Dietary Approaches to Prevent Hypertension

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Abstract

Elevated blood pressure arises from a combination of environmental and genetic factors and the interactions of these factors. A substantial body of evidence from animal studies, epidemiologic studies, meta-analyses, and randomized controlled trials has demonstrated that certain dietary patterns and individual dietary elements play a prominent role in the development of hypertension. Changes in diet can lower blood pressure, prevent the development of hypertension, and reduce the risk of hypertension-related complications. Dietary strategies for the prevention of hypertension include reducing sodium intake, limiting alcohol consumption, increasing potassium intake, and adopting an overall dietary pattern such as the DASH (Dietary Approaches to Stop Hypertension) diet or a Mediterranean diet. In order to reduce the burden of blood pressure-related complications, efforts that focus on environmental and individual behavioral changes that encourage and promote healthier food choices are warranted.

Keywords

Hypertension; High blood pressure; Prevention; Diet; Fruits and vegetables; Dietary patterns; Macronutrients; Micronutrients; Sodium; Potassium; Magnesium; Calcium; Alcohol; Fiber; Functional foods

Introduction

Hypertension exerts a staggering worldwide burden on human quality of life and health care system resources via contribution to increased mortality and risk of cardiovascular diseases such as myocardial infarction, angina pectoris, heart failure, and stroke [1, 2]. In the US, hypertension is the most common primary diagnosis with 35 million outpatient office visits annually [3]. Based on data from 2007 to 2010, over $50 billion is spent in treating one of every three adults 20 years of age or older in the US who have hypertension and costs continues to rise [1, 2]. Among the estimated 78 million US adults with hypertension, 82 % are aware of their condition, and 75 % of those diagnosed with hypertension are managed with antihypertensive medications [1]. Unfortunately, successful reductions to recommended blood pressure goals are obtained in only 53 % of those with documented hypertension [4].

Even a small downward shift in the distribution of blood pressure in the general population could have a substantial impact on the risk of cardiovascular disease. A 2- mmHg reduction in the population average of diastolic blood pressure could be expected to result in a 17 % reduction in the prevalence of hypertension, a 6 % reduction in the risk of coronary heart disease, and a 15 % reduction in the risk of stroke [5].

Dietary modifications have been widely regarded as a lifestyle modification strategy with enormous potential for preventing hypertension at a cost that is often less than current pharmacologic interventions. Such successful historical interventions are reflected in dietary recommendations advocating weight loss, reduced intake of dietary sodium, and moderation in alcohol consumption, and more recently revised to reflect the blood-pressure lowering effect of potassium supplementation and a dietary eating pattern [4]. This article reviews the consistency of blood pressure results regarding proven dietary interventions as well as several new dietary targets.

Dietary Patterns

DASH Diet

One of the most well-known dietary strategies for lowering blood pressure is the Dietary Approaches to Stop Hypertension (DASH) pattern [6], which significantly reduced blood pressure among normotensives as well as those with hypertension [7]. The DASH dietary pattern, which emphasizes a diet rich in fruits, vegetables, and low-fat dairy products and reduced saturated and total fat, has been tested in multiple randomized controlled trials in specific populations including obese hypertensives [8] and individuals with type 2 diabetes [9], both alone and in combination with other lifestyle interventions [10], with consistent results. The Optimal Macro-Nutrient Intake to Prevent Heart Disease (OmniHeart) trial

demonstrated that within a DASH-like dietary pattern, substituting protein for carbohydrate or substituting fat (primarily monounsaturated) for carbohydrate additionally lowered blood pressure [11].

