Heart Foundation

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Dietary electrolytes &
cardiovascular disease

Summary of Evidence

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This summary of evidence statement was informed by an evidence-based review of the scientific literature prepared by Bill Shrapnel who was contracted for this process, and a subsequent literature review performed by Tuesday Udell (NHFA staff). The evidence- based review paper was developed through an extensive review and consultation process. A Working Group consisting of the following members guided the development of the review paper and summary of evidence:

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This paper has been approved by the National Cardiovascular Health Advisory Committee (NCVHAC) and the National Board of the National Heart Foundation of Australia.

Contents

Terminology

Adequate intake (AI)	This number is used when a recommended dietary intake cannot be determined. It represents the average daily nutrient intake level that is assumed to be adequate to prevent a deficiency.
Blood pressure (BP)	Blood pressure represents the forces exerted by blood on the wall of the arteries and is written as systolic/diastolic (for example 120/80 mm Hg, stated as '120 over 80'). Systolic blood pressure reflects the maximum pressure in the arteries when the heart muscle contracts to pump blood. Diastolic blood pressure reflects the minimum pressure in the arteries when the heart muscle relaxes. There is a continuous relationship between blood pressure levels and cardiovascular disease risk. Therefore, there is no 'ideal' blood pressure reading. The following figures for clinical blood pressures can be used as a guide: Category [1] — Systolic (mm Hg) — Diastolic (mm Hg) Normal — < 120 — < 80 High-normal — 120-139 — 80-89 High — = 140 — = 90 In this paper high blood pressure is defined using these criteria.
Calcium (Ca)	Calcium is the most common mineral in the human body. It is required for the normal development and maintenance of the skeleton as well as proper functioning of neuromuscular and cardiac function.
Cardiovascular disease (CVD)	Cardiovascular disease refers to disease and conditions of the circulatory system including heart, stroke and vascular disease [2].
Conversion	Sodium: 4 g salt contains 70 mmol sodium = 1600 mg sodium 6 g salt contains 100 mmol sodium = 2300 mg sodium 9 g salt contains 150 mmol sodium = 3510 mg sodium Potassium: 1 mmol potassium = 39 mg potassium
Coronary heart disease (CHD)	The underlying cause of coronary heart disease is a gradual clogging of the coronary arteries which supply blood to the heart. Coronary heart disease can lead to angina or heart attack.
Electrolytes	Electrolytes are salts that dissolve in water and dissociate. Important cations (positively charged ions) are sodium, potassium, calcium and magnesium.
Hypertension	Hypertension is a term used for high blood pressure, (systolic, diastolic and combined). It is an important risk factor for cardiovascular disease.
Hypertensive individuals	Hypertensive individuals have a high blood pressure reading.
Magnesium (Mg)	Magnesium is the second most abundant intra-cellular cation in the body. It plays an essential role in a wide range of fundamental cellular reactions.
Normotensive individuals	Normotensive individuals have a normal blood pressure reading.

Terminology

Potassium (K)	Potassium is the major cation of intracellular fluid and is found in nearly all foods.
Salt (NaCl)	Salt is also called sodium chloride. About eighty-percent of the salt consumed comes from processed food, such as breakfast cereals, soups, sauces, ready meals and biscuits [3, 4].
Sodium (Na)	Sodium is the principal cation in the extracellular fluid and plays an essential role in the regulation of body fluids. It is thought that most Australians consume more sodium than their body needs. Approximately 90% of ingested sodium is excreted in the urine. Therefore, sodium intake may be estimated by measuring urinary sodium excretion over 24 hours (mmol/day).
Suggested dietary target (SDT)	These are higher/lower intakes of nutrients that may prevent chronic diseases such as heart disease [5].
Upper limit (UL)	This is the highest average daily intake likely to pose NO adverse health effects to almost all individuals in the general population.

Important findings

Based on the following summary of the evidence, the Heart Foundation's findings on dietary electrolytes and cardiovascular disease are listed below. These findings are consistent with those of the National Health and Medical Research Council[5], the (UK) Food Standards Agency[6] and the American Heart Association[7].

Sodium

Reducing dietary sodium is associated with a fall in blood pressure in hypertensive and normotensive individuals. This is supported by good evidence in the scientific literature to indicate that:

- A reduction in dietary sodium from 140 to 100 mmol/day is associated with a fall in systolic blood pressure of 2 mm Hg from an average systolic blood pressure of 135 mm Hg.

- A reduction in dietary sodium from 140 to 65 mmol/day is associated with a fall in systolic blood pressure of 7 mm Hg from an average systolic blood pressure of 135 mm Hg.

- A reduction in dietary sodium of approximately 75 mmol/day is associated with a fall in systolic blood pressure of 4-5 mm Hg in hypertensive individuals (baseline systolic blood pressure = 140 mm Hg) and a fall in systolic blood pressure of 2 mm Hg in normotensive individuals (baseline systolic blood pressure < 120 mm Hg).

There is moderate evidence in the scientific literature to indicate that:

- High dietary sodium intake is associated with increased stroke incidence, and mortality from coronary heart disease and cardiovascular disease.

There is weak evidence in the scientific literature to indicate that:

- A reduction in dietary sodium along with weight loss is associated with a greater fall in systolic blood pressure than reducing dietary sodium alone.

Potassium

Increasing dietary potassium is associated with a fall in blood pressure in hypertensive and normotensive individuals. This is supported by good evidence in the scientific literature to indicate that:

- An increase in dietary potassium intake of approximately 54 mmol/day is associated with a fall in systolic blood pressure of 4-8 mm Hg in hypertensive individuals (baseline systolic blood pressure = 140 mm Hg) and a fall in systolic blood pressure of 2 mm Hg in normotensive individuals (baseline systolic blood pressure < 120 mm Hg).

