Sodium Intake and Hypertension

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In current diets, the level of sodium is very high, whereas that of potassium, calcium, and magnesium is low compared with the level in diets composed of unprocessed, natural foods. We present the biologic rationale and scientific evidence that show that the current salt intake levels largely explain the high prevalence of hypertension. Comprehensive reduction of salt intake, both alone and particularly in combination with increases in intakes of potassium, calcium, and magnesium, is able to lower average blood pressure levels substantially. During the past 30 years, the one-third decrease in the average salt intake has been accompanied by a more than 10–mm Hg fall in the population average of both systolic and diastolic blood pressure, and a 75% to 80% decrease in both stroke and coronary heart disease mortality in Finland. There is no evidence of any harmful effects of salt reduction. Salt-reduction recommendations alone have a very small, if any, population impact. In the United States, for example, the per capita use of salt increased by approximately 55% from the mid-1980s to the late 1990s. We deal with factors that contribute toward increasing salt intakes and present examples of the methods that have contributed to the successful salt reduction in Finland.

Hypertension is the leading cause of death in developed countries.[1] Reduction of salt intake is recommended as a key measure in the prevention and basic treatment of hypertension both in the United States and worldwide (see, for example, Refs. 2-5). In this paper, we provide evidence that strongly suggests that the progressive decrease in salt intake, which has continued in Finland for 25 to 30 years, has played an important role both in the impressive fall in the average blood pressure of the population and in the pronounced 75% to 80% decrease in both stroke and coronary heart disease mortality in the population younger than 65 years. Evidence is presented to indicate that the comprehensive salt reduction has also played an important part in the remarkable 5- to 6-year increase in the life expectancy of the Finnish population during the past 25 to 30 years.

However, beverage and food companies and organizations representing industrial and commercial interests actively promote high salt intakes and maintain that there is no scientific justification for any salt reduction at the population level.[6-8] The salt-promotion activities have recently proved highly successful. Before the mid-1980s in the United States, the total sales of food-grade salt[9] and the prevalence of hypertension[10] had shown decreasing trends. However, recently, the use of salt has remarkably increased. In 1998, the total sales of food-grade salt in the United States were as much as 86% higher, and the per capita sales approximately 55% higher, than in 1983.[9] Since the late 1990s, the per capita sales of food-grade salt have remained rather constant at a high level.[9] Dietary surveys have also indicated that in 1999 to 2000 salt intakes in the United States were remarkably higher than in the late 1970s.[11] It is of considerable public health interest that, since the late 1980s and early 1990s, the age-adjusted prevalence of high blood pressure has also shown a turn to a marked increase in the US population aged 20 years and older.[10,11] The discrepancy between the science-based recommendations and the actual development in salt

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use may, at first sight, appear rather astonishing. However, one has to realize that the high use of salt is highly advantageous from the industrial and commercial points of view.

In this paper, we present the biologic rationale and scientific evidence that the current salt intake levels are a major etiological factor in the high prevalence of hypertension. On a scientific basis, a remarkable reduction in salt intakes is justified highly desirable worldwide. The particular importance of salt reduction, which is added in industrial food manufacturing, will be illustrated. Some reasons for the salt-promotion activities will also be discussed. As Finland, so far, appears to be one of the few countries where it has been possible to produce a marked population-wide reduction in salt intake, we describe some of the key methods and approaches that have made possible the progressive fall in salt intake. Finally, we discuss some measures that could be useful in combating the health problems caused by the current heavy use of salt.

Physiologic Sodium Intake Levels: Biologic Considerations

Sodium Intake From Unprocessed Foods

According to a general biologic principle, there is a physiologic, healthy intake range for all essential nutrients. Sodium, as one of the essential nutrients, is no exception to this rule. Hence, if the sodium intake is below the physiologic range for prolonged periods, deficiency conditions are likely to develop. Conversely, if the sodium intake exceeds the physiologic range for prolonged periods, adverse effects and even severe toxicity are likely to develop. There is plenty of evidence that the optimum dietary basis for good health is provided by a diet, which is in agreement with our genetic programs. According to Eaton and Konner,[12] there is an optimum type and composition of food that each species, including man, is genetically programmed to eat and metabolize. For example, the lion is programmed to eat animal food only, whereas the antelope is programmed to eat plant food only. The nutrients provided by such foods are believed to provide optimum nutrition for the lion and antelope, respectively. In the case of wild animals, it is evident, a priori, that the genetic programming does not include any processing of food in the form of removal of, or enrichment with, any nutrient components. Human beings are believed to be programmed to eat and metabolize both plant and animal foods.[12,13] It is believed that the genetic program, which has remained essentially unchanged for at least the past 100 000 years, is best compatible with unprocessed mixed foods, that is, foods without complete or partial removal of any nutrient components and without enrichment with any nutrients.[12,13] According to this hypothesis, marked man-made changes in the composition of foods and diets would cause, or at least predispose to, a number of pathologic conditions, including elevated blood pressure.[14]

