Salt Consumption in Children and Adolescents - Impact on Blood Pressure and Cardiovascular Health

Beatriz Ribeiro[1,2], Sara Monteiro[3], Alberto Caldas Afonso[1,4,5,6], Manuela Morato[7,8] and Liane Correia-Costa[1,4,5,6,9]

1 Instituto de Ciências Biomédicas Abel Salazar, Universidade do Porto, Porto, Portugal.
2 Unidade de Saúde Familiar "Ao Encontro da Saúde", Unidade Local de Saúde do Médio Ave.
3 Serviço de Pediatria, Centro Materno-Infantil do Norte, Centro Hospitalar Universitário de Santo António, Porto, Portugal.
4 Unidade de Nefrologia Pediátrica, Centro Materno-Infantil do Norte, Centro Hospitalar Universitário de Santo António, Porto, Portugal.
5 EPIUnit – Instituto de Saúde Pública, Universidade do Porto, Porto, Portugal.
6 Laboratório para a Investigação Integrativa e Translacional em Saúde Populacional (ITR), Universidade do Porto, Rua das Taipas, n° 135, 4050-600 Porto, Portugal.
7 Laboratório de Farmacologia, Departamento de Ciências do Medicamento, Faculdade de Farmácia, Universidade do Porto, Portugal;
8 LAQV/REQUIMTE, Faculdade de Farmácia, Universidade do Porto, Porto, Portugal.
9 CAC ICBAS-CHP – Centro Académico Clínico Instituto de Ciências Biomédicas Abel Salazar – Centro Hospitalar Universitário de Santo António, Porto, Portugal.

ABSTRACT

Sodium is the major cation of extracellular fluid and has the physiological role of plasma volume maintenance. Even though dietary sodium intake is crucial for the organism, nowadays its consumption worldwide markedly exceeds the amount recommended by the World Health Organisation. This represents a great concern since in adulthood, sodium intake is associated with high blood pressure (BP) and poorer outcomes in cardiovascular health. Knowing that blood pressure follows a tracking pattern from childhood to adulthood, it is fundamental to understand the effects of sodium intake on the BP of children and adolescents, in addition to the cardiovascular events related to sodium intake in these ages. However, evidence for this age group is scarcer and more controversial than data for the adult population.

With the aim of providing an updated, comprehensive review of how sodium intake during childhood and adolescence affects BP and cardiovascular health, we conducted a methodical search of the published literature on the electronic database PubMed. The included articles dated preferentially from the last 20 years and were written in English, French, Spanish or Portuguese.

Several studies demonstrated a positive, significant relation between high dietary salt intake and BP during childhood. Additionally, studies show that cardiovascular events in childhood are related to high sodium intake and increased BP, even though there is a limited number of studies on this issue. We conclude that sodium intake reduction programmes should be implemented from an early age in order to prevent hypertension and, moreover, cardiovascular disease.

Keywords:

Salt intake, sodium chloride, blood pressure, cardiovascular risk, children, adolescents.

Corresponding author:
Email: lianecosta@icbas.up.pt
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INTRODUCTION

Throughout human history, salt or sodium chloride has formed a part of civilizations. Even though sodium is a physiological need, most countries have an excessive sodium intake, with mean estimated values ranging between 9 to 12 g/day, even reaching more than 12 g/day in some Asian countries[1].

It has been suggested that a rise in blood pressure (BP) might start during childhood, with a contribution of events from the prenatal and postnatal period, in addition to following a tracking pattern from childhood into adulthood. In children and adolescents, evidence about the impact of salt intake on BP is scarce and controversial[2].

Hypertension persists as a critical public health problem, is the largest contributor to cardiovascular (CV) disease and the major modifiable risk for CV mortality worldwide[3]. For several decades now, the World Health Organization (WHO) has recommended a reduction in sodium intake and, more recently, defined levels of consumption by age groups[4]. Prevention of a salt-associated rise in BP at early ages is essential since it can prevent the development of hypertension later in life and attenuate the public health burden of all its associated diseases and complications[2].

This bibliographic review aims to provide an updated overview of the evidence relating to sodium intake and health, with a particular focus on BP and CV health and emphasis on the period of childhood and adolescence.

METHODS

A methodical search of scientific articles was conducted on the electronic database PubMed, with the following key words: "infants", "children", "childhood", "adolescents", "adults", "adulthood", "blood pressure", "hypertension", "sodium intake", "salt intake", "cardiovascular events", "salt sensitivity", "tracking" and "programming". Additionally, we performed a search in the references of the selected articles to find other important articles not included in the results of the primary search.

The present review included articles written in English, French, Spanish or Portuguese, preferentially dated within the last two decades (2001-2023). However, we also included several especially relevant articles published before that date.

DIETARY SALT INTAKE DURING CHILDHOOD AND ADOLESCENCE

Physiological needs and daily recommended intake

Over the years, several guidelines have been published with the objective of recommending ideal value ranges of sodium consumption according to age groups. The most recent of these are the Dietary Guidelines for Americans 2020-2025 (Table I), which recommend the sodium intake for people over the age of 14 years should be inferior to 2.3 g/day of sodium. For the age groups of 6 to 11 months, 1 to 3 years, 4 to 8 years and 9 to 13 years, the daily sodium goal should be 0.37 g/day, 1.2 g/day, 1.5 g/day and 1.8 g/day, respectively (Table I)[5]. Other guidelines, such as the ones released in 2003 by the Scientific Advisory Committee on Nutrition and a consensus study report dating from 2019, present different ranges of values, as Table 1 shows. Even though the three reports presented in Table I recommend slightly different value ranges for sodium intake, the values are concordant with WHO recommendations, which state that the maximum salt intake per day for children should be adjusted downwards based on their energy requirements. For adults, the WHO recommendation is that salt intake should not exceeded 5 g/day[4].