There is moderate evidence in the scientific literature to indicate that:

- High potassium intake is associated with decreased stroke mortality.

There is weak evidence in the scientific literature to indicate that:

- High potassium intake is associated with decreased cardiovascular disease mortality.

Calcium and magnesium

There is weak evidence in the scientific literature to indicate that:

- An increase in calcium intake reduces the risk of ischaemic stroke.

Sodium/Potassium ratio

There is weak evidence in the scientific literature to indicate that:

- Blood pressure responsiveness to increased dietary potassium intakes is greater in subjects with high sodium intakes
- Blood pressure responsiveness to decreased sodium intakes is greater in subjects with low potassium intakes

Dietary intake

There is good evidence in the scientific literature to indicate that:

- A general reduction in sodium intake could be better achieved by a general reduction in the sodium content of manufactured food products than by dietary advice alone
- Whole foods have a greater effect on blood pressure than supplements; note that supplemental potassium has the potential for toxicity.

Rationale

A high dietary intake of sodium and/or low dietary intake of potassium, calcium and magnesium have been associated with the rise in blood pressure (BP) that occurs with age. Raised BP is a major, preventable risk factor for cardiovascular disease (CVD) including: stroke, coronary heart disease, heart failure, peripheral vascular disease and kidney failure[8]. The risk of disease increases as the level of BP increases. In addition to the physiological effects resulting from variations in the intakes of electrolytes, there may be significant interactions between them that affect CVD risk.

Although Australian age adjusted death rates for CVD have been falling steadily over the last 30 years, it still remains the leading cause of death for Australians[8]. Coronary heart disease and cerebrovascular disease were the two leading specific causes of death in 2004 and it was estimated that 36% of all deaths in Australia were attributed to CVD. With 3.7 million Australians aged 25 years or over having high BP[9] a change in dietary sodium could affect the incidence of CVD in a considerable part of the population.

Objectives

The objectives of this summary of evidence of the relationships between dietary electrolytes and cardiovascular disease are to:

- determine whether a causal association exists between a decrease in dietary sodium intake and reduction in CVD risk, with a focus on BP and clinical end points of CVD

- determine whether a causal association exists between an increase in dietary potassium, calcium and magnesium and a reduction in CVD risk, with a focus on BP and clinical end points of CVD

- examine the evidence for each electrolyte (sodium, potassium, calcium and magnesium) in isolation and also in combination with the each other and their effect on BP

- determine population-based recommendations for sodium and potassium in order to reduce BP.

The evidence obtained from a systematic review of all relevant randomised controlled trials is considered to be the most robust and good quality evidence[10]. Our paper has based its conclusions on the highest quality evidence available after assessing each paper individually. Our criteria used to appraise the scientific evidence was based on study design (systematic review, randomised controlled trial, observational study) consistency in findings, the quality of each study and consideration of measurement bias, the size of the effect and the demonstration of a biologically plausible mechanism. The terms 'good', 'moderate' and 'weak' evidence were used to assess the strength of the scientific evidence.

The following framework was used to assess the evidence in this paper:

	'Good' evidence	'Moderate' evidence	'Weak' evidence
Study design	Systematic reviews and randomised controlled trials	Randomised controlled trials, observational studies	Randomised controlled trials, observational studies
Level of evidence	Consistent findings, large studies	Large studies; use of surrogate measures; limited number and type of studies	Small, individual trials; Inconsistency across study findings; limited number and type of studies
Quality of evidence	Measurement bias adequately minimised	Limited in quality	Limited in quality
Size of effect	Statistically significant	Effect possibly due to measurement bias	Effect possibly due to measurement bias
Mechanism	Metabolic studies in humans	Metabolic studies in humans	Metabolic studies in humans

Focus of this paper

This summary of evidence statement has focused on BP and clinical end points of CVD. In particular it has focused on changes in systolic BP in both hypertensive and normotensive individuals. Historically the risks associated with hypertension have been based on the level of diastolic BP. In 1971 the Framingham Heart Study showed that systolic BP more accurately described the risk of all complications attributed to hypertension, than did diastolic BP [11]. Systolic BP is now accepted as a significantly more informative reading than diastolic BP for predicting strokes and CHD [12, 13].

Dietary electrolytes, blood pressure and cardiovascular disease endpoints

Dietary sodium

There is good evidence that reducing dietary sodium from 140 to 100 mmol/day is associated with a fall in systolic blood pressure of 2 mm Hg from an average systolic blood pressure of 135 mm Hg.

There is good evidence that reducing dietary sodium from 140 to 65 mmol/day is associated with a fall in systolic blood pressure of 7 mm Hg from an average systolic blood pressure of 135 mm Hg.

There is good evidence that a reduction in dietary sodium of approximately 75 mmol/day is associated with a fall in systolic blood pressure of 4-5 mm Hg in hypertensive individuals (baseline systolic blood pressure = 140 mm Hg) and a fall in systolic blood pressure of 2 mm Hg in normotensive individuals (baseline systolic blood pressure < 120 mm Hg).

There is weak evidence that reducing dietary sodium along with weight loss is associated with a greater fall in systolic blood pressure than reducing dietary sodium alone.

Effect of dietary sodium on blood pressure

Animal studies have demonstrated a dose-dependent relationship between sodium intake and BP establishing evidence of a causal relationship [14, 15]. While it is well established that dietary sodium restriction in humans will reduce BP, the relationship between dietary sodium and BP varies in both hypertensive and normotensive individuals. Some of this variation may be due to increased 'salt sensitivity' that is associated with older age, race, medication use and obesity. These variations have been the basis of the debate around the extent of salt reduction required in the entire population and in hypertensive individuals.

