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Impact of Salt Intake on the Pathogenesis and Treatment of Hypertension

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Abstract

Excessive dietary salt (sodium chloride) intake is associated with an increased risk for hypertension, which in turn is especially a major risk factor for stroke and other cardiovascular pathologies, but also kidney diseases. Besides, high salt intake or preference for salty food is discussed to be positive associated with stomach cancer, and according to recent studies probably also obesity risk. On the other hand a reduction of dietary salt intake leads to a considerable reduction in blood pressure, especially in hypertensive patients but to a lesser extent also in normotensives as several meta-analyses of interventional studies have shown. Various mechanisms for salt-dependent hypertension have been put forward including volume expansion, modified renal functions and disorders in sodium balance, impaired reaction of the renin-angiotensin-aldosterone-system and the associated receptors, central stimulation of the activity of the sympathetic nervous system, and possibly also inflammatory processes.

Not every person reacts to changes in dietary salt intake with alterations in blood pressure, dividing people in salt sensitive and insensitive groups. It is estimated that about 50–60 % of hypertensives are salt sensitive. In addition to genetic polymorphisms, salt sensitivity is increased in aging, in black people, and in persons with metabolic syndrome or obesity. However, although mechanisms of salt-dependent hypertensive effects are increasingly known, more research on measurement, storage and kinetics of sodium, on physiological properties, and genetic determinants of salt sensitivity are necessary to harden the basis for salt reduction recommendations.

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Currently estimated dietary intake of salt is about 9–12 g per day in most countries of the world. These amounts are significantly above the WHO recommended level of less than 5 g salt per day. According to recent research results a moderate reduction of daily salt intake from current intakes to 5–6 g can reduce morbidity rates. Potential risks of salt reduction, like suboptimal iodine supply, are limited and manageable. Concomitant to salt reduction, potassium intake by higher intake of fruits and vegetables should be optimised, since several studies have provided evidence that potassium rich diets or interventions with potassium can lower blood pressure, especially in hypertensives.

In addition to dietary assessment the gold standard for measuring salt intake is the analysis of sodium excretion in the 24 h urine. Spot urine samples are appropriate alternatives for monitoring sodium intake. A weakness of dietary evaluations is that the salt content of many foods is not precisely known and information in nutrient databases are limited. A certain limitation of the urine assessment is that dietary sources contributing to salt intake cannot be identified.

Salt reduction strategies include nutritional education, improving environmental conditions (by product reformulation and optimization of communal catering) up to mandatory nutrition labeling and regulated nutrition/health claims, as well as legislated changes in the form of taxation.

Regarding dietary interventions for the reduction of blood pressure the Dietary Approaches to Stop Hypertension (DASH) diet can be recommended. In addition, body weight should be normalized in overweight and obese people (BMI less than 25 kg/m^2), salt intake should not exceed 5 g/day according to WHO recommendations (<2 g sodium/day), no more than 1.5 g sodium/d in blacks, middle- and older-aged persons, and individuals with hypertension, diabetes, or chronic kidney disease, intake of potassium (~4.7 g/day) should be increased and alcohol consumption limited. In addition, regular physical activity (endurance, dynamic resistance, and isometric resistance training) is very important.

Keywords

Physiology of sodium chloride • Renin-angiotensin-aldosterone system • Hypertension • Cardiovascular diseases • Salt sensitivity • Mechanisms of salt induced hypertension • Salt intake • Assessment of salt intake • Salt intake recommendations • Salt reduction strategies

Debates on whether current salt intake is too high for health reasons are ongoing for years. To take on the worldwide non-communicable disease challenge the recommendation for dietary salt reduction is one of the top priority actions of the WHO and member nations are stimulated to take action too (WHO and FAO Expert Consultation 2003; WHO 2012, 2014). Convincing scientific and medical evidence which associates excessive sodium intake to high blood pressure

and secondary consequences such as cardiovascular disease (CVD), stroke, and cardiac-related mortality supports these efforts (Aburto et al. 2013a). Nevertheless, concerns have been raised that a low sodium intake may adversely affect health by influencing blood lipids and insulin resistance (Nakandakare et al. 2008). This is in conflict with numerous recommendations and strategies of scientific institutions and professional health associations which have faced sodium reduction in the population to reduce these hazards.

This critical review summarizes the nutritional physiology of sodium chloride and the effect of salt intake on hypertension and other diseases. Putative mechanisms, determinants of salt sensitivity and the role of potassium in hypertension will be discussed separately. Furthermore potential dangers of a low salt diet and strategies for a reduction of salt intake will also be addressed in separate chapters.

1 Physiology of Sodium Chloride

Sodium chloride (NaCl, or common salt) is an ionic compound required to perform a variety of essential functions. Sodium is the major cation and chloride the major anion in the extracellular fluid. The concentration of Na^+ in the extracellular fluid is regulated at about 135–145 mmol/L; the distribution of Cl^- follows this of Na^+ with an extracellular concentration of about 110 mmol/L. Therefore, Na^+ and Cl^- are mainly responsible for the osmolarity of the extracellular fluid and constitute the most important electrolytes in the regulation of body fluids (Elmadfa and Leitzmann 2015; Gibney et al. 2009).

The intestinal tract absorbs nearly all dietary sodium, and the kidneys retain more than 90 % of the filtered Na^+. As a consequence of excessive excretion of sodium by extreme vomiting, diarrhea, or sweating blood sodium concentrations can drop and cause hyponatremia (serum sodium concentrations less than 135 mmol/l). Without treatment hyponatremia can lead to osmosis with the central nervous being especially vulnerable. Headache, confusion, or in the worst coma could be the consequence. Many diseases such as those of the kidneys, cancer, and heart disease can be associated with low blood sodium levels. On the contrary, especially dehydration and also more seldom rapid intake of large quantities of sodium can result in hypernatremia leading to neurological symptoms (Stipanuk and Caudill 2006).

Besides its importance with respect to the regulation of the water and fluid balance, sodium is vital for the excitation of muscle and nerve cells and is also partly involved in the control of the acid-base balance. Moreover, sodium helps to release digestive secretions and controls the absorption of some nutrients, such as amino acids, glucose, galactose, and water.

The renin-angiotensin-aldosterone system (RAAS), plays a key role in the regulation of sodium balance and blood pressure. Under normal physiological conditions a low salt diet stimulates RAAS by an increased release of renin from the juxtaglomerular cells of the kidneys which leads to an increase of angiotensin I stimulating angiotensin converting enzyme (ACE) in the lungs and release of angiotensin II. Angiotensin II is a potent vasoconstrictor and it stimulates aldosterone secretion from the adrenal cortex resulting in especially late tubular Na^+ and water reabsorption with increases in blood volume and blood pressure. In response to a high salt diet the RAAS is suppressed to some extent (Majid et al. 2015; Rassler 2010).

2 Dietary Requirements of Sodium Chloride

In terms of "how much" it should be noted that the human body contains about 0.15 % by weight sodium and chloride, respectively. This means that total body sodium as well as chloride have been considered at 60 mmol (1.38 g)/kg body weight or about 100 g for a 70 kg human.

For balance in the body the amount consumed must be equal to the amount lost. By estimation of obligatory losses in urine and faeces (1 mmol/day), and sweat (2–4 mmol/day) a minimum requirement of 1 mmol (23 mg) per 100 kcal or 24 mmol (550 mg) sodium per day was

calculated for healthy adults. When sweating heavily sodium loss is more than 0.5 g and required intake increases. Accordingly, under normal living conditions and physical activity an intake of 5 g salt per day is considered to be sufficient. Highest sodium retention of 1.2 mmol/day was shown in newborn due to their rapid growth during the first 4 month of life. During pregnancy and lactation there is an additional need of sodium of 3 and 6 mmol/day, respectively. People with large losses, like patients with cystic fibrosis, require substitution (Deutsche Gesellschaft für Ernährung (DGE), Österreichische Gesellschaft für Ernährung, Schweizerische Gesellschaft für Ernährung (SGE) (Hrsg.) 2015).