A daily diet comprising, on energy basis, approximately two thirds of plant foods and one third of animal foods provides approximately 0.6 g of sodium in the absence of added salt. A daily diet that consists of plant foods only provides less than 10 mmol (0.23 g) of sodium.[15] The highest sodium intake is derived from diets that comprise almost exclusively of animal food. In such diets, the amount of sodium, without salt additions, is approximately 0.8 g/d.[16] It is almost impossible to compose a diet consisting of unprocessed natural foodstuffs to provide sodium in excess of 50 mmol (1.2 g) a day. Therefore, on the basis of the variation of sodium content in diets consisting of natural foodstuffs without artificial additions, one could expect that our genetic mechanisms are programmed to sodium intake levels that are lower than 50 mmol (1.2 g) a day, corresponding to less than 20 mmol (0.5 g sodium) per 4184 kJ (1000 kcal).

Evidence From the Renin-angiotensin-aldosterone System

Activation of the renin-angiotensin-aldosterone (RAA) system increases the retention of sodium and water. It can be reasoned that the RAA system has most likely been genetically programmed to respond to changes in salt intake levels, which may occur under natural conditions. This appears, in fact, to be true. The RAA system is maximally activated in the presence of prolonged very low sodium intakes of less than 5 mmol a day.[17] Half-maximal stimulation (or inhibition) of plasma renin activity takes place at sodium intake levels of approximately 30 mmol a day. Sodium intake at the level of 50 mmol a day suppresses secretion of the sodium-retaining hormone, aldosterone, almost completely.[17] The control range of the RAA mechanism is therefore in excellent agreement with the sodium amounts, which can be derived from diets comprising only natural foodstuffs without artificial additions of salt or other sodium compounds. These findings strongly support the view that human beings are genetically programmed to eat foods that contain sodium in amounts that are naturally present but do not contain added salt.

Current Salt Intakes Exceed Physiologic Intakes at Least 5-Fold

The Intersalt study[18] as well as combined data from other studies[19] has shown that, in industrialized communities, the average sodium intakes are approximately 3000 to 4500 mg/d. In the United States, the average sodium intake during the mid-1990s was about 3500 mg/d at an average energy intake of 10000 kJ (2400 kcal).[20] These figures are in good agreement with a recent report that sodium intake in the United States is approximately 1.5 mg/kcal.[21] At energy intake levels of 10000 kJ (2400 kcal), this value corresponds to a daily sodium intake of approximately 3600 mg, which is equal to 9 g as sodium chloride. Recently, the use of salt has substantially increased in the United States as compared with the figures during the early 1980s.[7,9] In natural diets without added salt or other sodium compounds, the sodium level is approximately 600 mg only.[16] Hence, the average intakes in the United States and other communities are approximately 5- to 6-fold as compared with the levels provided with a natural diet and the same food items without added salt.

Elevation of Blood Pressure is an Expected Pathophysiologic Response to Excessive Salt Intake

Necessity of Adequate Renal Salt Excretion

More than 95% of the ingested salt is absorbed from the gastrointestinal tract (see Ref. 22). Extra-renal loss of salt may become significant only in massive diarrhea and vomiting or prolonged strenuous exercise with profuse sweating.[22] Otherwise, extra-renal loss of salt is minimal, with sweating accounting usually for approximately 1 mmol (0.058 g) and other extra-renal losses for 0.002 to 0.18 g/d only. Therefore, to maintain the extracellular sodium concentration ($\approx$142 mmol/L) and total body salt content at constant levels, renal salt excretion has to be almost equal to salt intake. Even a small increase in serum sodium concentration after absorption of dietary salt from the gastrointestinal tract triggers thirst and causes fluid intake until the normal serum concentration is restored. The necessity of sufficient renal salt excretion can be illustrated by the fact that a daily excess in salt intake of 8.3 g (3266 mg sodium) must be accompanied by a 1-L increase in water intake each day to maintain the normal extracellular sodium concentration of 142 mmol/L. Theoretically, in the full absence of renal sodium excretion capacity, approximately 250 g of salt and 30 L of water would accumulate in the body during 1 month.

Suppression of the RAA Mechanism is Not Sufficient

As described above, salt intakes that exceed 50 mmol ($\approx$3 g) are not able to substantially suppress the level of the sodium-retaining hormone, aldosterone. Therefore, other mechanism(s) than suppression of the RAA system only is needed to excrete sodium and to maintain sodium and water homeostasis when dietary salt intake is excessive.

Rise in Blood Pressure Prevents Acute Salt and Fluid Toxicity

Blood pressure serves 2 important functions in the body. One is maintenance of tissue perfusion. The other important and extremely potent function is control of sodium balance, which largely determines the extracellular fluid volume. By increasing the blood pressure level, the body is able to get rid of excess sodium and water through the pressure-natriuresis mechanism.[22,23] Blood pressure is, in fact, the most powerful physiologic mechanism in the maintenance of sodium and water balance. The development of sodium deficiency and decreased extracellular fluid volume during a prolonged very small sodium intake or losses due to gastrointestinal causes, sweating, or blood loss, can be effectively prevented by decreasing the blood pressure. By lowering the blood pressure, the body is able to prevent renal sodium and fluid excretion completely. On the other hand, in the case of high salt intake the body is able to effectively prevent salt and fluid accumulation by raising the blood pressure to such an extent that pressure-induced increase in salt and water excretions matches the intakes.