The meta-analyses discussed below are summarised in Table 1.

Many systematic reviews and meta-analyses have been conducted to pool the results of the numerous randomised controlled trials (RCTs) conducted to asses the efficacy of salt reduction on hypertension [16-20] and whether advice on dietary salt restriction is effective in lowering BP [21, 22].

He and MacGregor [17] conducted a meta-analysis where trials reduced salt intake for four or more weeks. Hypertensive individuals achieved a median reduction in sodium excretion of 78 mmol/day and a fall in systolic BP of 5 mm Hg. Normotensive individuals achieved a median reduction in sodium excretion of 74 mmol/day and a fall in systolic BP of 2 mm Hg. The authors concluded that within the daily intake range of 3 to 12 g salt/day, the lower the salt intake achieved, the lower the BP. A meta-analysis by Law et al., [19] estimated that sodium excretion reduction of 50 mmol/day can lower systolic BP by an average of 7 mm Hg in hypertensive individuals and by 5 mm Hg in normotensive individuals. Jurgens and Graudal found that for Caucasians with elevated BP, short-term (4-52 wks) sodium reduction decreases systolic BP by about 4 mm Hg[18]. Midgley et al.,[20] conducted a meta-analysis of 28 trials of hypertensive individuals. A decrease in sodium excretion of 100 mmol/day was associated with a fall in systolic BP of 3.7 mm Hg.

Hooper et al., assessed the long-term effects of advice to restrict dietary sodium [22]. The analysis found that systolic BP was reduced by 8 mm Hg at 6 to 12 months in those given low sodium advice compared to controls. Dickinson et al., [21] found advice to restrict dietary sodium reduced systolic BP by 5 mm Hg in hypertensive subjects participating in short to long-term interventions.

Over 100 RCTs have been conducted to examine the ability of dietary sodium to lower BP. Even so, very few of these trials have been conducted in Australia. The results of the more significant trials are summarised in Table 2 and are discussed below.

Three well-controlled dose-response trials that tested at least three sodium levels provide clear evidence indicating that the lower the salt intake the lower the BP [23-25]. The largest of the dose-response trials was the DASH-sodium trial [23]; it tested the effect of three different levels of dietary sodium (65 low, 100 medium and 140 high mmol/day) in two distinct diets: the Dietary Approaches to Stop Hypertension (DASH) diet, rich in fruits, vegetables, and low-fat dairy products, and a control diet, with typical Western foods. The mean baseline systolic BP was 134±10 and 135±10 mm Hg in the DASH and control diet groups respectively. Sodium reduction in both the control and DASH-diet lowered BP in hypertensive and normotensive individuals. As compared to the DASH-diet with high sodium level, the DASH-diet with medium sodium level decreased systolic BP by 1.3 mm Hg. Even on a typical Western diet, reducing sodium levels from high to medium reduced systolic BP by 2.1 mm Hg and from high to low reduced systolic BP by 6.7 mm Hg. The DASH diet, as compared with the control diet, resulted in a significantly lower systolic BP at every sodium level. The combination of the DASH diet and low sodium resulted in 9.5 mm Hg lower systolic BP in non-black hypertensives – the equivalent effect to those on a single-drug therapy. Subgroup analysis showed that normotensive individuals also had significantly reduced systolic BP on the Western diet when they reduced their dietary sodium intake.

The Trials of Hypertension Prevention (TOHP) Phase II was a longitudinal study that evaluated the effects of reduced salt intake and weight loss on BP. Overweight men and women were randomised to either the control group or to receive one of three interventions – counselling for weight loss, dietary sodium reduction or a combination of the two. The salt reduction group and the combined intervention groups achieved sodium intake levels of 104 mmol/day and 124 mmol/day respectively at six months. Systolic BP was significantly lowered by 2.9 mm Hg in the salt reduction group and by 4.0 mm Hg in the combined intervention group [26].

The Trials of Nonpharmalogic Interventions of the Elderly (TONE) evaluated the effects of dietary salt reduction, in older (60-80 years), obese, hypertensive individuals [27]. All subjects were receiving treatment with a single antihypertensive medication. The study reported that a moderate reduction in dietary sodium intake (40 mmol/day) resulted in a fall of 3.4 mm Hg in systolic BP. The trial found that weight loss and sodium reduction produced further reductions in systolic BP.

The International Study of Salt and Blood Pressure (Intersalt) was a large well-conducted observational trial of 52 populations [28]. Across the 52 populations, sodium excretion was significantly related to BP and the prevalence of hypertension. For within population analyses (n=10,074), a difference in sodium excretion of 100 mmol/day was associated with a difference in systolic BP of 3-6 mm Hg in both normotensive and hypertensive individuals [29]. The significant association between sodium excretion and the changes in BP with age remained. Some have questioned the validity of these findings [30, 31] and as such the NHFA have not considered this data in our summary of evidence.

The Diet, Exercise, and Weight Loss Intervention Trial (DEW-IT) evaluated the effects of combined sodium restriction, the DASH-diet, weight loss and regular aerobic exercise [32]. Participants were hypertensive, overweight adults taking one antihypertensive agent. After nine weeks, systolic BP was significantly reduced by 9.5 mm Hg in the intervention participants compared with those in the control.

While there is agreement that restricting sodium intake in people with hypertension leads to a reduction in BP, variations in the results of trials of sodium reduction differ because of four important factors:

- Age of subjects; older subjects see a greater effect
- Length of trial; minimum of one month to see changes in BP
- Starting BP of subjects
- Magnitude of sodium difference [33].