Mediterranean Diet

The Mediterranean dietary pattern has many similarities with the DASH dietary pattern but is generally higher in fat, primarily monounsaturated fat from olive oil, nuts, and seeds (commonly close to 40 % of daily energy). The Prevención con Dieta Mediterránea (PREDIMED) Study examined the effects of a Mediterranean dietary pattern with extra-virgin olive oil or nuts as compared to a low fat dietary pattern on cardiovascular disease [12, 13] and blood pressure [14] among 772 men and women aged 55–80 years. Compared with the low-fat diet, the mean net changes in the Mediterranean diet with olive oil group and the Mediterranean diet with nuts group were −5.9 mmHg (CI, −8.7 to −3.1 mmHg) and −7.1 mmHg (CI, −10.0 to −4.1 mmHg), respectively, for systolic blood pressure [14]. A recent Cochrane systematic review of Mediterranean dietary patterns and cardiovascular risk factors included five trials reporting blood pressure [15•]. However, significant heterogeneity between trials precluded the pooling of results in this review. Significant reductions in blood pressure were present among three of five trials for both systolic and diastolic blood pressure. While the evidence is limited, taken as a whole, it is suggestive of a blood-pressure-lowering effect of Mediterranean style dietary patterns.

Macronutrients

Manipulations of macronutrients, including protein, fat, and carbohydrates, have been a cornerstone of strategies for weight loss and improving the cholesterol profile for many years. The evidence that particular macronutrients are also effective in reducing blood pressure is quite strong [16–18]. The largest body of evidence for any macronutrients' influence on blood pressure is that regarding protein.

Protein

A variety of studies, both observational and randomized controlled trials, have demonstrated that protein supplementation or the replacement of protein for fat or carbohydrate in an isocaloric diet results in lower blood pressures [19, 20, 21••, 22]. Observational studies have shown a strong and consistent inverse relationship between dietary protein and blood pressure [19, 20, 23–26]. In 2010, a systematic review of dietary protein and blood pressure identified 26 observational studies that examined the relationship using dietary assessment methods and/ or biomarkers of protein intake [19]. Cross-sectional studies that assessed protein intake via dietary questionnaires or interviews tended to show a weak inverse association, whereas the majority of prospective studies identified no association. Among observational studies that included a biomarker of protein intake, including the large INTERSALTand INTERMAP studies, there was a stronger and more consistent inverse association with blood pressure [19, 25–27].

Since the publication of the OmniHeart study, which showed a decrease in both systolic and diastolic blood pressure when protein was substituted for dietary carbohydrate [11],

additional large randomized controlled trials of protein supplementation have been published [28••, 29•], which strongly support the inverse relationship between dietary protein and blood pressure. In a 4-week parallel-group randomized clinical trial on the effects of protein supplementation on blood pressure, 60 g/ day of protein (30 % egg protein, 30 % milk protein, 20 % soy protein, 20 % pea protein) reduced systolic blood pressure by 4.9 mmHg (p =0.005) and diastolic blood pressure by 2.7 mmHg (p =0.05), as compared to 60 g/day of maltodextrin, among 99 overweight men and women with pre-hypertension or untreated stage I hypertension [29•]. In the Protein and Blood Pressure Study, a randomized, double-blind crossover trial among 352 adults with pre-hypertension or stage I hypertension, participants were assigned to consume 40 g/day soy protein supplement, milk protein supplement, or carbohydrate supplement for 8 weeks in a random order with 3-week wash-out periods in between [28••]. Soy and milk protein supplementation reduced systolic blood pressure by 2.0 mmHg (p =0.002) and 2.3 mmHg (p =0.0007), respectively. Diastolic blood pressure was also reduced, but not statistically significantly, and there were no differences in blood pressure reductions according to the type of protein supplement.

These well-controlled short-term trials have demonstrated a consistent effect of protein supplementation on blood pressure, but longer-term data from randomized controlled trials are sparse. A 2-year double-blind, placebo-controlled, parallel-design trial investigating the effects on blood pressure of whey protein supplementation as compared to carbohydrate in 219 women between 70 and 80 years of age was conducted by Hodgson and colleagues [30]. Relative to control, the estimated mean net differences in protein and carbohydrate intakes were 18 and −22 g/day at year 1 and 22 and −18 g/day at year 2. No significant differences in blood pressure between groups were found. Unfortunately, this trial is not closely comparable to the recent short-term trials because the dose of protein supplementation (and carbohydrate control) was much lower, on average 20 g/day as compared to 40 or 60 g/ day; more than half of participants were taking antihypertensive medications concomitantly; and the population demographics were quite different (70–80-year-old women only in the latter study).