Variations in the Need for Blood Pressure Rise

Importance of genetic factors

The magnitude of blood pressure increase, which is needed to get rid of a given amount of salt and water, depends strongly on the sodium-handling mechanisms of the kidneys. Genetic factors are most fundamental in determining to what extent blood pressure has to be increased or decreased to restore and maintain the salt and water balance.[15,24] In the presence of hereditarily hyperactive sodium reabsorption mechanisms, marked hypertension develops in the presence of average current salt intakes as a defense mechanism against acute salt poisoning.[24] Expectedly, hereditary sodium loosing defects lead to hypotension even in the presence of current high salt intakes, apparently as a defense mechanism against salt deficiency. Lifton et al[24] emphasized that, given the diversity of physiologic systems that can influence blood pressure, it is striking that all Mendelian forms of hypertension and hypotension solved to date converge on a final common pathway, altering blood pressure by changing net renal salt balance. As most of the known Mendelian forms of high and low blood pressure have now been solved, the findings on the key role of salt in hypertension do not reflect an obvious selection bias.[24] In the population, on average, the genetically determined mechanisms appear to be able to cope with the physiologic sodium intakes without any marked changes in blood pressure. Under the present genetic, dietary, and other environmental conditions, chronic elevation of blood pressure levels appears to be needed in more than half of the population for the prevention of salt accumulation and, hence, development of acute salt toxicity.[23]

Obesity enhances the hypertensive effect of salt

In the presence of normal genetic variations in salt-handling pumps and channels, the excretion of excess sodium is decreased in the presence of obesity.[25] Hence, elevation of blood pressure is needed for the excretion of salt loads. Several different mechanisms may participate in the mediation of this detrimental effect of obesity, which predisposes obese individuals to the development and worsening of hypertension. It is of considerable interest that, under current environmental conditions, high salt intake may be an important indirect cause of obesity. Hence, high salt intake may lead to a vicious cycle, which aggravates hypertension.

Diabetes enhances the hypertensive effect of salt

Hypertension in people with diabetes is characterized by increased salt sensitivity and volume expansion.[26] There is also some recent evidence which suggests that, under current environmental conditions, high salt intake may be a triggering factor for type 2 diabetes (see below).

Increased Intakes of Potassium, Calcium, and Magnesium Attenuate the Hypertensive Effect of Excess Salt

Interestingly, in the presence of normal genetic variations in salt-handling pumps and channels, the excretion of excess sodium is markedly improved by increased intakes of potassium, calcium, and magnesium.[22,27] Hence, a given amount of excess salt and water can be excreted in the presence of lower blood pressure than during a low intake of the said mineral nutrients.

Unfavorable Compositions of Processed Foods Enhance the Hypertensive Effect of Salt

Industrial processing of food items from natural foods causes dramatic distortion in the contents of sodium, potassium, calcium, and magnesium. In Fig 1, the effect of processing is illustrated for 2 food items: tomato ketchup and vegetable margarine. Modern diets, which are largely composed of various processed food items, provide sodium, potassium, calcium, and magnesium in

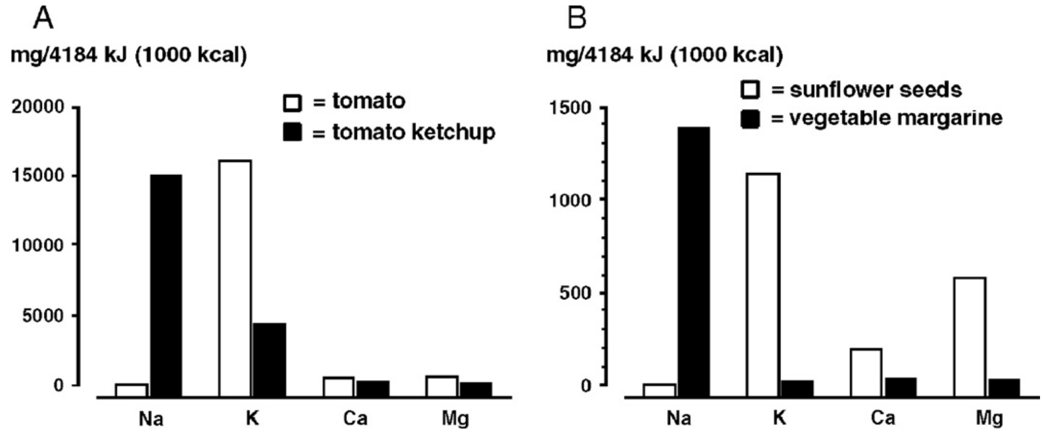

Fig 1. Sodium (Na), potassium (K), calcium (Ca), and magnesium (Mg) content of tomato and tomato ketchup (panel A), as well as of sunflower seeds and vegetable margarine processed from sunflower seeds (panel B). The values are expressed as milligrams per 4184 kJ (1000 kcal). Numeric values of Rastas et al.[28] were used for the illustration.

