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NUTRITION AND HYPERTENSION (T MORI, SECTION EDITOR)

The Effect of Behavioral Changes on the Treatment of Hypertension

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Abstract

Purpose of Review Hypertension is one of the leading causes of preventable premature death.

Recent Findings Strongly advocating for lifestyle changes to improve blood pressure control is of paramount importance in the successful management of hypertension.

Summary In this review, we will discuss the effect of various behavioral and lifestyle changes and review the evidence to support these changes to improve blood pressure control. These include dietary modifications, alcohol consumption, weight loss, various types of exercise, device-guided breathing, relaxation, and biofeedback techniques.

Introduction

Hypertension is one of the leading causes of preventable premature death affecting over 1.4 billion people worldwide [1]. Recent guideline recommendations redefined the threshold at which hypertension is diagnosed and data from the National Health and Nutrition Examination Surveys (NHANES) from 2017–2018 shows that with the new guidelines, the prevalence of hypertension has increased from 30.7 to 45.4% in US adults [2••]. The prevalence of hypertension is also related to the rising rates of obesity as the two are closely interrelated. Obesity is an independent risk factor for developing hypertension and there is a twofold increase in the incidence of hypertension in obesity [3, 4]. Globally, the burden of hypertension is projected to exceed 1.6 billion people by 2025 [5]. Lifestyle and behavioral changes have been found to prevent or delay the onset of hypertension and mitigate cardiovascular risk [6•]. In this review, we will discuss the various lifestyle changes and their effect on blood pressure reduction and these include dietary modifications from low sodium, increased potassium and the DASH diet, alcohol consumption, weight loss and bariatric surgery, and different types of exercise as well as relaxation and biofeedback techniques.

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Low-Sodium Diet

The relationship between dietary sodium intake and hypertension has been well studied and is now widely recognized as an important factor in hypertension but controversy still exists about the utility of sodium reduction in non-hypertensives and how far sodium intake should be reduced. Measuring sodium consumption is difficult and studies that rely on 24 h recall, food records, or food frequency questionnaires have major limitations. The closest estimate of actual sodium intake is reflected in urinary sodium excretion. The gold standard is measuring 24 h urine collection which reflects over 90% of the sodium consumed [7]. Several decades ago, the International Study of Salt and Blood Pressure (INTERSALT) Study evaluated both hypertensive and normotensive individuals and showed a significant and independent positive linear relationship between 24 h sodium excretion and systolic blood pressure. They estimated that an increase of salt intake by 100 mmol/day results in an increase in blood pressure by approximately 3–6/0–3 mmHg [8]. More recently, and in an effort to determine if this association varied according to participant characteristics or region, the Prospective Urban Rural Epidemiology (PURE) study also demonstrated a positive relationship but found it to be nonlinear. Their analyses showed an increase in blood pressure with each incremental increase in sodium intake but the slope of the association was steeper in hypertensives, with increased age and with

higher sodium intake [9•]. The positive association between sodium intake and rise in blood pressure was replicated in a representative US sample by Jackson et al. who used cross-sectional data from the 2014 NHANES survey which included 24 h urine collections. They also demonstrated that people in the highest quartile of sodium intake had four times greater odds of having hypertension than those in the lowest quartile [10••].

Further evidence of the causal relationship between sodium intake and elevated blood pressure has been illustrated by several randomized trials that compared the effect of sodium interventions on blood pressure. In a recent meta-analysis of 133 randomized trials, Huang et al. compared various levels of sodium intake as reflected by 24 h urinary sodium excretion and stratified the studies based on the length of the trial. They showed a dose–response relationship between sodium reduction and the magnitude of blood pressure lowering. This was consistent in both female and male adults, in all ethnic groups, and in both normotensive and hypertensive individuals. The effect was greatest in those who had higher blood pressure and were older and of non-white race. They demonstrated a mean reduction in blood pressure of 4.26/2.07 mmHg [11].

The effect of dietary sodium intake has also been studied in people with resistant hypertension. By using a randomized crossover trial of high- and low-salt diet and measuring both in-office as well as ambulatory blood pressure monitoring (ABPM), patients with resistant hypertension had a mean reduction of 22.7/9.1 mmHg in office and 20.7/9.6 mmHg on ABMP in response to a low-salt diet. The magnitude of reduction in blood pressure in patients with resistant hypertension is greater than previously observed in prior studies. This reinforces how salt sensitive resistant hypertensive patients are and the importance of strongly encouraging a low-sodium diet in their management [12].