Sodium consumption below the recommended minimal value or above the upper limit might be associated with several deleterious effects[6]. However, it is important to underline that these limits may need to be adjusted according to interindividual variability, which is dependent on several factors such as age, genetic predisposition, and environmental conditions.

Methods to assess sodium intake

Today, there are several methods for measuring dietary sodium intake, which include self-report assessments and biochemical measurements, although these pose challenges associated with precision. The current gold standard is quantification of the excretion of sodium in a 24h urine sample, as 90% of consumed sodium is excreted in urine. This method is expensive, a considerable inconvenience for subjects, and unpractical when contemplating large populations or if repeated measurements are necessary. Additionally, 24h urine collection in infants presents numerous problems such as contamination, leakage and micturition loss. As an alternative, biochemical analysis may be performed on 12h urine samples, spot urine and/or overnight urine samples. These methods are less reliable than using 24h urine sample collection because the rate of renal sodium excretion varies throughout the day due to salt intake pattern, individual posture, and neurohormonal influence[7].

Table I. Recommendations for daily intake of sodium based on age groups (adapted from 5, 6, 54).

"DIETARY GUIDELINES FOR AMERICANS 2020-2025", U.S. DEPARTMENT OF HEALTH AND HUMAN SERVICES[5]	
Age	**Recommended Daily Intake of Sodium**
6 – 11 months	0.37 g/day
1 – 3 years	1.2 g/day
4 – 8 years	1.5 g/day
9 – 13 years	1.8 g/day
≥14 years	<2.3 g/day
"DIETARY REFERENCE INTAKES FOR SODIUM AND POTASSIUM", NATIONAL ACADEMIES OF SCIENCES, 2019[54]	
Age	**Recommended Daily Intake of Sodium**
0 – 6 months	0.11 g/day
7 – 12 months	0.37 g/day
1 – 3 years	0.8 g/day
4 – 8 years	1 g/day
9 – 13 years	1.2 g/day
14 – 18 years	1.5 g/day
"SALT AND HEALTH", SCIENTIFIC ADVISORY COMMITTEE ON NUTRITION, 2003[6]	
Age	**Recommended Daily Intake of Salt**
0 – 6 months	0.24 g/day
7 – 12 months	0.336 g/day
1 – 3 years	0.512 g/day
4 – 6 years	0.72 g/day
7 – 10 years	1.224 g/day
11 – 14 years	1.632 g/day
≥15 years	2.4 g/day

Self-report methods include dietary recalls (24h or 48h), food records (over 3, 4 or 7 days), food frequency questionnaires and discretionary salt use. These are widely applied since they are easy, practical and very low cost. However, a possible change of behaviour with under-reporting of sodium intake represents one of the major disadvantages inherent to this methods[7].

Salt intake in the world

In 2009, Brown *et al.* published an overview of salt intake worldwide and concluded that in most populations, salt intake was greater than the recommended dietary intake. During childhood, sodium intake over 100 mmol/day (equivalent to 5.8 g/day) was commonly found among 5-year-old children and the tendency was to increase from that age. Regarding the main sources of dietary sodium, in European and Northern American countries a significant amount of ingested sodium is added in food manufacture, whereas in developing countries sodium intake is mainly associated with the addition of salt in meal preparation and sauces[8].

More recently, Thout *et al.* identified 13 nationally representative studies from 13 different countries that exceeded the WHO recommended salt intake of 5 g/day. The mean daily salt intake reported ranged from 6.75 g/day in Barbados to 10.66 g/day in Portugal. In only 4 countries (Italy, England, Canada and Barbados) was the amount of salt intake lower than the previous report, The Global Burden of Disease 2010, probably due to the implementation of salt intake reduction programmes in these countries. Conversely, in Fiji, Benin and Samoa, the amount of salt intake reported was higher than that found by The Global Burden of Disease 2010, which could be explained by the nutritional transition from traditional to processed foods that is happening in many low- and middle-income countries[9].

According to the latest European Commission data (2014), Portugal ranked fourth among the countries with the highest salt consumption, with an estimated 12.3 g/day, while Spain had a slightly lower consumption, of around 11.5 g/day. With implementation of the European Union Salt Reduction Framework, Portugal and Spain have developed specific national benchmarks for salt reduction, covering between 1 and 80 food categories[10].

EFFECTS OF SALT ON BLOOD PRESSURE

Evidence during childhood and adolescence

Several observational studies have analysed and demonstrated the importance of salt intake as a contributing factor to developing changes in BP among children and adolescents. Pomenraz *et al.* conducted a study with 867 fourth and fifth graders from Israel, showing changes in BP when children ingested water containing high levels of sodium and nitrate[11]. Yang *et al.* led a study in the USA, which included 6235 children and adolescents from the National Health and Nutrition Examination Survey (NHANES) 2003-2008, aged 8 to 18 years. The study population included 37% overweight or obese individuals. Participants consumed an average 3.387 g/day of sodium; increments of 1 g/day in sodium were associated with an increase in SBP of approximately 1.0 mmHg among all participants, and approximately 1.5 mmHg among overweight/obese individuals. The increases in BP were more evident among individuals in the highest sodium intake quartile and among overweight/obese participants[12]. Another observational study, which included 1424 healthy Italian children and adolescents, aged 6-18 years, aimed to investigate the relation between dietary sodium and potassium intake, BMI and BP. The authors concluded that the high sodium intake verified among the participants was directly associated with BP and BMI levels[13]. In a study conducted by our research group, we observed a distinct effect of salt on blood pressure between genders. Overweight/obese boys exhibited a daytime systolic blood pressure increase of around 1.0 mmHg per gram of daily salt intake, a trend not observed in normal-weight boys or girls[14].