remarkably different amounts and ratios than diets composed of unprocessed foods (Fig 2). The potassium intake in the United States is as low as 2000 mg per 10000 kJ (2400 kcal),[20] which is only 24% of the amount provided by the natural diet. From the current diets, the daily intakes of calcium are approximately 500 mg[20] or 40% only as compared with the amounts derived from diets comprising only unprocessed foods. The usual intakes of magnesium ($\approx$206 mg[20]) are also very low ($\approx$23% only) as compared with the amounts provided by unprocessed foods. In the presence of lower potassium, calcium, and magnesium intakes, higher blood pressure is needed to excrete sodium loads.[22,27] Therefore, it seems likely that the distortion of the levels of mineral nutrients in the present diets from those in the genetically programmed unprocessed diets is an important cause of the high prevalence of hypertension.

Recommended Sodium, Potassium, Calcium, and Magnesium Intakes

Recently, the recommended Dietary Reference Intakes (DRIs) have largely replaced the 1989 Recommended Dietary Allowances (see Ref. 29). The DRI for sodium is 1500 mg/d, whereas 2500 mg has been given as the maximum level of daily intake that is likely to pose no risk of adverse effects. Hence, the average current sodium intakes of 3000 to 4500 mg/d in various westernized communities[18,19] exceed clearly even the highest sodium intake level, which has been estimated to pose no (acute) risk. The recommended intakes of potassium for adolescents and adults are 4700 mg/d. Recommended intakes of potassium for children 1 to 3 years of age are 3000 mg/d; for 4 to 8 years of age, 3800 mg/d; and for 9 to 13 years, 4500 mg/d.[29] Hence, the current average potassium intakes in the United States are very low, only about 43% of the recommended level. The DRIs for calcium are 1000 to 1300 mg/d. Therefore, the usual US intakes are only 38% to 50% of the DRIs. The magnesium intake recommendation is 420 mg

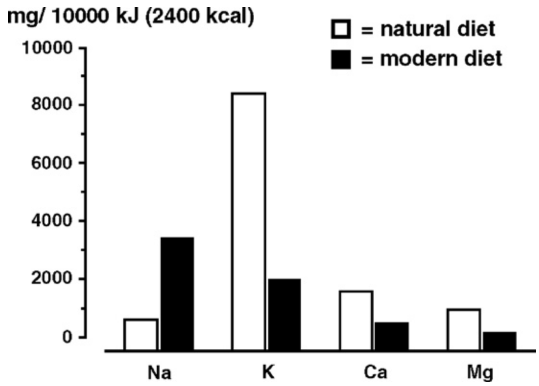

Fig 2. Sodium, potassium, calcium, and magnesium contents (calculated per 10000 kJ [2400 kcal]) in the unprocessed diet ("natural diet") and in the diet containing processed food items ("modern diet", ie, average US diet, which served as the control diet in the DASH study).[20] Numeric values, extrapolated from Eaton and Eaton,[13] were used for the illustration of the levels in "natural diet."

for adult men.[29] No exact figures have been given for other groups, but the weight-based corresponding value for women would be approximately 300 mg/d. Therefore, the usual US intakes of 180 mg are only approximately 60% of the recommended level.

Salt Reduction Lowers Blood Pressure

In the second Dietary Approaches to Stop Hypertension (DASH) study,[30] the rather vigorous sodium restriction alone, to approximately 40% of the usual level, during a control diet produced a fall of 6.7 mm Hg in systolic blood pressure and 3.5 mm Hg in diastolic blood pressure. A moderate one-third sodium reduction to approximately 67% of the usual level produced a smaller 2.1/1.1 mm Hg fall in blood pressure. Two recent meta-analyses[31,32] have revealed that an approximately 75 mmol/d (about 50%) reduction in the intake of sodium lowers blood pressure both in subjects with hypertension and in normotensive individuals. In hypertensives, the fall in systolic blood pressure is about 5 mm Hg and that in diastolic blood pressure approximately 3 mm Hg. In normotensives, the fall in systolic blood pressure is approximately 1.3 to 2 mm Hg and that in diastolic blood pressure about 1 mm Hg. Moreover, weighted linear regression analyses have convincingly shown a correlation between reduction in urinary sodium, an indicator of sodium intake, and reduction in blood pressure.[33]

Increased Intakes of Potassium, Calcium, and Magnesium have a Blood Pressure–Lowering Effect

As the excretion of excess sodium is markedly improved by increased intakes of potassium, calcium, and magnesium,[22,27] one could expect that prolonged increased intake of these mineral nutrients could have antihypertensive effects (see above).