> There is moderate evidence that *high* dietary sodium intake is associated with increased stroke incidence, and mortality from coronary heart disease and cardiovascular disease.
>
> There is no conclusive evidence that *low* dietary sodium intake is associated with a lower incidence of stroke, mortality from coronary heart disease and cardiovascular disease.

Effect of dietary sodium on cardiovascular disease end points

It has been estimated that a reduction of 2 mm Hg in systolic BP would result in 6% reduction in risk of stroke and a 4% reduction in risk of CHD, and an overall reduction in mortality of 3% [34]. In another study a reduction of 10 mm Hg in systolic BP is predicted to reduce stroke by approximately one third, CHD by one quarter and heart failure by one quarter in those between 60-80 years with systolic hypertension [35].

Studies linking sodium intake to reduced risk of CVD, are few and have produced varying results. A recent systematic review by Hooper et al., looked at the long-term effects of advice to reduce dietary salt in patients with elevated or normal BP [22]. The 11 RCTs in the review provided few data on CVD end points. The review found that deaths and cardiovascular events were inconsistently defined and reported, and suggested no significant difference in cardiovascular morbidity between low sodium and control groups.

A large prospective study in Finland followed subjects over 13 years. For men, the risk of CHD and CVD, and all-cause mortality was associated with higher sodium excretion [36]. A Scottish longitudinal study found an association between sodium excretion and the incidence of coronary events in the women studies, but not the men [37].

Among obese people, a high salt intake may be associated with increased risk of cardiovascular events. A prospective large study by He et al., found that in participants who were overweight, sodium intake was associated with increased frequency of stroke, mortality from CHD, CVD and all-cause mortality [38].

Conflicting evidence from an observational study of lower salt intake in hypertensive men found association with higher levels of CVD, including myocardial infarction [39] in direct contrast to all other evidence. This analysis has been criticised because it did not use 24hr urine collections which all other studies have used [40].

In a recent analysis of the National Health and Nutritional Examination Survey II (NHANES II) individuals who reported consumption of sodium < 2.3 g/day (100 mmol/day) had 37% higher CVD mortality and 28% higher mortality from all causes compared with those reporting sodium intake > 2.3 g/day [41]. Data collection had been criticised because it was limited by a single sodium measure at baseline, with no measure of table or cooking salt that might have been added.

In several studies a high salt intake has been found to increase left ventricular mass independently of BP [42-44].

Dietary potassium

An increase in dietary potassium intake of approximately 54 mmol/day is associated with a fall in systolic blood pressure of 4-8 mm Hg in hypertensive individuals (baseline systolic blood pressure = 140 mm Hg) and a fall in systolic blood pressure of 2 mm Hg in normotensive individuals (baseline systolic blood pressure < 120 mm Hg).

Effect of dietary potassium on blood pressure

The four meta-analyses discussed below are summarised in Table 3.

Findings on the association between a high dietary potassium intake and reduced BP are inconsistent. Four meta-analyses have pooled randomised trials of potassium supplementation [45-48]. Three of these analyses have documented a significant inverse relationship between dietary potassium intake and BP [45-47]. In particular the meta- analysis by Whelton et al., (33 trials) found an increase in potassium excretion of 50 mmol/day was associated with an average systolic BP reduction of 4.4mm Hg in hypertensive and 1.8mm Hg in normotensive individuals [46]. This analysis has been criticised because it did not specify a minimum length of follow-up and included trials with a very short follow-up period (4 days) [48]. The most recent meta-analysis of RCTs with a follow-up = 8 weeks (4 trials) found no statistically significant effect of potassium supplementation on BP but acknowledged heterogeneity between the findings of included trials [48].

The Australian NHMRC Dietary Salt Study subjects (average 52 years) were randomised into four diet groups; control, high-potassium, reduced-sodium or a combination diet, for 12 weeks [49]. Potassium excretion rose to 96 mmol/day and systolic BP fell by 7.7 mm Hg in the high potassium group. The urine sodium/potassium ratios were reduced in each of the three dietary intervention groups with no significant difference in falls in BP between them.

No trials have tested the effects of three or more levels of dietary potassium intake on BP which would provide firm evidence for recommendations of a specific level of potassium.

However, the average intake of potassium in clinical trials [46, 48] and the highest dose in a trial with two levels of potassium [50] was 120 mmol/day (4700 mg/day).

While clinical trials have provided simple oral potassium supplements [48], the preferred strategy for potassium supplementation is from foods because it is also accompanied by a variety of other nutrients. In the DASH trial, increasing fruit and vegetables, which elevated potassium to 120 mmol/day, was associated with a lower BP [23, 51]. A trial of cardiac patients randomised to either pills or diet found no significant difference in serum potassium levels between the two groups and 79% of the patients surveyed preferred the diet method [52].

There is moderate evidence that high dietary potassium intake is associated with decreased stroke mortality.

There is weak evidence that high dietary potassium intake is associated with decreased cardiovascular disease mortality.

Effect of dietary potassium on cardiovascular end points

Negative associations between potassium intakes and stroke mortality have been observed in some [53-56] but not all [57, 58] epidemiological studies that have investigated the issue. The association between potassium intake and risk of CHD was not significant in studies by Tunstall-Pedro et al., [37] and Bazzano et al., [57].

In a randomised trial, Chang et al., showed a long-term beneficial effect on CVD mortality associated with a switch from regular salt to potassium-enriched salt in a group of elderly men [59].

It has been suggested that potassium may protect against stroke and other CVD by mechanisms which are not related to BP [60].

Dietary calcium and magnesium

There is no evidence to support calcium supplementation for the prevention and management of hypertension

There is no evidence to support magnesium supplementation for the prevention and management of hypertension.