Due to the dose-dependent effect of sodium on blood pressure and the well-known relationship between hypertension and cardiovascular disease, models have been established to extrapolate the effect of sodium reduction on cardiovascular disease but they have yielded variable results. The Trials of Hypertension Prevention (TOHP) trial used three different models to assess the effect of sodium reduction on cardiovascular mortality and projected a substantially reduced risk by tens of thousands each year [13••]. However, meta-analyses of randomized controlled trials as well as cohort studies have suggested that both high sodium and low sodium intakes are actually associated with increased cardiovascular mortality [14, 15]. This has sparked much discussion about why different sodium reduction studies have produced varying results. Some explanations include confounding, measurement error, heterogeneity across study populations, or reverse causation [16]. In the meta-analysis mentioned earlier, Huang et al. stratified studies by length and found the studies that showed a limited effect of sodium reduction on blood pressure in normotensive individuals and those that noted adverse effects on markers of cardiovascular risk were in fact short-term studies. They suggested that effects of dietary sodium take weeks to become evident and argued that the benefit of blood pressure lowering outweighs the perceived increased cardiovascular risk as this was not replicated in longer term studies [11].

Current guidelines recommend a daily intake of ≤ 2300 mg of sodium per day [17]. The Institute of Medicine has found inconsistent evidence that lowering sodium intake below 2300 mg/day neither increases nor decreases the risk of cardiovascular disease, stroke, or all-cause mortality. In patients with diabetes, chronic kidney disease, and heart disease, the evidence remains inconclusive whether these patients should adhere to more stringent sodium restriction of less than 1500 mg/day [18]. Of note, current dietary consumption in the USA far exceeds these thresholds. Two-thirds of sodium intake is in food consumed outside the home and only 11% is from salt added at the table or during cooking [19, 20••]. Counseling patients on reducing intake of fast food, reading labels on packaged food, and preparing freshly made food at home will help achieve the dietary threshold recommended.

DASH Diet

In addition to assessing the effect of dietary sodium intake, the Dietary Approaches to Stop Hypertension (DASH) Sodium trial also assessed the effect of a healthier diet on blood pressure. The DASH diet includes increased intake of vegetables, fruits, and whole grains, fat-free or low-fat dairy products, fish, poultry, beans, nuts, and vegetable oils and limits foods that are high in saturated fat. Participants were randomized to DASH or control diets with high (3.3 g/day), medium (2.4 g/day), and low (1.5 g/day) sodium intake for 1 month. The study showed a graded reduction in blood pressure with progressively lower levels of sodium intake, and when compared to the control diet, the DASH diet resulted in significantly lower blood pressure at every sodium level [21••]. In evaluating the effects of various dietary approaches on blood pressure control, a recent systematic review of dietary pattern interventions and meta-analysis of aggregate blood pressure effects found the DASH diet to have the largest net effect with 7.6/4.2 mmHg reduction in blood pressure [22]. Even when modestly adhered to, the DASH diet has been associated with lower all-cause mortality and the higher adherence, the stronger the risk-reducing association [23].

The DASH diet also recommends a diet replete in potassium as evidence has shown that potassium intake is an essential determinant of blood pressure independently of

sodium [8, 21••]. Several observational studies including INTERSALT and PURE have shown a significant inverse association between potassium intake and blood pressure [8, 9•]. Interventional studies have also examined this relationship and there is now high-quality evidence showing that increased potassium intake decreases blood pressure in hypertensive patients [24]. A meta-analysis of randomized controlled trials evaluating the effect of potassium intake on blood pressure in hypertensive patients that were not taking antihypertensive medications found a reduction in blood pressure of 6.8 mmHg/4.6 mmHg with increased potassium intake [25]. Furthermore, several studies have examined the sodium to potassium ratio (Na/K) and have shown that it is a better marker than either sodium or potassium alone in evaluating the relationship between dietary intake and blood pressure [26]. In the INTERSALT trial, blood pressure reduction was greater with Na/K compared with sodium and potassium analyzed separately [8]. The latest NHANES survey that included 24 h urine collection also supported these findings where potassium excretion was inversely associated with blood pressure and the Na/K was directly associated with systolic blood pressure [10••]. Data thus far supports increased potassium intake for blood pressure control in people without impaired renal handling of potassium.