The human body tolerates a large range of sodium intake being considerably different between cultures (0.2 g/day in Yanomami Indians (Brazil) up to 10.3 g/day in northern parts of Japan). Maximum adaptation of sodium urine excretion permits an intake of 0.18 g (about 8 mmol) per day with a minimum loss of sweat. However it is uncertain that a diet with such low sodium content can meet the need of other nutrients (Institute of Medicine 2005).

3 Assessment of Salt Intake

The most common methods used to measure sodium intake are 24-h dietary recall, food frequency questionnaire (FFQ), or food record with their advantages and limitations. Although dietary sodium intake is very complex, useful informations can be obtained by these methods when measurement errors like underreporting or underestimation of amounts during a 24 h dietary recall or limited food selection of a FFQ are considered.

However, in a previous study Kersting et al. for example showed that urinary sodium excretion was 1.4–1.7 times higher than the sodium intake estimated by dietary records (3-day food diary). This implies that sodium intake assessed by dietary reports may be underreported by an average of 29–41 % (Kersting et al. 2006).

A major challenge of dietary assessment is that sodium intake is highly correlated with total energy intake whereby underreporting of food intake leads to underestimation of sodium intake. In addition, sodium content in recipes is highly variable as well as salt used in home cooking and at the table. A FFQ is a less reliable estimate of intake but provides good information of sources of sodium intake which is essential for public health interventions. Nevertheless, dietary assessment also enables recognition of relationships between sodium intake and supply with other nutrients or dietary pattern associated with specific diseases (McLean 2014).

In addition to dietary assessment, urine sodium excretion is measured as an indicator of salt intake. As more than 90 % of consumed sodium is absorbed and excreted in the urine (Holbrook et al. 1984), 24-h urine sodium excretion has been considered as the gold standard to assess dietary sodium intake. In hot climates and among highly physically active people the losses through sweat and faeces can be higher than 10 % which have been estimated under normal conditions. A correlation of 0.75 between sodium intake measured by a nutrition survey and 24-h urine sodium excretion over a 9-day collection were calculated by Luft and colleagues (Luft et al. 1982). To minimize errors caused by under-/overcollection of urine samples 24-h urine creatinine excretion can be assessed. Under physiological conditions, 24-h urine creatinine excretion is influenced only to a minor extent by kidney function itself, but correlates mainly with muscle mass and dietary meat ingestion. To assess completeness of urine collection para-aminobenzoic acid tables can be used. However there are limitations like decreased excretion with increasing age or interaction with other medications (McLean 2014).

Alternatively spot urine samples can be collected and evaluated. This requires correction for urine tonicity, which is accomplished by referring to urine creatinine (Kawasaki et al. 1993; Tanaka

et al. 2002; Toft et al. 2014). Because creatinine excretion depends on proportion of muscle mass, which is lower in women, older people, and individuals with lower body weight formula to correct creatinine excretion were developed. By adjusting for estimated creatinine excretion the correlation of spot urine sodium-to-creatinine ratio with 24-h urine sodium can be improved (Rhee et al. 2014). Actually several formulae have been developed but no single formula has been accepted for international use. This is challenging because validity of estimates is different between women and men as well as in different ethnic groups (McLean 2014).

Spot urine samples have greater intra-individual variability of sodium concentrations than 24 h samples and therefore are a poor predictor of individual sodium intake but an appropriate tool for monitoring. Huang et al. (2016) confirm in their systematic review and meta-analysis that estimates of mean population salt intake determined from spot urine samples were comparable to estimates based upon 24-h urine collection with a sensitivity of 97 % and specificity of 100 % for the 5 g/day WHO threshold (Huang et al. 2016). These results support that estimates of NaCl intake evaluated by spot urine samples can be used to make decisions on salt reduction programmes and evaluation of strategies. Nonetheless, the authors recognised an overestimation of intake by the equations at lower levels of intake and an underestimation at higher salt intake levels. Therefore, the collection of 24-h urine in a subsample is recommended.

Measuring sodium excretion in urine underestimates dietary salt intake due to unrecognised loss in sweat which is approximately 400 mg/day (equivalent to ~ 1 g NaCl) (Maughan and Leiper 1995). This amount of sodium is almost equal to the intake of sodium from natural food sources (400–500 mg/day) and therefore compensates losses by sweat whereby urine sodium excretion reflects actual salt intake quite well (Mattes 1990).

While a limitation of the urine assessment is that dietary sources contributing to salt intake cannot be identified, a weakness of the dietary evaluations is that the salt content of many foods is not precisely known and information in nutrient databases are limited.

4 Recommendations for Salt Intake

Dietary sodium is consumed mainly as salt: NaCl = Na (g) × 2.54

1 mmol sodium corresponds to 23.0 mg,
1 mmol chloride to 35.5 mg;
1 g NaCl consists of ~ 17 mmol sodium and chloride each.

The Word Health Organization (WHO) recommends a maximum salt intake of 5 g/day, equivalent of one teaspoon (WHO 2012). Due to the suggested potential to prevent and control non-communicable diseases the WHO has recommended reduction of salt intake in the extent of 30 % by 2025 (WHO 2013a). For children younger than 9 month no salt should be added to food. For children aged 18 months to 3 years, salt intake should be no more than 2 g per day (WHO 2012; WHO 2016). Based on the WHO recommendation the European Society of Hypertension/European Society of Cardiology (ESH/ESC) guidelines also propose to reduce dietary salt intake to 5 g/day for the management of hypertension (Mancia et al. 2013).

The Dietary Reference Intake (DRI) recommendation for sodium intake is less than 2.3 g/day (~6 g NaCl/day; UL = maximum level of daily nutrient intake) for healthy adults. The Adequate Intake (AI) is defined as an amount to obtain a nutritionally adequate diet and to meet the needs for sweat losses which result from recommended levels of physical activity (Institute of Medicine 2013). As most people consume far too much sodium this recommendation is set at an upper limit. Special population groups including hypertension patients should limit sodium consumption to 1.5 g/day. Thus, the American Heart Association advice to eat no more than 1.5 g of sodium per day for optimal heart health (American Heart Association 2016).

Table 1 Sodium intake recommendations

Life stage	AI (g/day) (DRI 2004)	UL (g/day) (DRI 2004)	Estimate value for min. intake (g/day) (DGE et al. 2015)
Infants:			**Infants:**
0–6 month	0.12	Not determinable	0– < 4 month: 0.1
7–12 month	0.37		4– < 12 month: 0.18
Children:			**Children:**
1–3 year	1.0	1.5	1– < 4 year: 0.3
4–8 year	1.2	1.9	4– < 7 year: 0.41
			7– < 10 year: 0.46
			10– < 13 year: 0.51
			13– < 15 year: 0.55
Adults:			**Adolescents/Adults:**
9– > 70 year	1.5	2.3	0.55
Pregnancy	1.5	2.3	
Lactation	1.5	2.3	

Deutsche Gesellschaft für Ernährung (DGE) et al. (2015), Institute of Medicine (2005)

The estimate value for minimum intake according to DACH reference values is about 550 mg/day for adolescents and adults (Deutsche Gesellschaft für Ernährung (DGE) et al. 2015) (Table 1).

Similar to the recommendations in USA, the Scientific Committee on Food established as acceptable range of sodium intakes for adults 25–150 mmol/day (0.6–3.5 g/day) (SCF 1993). The Reference Nutrient Intake in UK is 70 mmol/day (1.6 g/day) (Dietary reference values for food energy and nutrients for the United Kingdom 1991). The current sodium intake across Europe is much higher than the amounts required for normal function. For the reason that increased sodium intake is associated with high blood pressure, which in turn could result in cardiovascular and renal diseases, salt reduction is highly recommended.

