 412 adults with BP >120/80 and ≤159/95 mm Hg were randomly assigned to either a control diet typical of the US intake or the DASH combination diet.¹⁹ Within each group, participants were further assigned to low Na⁺ (50 mmol/day), intermediate (100 mmol/day), or high Na⁺ (150 mmol/day) intake for 30 days in a random cross-over design. Na⁺ intake reduction significantly lowered both systolic and diastolic BP in a stepwise manner with both control and DASH diets. Level of Na⁺ intake had about twice the effect on BP with the control diet (-6.7 mm Hg), as it did with the DASH diet (-3 mm Hg).¹⁹

Importantly, the DASH diet with low Na⁺ (as compared with control diet/high Na⁺) led to a systolic BP 11.5 mm Hg lower in hypertensives (which is greater than or equal to the effects of single-drug therapy) and 7.1 mm Hg in

non-hypertensives.¹⁹ The combination of two dietary modifications (DASH and Na⁺) also lowered systolic BP significantly more in women than in men.¹⁹ However, the combined effects of DASH and low Na⁺ were not strictly additive. The authors speculated that low levels of Na⁺ attenuated the hypotensive effects of K⁺ in DASH, or high K⁺ content attenuated the effects of low Na⁺.

Weight loss

In TOHP I, seven interventions were tested in 2182 participants with prehypertension: three lifestyle changes—weight reduction, Na⁺ reduction, and stress management—compared with unmasked non-intervention controls, and four nutritional supplements—K⁺ (60 mmol or 4.5 g), calcium (25 mmol or 1 g), magnesium (15 mmol or 360 mg), and fish oil (6 g with 3 g of ω-3 fatty acids)—compared singly with placebo in a double-blind manner. Follow-up for the lifestyle changes interventions was 18 months to test maintenance of behavioral changes. Intervention included counseling on food selection, and the weight reduction group incorporated a moderate increase in caloric expenditure by walking briskly for 45 min 4–5 times weekly.²⁰

Weight reduction was the most effective strategy, producing a net weight loss of 3.9 kg and a BP change of -2.3/-2.9 mm Hg ($P < 0.01$). Effect of Na⁺ reduction on BP was discussed above. Stress management and nutritional supplements did not reduce BP significantly despite good adherence.²⁰

Achieved weight loss was greater in men than in women. The effect on BP was linearly associated with the amount of weight lost. After 7 years of follow-up, the odds of hypertension were reduced by 77% ($P = 0.02$) in the weight loss group compared with controls. These data suggest that weight loss may be effective in long-term primary prevention of hypertension.²¹

Combination of weight loss and Na⁺ reduction

The Phase II of TOHP was 2 × 2 factorial trial that randomized 2382 participants to one of four groups: weight

loss alone, Na⁺ reduction alone, combination of both, or usual care.²² Intervention counseling aimed at achievement of desirable weight or a ≥ 4.5 -kg weight loss and/or Na⁺ intake of 80 mmol/day.

Compared with usual care, the weight loss and combined groups had similar weight reduction (4.1–4.4 kg) at 6 months ($P < 0.001$ for both).²² Weight reduction in the Na⁺ alone group was 1.1 kg, 1.2 kg less than usual care ($P < 0.001$). However, by 36 months, weight regain occurred in all groups, resulting in a weight close to baseline in the weight loss and combined groups. Similarly, the main effect of the Na⁺ intervention fell short of goal, and the net reduction was 48 mmol/day.²²

BP reductions at 6 months for each group versus usual care are listed in Table 1 ($P < 0.001$ for all comparisons).²² However, at 36 months, these reductions were attenuated and remained statistically significant only for diastolic and systolic BP in the weight loss group and for systolic BP in the Na⁺ group. This trial revealed that long-term interventions for weight loss and dietary Na⁺ reduction are difficult to maintain. In addition, long-term maintenance of weight loss was less successful than Na⁺ reduction.