Although there is less evidence available for children and adolescents, it does appear to be comparable with the findings of adult studies, demonstrating that the linear positive association between BP and sodium intake is present from early ages. It is important to note that even though differences in BP values of around 1 to 2 mmHg might seem clinically modest, particularly at an individual level, previous studies in adults that compared the effect of sodium reduction interventions with control groups showed that such differences were estimated to translate into a reduction in the relative risk for CV events of around 25%[15].

Tracking and programming

Events or exposure that occur in the prenatal and postnatal period of human life are considered a key component in the development of diseases such as high BP and hypertension in adulthood[16]. Besides having its roots in early life, BP additionally follows a tracking pattern, implying that children and adolescents with high BP values will most likely maintain them in adulthood. Both experimental and clinical studies support this evidence. Considering that hypertension is one of the major risk factors for CV disease and that the obesity epidemic is strongly related to higher BP values in childhood, the phenomenon of BP tracking has major public health repercussions and should be comprehensively studied[17].

The mechanisms of BP programming are dependent on maternal and placental factors that can independently or co-dependently control the in-utero and postnatal environments, influencing the risk of CV development later in life. The main systems affected by early-life environmental factors that can lead to hypertension are the renal and the vascular systems, and it is possible that many of the early changes involve epigenetic mechanisms[16]. Some variables that can affect BP tracking and programming include low birth weight (LBW), uteroplacental insufficiency and exposure to glucocorticoids, as described below.

Several studies performed both during childhood or adulthood consistently demonstrate that LBW has an inverse relation with hypertension, even after correction for gender, current weight at the time, smoking status and use of oral contraceptives[18]. Huxley *et al.* concluded that postnatal catch-up growth is associated with BP, and this relation is greater among individuals with LBW and subsequently accelerated postnatal growth[19]. Experimental studies support clinical evidence and suggest that the explanation for this phenomenon lies in nephron deficit, since impaired nephrogenesis is believed to lead to a less efficient kidney excretion of salt and, consequently, to a higher risk of developing hypertension and chronic kidney disease (CKD)[20].

Uteroplacental insufficiency results from inadequate blood flow from the mother to the foetus and therefore can result in intrauterine growth restriction (IUGR) with associated LBW. The greatest impact on adult BP appears to be when IUGR happens in synchrony with the period of nephrogenesis, which results in reduced nephron endowment, reduced renal mass and increased protein excretion, indicating the key role of the kidney in hypertension programming[21]. Interestingly, there seem to be sex-specific differences in the development of programmed hypertension in IUGR offspring. Ojeda *et al.* demonstrated that while postpubertal male IUGR offspring maintained hypertension in adulthood, postpubertal females tended to normalise BP values. These findings echo the well-known protective role of oestrogen in the development of hypertension[22]. In another study, Ojeda *et al.* showed that testosterone contributes to higher mean arterial pressure in postpubertal male IUGR offspring, probably due to inappropriate stimulation of the renin-angiotensin-aldosterone system (RAAS) and inhibition of vasopressin in the hypothalamic-pituitary-adrenal axis[23].

Salt sensitivity and special populations

Salt sensitivity is a physiological trait which leads to BP changes in some individuals that parallel changes in salt intake[24], representing an independent risk for CV disease and mortality[25]. Therefore, considering a population with a high salt intake, some individuals can excrete salt without increasing BP (salt-resistant, SR) while others (salt-sensitive, SS) cannot. Salt sensitivity prevalence is projected to be 25% in the general population and 50% in individuals with hypertension[26]. Weinberger *et al.* conducted a 27-year follow-up study of 430 normotensive and 278 hypertensive individuals and concluded that salt sensitivity is associated with a worse prognosis, even for normotensive individuals, with an increased mortality risk ratio and similar cumulative mortality among normotensive and hypertensive groups[27]. In an 18-year follow-up study, Mu *et al.* investigated the effects of salt sensitivity on the development of hypertension in 310 adolescents (101 SS and 209 SR) and established that SS participants had a higher incidence rate of hypertension than SR ones[28].

There are several risk factors associated with salt sensitivity (physiological, environmental, genetic and demographic such as sex, race and age) which make this phenomenon phenotypically heterogeneous[25]. Salt sensitivity has been linked to ethnicity (especially people with African ancestry), obesity, kidney disease or LBW. Conversely, it is also worth noting that some heterozygous carriers of mutations associated with salt-wasting tubulopathies, such as Gitelman syndrome, might be protected from the development of hypertension[29].

▪ Ethnicity

Among people of African ancestry, BP is indisputably higher than among people of European ancestry (Caucasians) with this ethnic difference presumably explained by how the kidney handles sodium. One study suggested that the higher sodium retention found among subjects of African descent was possibly imputable to an adaptive mechanism for regions with hot environments, where salt was a rarer resource. Now, this mechanism is considered unfit, leading to increased extracellular fluid volume and hypertension. Moreover, plasma levels of renin and aldosterone are consistently lower in people of African ancestry, with no apparent association between plasma renal activity and sodium intake[30]. Tu *et al.* also demonstrated that aldosterone and renin levels were significantly lower in people of African ancestry, whether adults or children, and that BP and plasma aldosterone levels had a significant positive association[31].

▪ Obesity

Visceral obesity and sugar consumption are known to be related with hypertension and directly associated with sodium intake[32,33]. During an early phase, obese individuals have a high glomerular filtration rate (GFR) and renal blood flow, which enhances sodium reabsorption, while maintaining excessive weight leads to severe hypertension and loss of nephrons and kidney function. The mechanisms that explain increased sodium reabsorption include compression of the kidneys due to excessive weight, activation of the sympathetic nervous system, overactivation of the RAAS and of the aldosterone/mineralocorticoid receptor system[32].