5 Salt Intake and Hypertension

According to the WHO hypertension is the number one risk factor for mortality worldwide (WHO 2009). Furthermore hypertension is the primary contributor to DALYS (Disability-Adjusted Life Years) in the world (Lim et al. 2012) and a major risk factor for cardiovascular diseases, heart failure, kidney disease including nephrosclerosis, and retinopathy. Several factors are associated with a high blood pressure, such as especially genetic predispositions, but also age, overweight and obesity, low physical activity, and chronic stress (Dorner et al. 2013). In addition, there is convincing evidence that the diet, in front salt (sodium chloride) intake, has significant effects on the blood pressure (Dorner et al. 2013; Appel et al. 2006). The fact that sodium plays a prominent role in managing blood pressure has been well established for long now (Ekmekcioglu et al. 2013). Many trials have been published, showing that a reduction of sodium intake is associated with a reduction in systolic and diastolic blood pressure, especially in hypertensive but also in normotensive persons (He and MacGregor 2002).

Already in 1904 Ambard und Beaujard published a study showing the blood pressure rising effects of salt (Ambard and Beaujard 1904). More than 40 years later Dr. Walter Kempner impressively presented that an extreme salt deficient rice diet could lower the blood pressure of patients with severe hypertension for an average of 47 mmHg systolic and 21 mmHg diastolic (Kempner 1948). These remarkable effects are comparable with an intensive, modern antihypertensive drug therapy. However only approx. 60 % of Dr. Kempners

hypertensive patients reacted on salt reduction with noteable lowering of blood pressure. These patients are known as salt sensitive. This is described below (Dorner et al. 2013; Luft et al. 1979).

In the last decades the effects of salt on human blood pressure was investigated in several epidemiological and interventional studies. In one of the most famous and global, the Intersalt study, which included 32 countries and 52 different populations, it was shown that a 100 mmol higher urinary sodium excretion was associated with an average 6 or 3 mmHg higher systolic blood pressure (with or without adjustment for body mass index) (Elliott et al. 1996). Furthermore in a high British sample of more than 23 000 persons in the age of 45–79 years those with the lowest salt intake showed an average 7.2/3.0 mmHg (systolic/diastolic) lower blood pressure compared to the group with the highest intake. (Khaw et al. 2004).

Several interventional studies looked at the effect of salt reduction on blood pressure in hypertensive and normotensive individuals. Most of the studies lasted 2–8 weeks and the daily salt reduction was in the range of 4.3–9.3 g/day. This resulted in a reduction of blood pressure in the range of 3.9–5.9/1.9–3.8 mmHg (systolic/diastolic) in hypertensives and 1.2–2.4/0.3–1.1 mmHg (systolic/diastolic) in normotensives as a half a dozen meta-analyses have calculated (Fig. 1) (Aburto et al. 2013a; He and MacGregor 2002; Kotchen et al. 2013; Midgley et al. 1996; Cutler et al. 1997; Graudal et al. 1998; He et al. 2013).

In a recent meta-analysis, by including 103 studies, Mozaffarian and coworkers found a strong evidence for a linear dose-response effect with each reduction of sodium intake by 2.3 g/day (equivalent to approx. 5.8 g salt) being associated with a reduction of 3.82 mmHg systolic blood pressure (Mozaffarian et al. 2014).

Also the blood pressure of children is beneficially affected by salt reduction. In a large study in 650 children, a reduction in salt intake of 15–20 % through changes in food purchasing and in preparation practices in the schools' kitchens resulted in a significant fall in blood pressure after 6 months (Ellison et al. 1989), and in a meta-analysis by He and MacGregor of controlled trials it was concluded that an average reduction in salt intake by 42 % in children is associated with immediate decreases in blood pressure and, if continued, may prevent the subsequent rise in blood pressure with age (He and MacGregor 2006).

In addition to adverse effects on blood pressure a high salt consumption also may lead to other adverse outcomes on the cardiovascular system, such as endothelial dysfunction, and ventricular hypertrophy (Baldo et al. 2015; Du Cailar et al. 1992; Todd et al. 2010; Oberleithner et al. 2007). For example the acute intake of salt impairs the flow-mediated dilation of the brachial artery in healthy individuals (Dickinson et al. 2011). Importantly, excess salt intake also impairs endothelium-dependent dilation in salt resistant humans (DuPont et al. 2013).

Regarding cardiovascular risk recent meta-analyses calculated a reduced risk in cardiovascular events of approximately 10–20 % for a lower vs. higher salt intake (He and MacGregor 2011; Strazzullo et al. 2009).

5.1 Mechanisms of Salt-Dependent Hypertension

Arterial blood pressure is dependent on the cardiac output (heart rate × stroke volume) and total peripheral vascular resistance. Short and long term mechanisms are involved in the regulation of blood pressure by influencing these two variables (Porth 2009). In the short-term arterial and cardiopulmonary baroreflexes regulate mean arterial blood pressure by mainly modulating the activity of the autonomic nervous system. On the longer term especially endocrine mechanisms, in front the RAAS and vasopressin are involved in the regulation of blood pressure with the kidneys playing an important role.

Studies from Guyton from the early 60s showed that sodium loading lead to extracellular volume expansion and volume loaded hypertension in the context of induced renal dysfunction in dogs (Farquhar et al. 2015). This was in