Effect of dietary calcium and magnesium on blood pressure

Numerous meta-analyses have found an inverse association between calcium and BP [61- 66]. A meta-analysis of observational studies indicated a modest inverse association between dietary calcium intake and BP [61]. While meta-analyses of RCTs have reported a modest reduction in BP in hypertensive subjects [62, 63, 67] none have recommended calcium supplementation for the prevention and treatment of hypertension. Dietary calcium has been significantly associated with low levels of systolic BP in the general population [65], which may be due to higher calcium intake being a marker of a healthy diet. A recent Cochrane review included 13 RCTs (n=485 subjects), with between eight and 15 weeks follow-up [68]. Participants receiving calcium supplementation (0.4 to 2 g/day) as compared to the control group had a statistically significant reduction in systolic BP of 2.5 mm Hg but heterogeneity between trials could not be explained by dose of calcium or baseline BP. The author's concluded that the association between calcium supplementation and BP reduction was weak and probably due to bias.

Inconsistent evidence implicating magnesium as a major determinant of BP has precluded NHFA from recommending magnesium supplementation as a means to lower BP. In some trials, magnesium has not been associated with any changes in BP [69-71]. A systematic review of RCTs found that magnesium was not associated with prevention of hypertension, nor was it effective in reducing high BP [72]. One pooled analysis of observational studies did find a significant inverse association between dietary magnesium and BP [73] and a recent Cochrane review found that magnesium supplementation significantly reduced diastolic BP [74]. The authors concluded that the poor quality of included trials and the heterogeneity between trials meant the evidence in favour of a causal association between magnesium supplementation and BP reduction was weak and probably due to bias.

There is weak evidence that a high calcium intake reduces the risk of ischaemic stroke.

There is conflicting evidence that magnesium intake is associated with risk for total stroke, coronary heart disease or sudden cardiac death.

Effect of dietary calcium and magnesium on cardiovascular end points

Two prospective cohort studies have found that dietary calcium intake was not associated with the risk of developing coronary heart disease [75, 76]. Large prospective cohort studies have shown calcium intake [77-79] and milk consumption [80] to be inversely associated with the risk of ischaemic stroke while other studies have failed to show this association [81, 82]. Elwood and colleagues [82] and the Nurses' Health Study [77] have suggested that any effect of dairy products on the risk of stroke may, at least in part, be mediated by constituents other than calcium. Differences between high and low milk consumers in life-style and other factors relevant to vascular disease could account for differences in risk of CHD and stroke.

A large prospective cohort study found no significant association between magnesium intake and the incidence of total CVD, CHD, nonfatal myocardial infarction or stroke [83]. The Nurses' Health Study showed no significant associations between magnesium intake and total stroke [77], whilst the Health Professionals' Follow-up Study showed dietary magnesium intake was inversely associated with risk for total stroke [55].

In a randomised trial, high risk patients followed a magnesium-rich diet or usual diet for 10 years [84]. Total mortality and sudden deaths in the group with the magnesium-rich diet were significantly less than in the control group. In contrast, magnesium has been associated with an increase in the risk of developing a cardiac event in one randomised parallel study [85].

Electrolyte interactions

Blood pressure responsiveness to increased dietary potassium intakes is greater in subjects with high sodium intakes.

Blood pressure responsiveness to decreased sodium intakes is greater in subjects with low potassium intakes.

The effects of sodium and potassium on BP and cardiovascular risk are not independent of one another, and may have some degree of addition. The potassium / sodium ratio is more strongly related to blood pressure than either nutrient alone [86]. Sodium-induced increases of BP appear to be augmented by diets deficient in potassium [87].

For those with a low sodium intake [46, 88] or in those on a low salt diet [89] the effects of potassium supplementation do not significantly further reduce BP. While in another study supplemental dietary potassium attenuated the blood-pressure raising effect of high dietary sodium [90].

A recent review evaluated the effects of combined mineral supplementation as a treatment for primary hypertension in adults. The review included three RCTs (n=277) with between 24 and 28 weeks follow-up. Three combinations of minerals were investigated: potassium and magnesium; calcium and magnesium; and calcium and potassium. No evidence that supplements of any combination of potassium, magnesium or calcium reduce mortality, morbidity or BP in adults was found [91].

Modifying dietary intake

There is good evidence that a general reduction in sodium intake could be better achieved by a general reduction in the sodium content of manufactured food products than by dietary advice alone.

There is good evidence that whole foods have a greater effect on blood pressure than supplements; note that supplemental potassium has the potential for toxicity.

Sodium

Current intakes

In the Western diet, processed foods contribute about 80% of dietary sodium [3, 4], with the major sources including staple foods such as bread, processed meats and mixed dishes [92-94]. Grain products have been shown to be the main source of dietary sodium for elderly individuals [95].

The 2006 National Health and Medical Research Council (NHMRC) Nutrient Reference Values for Australia and New Zealand recommends an upper limit of sodium for adults of 100 mmol/day (2.3 g/day, 6 g salt/day), and a suggested dietary target of 70 mmol/day (1.6 g/day, 4 g salt/day) to reduce chronic disease risk (5). Australian adult sodium intakes have been estimated to be about 144-148 mmol/day (9 g salt) [96, 97]. A Heart Foundation funded study of 194 individuals living in Hobart, found only 36% of females and 6% of males were achieving the dietary sodium target of less than 100 mmol/day [96].

Potassium

Current intakes

Dietary potassium is widely distributed in foods particularly in vegetables, fruit, legumes and wholegrain cereals. For adults the food group contributing the largest proportion of potassium is vegetables (around 24%). The milk group, cereals and cereal based products, and the meat group each contribute 10-20% of dietary potassium [98]. The fruit group contributes about 5-10%, with this figure rising to 9-14% if fruit and vegetable juices are included.