Mediterranean Diet

The Mediterranean diet (MedDiet) has also been evaluated for its effect on reducing blood pressure and cardiovascular risk. This diet centers around fruits, vegetables, nuts, whole grains, vegetable oils, and fish with moderate consumption of poultry and dairy and limited intake of red and processed meats [27]. The largest study to date was the observational European Prospective Investigation into Cancer and Nutrition (EPIC) study that examined over 20,000 normotensive participants and found a significant negative association between the MedDiet and both systolic and diastolic blood pressures [28]. As for intervention studies, the Prevención con Dieta Mediterránea (PREDIMED) study randomized over 7000 participants, 80% of whom had hypertension, to a low-fat controlled diet vs the MedDiet but did not find a significant change in SBP in both groups [29]. More recently, a randomized controlled trial, NU-AGE (New Dietary Strategies Addressing the Specific Needs of Elderly Population for Healthy Aging in Europe), randomized 1294 participants to a MedDiet vs their habitual diet and found a significant reduction in SBP in males but not in females [30]. As for meta-analyses of randomized control trials, two studies have been published to date but have resulted in different conclusions. Nissensohn et al. systemically reviewed RCTs comparing the MedDiet to a low-fat diet and found a reduction of 1.4/0.7 mmHg in those who adhered to the MedDiet for at least a year. They found, however, that the number of studies was small and highly heterogenous which compromised the validity of their pooled estimates [31]. Ndanuko et al. conducted a meta-analysis of 17 RCTs examining the effect of various dietary interventions on blood pressure and found the MedDiet decreased blood pressure by 3 mmHg/2 mmHg. However, only five studies included the MedDiet specifically and two of them did not identify significant effects on blood pressure [32]. The MedDiet is undoubtedly a healthy diet model but further studies are needed to evaluate its effect on blood pressure reduction.

Low-Calorie Diet

Multiple studies have assessed the effect of caloric restriction on blood pressure reduction. Compared to a standard diet, low-calorie diet has been found to reduce both systolic and diastolic blood pressures in males and females, in diabetics and non-diabetics, and in both normal weight and overweight individuals [33]. A recent systematic review and meta-analysis of randomized control trials found that calorie-restricted interventions lasting 1–4 weeks lead to a significant blood pressure reduction of 6/3 mmHg [34•]. The mechanism of blood pressure reduction is in part related to weight loss which will be discussed in further detail below.

In comparing the effects of 13 different dietary interventions on blood pressure reduction including various types of low-calorie diets, low-sodium diet, Mediterranean diet, and others, a systemic review and meta-analysis found that the DASH diet remains the most effective dietary approach to reduce both systolic and diastolic blood pressures with high quality of evidence supporting its use [35].

Alcohol

Several intervention trials and Mendelian randomization studies have established a causal association between alcohol consumption and elevation in blood pressure [36•, 37, 38, 39••]. Studies have also investigated the effect of reduction in alcohol intake and its effect on blood pressure. A meta-analysis of 36 trials including 2865 participants found that reducing alcohol intake has a dose-dependent decrease in blood pressure with an apparent threshold effect. Reducing alcohol consumption in people who drank more than two drinks a day was associated with a mean reduction of 5 mmHg of systolic blood pressure. However, in those who drank two or fewer drinks per day, further reduction in alcohol consumption did not result in significant effect on blood pressure [40•]. Alcohol consumption has also been associated with masked hypertension. A recent prospective study followed normotensive participants for almost 3 years and found an increased relative risk of 1.65 of masked

hypertension in those who consumed six or more drinks per week [41••]. When evaluating patients with hypertension or risk factors for developing incident hypertension, it is important to gather history regarding their alcohol consumption and counseling for reduction should be considered if appropriate. The ACC/AHA guidelines recommend that males should not consume more than 2 alcoholic beverages per day and females should not consume more than 1 per day in an attempt to lower blood pressure [42••].