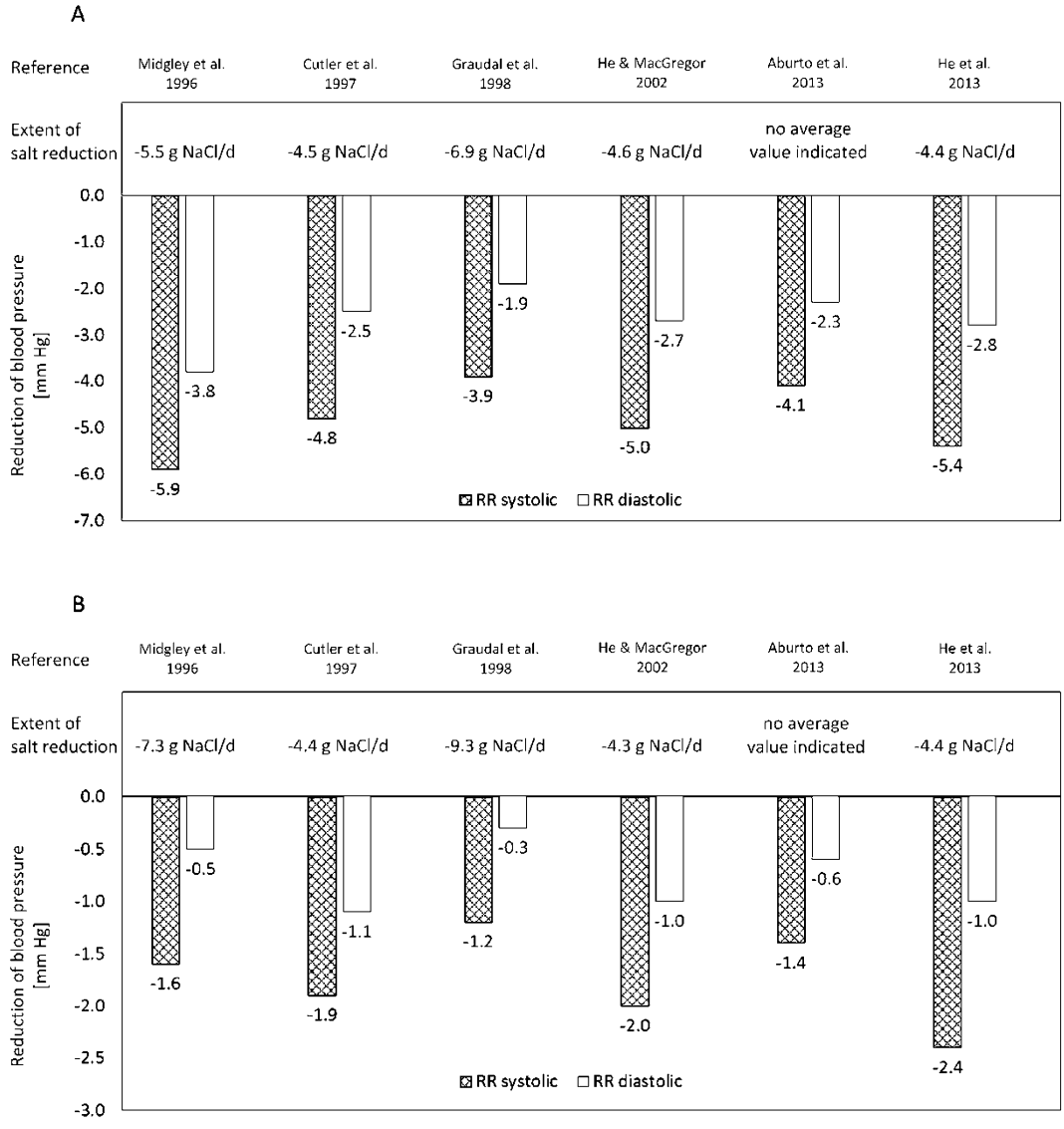

Fig. 1 (**a**) Effect of a salt reduction on the blood pressure of hypertensive patients. (**b**) Effect of a salt reduction on the blood pressure of normotensive persons. Average values are given for salt and blood pressure reduction

accordance with clinical studies in patients with chronic kidney disease (Koomans et al. 1982). Also according to Guyton, a rise in blood pressure above the pressure natriuresis equilibrium point, leads to an increase in sodium and water excretion, in turn lowering the blood pressure towards the previous levels (Guyton 1990; Luzardo et al. 2015). In salt sensitive individuals, the pressure natriuresis relationship is shifted to the right, meaning that higher blood pressure levels are necessary to increase renal sodium excretion and to maintain sodium balance (Guyton et al. 1972).

As mentioned before mean blood pressure is primarily dependent on (stroke) volume and peripheral vascular resistance. So salt induced increases in extracellular volume, and related to this stroke volume, would especially exert blood pressure raising effects if peripheral resistance does not decline compensatory (Schmidlin

et al. 2007). Therefore, an unchanged or increased peripheral resistance, in association with a salt-induced increase in cardiac output, would result in a salt-dependent blood pressure response, as shown in African Americans (Schmidlin et al. 2007).

Also an impaired reaction of the RAAS during a sodium manipulation may be linked to a salt sensitive blood pressure response. In this regard it is assumed that angiotensin II type 1 receptors may be involved in sodium-induced increases in blood pressure (Crowley et al. 2005). These are found in systemic as well as renal vasculature, and also in the central nervous system, where they are important for blood pressure and/or fluid volume regulation. In this regard high salt intake increases several components of the central RAAS, such as angiotensin II and aldosterone, in addition to the AT1 receptor, renin and ACE expression (Baldo et al. 2015; Huang et al. 2006). For example mice lacking renal angiotensin II type 1 receptors become salt sensitive (Mangrum et al. 2002). Furthermore the ChineseGenSalt studies identified angiotensin II type 1 gene variants as predictive of salt sensitivity (Gu et al. 2010).

In addition to the RAAS also modulation of the autonomic nervous system may be involved in salt sensitive hypertension. For example it is suggested that in rodents a salt induced central stimulation of the activity of the sympathetic nervous system leads to a rise in blood pressure (Farquhar et al. 2015; Brooks et al. 2005; Stocker et al. 2010). In humans for example, salt-sensitive individuals react with a higher increase in heart rate to mental stress compared to salt-resistant controls (Buchholz et al. 2003). A stimulatory effect of sodium on angiotensin II may also increase sympathetic outflow (Guild et al. 2012). Furthermore sodium induced temporary increases in osmolality may also affect sympathetic outflow (Farquhar et al. 2006). On the other hand also an acute, drastic lowering of sodium intake may activate the sympathetic nervous system in humans (Anderson et al. 1989). This can be explained as a stress reaction to acute salt (and volume) depletion.

The kidneys have a prominent role in salt dependent hypertension. Several experimental findings in genetically hypertensive rat strains provided evidence that renal mechanisms and disorders in sodium balance are involved in salt sensitive hypertension (Majid et al. 2015). Further evidence to the critical role of the kidneys in the development of hypertension stems from monogenic forms of human hypertension with abnormalities in tubular sodium transport leading to increased sodium reabsorption (Lifton et al. 2001; Shimkets et al. 1994).

Furthermore relating to animal studies it is suggested that serum- and glucocorticoid-inducible kinase (SGK), a downstream mediator of mineralocorticoid receptors (MRs) that activates the epithelial sodium channel in renal tubules, may be involved in the adaptation to salt and the pathogenesis of hypertension (Luzardo et al. 2015; Farjah et al. 2003). In Dahl salt-sensitive hypertensive rats for example, sodium intake upregulates the expression of SGK1, suggesting that MRs are activated in an aldosterone-independent manner (Farjah et al. 2003). Furthermore, an impairment of renal sodium excretion could be also due to renal inflammation, as suggested in experimental models (Rodriguez-Iturbe et al. 2012).

5.2 Salt Sensitivity

The blood pressure response to changes in sodium intake varies considerably among individuals. Whereas some persons can eat high amounts of salt without any or marginal effects on their blood pressure, others would react with a significant rise in blood pressure as a consequence of a sodium-rich diet indicating that the response to changes in blood pressure by dietary sodium is variable dividing the people in salt-sensitive and insensitive groups (Kawasaki et al. 1978; Luft et al. 1991). Weinberger et al. defined salt sensitivity if at least a 10 % increase in mean arterial pressure is found after a high salt vs. low salt challenge. Persons having smaller increases were defined as salt-resistant (Weinberger 1996). However, in general there

is no clear consensus on the definition of salt sensitivity in clinical practice (Luzardo et al. 2015; Rodriguez-Iturbe and Vaziri 2007).

In the literature approx. 50 % of hypertensives are estimated to be salt sensitive (Felder et al. 2013). In particular genetic polymorphisms have been linked to salt sensitivity, hypertension and cardiovascular disease (Trudu et al. 2013). Possible candidate genes include especially those that increase or decrease the expression of proteins which are involved in renal sodium transport (Armando et al. 2015). In addition to hypertensives and genetic polymorphisms salt sensitivity is especially also increased in aging (Weinberger and Fineberg 1991), in black people (Jenni and Suter 2011), and in persons with metabolic syndrome or obesity (Chen et al. 2009; Fujita 2014).

What is also important is that salt sensitivity in normotensive adults predicts future hypertension (Weinberger and Fineberg 1991; Sullivan 1991). Furthermore salt sensitivity has been associated with increased mortality in normal and hypertensive persons (Weinberger 2002).

6 High Salt Intake and Other Diseases

In addition to cardiovascular diseases a high dietary salt intake was also shown to be associated with an increased risk for gastric cancer and kidney disease. Furthermore in the last years there is accumulating evidence for a link between high dietary salt intake and risk for overweight and obesity.