Adipose tissue produces many RAAS components such as angiotensin II, which will contribute to activation of the sympathetic nervous system and an increase in sodium retention[34]. On the other hand, activation of mineralocorticoid receptors induced by sodium intake may result in inappropriate aldosterone circulating levels, and consequently contribute to SS hypertension[32].

Obese hypertensive individuals often present with SS BP and increased renal sympathetic nervous system activity, indicating that these two mechanisms may be linked[32]. Leptin, a hormone predominantly secreted by adipocytes that inhibit feeding behaviour and induce thermogenesis, has been shown to increase sympathetic nerve activity in the kidneys and the adrenal glands. Additionally, leptin has a clear association with BP independently of weight, and this association is clearer

in children, which suggests an early role of leptin in inducing BP. Even though obese individuals exhibit high concentrations of leptin, adipocyte mass remains relatively equal, which suggests resistance to leptin's actions. However, in these individuals, the effects of leptin on BP are maintained. Therefore, obesity leads to hyperleptinemia with selective leptin resistance that induces sympathetic nervous system activation and hypertension[35].

· Chronic Kidney Disease

Chronic kidney disease is often related with the presence of SS hypertension resistant to treatment, which further contributes to the progression of kidney injury and CV disease. The mechanisms involved in SS hypertension in CKD are believed to include changes in the distal nephron sodium control induced by CKD itself, associated with renin-independent aldosterone secretion, activation of intrarenal RAAS, high sodium intake, metabolic acidosis, and proteinuria-induced sodium reabsorption[36].

Chronic kidney disease induces changes in sodium handling in the distal nephron, causing sodium reabsorption that leads to hypertension, but does not explain how CKD leads to SS hypertension. It is likely that in patients with CKD, factors other than hyperreninemia or hyperkalaemia can promote aldosterone secretion, and the candidates for this are metabolic acidosis, endothelin-1, adrenocorticotropic hormone, catecholamines, vasopressin and factors related with adipocytes[36].

In SS individuals, increased salt intake might promote sodium reabsorption independently of the RAAS, by direct activation of the mineralocorticoid receptor, in contrast to SR individuals, whereas increased salt intake promotes natriuresis and suppression of RAAS[36].

Moreover, CKD causes chronic metabolic acidosis, with diminished HCO3- and systemic pH levels, which leads to the activation of compensatory mechanisms to increase the acidification of urine[36]. In 2014, Krupp *et al.* conducted a study of 257 healthy children that found a significant association between dietary renal acid load and increased BP[37].

· Low Birth Weight

It is thought that the relation between LBW and the salt sensitivity of BP is caused by a shift in the pressure-natriuresis curve, which can be explained by several mechanisms, including congenital nephron deficit. Nephron deficit can lead to hypertension due to compensatory glomeruli hyperfiltration and hypertrophy that, over time, results in a shift in the pressure-natriuresis curve and lower GFR in LBW. Uric acid can also incite a pressure-natriuresis shift due to microvascular renal injury. De Boer *et al.* led research aiming to prove that LBW was associated with the salt sensitivity of BP and to explore the association between LBW and uric acid levels. The study concluded that an inverse relation between birth weight and salt sensitivity of BP exists and also found a positive association with uric acid. Additionally, renal microvascular injury caused by elevated levels of foetal uric acid can result in nephron deficit which, along with a significant association between the salt sensitivity of BP and uric acid found in the study, suggested that high levels of uric acid may be a risk factor for the development of SS hypertension[38]. In 2008, Simonetti *et al.* conducted a study of 50 children, 35 of whom had LBW, and found that children with LBW had impaired kidney size, which was inversely related to the SS increase in BP. Even though reduced renal mass is not a clear indicator of GFR or the number of nephrons, in the Simonetti study, children born with LBW presented reduced GFR in comparison to children with adequate weight for gestational age[39]. Recently, Ruys *et al.* led a cohort study which found the SS of BP was associated with LBW, lower fat mass, and BMI in 16% of the children under evaluation. Another mechanism that can relate the SS of BP and LBW is endothelial dysfunction. Endothelial dysfunction can result from decreased vasodilation mediated by NO or insulin insensitivity and might lead to an increase in renal vascular resistance and, consequently, to increased BP[40].

Impact of salt on cardiovascular risk

In spite of the fact that the relationship between salt intake and BP is well recognised, the association between salt intake, CV events and mortality is controversial, with prospective cohort studies demonstrating varying associations between salt intake, rates of CV events and death[41].

During childhood and adolescence CV events are very rare. Nonetheless, some authors report BP values to be associated with subclinical CV disease, which can start during childhood and lead to an increased risk of adverse CV events during adulthood[42].

A review conducted by Emmerik *et al.* summarised the existing evidence on the association between sodium intake during early life (first 6 months) and CV health outcomes later in life. The review included 25 studies (18 human and 7 animal studies) and the authors concluded that higher amounts of sodium intake shortly after birth may in fact increase the risk for CV events later in life[43].

Pulse wave velocity is considered the most accurate non-invasive method to assess arterial stiffness and has been associated not only with CV events but also with CV mortality in adult studies. Lurbe *et al.* conducted research of children and adolescents with normal BP, high-normal BP and hypertension. They found that pulse wave velocity was higher in the hypertensive and in the high-normal BP groups, demonstrating the presence of vascular function abnormalities at an early age. The authors also reported that in obese individuals with high-normal BP or with hypertension, the increase in pulse wave velocity values was of lower magnitude than in their normal weight counterparts, suggesting that the association of BP and arterial stiffness may be modified in the presence of obesity[44].