Several recent meta-analyses and systematic reviews of randomized controlled trials have also supported a blood pressure-lowering effect of dietary protein intake, reaching similar conclusions [19, 21••, 22, 29•]. Increased protein intake significantly reduced blood pressure compared to carbohydrates, but there was no significant difference in blood pressure reduction between animal and vegetable protein sources.

The exact mechanisms relating dietary protein intake to blood pressure remain unclear, although several have been proposed [29•, 31, 32]. Increases in dietary protein intake may impact plasma amino acid concentrations, which in turn may affect blood pressure regulation [32]. For instance, cysteine, glutamate, arginine, leucine, taurine, and tryptophan have all been suggested to have blood pressure-lowering effects through their influence on processes and metabolites including insulin resistance, advanced glycation end products, oxidative stress, renal function, nitric oxide bioavailability, and the renin-angiotensin aldosterone system [32]. L-arginine in particular has been implicated in blood pressure lowering as a substrate of nitric oxide synthase, and evidence from supplementation trials suggests a potential role for this amino acid [33]. Despite the lack of a clear mechanism,

clinical trials have shown consistent evidence of the safety and efficacy of dietary protein supplementation such that health care providers should consider advising their patients with pre-hypertension or untreated stage I hypertension to replace carbohydrates with protein as part of a dietary strategy to prevent and treat hypertension.

Fats

Given the long history of the diet-heart hypothesis, dietary fats have also been a focus of investigation in the area of hypertension and blood pressure [34]. Total dietary fat intake includes intakes of saturated, omega-3 polyunsaturated, omega-6 poly-unsaturated, and monounsaturated fatty acids. There has been great interest in the possible effects of monounsaturated fats and omega-3 polyunsaturated fatty acids in regulating blood pressure [35, 36]. The OmniHeart trial demonstrated that partial replacement of carbohydrate with dietary fat (37 % of daily energy from total fat with 21 % from monounsaturated fat), primarily olive and canola oils, reduced systolic blood pressure by 2.9 mmHg [11]. A recent meta-analysis examining the effect of monounsaturated fats on blood pressure included nine randomized controlled trials of high monounsaturated fat diets and concluded that systolic (pooled mean net change: −2.26 mmHg, 95 % CI: −4.28, −0.25) and diastolic (pooled mean net change: −1.15 mmHg, 95 % CI: −1.96, −0.34) blood pressure reductions were significantly greater among participants assigned to these diets than for those assigned to control diets [36]. The evidence of the effects of omega-3 fats from fish oils on blood pressure is also generally consistent with at least five meta-analyses finding statistically significant reductions in blood pressure [37–39, 40•, 41]. The most recent of these analyses focused exclusively on fish oil supplementation and included 17 randomized controlled trials, with a total of 1,524 participants. The authors found a statistically significant reduction in systolic and diastolic blood pressure (−2.56 mmHg and −1.47 mmHg, respectively) among the eight trials including hypertensive participants, but a nonsignificant reduction in both systolic and diastolic blood pressure among the nine studies that included normotensive participants [40•]. Two meta-analyses that focused exclusively on the effect of fish oil supplementation on blood pressure in patients with type 2 diabetes had inconsistent findings [42, 43].

Micronutrients

Sodium

Sodium is ubiquitous among most foods and beverages. Therefore, the amount of sodium intake among a population is primarily dictated by a complex interaction of cultural context and dietary habits [44]. Sodium is a main chemical component in common table salt, but only 11 % of sodium intake in the US is attributable to salt added during cooking or at the table [45]. In contrast, the majority comes from processed foods. The average self-reported daily sodium intake for Americans aged 2 years and older is 3.6 g (equivalent to approximately 9.4 g salt/day as sodium chloride) [46, 47]. These levels are in excess of the 2 g/day (equivalent to 5 g/day of salt) recommended by World Health Organization (WHO) or 2.3 g/day recommended by the Institute of Medicine (IOM) as a tolerable upper intake level [48, 49].