6.1 Stomach Cancer

A recent meta-analysis of prospective cohort studies showed that dietary salt intake is directly associated with risk of gastric cancer, with progressively increasing risk across consumption levels (D'Elia et al. 2012). Furthermore 24 % of stomach cancer cases in the UK in 2010 were suggested to be attributed to high salt consumption (Parkin 2011). Various mechanisms, including an increased gastric *H. pylori* colonization, mutations, or exposure to carcinogens such as N-nitroso compounds from certain salty foods, are hypothesized to be involved in a higher gastric cancer risk by high dietary salt intake (Ge et al. 2012). According to the International Systematic Literature Review (2015) of the World Cancer Research Fund there were not enough data to conduct dose-response meta-analysis. The review did not observe a significant association comparing the highest versus lowest salt intake (measured by food frequency questionnaire) as well as comparing the highest versus lowest added salt intake. Nonetheless a significant positive association was observed for stomach cancer and with salted food intake and comparing preference for salty food versus no preference (Norat et al. 2015).

6.2 Renal Disease

Epidemiological studies reported an association between dietary salt intake and urinary albumin excretion, independent of blood pressure (du Cailar et al. 2002). In this regard it is known that urinary albumin levels are a risk factor for the development and progression of kidney disease and are also strong predictors for cardiovascular risk (Cerasola et al. 2010). In an interventional study in three ethnic groups, a reduction in salt intake of about 3.2 g per day over 6 weeks lead to significant reductions in blood pressure and urinary albumin excretion (He et al. 2009). Furthermore it was demonstrated that reduced salt intake may lower the risk of estimated glomerular filtration rate decline (Lin et al. 2010).

6.3 Obesity

Dietary salt induces hyperosmolar thirst in the hypothalamus leading to higher water intake and renal water excretion (Cowley et al. 1983). Many people, especially children and adolescents, prefer caloric, sugar-sweetened beverages (SSBs) instead of tap water or low energy drinks (Duffey et al. 2012). In a cross-sectional study in young British children and adolescents it was demonstrated that 31 % of total fluid intake were by SSBs (He et al. 2008) and a difference of 1 g/day in salt intake was associated with a difference of 100 and 27 g/day in total fluid and

SSBs consumption, respectively. Other studies also found a positive association between urinary sodium excretion/dietary salt intake and beverage consumption (Alexy et al. 2012; Grimes et al. 2013).

In a recent paper by Ma et al. in a collective of 458 British children and 785 adults it was demonstrated that salt intake was higher in overweight and obese individuals (Ma et al. 2015). A 1-g/day increase in salt intake was associated with an increase in the risk of obesity by 28 % (CI 95 %:1.12–1.45) in children and 26 % (CI 95 %: 1.16–1.37) in adults after adjusting for various factors. The results were independent from energy intake suggesting that other mechanisms such as higher consumption of sugar-sweetened soft drinks might have played a role. An experimental study for example showed that high dietary sodium intake in rats leads to higher plasma leptin concentrations and excessive accumulation of white adipose fat compared with the rats with lower salt intake (Fonseca-Alaniz et al. 2007).

Also human studies in healthy adolescents suggest a positive association between dietary salt intake and subcutaneous abdominal adipose tissue, independent of energy intake (Zhu et al. 2014). Future studies will gain more insight into the mechanisms between dietary salt intake and obesity.

In summary, the negative effects of a high sodium/salt intake are not only restricted to the cardiovascular and renal systems, but may also adversely affect our metabolism and energy intake. However, it should also be mentioned that regarding nutrition not only a low dietary intake of salt, but also a higher consumption of potassium-rich fruit and vegetables, as important components of a healthy diet, has preventive effects on chronic diseases including hypertension (Boeing et al. 2012). For example, several publications in the last years provided a high degree of evidence that a Dietary Approaches to Stop Hypertension (DASH)-style diet, which is based on fruits and vegetables with low-fat dairy products and low in saturated and total fat, exerts blood pressure lowering and cardioprotective effects (Dorner et al. 2013; Appel et al. 1997; Salehi-Abargouei et al. 2013).

7 Potassium and Hypertension

The association between potassium and blood pressure was already put forward for the first time in 1928 by W.L. Addison (Bulpitt 1981). Ever since then, many trials suggested or showed the blood pressure lowering effects of potassium. These were summarized and analysed in a handful of meta-analyses (Cappuccio and MacGregor 1991; Whelton et al. 1997; Dickinson et al. 2006; Aburto et al. 2013b; Geleijnse et al. 2003). All of these provided evidence that potassium rich diets or interventions with potassium can lower blood pressure, especially in hypertensives. In the most recent meta-analysis by Aburto et al. (Aburto et al. 2013b) it was for example shown that a higher potassium intake in the range of 90–120 mmol/day reduced blood pressure and was associated with a lower risk of stroke incidence. However, dietary amounts above 120 mmol/day seem to be not associated with additional beneficial effects. In addition, in combination with a recommended sodium intake of less than 2 g/day (about 5 g/day salt), sodium/potassium ratios with positive health effects can be obtained according to the authors. Furthermore, it was concluded that potassium may be more effective in reducing blood pressure at higher levels of sodium intake, consistent with previous findings (Whelton et al. 1997). The largest benefit was analysed when sodium intake was more than 4 g/day. However, potassium is also beneficial at lower intake values of sodium (Aburto et al. 2013b). In this regard, a recent meta-analysis found that potassium has relevant blood pressure reducing effects in hypertensive patients with salt-rich diets (van Bommel and Cleophas 2012). The effects were in the magnitude of −9.5 mmHg (95 % CI: −10.8 to −8.1) for systolic and −6.4 mmHg for diastolic blood pressure values (95 % CI: −7.3 to −5.6). Patients with reduced salt intake showed little effects from potassium treatment. Concomitantly to these results in the recent PURE study, a prospective cohort study of 102 216 participants from 18 countries with average cardiovascular risk, it was shown that a high salt intake was

more strongly associated with increased blood pressure in individuals with lower potassium excretion (Mente et al. 2014).

Finally, the advantages of dietary potassium on blood pressure may be strongest in salt-sensitive individuals (Dietary Guidelines Advisory Committee 2010). Therefore it is reasonable and important to not only recommend salt reduction but also to increase potassium intake (Aaron and Sanders 2013).

Potassium might exert blood pressure lowering effects through many pathways (reviewed in (Ekmekcioglu et al. 2016)). These include (1) stimulation of natriuresis, (2) improvement of endothelial function and NO release, (3) stimulation of the sodium/potassium pump and plasma membrane potassium channels leading to endothelial hyperpolarization and decrease in cytosolic smooth muscle calcium, and (4) decrease in the activity of the sympathetic nervous system with vascular smooth muscle relaxation.

Some authors also suggest an antioxidant effect of dietary potassium (Ishimitsu et al. 1996). Carotid artery rings from rabbits fed a low potassium diet for example showed an approximately 100 % higher formation of superoxide anions, enhanced norepinephrine contraction, and suppressed acetylcholine relaxation (Yang et al. 1998). In addition, dietary potassium supplementation suppressed ROS overproduction in injured arteries of salt-loaded Dahl S rats (Kido et al. 2008).

8 Potential Dangers of a Low-Salt Diet

A considerable restriction of sodium in the diet may bear some potential dangers (Burnier et al. 2015). One of these is iodine insufficiency, which is common in Alpine countries such as Austria (Burnier et al. 2015). The iodization of salt is an important and cost efficient strategy to combat iodine deficiency and related to this hypothyroidism in the general population. Reducing salt intake in the population may worsen the iodine status of especially people with suboptimal or marginal iodine intake. Different scenarios could estimate the dietary supply of iodine in case of salt reduction. For the Netherlands for example it was estimated that up to 10 % of the population would have an insufficient iodine supply when the dietary salt intake would be reduced by 50 % (Vandevijvere 2012; Verkaik-Kloosterman et al. 2010). A strategy to overcome this problem could be to increase the iodine content of salt.

Furthermore a low salt diet could increase the risk of volume depletion and hypotension in patients with acute dehydration or diarrhoea. Also, in elderly people, reducing salt in the diet could lead to altered food taste, which in turn my increase the risk of low energy intake and malnutrition (Zeanandin et al. 2012).