A three-pronged approach—DASH diet, reduced Na⁺ and weight loss—was investigated in the Diet, Exercise and Weight Loss Intervention Trial (DEW-IT), where 44 hypertensive overweight adults with a BP of 130–170/80–100 mm Hg on stable dose of a single antihypertensive medication or combination pill were randomized to a lifestyle or control group for 9 weeks.²³ The lifestyle group was fed a hypocaloric version of DASH providing 100 mmol/day of Na⁺ and participated in a moderate-intensity aerobic exercise of 30–45 min three times a week. All foods were provided to the participants. There were no interventions in the control group.²³

Mean net weight loss in the lifestyle group was 4.9 kg, and net mean reduction in 24-h ambulatory BP (the primary outcome) was 9.5/5.3 mm Hg ($P < 0.001$). The main conclusions were: (1) BP reduction in DEW-IT was similar to that achieved in the DASH–Sodium Trial in the hypertensive subgroup, not on antihypertensive medication and (2) the BP reduction magnitude was similar to BP reductions achieved with drug therapy.²³

The PREMIER clinical trial of comprehensive lifestyle modification for blood pressure control randomized 810 adults with prehypertension or stage I hypertension not on drug therapy to: (1) established, a behavioral intervention that implemented the established JNC (Joint National Committee on Prevention, Detection and Evaluation of High Blood Pressure) VI recommendations; (2) established plus DASH, which added the DASH diet; or (3) advice-only comparison group, which received advice at randomization. Interventions included: (1) weight loss of at least 15 lb (6.8 kg) if body mass index ≥ 25 kg/m²; (2) moderate-intensity exercise of ≥ 180 min/week; (3) ≤ 100 mmol/day of Na⁺ intake; (4) ≤ 2 alcohol drinks/day for men and ≤ 1 for women; and (4) 18 counseling sessions.²⁴

Mean net BP reduction at 6 months compared with the advice-only group was 3.7/1.7 mm Hg in established, and

4.3/2.6 mm Hg in established plus DASH. The addition of DASH only provided an incremental 1.7/1.6 mm Hg BP reduction. Corresponding BP reductions for hypertensive participants were higher at 4.6/2.0 and 6.3/3.6 mm Hg, respectively.²⁴

Why were BP reductions achieved in PREMIER smaller than achieved in previous trials? In DEW-IT and DASH, food was provided to the participants but in PREMIER, participants purchased their own food; hence, the same intensity of intervention may not have been achieved. In addition, 62% of DEW-IT and 57% of DASH but only 34% of PREMIER participants were African-Americans.²⁵ Therefore, salt sensitivity, more prevalent in African-Americans, may have had a role. Finally, the duration of intervention in PREMIER was 6 months, whereas it was shorter in the other trials: 30 days in DASH and 9 weeks in DEW-IT.²⁵ Similarly, the BP reductions in TOHP I were small at 18 months.²⁰ This may be due to difficulty in maintaining lifestyle changes over a prolonged period.

Increased K⁺ intake

INTERSALT showed a negative association between 24-h K⁺ excretion and systolic BP, which after adjustment for age, gender, body mass index, alcohol consumption, and Na⁺ excretion was statistically significant in only 3 of 52 centers.¹⁰ However, less than 10% of participants were Black and stratification by race was not undertaken.¹⁰ Previous studies demonstrated that K⁺ intake may have an important role in salt-sensitive hypertension particularly in Blacks.^{26,27} Salt loading increased mean arterial BP by 6.8 mm Hg in Black versus 1.9 mm Hg in White participants given a low K⁺ diet. This effect was attenuated when K⁺ intake was increased.²⁷ This and other studies implicated the importance of well-representing African-Americans in trials of K⁺-intake manipulation, especially as this racial group not only is at higher risk for hypertension and its clinical consequences^{28–32} but also has lower dietary K⁺ intake than Whites, as reported in NHANES III.²⁹