To improve blood pressure control, the American Society of Hypertension (ASH) and the 2010 Dietary Guidelines for Americans recommended reducing sodium intake to a goal of <2,300 mg/day in the general population and a lower goal of <1,500 mg/day for populations predisposed to salt sensitivity: African Americans, middle- and older-aged persons, and individuals with hypertension, diabetes, or chronic kidney disease [50, 51]. However, there is significant difficulty in achieving these dietary sodium reductions. Furthermore, there is an unequal probability of adherence to reducing dietary sodium with respect to sex and race suggested by studies using sodium excretion as an index of sodium intakes [52]. This leads many to entertain the strategy by which sodium reduction may be accomplished. With the predominance of dietary sodium derived from processed foods, organizations such as the American Heart Association (AHA), American Medical Association (AMA), American Public Health Association (APHA), and IOM advocate government-sponsored requirements for food producers to reduce salt content incrementally over 5–10 years [53, 54]. Those advocating such interventions note existing programs in Finland, the UK, Ireland, Australia, and New Zealand [45]. The benefits of overcoming the difficulties to reduce sodium intake are compelled by predicted reduction of mortality and morbidity as well as significant savings in health care costs similar to those observed in Canada and Norway [55].

The evidence that dietary sodium and blood pressure are positively linked is strong and consistent and includes results from a large number of randomized controlled trials. The well-known DASH and DASH-Sodium trials demonstrated the effects of a DASH diet as compared to a typical American diet at 3.6 g/day, 2.3 g/day, and 1.2 g/day of sodium, with progressively lower blood pressure results [56, 57]. A recent meta-analysis of 37 randomized controlled trials also demonstrates the strong and consistent relationship that has been observed between dietary sodium and blood pressure [44].

Some lines of evidence have also suggested targeting sodium reduction to <1.5 g/day among those who may be particularly sensitive to sodium [56, 58, 59]. In contrast, the recent IOM Report, *Sodium Intake in Populations: Assessment of Evidence*, commissioned by the Centers for Disease Control and Prevention (CDC) to review evidence from recent studies examining the effects of sodium on clinical events rather than blood pressure as a surrogate endpoint, concluded that there was insufficient evidence of benefit and some evidence suggesting risk of adverse outcomes associated with sodium intake <2.3 g/day [48]. This report indicated that studies with clinical events as the outcome were too few and of inconsistent quality to conclude that lowering sodium intake to <2.3 g/day either increased or decreased the risk of heart disease, stroke, or all-cause mortality in the general US population, and it suggested a higher risk of adverse health outcomes among those with mid- to late-stage heart failure receiving aggressive medical treatment. Consistent with these conclusions, a meta-analysis of short-term studies found that, on average, 2-weeks of dietary sodium restriction to <1.5 g/day increased renin, aldosterone, catecholamines, and lipids [60]. In opposition to the conclusions of the IOM report, the AHA issued its *2012 Presidential Advisory, Sodium, Blood Pressure, and Cardiovascular Disease: Further Evidence Supporting the American Heart Association Sodium Reduction Recommendations*, suggesting that recommendations for sodium reduction to 1.5 g/day in specific populations should persist based on evidence of improved blood pressure reduction [61].

Potassium

Introduction of the DASH diet saw greater blood pressure effects at higher than lower sodium intakes, raising the question of whether increased potassium intake could be responsible for such findings [56]. Indeed, potassium supplementation reduces blood pressure substantially in hypertensive patients with salt-rich diets [62]. ASH and IOM recommend daily potassium intake of 4.7 g as a dietary approach to lowering blood pressure [48, 50]. Unfortunately, the prevailing Western dietary pattern is dominated by prepared foods high in sodium and drastically less in potassium-rich fruits and vegetables, diametrically opposite of the recommendations [63].

Despite these realities, a well-established body of evidence demonstrates that a variety of potassium intake goals reduces blood pressure. Based on estimates from the INTERSALT study, a 0.6 g/day increase in potassium intake results in a 1.0 mmHg reduction in systolic blood pressure and is consistent with the daily potassium supplementation of 51 mmol (nearly 2 g) resulting in a 3.3 and 2.1 mmHg reduction of systolic and diastolic blood pressure, respectively [58, 64].