Although the benefits of salt reduction on blood pressure and human health is overwhelming there are also few studies showing an inverse or J-shaped association meaning that not only a high but also a low dietary salt intake might be associated with adverse health outcomes, especially on the cardiovascular system (Van Horn 2015).

For example the results of the ONTARGET and TRANSCEND trials in 28,880 people at high cardiovascular risk showed a J-shaped association with an increased risk for cardiovascular mortality in those consuming <3 g or >7 g sodium (approximately <7.5 salt or 17.5 g salt) per day (O'Donnell et al. 2011). A similar association was shown in the PURE study with low (<3 g/day) or high (≥ 7 g/day) sodium intakes being associated with higher risk of death or major vascular events (O'Donnell et al. 2014). A J-shaped relationship for all-cause or cardiovascular mortality was also shown in patients with type 1 and 2 diabetes mellitus, respectively (Thomas et al. 2011; Saulnier et al. 2014). An inverse association was reported in the Flemish Study on Genes, Environment and Health Outcomes and the European Project on Genes in Hypertension with an increased risk for cardiovascular disease (CVD) mortality in the lowest tertile of sodium intake (Stolarz-Skrzypek et al. 2011).

Since there are few indications that a low salt diet seems to be also, at least in part, associated

with an increased incidence of cardiovascular events and mortality, the important 2 questions are: what are the reasons for these negative outcomes and what are the suggested mechanisms? Is this due to the low sodium/salt intake per se or to one or more additional factors that might affect patients' survival? Another question might be whether the low salt intake in the patients is a consequence or a cause of their disease. This limiting issue is defined as reverse causality meaning that compromised patients may consume less sodium, because of medical advice or an illness-related reduction in food consumption (Cobb et al. 2014). It may also be relevant that some of the studies showing J-shaped or inverse associations included sick persons or were based on secondary analyses of studies not primarily intended to test these relationships.

One further major drawback in these studies are suboptimal methods in the assessment of sodium intake including food frequency questionnaires, or spot or overnight urine collection (Cobb et al. 2014).

9 Strategies for Reduction of Salt Intake

For millions of years, dietary salt intake was very low (0.1–1 g/day). Main source of NaCl was meat containing about 1.2 g/kg (Ha 2014; MacGregor and de Wardener 1998). Until the invention of the refrigerator great amounts of salt were used for cooking and preserving foods whereby around the nineteenth century salt intake reached a peak comparable to amounts of about 9–12 g/day, significantly above recommended levels (Brown et al. 2009). A comparison of world salt consumption observed highest consumption in Asian people, followed by Europeans, people in Middle East and North Africa, USA/Canada, Australia/New Zealand, Latin America and the Caribbean, Oceania, and Sub Saharan Africa (Powles et al. 2013).

Within the "WHO Global Strategy on Diet, Physical Activity and Health" an action plan to control and prevent non-communicable diseases has been established. A primary goal is the reduction of salt (WHO 2013a). Since now most Europeans consume salt above the recommended level of less than 5 g/day (<2 g sodium/day).

Studies found that in industrial countries only 5–10 % of sodium intake comes from food naturally rich in sodium bicarbonate, sodium glutamate, and sodium citrate like smoked meat, processed foods, and canned vegetables. 75–80 % of daily sodium consumption comes from processed food like bread, cereals and bakery products, meat and meat products, cheese and dairy products, fish products, ready-to-eat meals, and salty snacks, 10–15 % from table salt added during cooking or at the table (European Commission 2012), while in developing countries salt used for seasoning is much more important. For example in China and Japan soy sauce contributes significantly to salt intake. Worldwide, the sodium content of processed foods plays a more important role compared to that of natural foods.

Many studies detected a wide range of sodium content within various food categories. Also salt content of products of global brands varied in different countries. This may be due to traditional diet habits and taste preferences of different population groups. Certain individuals such as men, adolescents, and people with lower socioeconomic status consume greater amounts of salt, supposing that these population groups consume more meat, high-sodium processed and packaged foods than other consumer groups.

Opportunities for supporting the reduction of salt intake to moderate levels are manifold and varied. They reach from nutritional education, improving environmental conditions (make the healthier choices the easier choices) up to mandatory nutrition labeling and regulated nutrition/health claims, as well as legislated changes in the form of taxation. Current knowledge makes the importance of combining reformulation approaches, improvement of the quality of communal catering, and education to raise awareness evident.

Ekmekcioglu et al. established a simple model of how salt intake can be reduced in the

population. This model emphasises the need for a holistic approach in the improvement of optimal salt intake (Fig. 2) (Ekmekcioglu et al. 2013).

9.1 Association Between Knowledge on Salt and Salt-Related Dietary Practices

Gathering and exploiting knowledge about the awareness of the people on the relationship between salt consumption and health or disease risk, about levels of uptake, and drivers of salt intake, provide the basis for improving the current situation.

Therefore, Newson et al. evaluated self-rated and calculated salt intake, sources of salt consumption, concern in salt reduction, knowledge about salt intake recommendations, and importance of salt reduction in health issues in eight countries (Germany, Austria, United States of America, Hungary, India, China, Brazil, and South Africa) by a comprehensive web-based questionnaire. Mean salt intake calculated from data of the FFQ was 9.5 g per day, ranging from 7 to 13 g/day. On average 83 % of salt intake was derived from In-Home-Foods and 17 % came from Out-of the House-Consumption. While people perceive that salt added during cooking is the main source of intake, calculated data recognised processed food as a primary source. There was also a misperception of personal intake. One third of participants were not interested in salt reduction and only 13 % of all participants could correctly identify the salt intake recommendations (Newson et al. 2013). Although, numerous studies showed that consumers were able to identify the health risks associated with high salt intake, their knowledge of recommendations, and of foods that contribute most salt to their diet is poor. Therefore, findings support the importance of information, of increasing awareness, and motivation, as well as reformulation of food stuff (Newson et al. 2013).

Most important for behavioural changes according to the health belief model (Janz and Becker 1984) is motivation which can be achieved by increasing awareness, information, and therefore self-efficacy (Ekmekcioglu et al. 2013).

Individuals affected by diseases like hypertension become aware of the importance of behavioural changes and are more motivated to change dietary habits compared to healthy people. Nakano and colleagues for example showed that regular 20-min educational sessions with nutritionists can be effective in lowering urinary sodium excretion, ambulatory BP monitoring (ABPM), and clinic BP in hypertensive patients (Nakano et al. 2016). This study is probably the first that demonstrates the effectiveness of patient education for hypertension management. Participants who didn't reach the goal of 6 g/day tended to have higher BMI and therefore had a higher salt intake because of their higher food consumption. The effect of potassium can be excluded because urinary excretions were the same in the intervention and control groups. Due to the short duration of the study (12 weeks) patients didn't lose weight, which might have an impact on blood pressure. Limitations might be the small sample size of 51 participants in the education group and 44 in the control group, the Hawthorne effect and different medications (Nakano et al. 2016).

9.2 Reduction of Salt Intake by Reformulation

Part of the strategies to reduce salt consumption is cooperating with food companies to reduce the amount of salt in processed foods and improving consumers' awareness of the impact of salt on human health.

This can be achieved through limiting salt by food reformulation. Since the WHO launched the "Global Strategy on Diet, Physical Activity and Health" to limit the levels of salt in foods, many companies have reformulated their products and reduced salt content by 10–40 % in many food categories including bread, breakfast cereals, processed meat, cheese, soups and sauces, ready-to-eat meals as well as snacks.