Effect of Increased Potassium Intake Alone

An increase in potassium intake by approximately 1.8 to 1.9 g/d has proved to lower the blood pressure of hypertensive subjects so that the average fall in systolic blood pressure is approximately 4 mm Hg and that in diastolic pressure about 2.5 mm Hg.[32,34] This increase in potassium intake is not sufficient to raise the potassium intake in the United States to the currently recommended level of 4.7 g/d. Several mechanisms, such as improved natriuresis, reduced sympathetic nervous activity, and decreased pressor response to noradrenaline and angiotensin II seems to be involved in the blood pressure–lowering effect of potassium.[35]

Effect of Increased Calcium Intake Alone

Calcium supplementations that have increased the total daily intake to more than 1000 mg/d have produced an average fall of 1.4 mm Hg in systolic and 0.8 mm Hg in diastolic blood pressure.[36] Improved sodium excretion, modulation of the function of the sympathetic nervous system, increased sensitivity to the vasodilatory action of nitric oxide, and decreased production of superoxide and vasoconstrictor prostanoids have been implicated in the antihypertensive effect of increased calcium intake.[35]

Effect of Increased Magnesium Intake Alone

According to a recent meta-analysis,[37] magnesium supplementation resulted in only a small overall reduction in blood pressure. The pooled net estimates of blood pressure change were −0.6 mm Hg for systolic blood pressure and −0.8 mm Hg for diastolic blood pressure. However, there was an apparent dose-dependent effect of magnesium, with reductions of 4.3 mm Hg in systolic and 2.3 mm Hg in diastolic blood pressure for each 10 mmol/d increase in magnesium dose. The antihypertensive effect of magnesium may be mainly due to its vasodilatory effects.[38]

Effect of Multiple Improvements

In view of the many and complex interactions between sodium, potassium, calcium, and magnesium in body physiology, one can easily realize that all deviations from the optimum levels should be simultaneously corrected for an optimum effect.[14,39] In the search for simple measures to combat high blood pressure, single-factor approaches aiming at sodium reduction

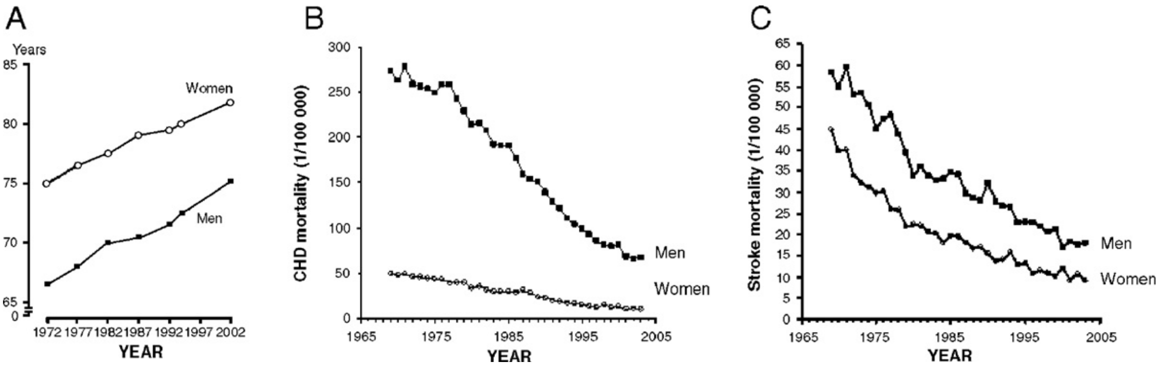

Fig 3. Life expectancy (panel A), the age-standardized coronary heart disease mortality rate (panel B), and the age-standardized stroke mortality rate in Finland (panel C). Numeric values from Refs. [41,42] and the Finnish Cardiovascular Disease Register (http://www.ktl.fi/cvdr/) were used for the illustration.

only, or increase of 1 beneficial mineral nutrient only, have been used in most studies. However, in the recent DASH studies,[20,30] the intakes of potassium, calcium, and magnesium increased simultaneously (Fig 2). These changes were produced through a change in the dietary pattern. As compared with a typical diet in the United States, the DASH diet contains more fruits, vegetables, low-fat dairy products, whole grains, poultry, fish, and nuts. It contains only small amounts of red meat, sweets, and sugar-containing beverages, and it contains decreased amounts of total and saturated fats and cholesterol. The DASH diet provides larger amounts of potassium, calcium, magnesium, dietary fiber, and protein than the typical diet.

Best Blood Pressure–Lowering Effect by Combination of Salt Reduction with Increased Intakes of Potassium, Calcium, and Magnesium

The reduced-sodium DASH diet has proved particularly effective for blood pressure reduction.[30] In this study, the DASH diet without sodium reduction produced a nearly 6–mm Hg average fall in systolic blood pressure and an approximately 3–mm Hg fall in diastolic blood