Weight Loss

Epidemiologic data has shown a linear and direct relationship between obesity and hypertension; as weight increases, blood pressure increases. The inverse has also been shown to be true; weight loss leads to a linear reduction in blood pressure, and with greater weight loss, there is a greater decline in blood pressure. Meta-analyses of randomized controlled trials demonstrated that every 1 kg of weight loss resulted in a decline in 1 mmHg of systolic pressure and significantly larger blood pressure reductions were observed when weight loss exceeded 5 kg [43, 44]. Weight loss after surgical intervention has led to better blood pressure control than lifestyle modifications alone. In a recent trial randomizing patients to bariatric surgery vs lifestyle modification, participants who underwent surgical intervention required 20–30% fewer antihypertensives than their counterparts. The difference is at least in part due to significantly greater weight loss achieved after bariatric surgery (21.8%) compared to lifestyle modification (9.6%) [45]. Another recent trial randomizing participants to Roux-en-Y gastric bypass surgery vs medical management of hypertension found ≥ 30% reduction in antihypertensives needed in the surgical group vs 13% in the medically managed group. Furthermore, they also found that over 50% of participants who underwent surgical intervention had complete remission of hypertension in contrast to none in the medically managed group [46]. As for comparing different types of bariatric surgery and their effect on hypertension, the SLEEVEPASS randomized clinical trial found that Roux-en-Y gastric bypass surgery resulted in improved blood pressure control when compared to sleeve gastrectomy [47]. It is important to note that the rates of hypertension remission after bariatric surgery have been inconsistent across studies as well as rates of perioperative adverse events remain significantly higher compared to non-surgical weight loss [48, 49•].

Exercise

Considerable evidence supports the blood pressure-lowering effect of exercise, but the degree of reduction has varied depending on the type of activity practiced. Numerous randomized control trials have evaluated different exercise modalities including endurance training, dynamic resistance, and isometric resistance exercises. Endurance training otherwise known as aerobic exercise involves repetitive activities that result in substantial increase in heart rate and energy expenditure such as running, swimming, or biking. Resistance training involves exercises that improve strength and may be dynamic (weightlifting, circuit training) or isometric where muscles tense without a visible change in joint position (planks or leg extensions).

In a meta-analysis of 93 randomized controlled clinical trials (RCTs) lasting more than 4 weeks and including over 5000 participants, Cornelissen et al. investigated the effect of these various forms of exercise on blood pressure. Endurance or aerobic exercise significantly decreased blood pressure with an average reduction of 8.3 mmHg/5.2 mmHg in hypertensive individuals. The magnitude of decrease was greater than in pre-hypertensives (4.3 mmHg/1.7 mmHg) and normotensives (0.75 mmHg/1.1 mmHg) [50•]. The effect of aerobic exercise has also been assessed in patients with resistant hypertension. A randomized controlled trial found a reduction in 6/3 mmHg in blood pressure measured by ABPM in patients with resistant hypertension who exercised three times a week for 8 weeks [51].

Dynamic resistance training has been shown by Cornilessen et al. to produce a more modest blood pressure reduction than other forms of exercise of approximately 1.8/3.2 mmHg [50•]. Another meta-analysis specifically evaluating the effect of dynamic resistance training on blood pressure included 64 RCTs and over 2000 participants found similarly modest results. However, a greater blood pressure reduction (5.7 mmHg/5.2 mmHg) was observed among those who had higher resting blood pressure and the most robust reduction (SBP 11.8 mmHg) was seen in those with untreated hypertension performing eight or more exercises per session [52].

Fewer studies have evaluated the effect of isometric exercise on blood pressure reduction but it has recently emerged as an alternative exercise modality for those who are limited in their physical ability to perform conventional endurance or resistance exercises. A recent meta-analysis of 11 RCTs including 300 participants found a reduction in blood pressure of 5.2/3.9 mmHg among participants. A larger reduction was seen (7.2 mmHg SBP) in those who participated in programs for longer than 8 weeks. Of note, only 3 out of the 11 studies totaling 61 participants enrolled hypertensive adults; in those studies, the decrease in blood pressure was 4.5/4.5 mmHg [53]. Further research is needed to evaluate the efficacy of isometric exercise on blood pressure reduction but as it remains a low-risk activity, it should be considered in those who are unable to participate in more rigorous exercise.

Other forms of exercise including yoga and tai chi have also been proposed to have a blood pressure-lowering effect but the available studies to date remain less robust.