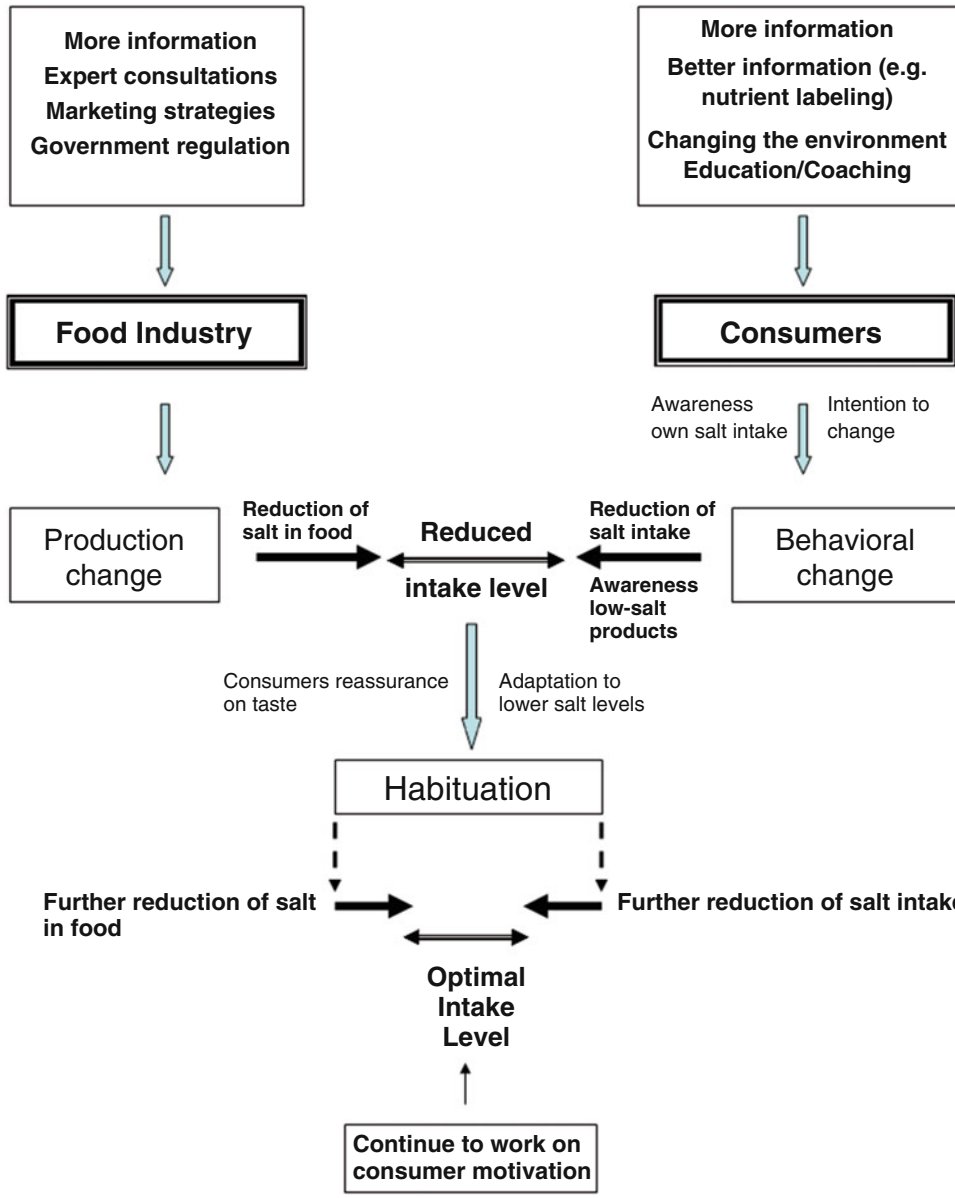

Fig. 2 A simple model of how dietary salt intake can be reduced in population (The figure is taken from Ekmekcioglu et al. (Ekmekcioglu et al. 2013). With kind permission from S. Karger AG, Medical and Scientific Publishers, 4009 Basel, Switzerland)

Sodium is responsible for the taste of a food by enhancing other aromatic ingredients and suppressing bitterness (Dötsch et al. 2009). Therefore, salt content in food stuff increases acceptance. But the human salt taste receptors can adapt to low salt concentrations (Blais et al. 1986) which makes a small, stepwise reduction of sodium content without reduced product acceptance possible, which in turn means that a cooperation of all manufacturers is required.

Beside the stepwise approach, salt reduction strategies include an increased use of spices and taste enhancers (Wilson and Incles 2012).

To ensure food safety and preservation in some cases addition of antimicrobial agents is necessary. Replacement of NaCl by KCl by 30–40 % has been made in meat and dairy products without any adverse effects on microorganism growth (Harper and Getty 2012). Even though, potassium chloride has similar antimicrobial effects and technological function, its application is limited because of its metallic and bitter off-taste (Buttriss 2013).

Salt reduction in bread and bakery products can be achieved by a stepwise sodium reduction of 5 % per week until 25 %, substitution of sodium chloride by potassium chloride (up to 10 %), and use of organic acids such as acetic and lactic acid. Replacement of NaCl up to 50 % by other salts/salt mixtures (potassium or magnesium chloride, potassium lactate, sodium diacetate), use of phosphates to promote water binding capacity of the proteins, and use of flake salt in dry-cured meat products are strategies used in reformulation of meat and meat products. Salt reduction in cheese is more difficult to manage than in bread and most meat products because salt controls the ripening process. Despite 30–40 % sodium reduction, taste and acceptance of ready-to-eat meals can be improved by the use of salt substitutes like potassium chloride and natural flavour enhancers (e.g. yeast extract or natural aroma sources such as garlic and herbs like oregano, rosemary). The composition of snacks can be optimised by the use of smaller salt particles which induce an increased initial perception of saltiness, as well as the use of spices (Kloss et al. 2015).

As protected designation of origin (PDO) products such as Parmesan, Prosciutto di Parma, Feta, and Camembert de Normandie must be produced according to traditional methods reducing salt content by reformulation is limited within these food stuffs (Wilson and Incles 2012).

In the meantime, impressive success stories can be reported on collaborations with food companies to reduce salt content followed by a decrease in blood pressure and in mortality rate related to heart disease and stroke (Ekmekcioglu et al. 2013). Thus, reformulation has along with other approaches such as healthier food choice editing, portion size control, as well as clear and comprehensible information provision, potential to increase the opportunities of healthier choices to improve public health. However, reformulation alone doesn't have the impact to provide a complete solution to the challenge of improving eating patterns and nutrient supply.

Table 2 Nutrition claims to salt/sodium content

Nutrition claim	Sodium content (per 100 g or 100 ml)	Equivalent salt content (per 100 g or 100 ml)
No added sodium/salt	0.12 g	0.30 g
Sodium-free/ salt-free	0.005 g	0.01 g
Very low sodium/salt	0.04 g	0.10 g
Low sodium/salt	0.12 g	0.30 g

Commission Regulation (EU) No 1047 (2012)

9.3 Reduction of Salt Intake by Legal Provision

Taxation of "unhealthy" high sodium food is discussed controversy. By introducing a tax for salty snacks (salt content of more than 1 g/100 g; for condiments >5 g/100 g) in Hungary in 2011 (0.8 €/kg salt) sales of salty snacks decreased by 26 %. Food prices influence food consumption on the one hand (Duffey et al. 2010), and changes consumer behaviour on the other hand by increased awareness of negative health effects.

Referring to salt/sodium content there are four nutrition claims (Table 2).

"A claim stating that sodium/salt has not been added to a food and any claim likely to have the same meaning for the consumer may only be made where the product does not contain any added sodium/salt or any other ingredient containing added sodium/salt and the product contains no more than 0.12 g sodium, or the equivalent value for salt, per 100 g or 100 ml.

A claim that a food is sodium-free or salt-free, and any claim likely to have the same meaning

for the consumer, may only be made where the product contains no more than 0.005 g of sodium, or the equivalent value for salt, per 100 g or per 100 ml.