One potential mechanism explaining these racial differences could be overexpression of long WNK1 (with no lysine kinase 1). A deletion in the first intron of the WNK1 gene increases expression of the long isoform and causes familial hyperkalemic hypertension, featured by hypertension and hyperkalemia.^{33–35} Long WNK1 stimulates Na⁺ reabsorption via the epithelial Na⁺ channel, leads to activation of the thiazide-sensitive Na⁺-Cl⁻ cotransporter by inhibiting WNK4,^{36–38} and inhibits K⁺ secretion via the apical K⁺ channel (ROMK).³³ Kidney-specific WNK1, a truncated form expressed only in kidney, antagonizes both long WNK1 effects, and, therefore, may decrease Na⁺ retention and increase K⁺ excretion. Dietary K⁺ restriction in rats increased whole-kidney long WNK1 mRNA levels while decreasing that of kidney-specific WNK1, and a high K⁺ diet resulted in the opposite.³⁹ Lower dietary K⁺ intake in African-Americans may increase the ratio of long WNK1: kidney-specific WNK1 in kidney, resulting in reduced renal K⁺ secretion to conserve K⁺, at the expense of increasing

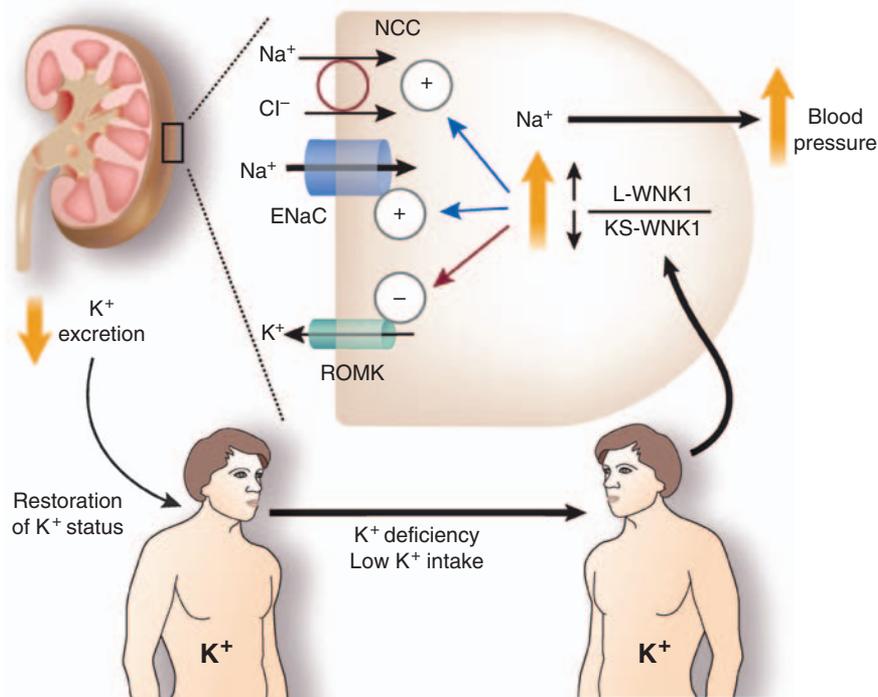


Figure 1 | Illustration of a model of sodium (Na⁺) retention causing hypertension in a state of dietary potassium (K⁺) deficiency, mediated by WNK1. During K⁺ depletion, to maintain K⁺ levels, ROMK is downregulated (by endocytosis of ROMK). This downregulation is mediated by an increase in the ratio of L-WNK1 to KS-WNK1 in the kidney, which decreases renal K⁺ secretion to conserve K⁺, but also enhances renal Na⁺ reabsorption via ENaC and NCC, resulting in Na⁺ retention and hypertension. Adapted from Huang *et al.*³³ Cl⁻, chloride; ENaC, epithelial sodium channel; Na⁺, sodium; NCC, Na⁺/Cl⁻ cotransporter; ROMK, renal outer medullary potassium channel; WNK1, with no lysine kinase 1; KS-WNK1, kidney-specific WNK1; L-WNK1, long WNK1.