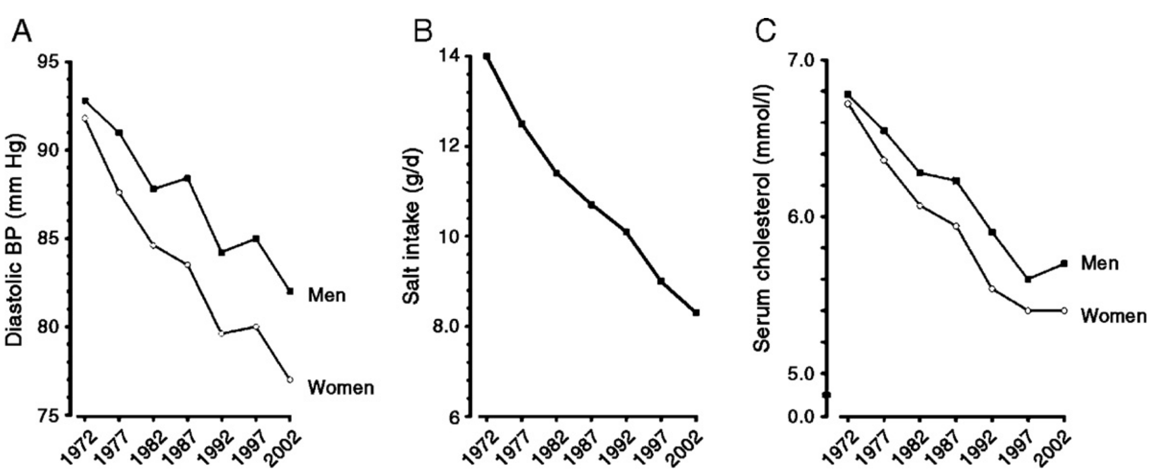

Fig 4. Lowering of population blood pressure (panel A), decrease in salt intake (panel B), and decrease in serum total cholesterol concentration (panel C) in Finland. Numeric values from Refs. [41,43-45] were used for the illustration.

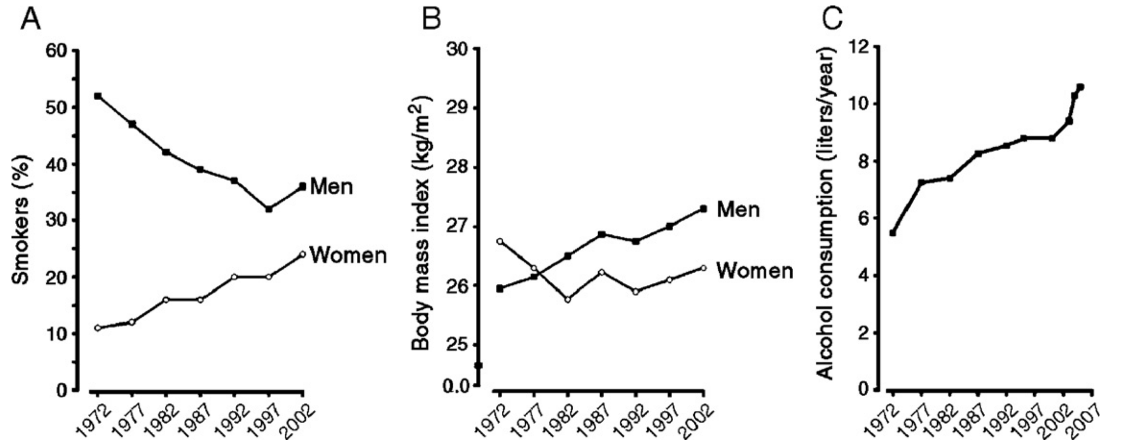

Fig. 5. Smoking (panel A), body mass index (panel B), and alcohol consumption (panel C) in Finland. Numeric values from Refs. [41,43,45,46] were used for illustration.

pressure. When even sodium was reduced from approximately 150 to about 60 mmol/d, the antihypertensive effect was further enhanced. The average systolic blood pressure was lowered by approximately 9 mm Hg, and the fall in diastolic blood pressure was about 4.5 mm Hg. During the control diet, the effect of sodium reduction alone was 6.7/3 mm Hg.

Dramatic Decreases in High Blood Pressure, Strokes, and Heart Attacks in Finland—The Role of Nationwide Salt Reduction and Other Factors

Average Salt Intake has Decreased and Population Health has Improved

During the past 3 decades, the age-adjusted overall mortality has decreased remarkably so that the life expectancy has increased by several years both among women and men[40] (Fig 3A). In the middle-aged population, death rates from both stroke and coronary heart disease have decreased dramatically, by approximately 80%[41,42] (Fig 3B and C). The lowering of the population average of both systolic and diastolic blood pressure (Fig 4A), which has been more than 10 mm Hg in diastolic blood pressure, largely explains the decrease in strokes and also accounts for a considerable proportion of the decrease in heart attacks. Unlike in most other countries, in Finland a progressive and marked decrease in the average intake of salt has taken place during this period[43] (Fig 4B). The fall in blood pressure has apparently been mainly due to the decrease in salt intake as both obesity and alcohol consumption have increased (Fig 5). Moreover, it is likely that the decreased intake of salt, in addition to the blood pressure lowering, has contributed to the decrease in heart attacks also by the pressure-independent beneficial effect on left ventricular hypertrophy.[22,47-49] Increased potassium intakes have also been important probably as the use of reduced sodium, potassium-, and magnesium-enriched salt as well as consumption of fruit and vegetables has increased. In the decrease in heart attacks, the lowering of average cholesterol levels (Fig 4C) has also played an important role. Hence, the findings in Finland are consistent with an overall beneficial effect of a comprehensive population-wide sodium reduction.