Seeking to prove that the well-known association of left ventricular mass and CV events in adulthood is also present in childhood and adolescence, Urbina *et al.* completed research with a total 723 participants aged 10 to 23 years. Left ventricular mass index was shown to be higher in the groups with pre-hypertension and hypertension. Additionally, diastolic function and lipid profile were better among the normotensive individuals[45].

Some studies report an association between high BP values in childhood and atherosclerosis later in life. A cohort study including 4,210 participants showed that increased carotid intima media thickness was higher among individuals with persistently high BP, both in childhood (4-18 years) and adulthood (23-46 years), as well as among individuals with high BP in adulthood but normal values during childhood. The subjects with higher BP values during childhood but normal BP in adulthood did not have a significantly increased risk of higher carotid intima media thickness[46].

Although some evidence exists for the association between childhood BP and CV events later in life, very few studies have attempted to ascertain the impact of salt intake on the risk of subclinical or overt CV disease. Since the evidence for this association is very limited, more well-designed studies that relate salt intake and CV events with adequate follow-up periods are necessary in order to obtain stronger evidence on this issue.

IMPACT OF STRATEGIES FOR DIETARY SALT INTAKE REDUCTION

Dietary salt intake reduction can be achieved through different strategies such as public education, individual dietary counselling, food labelling, government policies or regulations, and sodium reduction in the food industry.

Huang *et al.* conducted a systematic review and meta-analysis with the goal of exploring the dose-response relation between lower sodium intake and BP changes along with the impact of the duration of the intervention. The review analysed 133 studies (including 12,197 participants) and demonstrated that after a reduction in sodium intake, an overall mean change in 24 hour urinary sodium of -130 mmol (-145 mmol to -115 mmol, 95% CI) was observed, together with a mean change of -4.26 mmHg in SBP (-4.89 mmHg to -3.62 mmHg, 95% CI) and -2.07 mmHg in DBP (-2.48 mmHg to -1.67 mmHg, 95% CI). The effect of reducing sodium intake on BP was significant both among female and male participants, hypertensive and normotensive groups, and in all ethnic groups. Overall, the review did not identify a relation between the duration of the intervention (salt reduction) and changes in BP, except that in trials with interventions lasting less than 15 days, the effect of sodium restriction in BP may be undervalued. As stated by the authors, sodium reduction has benefits for normotensive participants, therefore it could be a significant element in delaying the development of hypertension with aging[47]. In another systematic review and meta-analysis including 34 trials (3,230 participants), He *et al.* reported that with a long-term (4 weeks or more) modest reduction in salt intake (within the range of 2.3 to 7.0 g/day of salt, equivalent to 40 to 120 mmol) there were no significant differences in the concentration of plasma hormones or lipids[48].

Dietary sodium intake reduction can also have positive effects on CV health, which can be independent of or cumulative to those observed in BP. Salt intake reduction can, for example, have a positive impact on the risk of stroke, left ventricular hypertrophy, renal disease and proteinuria[49]. Supporting this evidence, a 10 to 15-year follow-up study of TOHP I and II revealed that participants with prehypertension designated to the intervention group (individuals submitted to dietary sodium reduction) had a 25% to 30% reduction in risk of developing CV events[50]. Also, a study by Jablonski *et al.* demonstrated that macro- and microvascular endothelial dysfunction can be reversed in middle-aged/older individuals with high SBP by a dietary sodium reduction approach, through reducing oxidative stress and increasing the bioavailability of NO and one of its cofactors, tetrahydrobiopterin[51].

In a cluster randomised trial (School-EduSalt), He *et al.* analysed whether an educational programme targeted at schoolchildren could decrease salt intake in children and their families. Children from 28 primary schools in China (n=279; mean age of 10.1 years) and 553 adults (n=553 , mean age of 43.8 years) participated in the trial for a period of 3.5 months. The intervention group was first educated about the harmful effects of salt and how to reduce intake, and then the children presented the information to their families. The results demonstrated that salt intake decreased in the intervention group (both in children and adults) and increased in the control group, with the differences between the two groups being 1.9 g/day (-2.6 to -1.3 g/day, 95% CI) in children and 2.9 g/day (-3.7 to -2.2 g/day, 95% CI) in adults[51]. In the intervention group, SBP decreased 0.8 mmHg (-3.9 to -1.5 mmHg, 95% CI) in children and 2.3 mmHg (-4.5 to -0.04 mmHg, 95% CI) in adults, proving that educational programmes are effective at reducing salt intake and therefore decreasing BP[52].

He and MacGregor published a meta-analysis in 2006 that reviewed 13 trials in order to assess the effects of salt restriction on BP in infants, children and adolescents. In the 3 trials that included infants (a total 551 participants), the median salt intake reduction was of 54 %, and the median duration was 20 weeks (from 8 weeks to 6 months). The analysis showed a significant decrease in SBP of approximately -2.47 mmHg (-4.00 to -0.94, 95% CI). In the other 10 trials, which included children and adolescents (a total 966 participants), with a median age of 13 years (ranging from 8 to 16 years), the salt intake reduction was a median 42% with a median duration of 4 weeks (from 2 weeks to 3 years). The analysis showed a significant reduction in SBP of approximately -1.17 mmHg (-1.78 to -0.56, 95% CI) and approximately -1.29 mmHg (-1.94 to -0.65, 95% CI) in DBP[53].

A recent intervention review assessed the effects and safety on the cardiovascular health of adults, pregnant

women and children of reducing sodium intake by replacing salt with low-sodium salt substitutes (LSSS). The authors concluded that LSSS probably reduce blood pressure, non-fatal cardiovascular events and cardiovascular mortality slightly in adults. However, the evidence is still uncertain regarding children[54].