A claim that a food is very low in sodium/salt, and any claim likely to have the same meaning for the consumer, may only be made where the product contains no more than 0.04 g of sodium, or the equivalent value for salt, per 100 g or per 100 ml. This claim shall not be used for natural mineral waters and other waters.

A claim that a food is low in sodium/salt, and any claim likely to have the same meaning for the consumer, may only be made where the product contains no more than 0.12 g of sodium, or the equivalent value for salt, per 100 g or per 100 ml. For waters, other than natural mineral waters falling within the scope of Directive 80/777/EEC, this value should not exceed 2 mg of sodium per 100 ml." (Commission Regulation (EU) No 1047 (2012)).

There is one authorized health claim for foods with low or reduced sodium: "Reducing consumption of sodium contributes to the maintenance of normal blood pressure" in the European Union (EFSA 2011).

Different labeling confuses consumers because most of them are not aware that salt content is 2.54 times higher than sodium concentration. Therefore, the European Parliament and the Council determined in 2011 by The Regulation (EU) No 1169/2011 on the provision of food information to consumers that the term salt instead of sodium must be used on food labels (Regulation (EU) No 1169/2011 (2011)). In Finland warning labels must be used for products with high salt content, in the United Kingdom, there is a voluntary traffic light label and as front-of-package labeling the guideline daily amount (GDA) system is used (WHO 2013b). Food labeling is most effective in promoting buyers awareness and can help consumer make the healthier choice. Additionally this motivates food companies to reduce salt in their products.

Webster et al. evaluated global salt reduction initiatives and recognized that 59 countries from 83 cooperate with food industry to reduce salt. Most of the countries established voluntary targets while South Africa and Argentina had mandatory targets for many food products, and six European countries (Belgium, Bulgaria, Greece, Hungary, the Netherlands and Portugal) had mandatory targets for bread amongst others. Salt reductions in bread ranged from 6 % in Belgium to 38 % in Chile. For other products, reductions between 5 % (cornflakes, USA) and 81 % (frozen peas, USA) have been observed (Webster et al. 2014). Because consumer's knowledge on salt content in food is limited these partnerships are very important for public health concern.

The EATWELL research project (www.eatwellproject.eu) (Interventions to Promote Healthy Eating Habits: Evaluation and Recommendations) conducted between 2009 and 2013 evaluated the effectiveness of healthy eating interventions in EU Member States. Main topics were policies supporting informed choice (nutrition education, labelling), and changing the market environment (taxes, food reformulation, regulation of school and workplace meals). A common recommendation is to gather more and better evidence (Traill et al. 2013).

10 Practical Recommendations for Moderate Salt Intake

Well known dietary patterns for treatment of elevated blood pressure are the Dietary Approaches to Stop Hypertension (DASH) diet and the OmniHeart diet. The DASH diet is rich in fruits, vegetables, low-fat dairy products, contains poultry, fish, and nuts, whereas only small amounts of red meat, sweets, and sugar-containing beverages are consumed. Macronutrient composition is about 58 % carbohydrate, 15 % protein, and 27 % fat; sodium intake less than 2.3 g/day. Compared to a typical American diet DASH is reduced in saturated fat and total fat, modestly increased in protein (Sacks et al. 2001).

Because the types of macronutrients (carbohydrate, protein, or unsaturated fat) replacing saturated fat has been discussed controversial, slight variations of DASH have been evaluated within the Optimal Macronutrient Intake Trial to

Prevent Heart Disease (OmniHeart). The OmniHeart diet is a carbohydrate-rich diet which allows partially substituting carbohydrate with protein or unsaturated fat, similar to a Mediterranean-style diet. This offers more flexibility and makes it easier to eat a heart-healthy diet (Swain et al. 2008).

Generally, a DASH eating plan consists of 7–8 servings grains and grain products; 4–5 servings vegetables and fruits, each; 2–3 servings low-fat dairy products; 2 or less servings lean meats, poultry, and fish; 2–3 servings fats and oils per day, and 4–5 servings of nuts, seeds, dry beans, and peas; 5 or less servings sweets per week (U.S. Department of Health and Human Services 2003).

Along with the recommendations of the DASH diet, body weight should be reduced in overweight and obese people (BMI less than 25 kg/m^2), salt intake not exceed 5 g/day (<2.3 g sodium/day, no more than 1.5 g/day in blacks, middle- and older-aged persons, and individuals with hypertension, diabetes, or chronic kidney disease), intake of potassium (~4.7 g/day) should be increased and alcohol consumption limited to max. 10 g/day for female and 20 g/day for male (Appel, on Behalf of the American Society of Hypertension Writing Group 2009).

Yokoyama et al. described an association between vegetarian diets and lower blood pressure in their meta-analysis including 7 controlled trials and 32 observational studies. It remains to be clarified which type of vegetarian diet is most effective (Yokoyama et al. 2014).

Additionally, regular physical activity can lower blood pressure. There is evidence that 150 min physical activity per week may support antihypertensive medication. The American College of Sports Medicine recommends primarily endurance physical activity supplemented by resistance exercise in moderate-intensity (40–< 60 % of VO_2R) for at least 30 min daily (Pescatello et al. 2004). A Systematic Review and Meta-analysis done by Cornelissen and Smart concluded that endurance, dynamic resistance, and isometric resistance training lower SBP and DBP, whereas combined training lowers only DBP. Isometric resistance training is suggested for the largest SBP reductions (Cornelissen and Smart 2013).

The burden of hypertension raises with increasing prevalence of obesity. Therefore, weight reduction and control is very important in prevention and therapy of hypertension. A meta-analysis of 25 RCTs showed blood pressure reduction of ~1 mm Hg for each kilogram of body weight loss (Neter et al. 2003).

Salt reduction is difficult to achieve because in industrialised countries ~80 % of salt intake comes from industrial produced foods.

Average amount of salt consumed per daily food intake is about:

- 1 g from basic unprocessed foods (vegetables, potatoes, grain, milk, meat)
- 2–3 g from bread and bakery products
- 3–5 g from sausages, ham, cured meat products, cheese, fish sauce
- 4–5 g from industrially processed products like preserves/fish products and home-made dishes
- 1–2 g from salt added at the table

Therefore avoid adding salt at the table, and season with herbs and spices. Always read the food label and reduce consumption of ready-to-eat meals with high amounts of salt.

11 Conclusion

The positive relationship between salt and blood pressure is known since more than 100 years. Accumulating evidence especially began in the 1940s where severe arterial hypertension has been cured by drastic lowering of salt intake by the Kempner rice and fruit diet. In the 1950s Lewis K. Dahl observed a blood pressure lowering effect by a low-salt diet in rats with salt-sensitive hypertension. Most of the subsequent studies showed beneficial effects of a low salt diet on blood pressure. However, also some negative papers were published, which failed to find a relationship between salt and blood pressure. While selection of study participants (more salt sensitive people like elderly or people with

hypertension) can increase likelihood of the positive association between salt intake and blood pressure, dietary and other lifestyle factors like intake of potassium (from fruit and vegetable sources), physical activity level, as well as alcohol consumption have also to be considered (Drueke 2016).

A few studies also suggested that a low salt diet may have detrimental health outcomes, especially regarding cardiovascular diseases and mortality. (O'Donnell et al. 2014; Graudal et al. 2014). A recent study by Mente at al. for example observed an association between low sodium intake and increased risk of cardiovascular events and mortality in both hypertensive and normotensive individuals (Mente et al. 2016).

More reliable randomised controlled trials, as well as research on measurement, storage and kinetics of sodium, on physiological properties, and genetic determinants of salt sensitivity are necessary to explain these negative outcomes of a low salt diet. However, according to the current overwhelming state of knowledge people with hypertension and high sodium intake should be advised to lower their salt intake.

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