The 2006 NHMRC Nutrient Reference Values for Australia and New Zealand recommends an adequate intake of potassium of 100 mmol (3.8 g/day) for men and 72 mmol (2.8 g/day) for women, and a suggested dietary target of 120 mmol/day to reduce chronic disease risk.

Summary of evidence statement on the relationships between 18 dietary electrolytes and cardiovascular disease [5]. No upper limit has been set for potassium from dietary sources. Australian adult potassium intakes have been estimated to be about 70-78 mmol/day (men 2800-3200 mg/day, women 2600-2900 mg/day) [96,97].

Changing dietary sodium and potassium intakes

Modification of Australian intakes of sodium and potassium will require a concerted effort from health authorities, health professionals, food manufacturers and consumers alike.

Strategies to reduce dietary sodium intake include encouraging people to consume less salt and to buy low-salt food as well as population-based measures such as reducing the salt concentration of processed foods: a major barrier to achieving any meaningful reduction in sodium intake.

Population based strategies

Australian studies have shown that major food manufacturers have been lowering the salt content of foods in response to consumer demand and nutrition benchmarks, including those set by the NHFA's Tick program [93, 99, 100]. It has been shown that the sodium content of processed foods can be reduced without loss of product acceptability [100].

The food industry needs incentives to produce foods enriched with appropriate potassium compounds and whenever possible to decrease the sodium levels in products which have added salt or other sodium compounds [101].

There may be a potential beneficial effect of replacing salt with a 'potassium-enriched' salt substitute [59]. This may be one practical solution that combines the advantages of reducing sodium intake and increasing potassium intake. However, salt substitutes that contain potassium may cause hyperkalaemia with life threatening consequences in susceptible patients [102].

Targeted approaches

The Heart Foundation acknowledges that getting a population to change its dietary sodium intake through education programs is difficult [103-105]. Some studies have shown that older persons are able to make and sustain dietary changes, specifically weight loss and dietary sodium reduction over the longer term, which may be due in part to a desire to reduce their dependence on medication [27, 106].

Dietary intervention trials rely on highly motivated individuals with a readiness to change and who are met frequently by skilled health educators and dietitians. This facilitates short- term dietary change but is often not sustained over the long-term beyond the duration of the trial. Many trials have acknowledged that the level of sodium reduction does not meet target levels when individuals make their own food selections in the community, even when those individuals are highly motivated and extensively counselled [27, 107-109].

A meta-analysis by Hooper et al., [108] has shown the difficulty of reducing salt intake in the long term without the provision of processed foods with less salt - the mean salt reduction in the studies was only 2 g/day. This limited success of long-term dietary change highlights the need for environmental changes that encourage the adoption of a healthy lifestyle.

While Hooper et al., [108] included international trials only 2 of these were conducted in Australia. This highlights the limited evidence about whether advice to change dietary intake of sodium and potassium are achievable with Australia's present resources and food supply.

While many dietary intervention trials use supplements to increase mineral intake, those who use foods as the mineral sources have produced a greater effect on the BP of individuals [23, 51, 64]. This suggests that the food as a whole and the naturally occurring combination of minerals contributes to the BP-lowering effect.

High potassium intakes or the use of potassium sparing diuretics can cause gastrointestinal discomfort and stress, while arrhythmia can also arise from the resulting hyperkalaemia [5]. However, in otherwise healthy people, there have been no reports of hyperkalaemia from acute or chronic ingestion of potassium naturally occurring in food. It is advised that supplemental potassium be taken under careful medical supervision.

The DASH-diet has demonstrated that eating patterns containing ample fruits, vegetables, wholegrain and low-fat dairy products i.e. rich in potassium, calcium, magnesium and dietary fibre, and low in total fat, saturated fat and cholesterol, lower BP independently of and in conjunction with, sodium restriction. A modest reduction in sodium intake and an increase in vegetable and fruit intake to increase potassium intake, are both desirable.

Conclusions

The evidence reviewed suggests that reducing dietary sodium and/or increasing dietary potassium is associated with a clinically significant fall in systolic blood pressure for both normotensive and hypertensive individuals. An upper limit of 6 g salt /day has been set by NHMRC but estimates suggest that reducing salt to as low as 3 g salt/day would confer benefits on blood pressure.

There is evidence that high sodium diets are associated with increased stroke incidence, and mortality from coronary heart disease and cardiovascular disease. There is evidence that high potassium diets are associated with decreased stroke and cardiovascular disease mortality.

Evidence has shown that dietary changes are difficult to sustain in the long-term. Population-wide strategies to reduce dietary sodium must look at changes in the food supply.

Changes in the dietary electrolyte intake of Australians will require the enthusiastic support of community leaders including health professionals.

Other Heart Foundation policies

For further information on electrolytes and CVD please refer to:

Salt and Hypertension, NHFA 2002
www.heartfoundation.com.au/downloads/Salt_Hypertension_Feb_2002.pdf

Hypertension Management Guide for Doctors, NHFA 2004
www.heartfoundation.com.au/downloads/hypertension_management_guide_2004.pdf

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Tables of significant studies

Table 1: Summary of major meta-analyses on the effect of dietary sodium on blood pressure