CONCLUSIONS

Sodium intake exists in all cultures and countries worldwide. It is mostly consumed in processed foods and snacks, but it is also added to home-cooked meals. Even though the organism requires physiological quantities of sodium, in general, dietary salt intake is above WHO recommended values. This large consumption of sodium has negative effects on adults but also on children and adolescents. Several studies demonstrate that high dietary sodium intake is associated with higher values of BP. Children and adolescents with a higher BP are at increased risk of developing hypertension later in life, since BP follows a tracking pattern. Moreover, BP can be programmed depending on maternal and placental factors that control the in-utero and postnatal environments. The prevalence of hypertension is increasing, rendering this disease a global health problem. Sodium intake and BP during childhood are also known to be linked to CV events later in life but studies regarding this topic are few. To date sufficient evidence exists to suggest that the prevention and treatment of hypertension are crucial in the prevention of CV events and CKD.

Given that high sodium intake is associated with hypertension and CV health consequences, there is a compelling need to decrease the amount of sodium ingested and prevent these diseases. Cost-effective initiatives aimed at reducing sodium intake have the potential to lower the prevalence of cardiovascular diseases, thereby mitigating healthcare costs. Therefore, proactive endeavours should be undertaken to implement such programmes, particularly among young people.

HIGHLIGHTS

- Sodium intake is present among all cultures and countries worldwide. In most world countries dietary salt intake is higher than WHO recommended values.
- Hypertension is a global health problem, with increasing prevalence.
- Excessive salt consumption is known to be associated with higher values of BP, both in adults and in children.
- Sodium intake is also known to be linked to cardiovascular events later in life.
- Initiatives aimed at reducing sodium intake and lowering the prevalence of cardiovascular diseases, thereby mitigating healthcare costs, should be undertaken.

References

1. He FJ, MacGregor GA. Reducing Population Salt Intake Worldwide: From Evidence to Implementation. Prog Cardiovasc Dis. W.B. Saunders; 2010 Mar;52(5):363–82.
2. Leyvraz M, Chatelan A, Da Costa BR, Taffé P, Paradis G, Bovet P, *et al.* The Perils of Sodium Sodium intake and blood pressure in children and adolescents: a systematic review and meta-analysis of experimental and observational studies. Int J Epidemiol. 2018;47(6):1796–810.
3. Fisher NDL, Curfman G. Hypertension - A Public Health Challenge of Global Proportions. JAMA - Journal of the American Medical Association. American Medical Association; 2018. p. 1757–9.
4. WHO. Sodium intake for adults and children [Internet]. Geneva: WHO, http://www.who.int/nutrition/publications/guidelines/sodium_intake_printversion.pdf (accessed February 20, 2015). Geneva: World Health Organization (WHO); 2012. Available from: http://www.ncbi.nlm.nih.gov/books/NBK133309/
5. U.S. Department of Agriculture, U.S. Department of Health and Human Services. Dietary Guidelines for Americans, 2020-2025 . 2020 Dec.
6. Alan J, Committee & Salt subgroup. Salt and Health Scientific Advisory Committee on Nutrition . 2003.
7. Perin MS, Gallani MCBJ, Andrechuk CRS, São-João TM, Rhéaume C, Cornélio ME. What methods have been used to estimate salt intake? A systematic review. Int J Food Sci Nutr. Taylor and Francis Ltd; 2020 Jan;71(1):22–35.
8. Brown IJ, Tzoulaki I, Candeias V, Elliott P. Salt intakes around the world: implications for public health. Int J Epidemiol [Internet]. 2009/04/09. 2009 Jun [cited 2015 Jan 20];38(3):791–813. Available from: http://www.ncbi.nlm.nih.gov/pubmed/19351697
9. Thout SR, Santos JA, McKenzie B, Trieu K, Johnson C, McLean R, *et al.* The Science of Salt: Updating the evidence on global estimates of salt intake. Journal of Clinical Hypertension. Blackwell Publishing Inc.; 2019. p. 710–21.
10. Survey on Member States' implementation of the EU salt reduction framework - Publications Office of the EU [Internet]. [cited 2023 Dec 26]. Available from: https://op.europa.eu/en/publication-detail/-/publication/df7ef17e-d643-4593-94b3-84bacfa7a76a
11. Pomeranz A, Korzets Z, Vanunu D, Krystal H, Wolach B. Elevated salt and nitrate levels in drinking water cause an increase of blood pressure in schoolchildren. Kidney Blood Press Res. S. Karger AG; 2000;23(6):400–3.
12. Yang Q, Zhang Z, Kuklina E V, Fang J, Ayala C, Hong Y, *et al.* Sodium intake and blood pressure among US children and adolescents. Pediatrics [Internet]. 2012 Oct [cited 2014 Jul 31];130(4):611–9. Available from: http://www.ncbi.nlm.nih.gov/pubmed/22987869
13. Campanozzi A, Avallone S, Barbato A, Iacone R, Russo O, De Filippo G, *et al.* High Sodium and Low Potassium Intake among Italian Children: Relationship with Age, Body Mass and Blood Pressure. PLoS One [Internet]. 2015 Jan [cited 2015 Jun 3];10(4):e0121183. Available from: http://dx.plos.org/10.1371/journal.pone.0121183
14. Correia-Costa L, Cosme D, Nogueira-Silva L, Morato M, Sousa T, Moura C, *et al.* Gender and obesity modify the impact of salt intake on blood pressure in children. Pediatr Nephrol [Internet]. 2016 Sep 29 [cited 2015 Oct 1];31(2):279–88. Available from: http://www.ncbi.nlm.nih.gov/pubmed/26420679
15. Cook NR, Cutler JA, Obarzanek E, Buring JE, Rexrode KM, Kumanyika SK, *et al.* Long term effects of dietary sodium reduction on cardiovascular disease outcomes: Observational follow-up of the trials of hypertension prevention (TOHP). Br Med J. BMJ; 2007 Apr;334(7599):885–8.
16. Morton JS, Cooke CL, Davidge ST. In utero origins of hypertension: Mechanisms and targets for therapy. Physiol Rev. 2016;96(2):549–603.
17. Chen X, Wang Y. Tracking of blood pressure from childhood to adulthood: a systematic review and meta-regression analysis. Circulation [Internet]. 2008/06/19. 2008 Jun 24 [cited 2013 Dec 18];117(25):3171–80. Available from: http://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=3568631&tool=pmcentrez&rendertype=abstract
18. Mu M, Wang S-F, Sheng J, Zhao Y, Li H-Z, Hu C-L, *et al.* Birth weight and subsequent blood pressure: a meta-analysis. Arch Cardiovasc Dis [Internet]. 2012 Feb [cited 2015 Feb 13];105(2):99–113. Available from: http://www.ncbi.nlm.nih.gov/pubmed/22424328
19. Huxley RR, Shiell AW, Law CM. The role of size at birth and postna-