renal Na⁺ reabsorption and leading to salt retention and hypertension (Figure 1).³³

Clinical trials reported conflicting data about beneficial effects of increased K⁺ intake on BP,^{26,40-69} and evidence generally supports a positive effect in the short-term that is not sustained long-term. Heterogeneity of results may also be because of low representation of African-Americans and decreased efficacy of K⁺ intake in lowering BP when accompanied by low Na⁺ intake.⁶⁹ In a meta-analysis of 33 randomized controlled trials ($N=2609$), K⁺ supplementation was associated with a significant BP reduction of 3.1/2.0 mm Hg.⁷⁰ Treatment effects appear to be enhanced in trials where participants were concurrently exposed to a high Na⁺ intake or were hypertensive.^{70,71} K⁺ supplementation caused a modest 1.18 mm Hg reduction in diastolic BP at 3 months in the TOHP I Trial that was not significant at 6 months.⁶⁸ Finally, 96 mmol of KCl versus placebo did not reduce the need for antihypertensive medications in a 2-year trial of 287 hypertensive and predominantly White males.⁶⁹ Although long-term data to confirm the efficacy of K⁺ supplementation for BP lowering is not conclusive, it is possible that the effect of K⁺ intake on BP is small and not detected easily by clinical trials, but becomes clinically relevant from a population-based perspective, as observed in epidemiological studies such as INTERSALT.⁶⁹

Data are conflicting regarding the effects of KCl versus K⁺ alkali (bicarbonate or citrate) and vary from showing no

effect on BP of either KCl or K⁺ alkali,^{72,73} equivalent BP-lowering effects,⁷⁴⁻⁷⁷ to K⁺ alkali having a substantially stronger effect than KCl.⁷⁸ It is difficult to draw conclusions from these studies, given the possible confounding from variability of dosage and treatment durations, racial differences, and other dietary factors, such as Na⁺ and magnesium.

Increased magnesium intake

Epidemiological studies show an inverse relationship between dietary magnesium intake and hypertension prevalence despite limitations such as use of dietary questionnaires as measures of intake. In the Nurses' Health Study, the relative risk of hypertension for a magnesium intake >300 mg/day compared with an intake <200 mg/day was 0.78.⁷⁹ The Honolulu Heart Study reported that of 61 nutritional substances studied, magnesium intake had the strongest inverse association with BP.⁸⁰

Despite compelling epidemiological data, results of clinical trials are conflicting. Some studies show significant reductions in BP,⁸¹⁻⁸³ whereas others do not.⁸⁴⁻⁸⁶ A recent trial in hypertensives reported a statistically significant decline in office, home, and ambulatory BP after 8 weeks of 480 mg magnesium/day in the form of magnesium oxide.⁸⁷ Lind *et al.*⁸⁶ did not detect an effect of magnesium supplementation overall, but BP was lowered in a subgroup of patients with magnesium deficiency (low urinary magnesium

excretion). Dyckner and Wester⁸¹ reported that magnesium supplementation reduced BP by 12/8 mm Hg in patients on long-term diuretics, a subgroup of patients more likely to be magnesium depleted.

The discrepancies may be the result of small sample sizes, differing preparations and concentrations of magnesium, and heterogeneity of samples. Trials that showed no effect used smaller doses of magnesium, 10–15 mmol/day compared with ≥ 20 mmol/day in studies that demonstrated BP lowering.⁸⁸ Subgroups that demonstrated BP lowering included African-Americans and those on diuretics.