Role of Different Factors in the Decrease in Salt Intake

Availability of healthy salt alternatives and the role of publicity

Since the late 1970s, various population-wide measures have been implemented to decrease the intake of salt in the whole population. Moreover, various measures that decrease the toxicity of salt have been promoted. We have estimated that *Helsingin Sanomat*, which is the biggest newspaper in the Nordic countries and by far the most influential newspaper in Finland, has played a decisive role in the success of salt intervention.

The first big article emphasizing salt as a harmful dietary factor was published on January 11, 1978. Thereafter, this leading newspaper has published a big number of articles and editorials on this subject. Moreover, thanks to the extensive reports on the interventions in Finland of sodium-reduced, potassium-, and magnesium-enriched healthier salt alternatives, called "mineral salt" or "Pansalt," *Helsingin Sanomat* has increased the interest of the population and governmental organizations in salt. With very few exceptions, smaller newspapers as well as TV and radio channels have more or less taken the same position as *Helsingin Sanomat* in the salt issues. Since January 1978, there have been hundreds of reports on both the harmful effects of salt and on the availability of healthier, good-tasting alternatives.

Salt recommendations

Experience from our neighboring country, Sweden, clearly shows that official dietary and medical salt recommendations, which are not connected with other activities, have little, if any, effect on the average level of salt use. However, in Finland, the official recommendations to decrease the intake of salt to one half of the prevailing levels have encouraged media to take a clearer antisalt position than might have been the case in the absence of such recommendations.

Salt-labeling legislation

Since the early 1970s, industrially manufactured food items, meals, and canteen foods have played an increasing and, recently, a major role in the total intake of salt in Finland.[50] It was therefore concluded that the only effective way to produce a comprehensive decrease in salt intake is to reduce the salt levels in industrially manufactured fast foods and other food items, and canteen foods. To reduce the intake of salt from industrially manufactured food items, the Ministry of Trade and Industry, in cooperation with the Ministry of Social Affairs and Health, prepared new salt-labeling regulations in the early 1990s. The legislation applies to all food item categories, which contribute markedly to the intake of salt in the average Finnish diets. This legislation has been fully implemented since June 1, 1993. The most effective part of the legislation, leading to markedly reduced average salt contents in the most important food categories, has proved to be the "high salt content" warning. The "high salt content" label is required if the NaCl content is more than 1.3% in bread, 1.8% in sausages, 1.4% in cheese, 2.0% in butter, and 1.7% in breakfast cereals or crisp bread. The launch of this legislation reduced the average salt content in breads by approximately 20% from approximately 1.5% to about 1.2%. In sausages, the average decrease in salt content due to this legislation was approximately 10%. To make healthier choices possible for consumers, the content of NaCl in % has to be labeled in breads, sausages and other meat products, fish products, butter, soups and sauces, ready-made dishes, and salt-containing spice mixtures. Moreover, it is allowed to emphasize a lower than conventional level of salt (low-salt label) if the NaCl concentration does not exceed 0.7% in breads, 1.2% in sausages, 0.7% in cheese, 1.0% in fish products, breakfast cereals or butter, 0.5% in soups, sauces and ready-made dishes, and 1.2% in crisp bread. Unfortunately, this approach has not gained popularity so far. One of the main reasons appears to be the fact that a vast majority of the population, due to the experiences in the 1980s, still seem to consider that "low salt" also means lack of taste.

Consensus agreement of governmental and scientific organizations with the food industry and canteens

To promote cardiovascular health by reduction of salt use in the food industry and canteens and also by other means, the Ministry of Social Affairs and Health and the Finnish Heart Association arranged in November 1997 a consensus meeting for "the promotion of heart health." Sixty different groups representing the most important food companies and a big number of different organizations started the preparation of the consensus statement in February 1997. The statement strongly emphasizes the need for a 50% further decrease in the level of sodium in all food items and ready-made meals that contain added salt. A number of measures that are needed and believed to be useful for reaching the goal of reducing the intake of salt in the whole population to half of the 1997 level, that is, to below 5 g/d per person, are pointed out in the statement.[51]

Use of tempting health-related logos

Since the 1980s, an increasing number of companies have reduced the sodium content and increased the potassium and magnesium content of their food items by replacing the use of common salt by sodium-reduced, potassium-, and magnesium-enriched mineral salt.[22,52] Such products, including recently McDonald's hamburgers, usually have a visible "Pansalt" logo, which has proved to be a good marketing argument. Customers have learned that products with this logo offer a healthier choice without compromising the taste. A more recent approach is the "Better Choice" label, launched by the Finnish Heart Association in January 2000. Companies may buy the right to use the label on food items, which have lower sodium content and improved fat composition compared with the average products on the market. The exact criteria have been set for each food type. Many of the healthier food alternatives currently have both the "Pansalt" and "Better Choice" labels.