tal catch-up growth in determining systolic blood pressure: A systematic review of the literature. J Hypertens. Lippincott Williams and Wilkins; 2000;18(7):815–31.
20. Luyckx VA. Prenatal Antecedents of Chronic Kidney Disease. Chronic Renal Disease. Elsevier; 2020. p. 297–312.
21. Jones JE, Jurgens JA, Evans SA, Ennis RC, Villar VAM, Jose PA. Mechanisms of Fetal Programming in Hypertension. Int J Pediatr. Hindawi Limited; 2012;2012:1–7.
22. Ojeda NB, Grigore D, Robertson EB, Alexander BT. Estrogen protects against increased blood pressure in postpubertal female growth restricted offspring. Hypertension [Internet]. 2007 Oct [cited 2015 Feb 12];50(4):679–85. Available from: http://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=2850594&tool=pmcentrez&rendertype=abstract
23. Ojeda NB, Grigore D, Yanes LL, Iliescu R, Robertson EB, Zhang H, *et al.* Testosterone contributes to marked elevations in mean arterial pressure in adult male intrauterine growth restricted offspring. Am J Physiol - Regul Integr Comp Physiol. Am J Physiol Regul Integr Comp Physiol; 2007 Feb;292(2).
24. Elijovich F, Weinberger MH, Anderson CAM, Appel LJ, Bursztyn M, Cook NR, *et al.* Salt sensitivity of blood pressure : A scientific statement from the American Heart Association. Hypertension. Lippincott Williams and Wilkins; 2016 Sep;68(3):e7–46.
25. Pilic L, Pedlar CR, Mavrommatis Y. Salt-sensitive hypertension: Mechanisms and effects of dietary and other lifestyle factors. Nutr Rev. Oxford University Press; 2016 Oct;74(10):645–58.
26. Heinzel FR. The essential challenges of salt-sensitivity of blood pressure. Journal of Molecular and Cellular Cardiology. Academic Press; 2021. p. 1–2.
27. Weinberger MH, Fineberg NS, Fineberg SE, Weinberger M. Salt sensitivity, pulse pressure, and death in normal and hypertensive humans. Hypertension. Lippincott Williams and Wilkins; 2001. p. 429–32.
28. Mu J, Zheng S, Lian Q, Liu F, Liu Z. Evolution of blood pressure from adolescents to youth in salt sensitivies: a 18-year follow-up study in Hanzhong children cohort. Nutr J [Internet]. 2012 Jan [cited 2015 Jan 28];11:70. Available from: http://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=3502406&tool=pmcentrez&rendertype=abstract
29. Melander O, Orho-Melander M, Bengtsson K, Lindblad U, Råstam L, Groop L, *et al.* Genetic variants of thiazide-sensitive NaCl-cotransporter in Gitelman's syndrome and primary hypertension. Hypertension. 2000;36(3):389–94.
30. Lindhorst J, Alexander N, Blignaut J, Rayner B. Differences in hypertension between blacks and whites: An overview. Cardiovascular Journal of South Africa. Clinics Cardive Publishing (Pty) Ltd.; 2007. p. 241–7.
31. Tu W, Eckert GJ, Hannon TS, Liu H, Pratt LM, Wagner MA, *et al.* Racial differences in sensitivity of blood pressure to aldosterone. Hypertension. Lippincott Williams and Wilkins; 2014;63(6):1212–8.
32. Hirohama D, Fujita T. Evaluation of the pathophysiological mechanisms of salt-sensitive hypertension. Hypertension Research. Nature Publishing Group; 2019. p. 1848–57.
33. Genovesi S, Giussani M, Orlando A, Orgiu F, Parati G. Salt and Sugar: Two Enemies of Healthy Blood Pressure in Children. Nutrients [Internet]. Nutrients; 2021 Feb 1 [cited 2022 Oct 22];13(2):1–15. Available from: https://pubmed.ncbi.nlm.nih.gov/33671538/
34. Yiannikouris F, Gupte M, Putnam K, Thatcher S, Charnigo R, Rateri DL, *et al.* Adipocyte deficiency of angiotensinogen prevents obesity-induced hypertension in male mice. Hypertension. NIH Public Access; 2012 Dec;60(6):1524–30.
35. Kalil GZ, Haynes WG. Sympathetic nervous system in obesity-related hypertension: mechanisms and clinical implications. Hypertens Res [Internet]. 2012 Jan [cited 2015 Feb 2];35(1):4–16. Available from: http://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=3902842&tool=pmcentrez&rendertype=abstract
36. Bovée DM, Cuevas CA, Zietse R, Danser AHJ, Mirabito Colafella KM, Hoorn EJ. Salt-sensitive hypertension in chronic kidney disease: Distal tubular mechanisms. American Journal of Physiology - Renal Physiology. American Physiological Society; 2020. p. F729–45.
37. Krupp D, Shi L, Remer T. Longitudinal relationships between diet-dependent renal acid load and blood pressure development in healthy children. Kidney Int. Nature Publishing Group; 2014 Jan;85(1):204–10.