Increased calcium intake

Analysis of the Korean National Health and Nutrition Examination Survey III showed that calcium supplementation was inversely associated with diastolic BP.⁸⁹ In a meta-analysis, Mierlo *et al.*^{90,91} reported BP-lowering effect of calcium supplementation, although some studies had negative results. A Cochrane systematic review of 13 trials that included > 15,000 women reported calcium supplementation decreased risk of developing hypertension during pregnancy by 35%.⁹² However, a large double-blind placebo-controlled trial of 6 months duration, TOHP I, failed to show a BP-lowering effect with 1g/day of calcium supplementation.²⁰

Effects of exercise independent of weight loss

There is data suggesting exercise can lower BP independently of weight loss. Many of studies used conventional BP measurements, but studies using ambulatory-BP monitoring have more conflicting results. Interestingly, people who adhere to home-BP monitoring are more compliant with exercise programs.⁹³ It is believed that sedentary individuals experience an exaggerated increase in BP during physical activity, and some data suggest that aerobic exercise normalizes such an exaggerated response and lowers BP in these individuals.⁹⁴

In a meta-analysis of 54 randomized controlled trials ($N=2419$) whose intervention and control groups differed only in aerobic exercise, aerobic exercise was associated with a statistically significant reduction in BP of 3.8/2.6 mm Hg.⁹⁵ The reduction in BP was similar in normotensive versus hypertensive participants. Importantly, mean BP reduction was not associated with changes in body weight, and BP was reduced in participants that did not lose weight.

Another meta-analysis of 11 exercise trials ($N=320$) of both normotensives and hypertensives that included a randomized non-exercise control group, progressive resistance exercise as the only intervention, and duration of at least 4 weeks reported a BP reduction of $3 \pm 3/3 \pm 2$ mm Hg.^{96–107} In a recent study of 118 prehypertensives, those with endothelial nitric oxide synthase gene polymorphism had about 20% increase in NO and 10% decrease in BP in response to aerobic exercise.¹⁰⁸

In contrast to the above data, the effect of exercise on ambulatory-BP monitoring is not consistent. Some studies showed that low-intensity aerobic exercise for 6–12 months

reduced BP (mostly diastolic) by about 5 mm Hg,^{109–111} whereas other studies did not.¹¹² In a review of 23 studies that examined the effect of dynamic exercise on ambulatory-BP monitoring, there was an average decrease in 24-h systolic BP by 3.2 and diastolic BP by 1.8 mm Hg.¹¹³

Moderation in alcohol intake

Consumption of alcohol was associated with increased BP in observational studies.^{10,114,115} Abramson *et al.*¹¹⁴ showed that binge drinking and habitual alcohol consumption are associated with higher mean ambulatory BP in normotensive adults.¹¹⁴ Similarly, a Japanese study of 539 participants showed that alcohol intake was independently associated with an increase in morning BP.¹¹⁵

Clinical trials investigating the effects of alcohol reduction on BP were limited by small samples, short duration, and inconsistent findings.^{116–130} A meta-analysis of 15 randomized controlled trials ($N=2234$) in which alcohol reduction was the only intervention reported a significant decrease in BP of 3.3/2.0 mm Hg and a dose-response relationship between alcohol reduction and BP.¹³¹ Median length of trials was 8 weeks. Seven trials included behavioral interventions, and 8 used low-alcohol beer substitute. Effects were more pronounced in those with higher baseline BP.

On the other hand, the Prevention and Treatment of Hypertension Study that randomized 641 male veterans to a cognitive-behavioral alcohol reduction intervention or a control group failed to show a statistically significant difference at 6 months.¹³⁰ Lack of efficacy in this trial could include lower alcohol reduction intervention effect and longer duration of observation. In addition, a net weight reduction seen in some of the other alcohol intervention trials could have confounded the BP reduction observed.