Blood pressure responses to dietary potassium interventions have been examined in a variety of populations. The largest controlled feeding study of potassium supplementation effects on blood pressure was conducted among Chinese adults [65] and demonstrated a significant reduction in blood pressures that was reproducible after an average of 4.5 years [64]. Variations in baseline blood pressure appear to influence responses to potassium supplementation. Increased potassium intake reduces blood pressure in hypertensives more than nonhypertensives [58, 66]. Some studies have also suggested that blood pressure in African Americans may be particularly affected by potassium intake or lack thereof. African Americans have higher blood pressure at lesser degrees of potassium-deficiency and show greater blood pressure lowering when potassium is replete, particularly in the context of high salt intake [67]. In a cross-sectional study of 3,303 participants, blood pressure was higher in African Americans than non-African Americans for any given value of urinary sodium to potassium ratio, and men had larger increases in diastolic blood pressure per 3-unit increase in the urinary sodium-to-potassium ratio than women [68].

Many explanations have been offered to elucidate the blood pressure-lowering effect of increased dietary potassium including decreased vascular smooth muscle contraction by either by altering the membrane potential [69] or restoring endothelium-dependent vasorelaxation [70]. On the other hand, failure of the kidney to adapt to a diet lower in potassium has been linked to dysregulated sodium retention and development of hypertension [63]. Intrarenal ion abundance and hormone activity have been identified as potential mediators of potassium effects. Potassium-mediated blood pressure reductions have implicated ROMK in a uninephrectomized salt-sensitive animal model of hypertension [71] and in human AQP2, sodium-hydrogen exchanger type 3 [72], and sodium chloride cotransporter [73], causing a thiazide-like effect [74]. Potassium regulation of ion channel activity is heavily influenced by hormonal systems with the renin-angiotensin-aldosterone system chief among them [75]. Additionally, genetic variations in the renin-angiotensin-aldosterone system play an important role in determining individual blood pressure responses to dietary potassium intake [76].

Magnesium

Magnesium is the second most abundant intracellular cation in humans, and dietary repletion is generally facilitated by small intestinal absorption [77]. Repletion is favored by the wide availability of foods high in magnesium concentrations, including leafy vegetables, nuts, whole grains, fruits, and legumes [78]. As the typical Western diet is deficient in these magnesium-rich foods, low-concentration dietary magnesium supplementation can be accomplished with multivitamin injections, over the counter laxatives, or a number of oral magnesium preparations, of which magnesium gluconate has the greatest bioavailability [79].

Magnesium as a potential dietary antihypertensive has been investigated in numerous studies; however, many studies have failed to find an effect of magnesium on blood pressure. In a prospective evaluation of 41,541 women of the Nurse's Health Study, magnesium intake >0.35 g/day showed blood pressure reductions of −1.3/−1 mmHg compared with intake <0.2 g/day [80]. Even more encouraging are the results of magnesium supplements decreasing systolic and diastolic blood pressure 3 to 4 mmHg and 2 to 3 mmHg, respectively, with greater dose-dependent effects at supplementations >370 mg/day [79, 81, 82].

There is an emerging recognition of magnesium as a potential adjuvant for other nutrients currently recognized for their antihypertensive effect, namely potassium. When compared to persons using regular table salt as a seasoning, ingestion of a "Smart Salt," composed of 50 % sodium chloride, 25 % potassium chloride, and 25 % magnesium ammonium potassium chloride, led to significantly lower blood pressure over 8 weeks [83].

Other Dietary Factors

Alcohol

It is well established that excessive alcohol consumption is associated with elevated blood pressure and the development of hypertension [50, 84]. In a 2001 meta-analysis of 15 randomized controlled trials of alcohol reduction interventions, Xin et al. reported a dose-response relationship between alcohol reduction and blood pressure reduction. An average 67 % reduction in alcohol consumption resulted in significant reductions in mean systolic and diastolic blood pressures of 3.3 and 2.0 mmHg, respectively [85]. In a recent analysis of the 1999–2004 National Health and Nutrition Examination Survey that included adults aged 20–84 years who were free of cardiovascular disease and hypertension, alcohol consumption above recommended guidelines (more than 2 drinks per day in men and 1 drink per day in women) [50, 51] was associated with higher systolic blood pressure in both men and women [86•].