38. De Boer MP, Ijzerman RG, De Jongh RT, Eringa EC, Stehouwer CDA, Smulders YM, *et al.* Birth weight relates to salt sensitivity of blood pressure in healthy adults. Hypertension. Hypertension; 2008 Apr;51(4):928–32.
39. Simonetti GD, Raio L, Surbek D, Nelle M, Frey FJ, Mohaupt MG. Salt sensitivity of children with low birth weight. Hypertension. Hypertension; 2008 Oct;52(4):625–30.
40. Ruys CA, Rotteveel J, Van De Lagemaat M, Lafeber HN, Finken MJJ. Salt sensitivity of blood pressure at age 8 years in children born preterm. J Hum Hypertens. Nature Publishing Group; 2018 May;32(5):367–76.
41. Rhee MY, Jeong YJ. Sodium intake, blood pressure and cardiovascular disease. Korean Circulation Journal. Korean Society of Circulation; 2020. p. 555–71.
42. Appel LJ, Lichtenstein AH, Callahan EA, Sinaiko A, Van Horn L, Whitsel L. Reducing Sodium Intake in Children: A Public Health Investment. J Clin Hypertens. Blackwell Publishing Inc.; 2015 Sep;17(9):657–62.
43. Emmerik NE, De Jong F, Van Elburg RM. Dietary Intake of Sodium during Infancy and the Cardiovascular Consequences Later in Life: A Scoping Review. Annals of Nutrition and Metabolism. 2020. p. 114–21.
44. Lurbe E, Torro I, Garcia-Vicent C, Alvarez J, Fernández-Fornoso JA, Redon J. Blood pressure and obesity exert independent influences on pulse wave velocity in youth. Hypertension [Internet]. 2012 Aug [cited 2014 Jan 22];60(2):550–5. Available from: http://www.ncbi.nlm.nih.gov/pubmed/22733475
45. Urbina EM, Khoury PR, McCoy C, Daniels SR, Kimball TR, Dolan LM. Cardiac and vascular consequences of pre-hypertension in youth. J Clin Hypertens [Internet]. 2011/05/07. 2011 May [cited 2015 Mar 31];13(5):332–42. Available from: http://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=3092159&tool=pmcentrez&rendertype=abstract
46. Juhola J, Magnussen CG, Berenson GS, Venn A, Burns TL, Sabin MA, *et al.* Combined effects of child and adult elevated blood pressure on subclinical atherosclerosis: The international childhood cardiovascular cohort consortium. Circulation. Lippincott Williams & Wilkins Hagerstown, MD; 2013 Jul;128(3):217–24.
47. Huang L, Trieu K, Yoshimura S, Neal B, Woodward M, Campbell NRC, *et al.* Effect of dose and duration of reduction in dietary sodium on blood pressure levels: Systematic review and meta-analysis of randomised trials. The BMJ. BMJ Publishing Group; 2020.
48. He FJ, Li J, MacGregor GA. Effect of longer term modest salt reduction on blood pressure: Cochrane systematic review and meta-analysis of randomised trials. BMJ (Online). British Medical Journal Publishing Group; 2013.
49. He FJ, MacGregor GA. Salt, blood pressure and cardiovascular disease. Current Opinion in Cardiology. 2007. p. 298–305.
50. Cook NR, Cutler JA, Obarzanek E, Buring JE, Rexrode KM, Kumanyika SK, *et al.* Long term effects of dietary sodium reduction on cardiovascular disease outcomes: observational follow-up of the trials of hypertension prevention (TOHP). Bmj. 2007/04/24. 2007;334(7599):885–8.
51. Jablonski KL, Racine ML, Geolfos CJ, Gates PE, Chonchol M, McQueen MB, *et al.* Dietary sodium restriction reverses vascular endothelial dysfunction in middle-aged/older adults with moderately elevated systolic blood pressure. J Am Coll Cardiol. 2013 Jan;61(3):335–43.
52. He FJ, Wu Y, Feng X-X, Ma J, Ma Y, Wang H, *et al.* School based education programme to reduce salt intake in children and their families (School-EduSalt): cluster randomised controlled trial.
53. He FJ, MacGregor GA. Importance of salt in determining blood pressure in children: meta-analysis of controlled trials. Hypertension [Internet]. 2006/09/27. 2006 Nov [cited 2015 Jan 28];48(5):861–9. Available from: http://www.ncbi.nlm.nih.gov/pubmed/17000923
54. Brand A, Visser ME, Schoonees A, Naude CE. Replacing salt with low-sodium salt substitutes (LSSS) for cardiovascular health in adults, children and pregnant women. Cochrane database Syst Rev [Internet]. Cochrane Database Syst Rev; 2022 Aug 10 [cited 2023 Dec 26];8(8). Available from: https://pubmed.ncbi.nlm.nih.gov/35944931/
55. National Academies of Sciences E and M. Dietary Reference Intakes for Sodium and Potassium. Diet Ref Intakes Sodium Potassium. National Academies Press; 2019 Mar 5;