CONCLUSIONS

There is sufficient data to suggest that certain lifestyle modifications, such as weight loss and Na^+ intake reduction, are efficacious in lowering BP, reducing progression of prehypertension to hypertension, and perhaps diminishing long-term risk of CV events^{2,9,132,133} (Table 3). However, the effectiveness of such lifestyle modifications needs to be further established in population-based studies, as implementation of healthier lifestyles is challenging. For example, in both the DASH and the TOHP trials, the greatest BP-lowering effect was seen when Na^+ intake was reduced to very low levels (33–50 mmol/day), a goal that is difficult to achieve.¹³² One barrier is the affordability of a diet rich in fruits-and-vegetables and low in Na^+ , especially for racial groups where such dietary modifications ironically had the greatest impact on BP. In addition, reduction of discretionary salt may contribute little to moderation of total Na^+ intake, as in one study 77% of total Na^+ intake was derived from processing added salt, and cooking and table salt contributed only 11.3%.¹³⁴ Additional motivation would be needed in those with prehypertension who do not have to face the alternative of taking medications.²⁰ Long-term lifestyle

Table 3 | Lifestyle modifications to manage prehypertension and hypertension

Modification	JNC 7 recommendations ²	AHA recommendations ¹³³	Systolic BP reduction
Reduce weight	Maintain normal weight (BMI 18.5–24.9 kg/m ²)	Attain BMI < 25 kg/m ²	5–20 mm Hg/10 kg weight loss
Eat DASH diet	Rich in fruits, vegetables, low-fat dairy, reduced saturated and total fat	Same recommendation	8–14 mm Hg
Reduce dietary sodium	≤100 mmol/day (2.4 g Na ⁺ or 6 g NaCl)	Ideally 65 mmol/day (1.5 g Na ⁺ or 3.8 g NaCl)	2–8 mm Hg
Increase physical activity	Regular aerobic exercise 30 min/day, most days of week	None given	4–9 mm Hg
Moderate alcohol intake	Limit to ≤2 drinks ^a /day for men, ≤1 drink/day for women and those with lighter weight	Same recommendation	2–4 mm Hg
Increase potassium intake	None given	120 mmol/day (4.7 g/day) (Also provided in DASH diet)	Variable

Abbreviations: AHA, American Heart Association; BMI, body mass index; BP, blood pressure; DASH, Dietary Approaches to Stop Hypertension; JNC 7, the Seventh Report of the Joint National Committee on Prevention, Detection and Evaluation of High Blood Pressure.

^aOne drink is equivalent to 12 oz of beer, 5 oz of wine, or 1.5 oz of 80-proof liquor, each representing on an average 14 g of ethanol.

interventions are difficult to maintain, and simultaneous interventions using two or more lifestyle changes, such as weight loss and Na⁺ reduction, may have little effect over and above interventions designed to modify one aspect. However, modification of combination of dietary nutrients, such as DASH versus single nutrients met with greater success. The future challenge is developing and implementing effective public health strategies that lead to sustained lifestyle modification.¹³² New strategies could include an excise tax on the food industry to decrease Na⁺ content. Such a tax to decrease Na⁺ intake by 6% could save \$22.4 billion in medical costs.¹³⁵

Na⁺ retention is a major player in hypertension in chronic kidney disease patients,¹³⁶ although such patients are generally excluded from trials of non-pharmacological interventions. The DASH diet has higher K⁺, phosphorus, and protein content than what is generally recommended for patients with moderate-to-advanced chronic kidney disease and may not be ideal. Studies suggested that low-protein diets may slow chronic kidney disease progression.¹³⁷ Randomized trials of chronic kidney disease samples are needed to determine ideal diet and lifestyle modifications for BP lowering in this population.

DISCLOSURE

All the authors declared no competing interests.

ACKNOWLEDGMENTS

This work was supported by a pilot grant from the University of Texas Southwestern Medical Center O'Brien Kidney Research Core Center (P30DK079328) awarded to SSH. We acknowledge Chou-Long Huang and Orson Moe, both Professors of Medicine in the Division of Nephrology at University of Texas Southwestern Medical Center, for their review of this manuscript as well as contributions to Figure 1.

DISCLAIMER

The views expressed here are those of the authors and do not necessarily represent the views of the Department of Veterans Affairs.

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