The association between blood pressure and low to moderate levels of alcohol consumption is less clear. Observational cohort and cross-sectional studies have reported linear, J-shaped, or a threshold association between alcohol consumption and blood pressure [87–89]. Furthermore, the relationship between alcohol consumption and blood pressure may vary by gender, race/ethnicity, or presence of comorbidities [89, 90•, 91, 92]; thus, the recommendations may not be appropriate for all subgroups of the population. Sesso and

colleagues prospectively followed 28,848 women from the Women's Health Study and 13,455 men from the Physicians' Health Study who were free of cardiovascular disease and hypertension and found that low to moderate alcohol consumption decreased the risk of hypertension in women and increased the risk in men [92]. Alcohol consumption of four or more drinks/day in women was associated with hypertension, while consumption of just one or more drinks/day in men was associated with hypertension risk [92]. The Atherosclerosis Risk in Communities (ARIC) study demonstrated that moderate alcohol consumption among blacks but not whites was associated with increased risk of hypertension [89]. In the Reasons for Geographic and Racial Differences in Stroke (REGARDS) study, a national cohort of blacks and whites, heavy alcohol consumption was significantly associated with increased systolic blood pressure and a higher prevalence of hypertension. The association between alcohol consumption and hypertension was stronger among individuals who had diabetes than those without diabetes [90•].

Fiber

Dietary fiber includes soluble and insoluble components of food from plants that are indigestible. US Dietary Guidelines recommend 25–30 g/day of fiber from foods. However, fiber intake in the US and many other Western countries is only half that at 15 g/day [51]. There is strong evidence that dietary fiber reduces cholesterol and potentially reduces the risk of heart disease, but the evidence to support an association with hypertension is insufficient to warrant any recommendations [51, 93, 94].

Fiber intake and blood pressure have been reported to be inversely related [95, 96]. He and colleagues conducted a randomized controlled trial in 110 adults to determine the efficacy of water-soluble fiber intake [97]. Participants were randomly assigned to either a high or low fiber diet for 12 weeks. Although the net change in blood pressure between the two diets was not statistically significant, mean systolic and diastolic blood pressures were significantly reduced by 3.4 and 2.2 mmHg, respectively, in the high fiber group. In a comprehensive meta-analysis of 25 randomized controlled trials conducted in 1,477 individuals, Whelton and colleagues reported that fiber intake caused a modest reduction in diastolic blood pressure (−1.65 mmHg, 95 % CI, −2.70 to −0.61) but had no association with systolic blood pressure [98]. Fiber intake may have a greater effect on blood pressure in individuals with hypertension [96, 98]. In subgroup analyses involving five trials conducted among hypertensives, fiber intake significantly reduced both systolic and diastolic blood pressure by 5.95 and 4.20 mmHg, respectively [98].

Conclusions

Dietary approaches to modify blood pressure should be an important strategy of cardiovascular health promotion. There is extensive literature demonstrating that multiple individual dietary components and several dietary patterns affect blood pressure. The strongest evidence for lowering blood pressure or preventing hypertension through dietary intervention includes adopting a dietary pattern such as the DASH diet or a Mediterranean diet, eating less saturated fat and total fat, getting plenty of potassium, limiting the amount of sodium in the diet, and limiting alcohol consumption. It is likely that other dietary factors,

such as magnesium and fiber, may affect blood pressure, but the current evidence to support their recommendation is unsubstantiated. Additional research that includes population subgroups and explores the role of other nutrient factors, functional foods, and dietary patterns in preventing hypertension is warranted. Despite the proven benefits of a dietary pattern, there are many cultural and societal forces and commercial interests that have an impact on whether people adopt and follow such a diet. Effective clinical and public health interventions that incorporate individual behavior changes that lead to sustained dietary changes and environmental changes that encourage and promote greater access to healthy food choices are needed.

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