Study first author, date	Aim, Subjects and Intervention	BP of subjects	Outcome - Median reduction in Na intake (mmol/24hr)	Outcome - Mean change in systolic BP (mm Hg)	Inclusion/exclusion from Heart Foundation summary of evidence statement
Cutler, J 1997	**Aim:** The relation of change in sodium intake to change in systolic and diastolic blood pressure. **HT trials:** 22 **Duration:** median 2 mo (1- 24 mo) **NT trials:** 12 **Duration:** median 1 mo (2 wk – 36 mo)	HT+ NT	HT: 71 (27-171) NT: 90 (16-210)	HT: 4 (CI: -4.9 to -2.8) NT: 2 (CI: -2.1 to -1.0) Estimate of BP lowering per decrease of 100 mmol Na/day HT: 6 (± 1.88) NT: 3 (± 1.09)	**Included:** Hypertensive results Study length = 4 wks **Excluded:** Normotensive results Study length = 4 wks
Dickinson, H 2006	**Aim:** To quantify effectiveness of Na restriction for hypertension **HT trials:** 7 (n=520) **Age:** Mean 52 y **Duration:** Median 52 wk (range 8-52 wk) **Follow-up:** Median 52 wk (range 8-52 wk) **Advice:** Na restriction 70-100 mmol/day **Baseline systolic BP:** 151 mm Hg	HT	not reported	HT: 5 (CI: -7.2 to -2.2)	**Excluded:** Change in Na excretion not reported

Table 1: Summary of major meta-analyses on the effect of dietary sodium on blood pressure cont.

Study first author, date	Aim, Subjects and Intervention	BP of subjects	Outcome - Median reduction in Na intake (mmol/24hr)	Outcome - Mean change in systolic BP (mm Hg)	Inclusion/exclusion from Heart Foundation summary of evidence statement
He, F 2004	**Aim:** To assess the effect of modest salt reduction on BP. To assess whether there is a dose-response. **HT trials:** 20 (n=802) **Age:** median age 50y (range 24-73y) **Duration:** median 5wks (range 4-52wks) **Follow-up:** Median 52 wk (range 8-52 wk) **Baseline systolic BP:** median 149 mm Hg **NT trials:** 11 (n=2220) **Age:** median age 47y (range 22-67y) **Duration:** median 4wks (range 4wks-3y) **Baseline systolic BP:** median 127 mm Hg	HT+ NT	HT: 78 (53-117) NT: 74 (40-118)	HT: 5 (CI: -6.69 to -3.85) NT: 2 (CI: -3.48 to -1.14) Dose response, reduction of 100 mmol/day HT: 7 (CI: 5.6 to 8.8) NT: 4 (CI: 1.9 to 5.2)	**Included:** Trials = 4 wks Change in Na excretion and BP reported
Hooper, L 2004	**Aim:** Long-term effects of advice to restrict dietary Na. **HT trials:** 5 HT (n=387) **Age:** range 16-64y **Na goals:** 70-100 mmol/day **NT trials:** 3 (n=2326) **Age:** mean age 40y **Na goals:** 70-80 mmol/day	HT+ NT	6 to 12 months: 44 13 to 60 months: 34	6 to 12 months HT: 8 (CI: -15.8; -0.2) NT: 2 (CI: -3.1; -1.6) 13 to 60 months HT: 3.8 ns NT: 1 (CI: -1.9 to -0.3)	**Excluded:** Measure of effectiveness of advice on outcomes rather than the effect of actual sodium restriction.
Jurgens, G 2004	**Aim:** To estimate the effects of low sodium vs high sodium on BP. **HT trials:** 56 - Caucasians (n=3367) **Age:** mean age 49y (range 23-73y) **Duration:** median 28 days (4-52 weeks) **NT trials:** 57 - Caucasians (n=5096) **Age:** mean age 27y (range 15-67y) **Duration:** median 8 days (4-1100 days)	HT+ NT	HT: not reported NT: not reported	HT: 4 (CI: -5.08; -3.27) NT: 1 (CI: -1.76; -0.77)	**Excluded:** Reduction in Na excretion not reported

Table 1: Summary of major meta-analyses on the effect of dietary sodium on blood pressure cont.

Study first author, date	Aim, Subjects and Intervention	BP of subjects	Outcome - Median reduction in Na intake (mmol/24hr)	Outcome - Mean change in systolic BP (mm Hg)	Inclusion/exclusion from Heart Foundation summary of evidence statement
Law, M 1991	**Aim:** To determine if reduction in BP achieved in trials of dietary salt reduction is quantitatively consistent with estimates derived from BP and Na intake in different populations. **HT Trials:** 63 **Duration:** median 5 wks (0.7 to 104) **NT trials:** 15 **Duration:** median 1.5 wks (0.7 to 16)	HT+ NT	Not stated	Not stated	**Excluded:** Na and BP outcomes not stated The review estimates that in people aged 50-59 a reduction of 50 mmol Na/day would lead to a fall of 5 mm Hg in systolic BP in normotensives and a fall of 7 mm Hg in hypertensives.
Midgley, J 1996	**Aim:** To ascertain whether dietary Na restriction lowers BP. **HT trials:** 28 (n=1131) **Age:** mean 47 (range 8-73) **Duration:** median 29 days (4-730 days) **Baseline Na intake:** 158 mmol/day (146-171) **NT trials:** 28 (n=2374) **Age:** mean 26 (range = 10-65) **Duration:** median 14 days (4-1095 days) **Baseline Na intake:** 177 mmol/day (166-200)	HT+ NT	HT: 95 (71-119) NT: 125 (95-156)	For every 100mmol reduction in Na HT: 4 (2.35-5.05) NT: 1 (0.51-156)	**Excluded:** Studies in children and adolescents were included Very short studies were included

BP – blood pressure   CI – 95% Confidence interval
HT – hypertensive individual   Na – sodium
NT – normotensive individual   RCT – randomised controlled trial
ns – not significant

Table 2: Summary of significant randomised controlled trials on the effect of dietary sodium on blood pressure