The Lifestyle Modification and Blood Pressure Study II (LIMBS II) was a randomized prospective controlled trial that assessed the effects of yoga on ambulatory blood pressure by enrolling participants to a yoga program, a dietary intervention and walking program, or a combination of both. There was a significantly greater reduction in blood pressure at 12 weeks in the yoga and combination group compared to the diet and walking group; however, differences between interventions were no longer significant at 24 weeks which may reflect the difficulty in maintaining these interventions over longer periods of time [54]. Several other randomized controlled trials have assessed the effect of yoga on blood pressure reduction but there are noted issues with data quality and reproducibility. To date, systematic reviews of studies evaluating the effect of yoga on hypertension have reflected poor methodological quality of the conducted trials and insufficient evidence to draw conclusions regarding the efficacy of yoga on lowering blood pressure [55, 56]. Similarly, a recent review of trials examining the effect of tai chi on blood pressure has shown that most studies include a small sample size, lack appropriate randomization, and have yielded heterogenous results [57, 58].

Currently, the ACC/AHA recommends 90–150 min per week of aerobic or dynamic resistance exercises and three sessions per week of isometric resistance exercises to achieve blood pressure reduction [42••]. There is insufficient evidence to promote other types of exercise for treatment of hypertension.

Relaxation and Biofeedback

The use of biofeedback has been applied to the treatment of hypertension but evidence is lacking to support its effectiveness. In biofeedback training, patients are connected to an instrument that monitors their blood pressure and provides feedback when their BP drops to a set threshold. The signal aims to prompt patients to reflect on their thoughts or actions when their blood pressure was low and attempt to repeat the activity to maintain the desired blood pressure. This mechanism was hypothesized to help patients identify the feeling associated with reduction in blood pressure hoping that after training, they can maintain control of their blood pressure. A systemic review of RCTs assessing biofeedback intervention on the treatment of hypertension was conducted and found the majority of trials to be small with inadequate follow-up and yielded heterogenous results that precluded meta-analysis. When comparing biofeedback to pharmacological treatment, placebo, no intervention, or other behavioral therapies, there was no evidence to support its effectiveness on the treatment of hypertension [59].

Table 1 Considerable evidence supporting behavioral changes leading to significant reduction in blood pressure

Lifestyle intervention	Average BP reduction in hypertensives
Low-sodium diet	4.2/2.0 mmHg
DASH diet	7.5/4.2 mmHg
Alcohol consumption < 2 drinks/day	5 mmHg
Weight loss	1 mmHg reduction for every 1 kg lost
Aerobic exercise	8.3/5.2 mmHg
Dynamic resistance	1.8/3.2 mmHg
Isometric resistance	5.2/3.9 mmHg

Device-Guided Breathing

Device-guided breathing (DGB) has emerged as another potential behavioral modification that may aid in blood pressure control but its benefit remains controversial. Slow breathing decreases sympathetic activity and increases vagal tone, thereby reducing heart rate and blood pressure. Acute decrease in blood pressure is thought to augment baroreflex sensitivity and potentially reset the autonomic imbalance in hypertensives [51, 60]. A device that monitors respiratory rate (RR) is attached to a patient and instructs them to reduce their breathing to 10 breaths a minute for 10 min four times a week. A systematic review and meta-analysis of RCTs examining the effect of DGB on hypertension has shown a reduction of 3.1/2.4 mmHg in studies when blood pressure was measured in the office and 2.5/2.2 mmHg when BP was measured at home. Limitations of these studies included omission of patient adherence to the device and lack of long-term follow-up. Interestingly, when sensitivity analysis was conducted that excluded trials funded by the manufacturers, no significant effect on both SBP and DBP was seen [61, 62]. Currently, one device is approved by the Food and Drug Agency in the USA for the treatment of hypertension and the AHA has designated it a class IIA, level B evidence [63]. Despite regulatory approval, the evidence base remains inconclusive to recommend the use of DGB for treatment of hypertension.

Conclusion

Hypertension remains one of the most prevalent modifiable risk factors leading to morbidity and mortality. There is considerable evidence supporting behavioral changes leading to significant reduction in blood pressure such as low-sodium diet, DASH diet, decreased alcohol consumption, weight loss, and aerobic and resistance

exercises (Table 1). Further research with appropriate patient randomization and longer term follow-up is needed before the use of yoga, tai chi, relaxation, and biofeedback or device-guided breathing can be recommended as adjuncts in the treatment of hypertension. Lifestyle modification is important in prehypertension, sustained hypertension, and resistant hypertension and should be strongly encouraged.

Compliance with Ethics Standards

Conflict of Interest The authors declare no conflicts of interest relevant to this manuscript.

Human and Animal Rights and Informed Consent This article does not contain any studies with human or animal subjects performed by any of the authors.

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