Study first author, date, study name	Subjects and intervention	BP of subjects	Over-weight	Outcome - Na intake (mmol/day)	Outcome – WMD systolic BP (mm Hg)	Other
Miller, E 2002 DEW-IT (Australian)	**Subjects:** 43 adults (62% women), receiving a single antihypertensive drug **Age:** Mean 54y **Intervention included:** exercise and DASH- diet and low sodium. **Duration:** 9 wks	HT	Y	Intervention group compared to control: 9 wks: 61	Intervention group compared to control: 9 wks: 9.5	The number of participants was small. The intervention was demanding on volunteers.
Sacks, F 2001 DASH	**Subjects:** 412 adults, 41% hypertensives **Duration:** 30 d **Age:** mean 49y **Intervention:** 3 levels of sodium (3x2 design) **Mean baseline systolic BP:** DASH-diet – 134±10 and control diet 135±10 mm Hg	HT + mildly HT	N	3 levels of Na intake: high: 140 intermediate: 100 low: 65	DASH-diet: difference between high-Na and intermediate-Na: 1.3 DASH-diet: difference between intermediate-Na and low-Na: 1.7 Control diet: difference between high-Na and intermediate-Na: 2.1 Control diet: difference between intermediate-Na and low-Na: 4.6	

Table 2: Summary of significant randomised controlled trials on the effect of dietary sodium on blood pressure cont.

Study first author, date, study name	Subjects and intervention	BP of subjects	Over-weight	Outcome - Na intake (mmol/day)	Outcome – WMD systolic BP (mm Hg)	Other
TOHP Collaboration 1997 TOHP II	**Subjects:** Men and women (n=2382), not taking antihypertensive drugs **Age:** range 30-54y **Weight:** BMI representing 110% to 165% of desirable body weight. **Intervention:** control, Na reduction, Na reduction and weight loss	High-normal	Y	Change in Na reduction group compared to control: 6 mo: 50 36 mo: 40	Change relative to control: 6 mo: Na reduction: 2.9 Na+ wt loss: 4.0 36 mo: Na reduction: 1.2 Na+wt loss: 1.1	In overweight adults with high-normal BP, weight loss and reduction in sodium intake, individually and in combination, were effective in lowering systolic BP.
Whelton, PK 1998 TONE	**Subjects:** 585 obese participants, receiving a single antihypertensive drug **Age:** range 60-80y **Intervention:** reduced sodium intake, weight loss, both, or usual care (control) **Subjects:** 390 non-obese participants **Intervention:** reduced sodium intake or usual care (control) **Target Na intake:** 80 mmol or less	HT	Y	Change in intake of the Na reduction group compared to control: 9 mo: 47 18 mo: 49 30 mo: 40	Change at 30 mo compared to control: Na reduction: 3.4 Na+wt loss: 5.3	

BP – blood pressure
CI – 95% Confidence interval
HT – hypertensive individual
Na – sodium
NT – normotensive individual RCT – randomised controlled trial
WMD – weighted mean difference

Table 3: Summary of major meta-analyses on the effect of dietary potassium on blood pressure

Study first author, date	Aim, Subjects and Intervention	BP of subjects	Outcome - Increase in K intake (mmol/24hr)	Outcome - WMD systolic BP (mm Hg)	Inclusion/exclusion from Heart Foundation summary of evidence statement
Cappuccio, F 1991	**Aim:** To establish whether a K supplement does lower BP and whether a moderate increase in K intake should be advised. **HT trials:** 13 **NT trials:** 6 **Age:** median age 41y (range 21-58y) **Duration:** median 28d (range 5-112d)	HT+ NT	Median: 57 (range 23-123)	HT: 8 (CI: -9.1 to -7.3)	**Included:** Change in K excretion and BP reported
Dickinson, H 2006	**Aim:** to evaluate the effects of K supplementation on health outcomes and BP in people with elevated BP. **Trials:** 5 RCT (n=425), 4 RCT (excluding African study) **Follow-up:** median 12 wks (8-16wks) Age: mean 50y (36-52y) **Dose:** 48 – 120mmol/day	HT	Not reported	Four RCTs 4 (CI: -8.56 to 0.81) > 100mmol/day dose 4 (CI: -5.20 to -1.94) < 100mmol/day 7 (CI: -8.91 to -5.88)	**Excluded:** Change in K excretion not reported
Geleijnse, J 2003	**Aim:** to assess the BP response to changes in sodium and K intake. **Trials:** 27 **Duration:** 6 wks (2-114wks) **Age:** 45 ± 12y	HT + NT	(mean change) 51 ± 26	HT: 4 (-5.31 to -1.72) NT: ns	**Included:** Change in K excretion and BP reported

Table 3: Summary of major meta-analyses on the effect of dietary potassium on blood pressure cont.

Study first author, date	Aim, Subjects and Intervention	BP of subjects	Outcome - Increase in K intake (mmol/24hr)	Outcome - WMD systolic BP (mm Hg)	Inclusion/exclusion from Heart Foundation summary of evidence statement
Whelton, P 1997	**Aim:** To assess the effects of supplementation with oral potassium on BP. **Trials:** 33 (n=2609) **HT trials:** 21 (n=1560) **NT trials:** 12 (n=1005)	HT+ NT	(mean change) 53	All trials: 3 (CI: -1.91 to -4.31) HT: 4 (CI: -2.2 to -6.6) NT: 2 (CI: -0.6 to -2.9)	**Included:** Change in K excretion and BP reported

BP – blood pressure
CI – 95% Confidence interval
HT – hypertensive individual
K – potassium
NT – normotensive individual
WMD – weighted mean difference ns – not significant

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For heart health information and support, call our Helpline on 13 11 12 or visit heartfoundation.org.au