Promotion of healthier choices by measuring and publicizing the salt and potassium contents of popular food items

Studies comparing the sodium and potassium content between different brands of heavily consumed meat products, breads, ketchups, etc, have been published in newspapers, on TV, and on radio. Such comparisons have demonstrated to the population that equally good-tasting products may have several-fold differences in their sodium and potassium contents. Such comparisons have produced marked changes in the sales of different products. This, in turn, has promoted product planning, which has resulted in products with lower salt contents.

Connections Between Salt Use, Hypertension, and Obesity in the United States

Increases in Salt Use and Hypertension

In the United States, the total yearly sales of food-grade salt, which is a reliable indicator of changes in the total salt intake in the country, showed a clear continuous fall until 1983.[9] In 1978, the sales were 1003 million kilograms or 12.3 g per person a day and decreased gradually to the level of 10.1 to 10.2 in 1983 to 1985. Thereafter, a steep increase in salt sales took place. In 1998, the total food-grade salt sales exceeded 1500 million kilograms, corresponding to more than 15 g per person a day. The per capita use of salt increased approximately 55% from 1983 to 1998 (Fig 6B). Thereafter, the use appears to have stabilized at a high level. Although there are many uncertainties with dietary questionnaires, they also strongly suggest that a remarkable increase in salt intake has taken place in the United States.[11] In the US

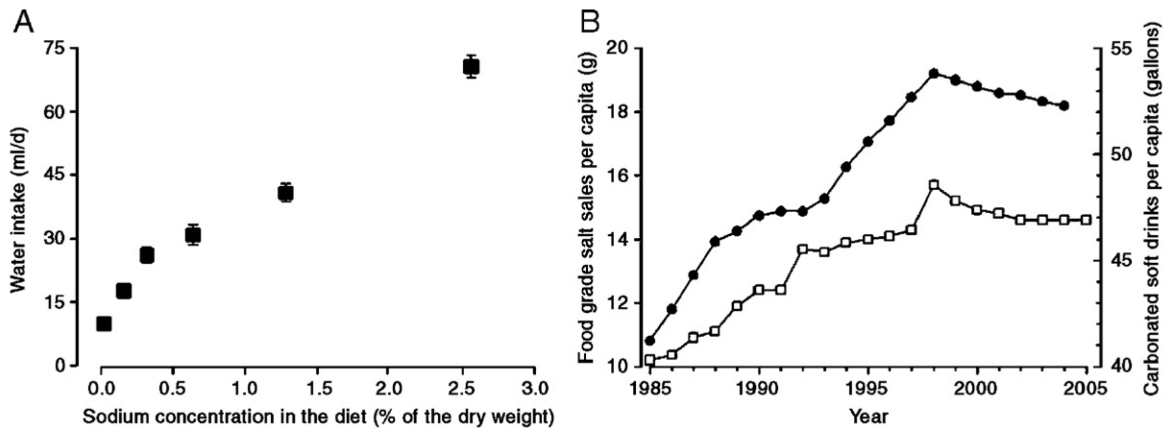

Fig. 6. Panel A shows dose-dependent effect of dietary sodium concentration on water intake in rats (n = 10 rats in each group). Panel B shows sales of food-grade salt (open squares) and consumption of carbonated beverages (solid circles) in the United States between 1985 and 2005. The per capita values were calculated from the data of Salt Institute,[9] United States Department of Agriculture,[53] and US Census Bureau.[54]

population, aged 20 to 74 years, blood pressure levels and prevalence of hypertension appeared to decrease markedly from the early 1970s until the late 1980s to the early 1990s. However, since the late 1980s and early 1990s, the age-adjusted prevalence of high blood pressure shows a marked increase in the population aged 20 years and older.[11] The turn of the prevalence of hypertension to an increase appears to coincide with the turn of the sales of food-grade salt from a decreasing trend to a rapid increase in the late 1980s and in the 1990s. Salt is mainly derived from industrially manufactured food items. Salt added during industrial processing of foods accounts for 3 quarters or more of an individual's total sodium intake.[50,55] Since the 1980s, the portion sizes of commercial energy-dense foods and beverages have increased remarkably.[56] This trend has caused an increased intake of energy. There is evidence that increased portion sizes promote obesity.[57,58] As there is no evidence of any reduction in salt concentrations in the increased portions, the increasing portion sizes also increase the intake of salt. This assumption is further supported by the finding that there is a strong correlation between energy and salt intakes.[21,59,60] Factors contributing to the increase in salt intake include larger portion sizes of foods, changes in snack habits, and increases in the percentage of the population eating away from home, particularly at fast-food restaurants.[11]

Salt intake, Beverage Consumption, and Obesity

Thirst, which causes water or beverage intakes, is an unavoidable physiologic response to the ingestion of foods with high salt content. There is a linear increase in the intake of water with increasing salt content in the diet of rats (Fig 6A). A similar effect of salt intake on the consumption of water or beverages has been demonstrated in man.[61] Although the per capita use of salt increased approximately 55% from 1983 to 1998, the per capita use of sweetened, carbonated soft drinks during the same period increased 45%.[53] Thereafter, both the use of salt and the consumption of carbonated soft drinks have remained rather constant at high levels. There is a striking parallelism in the changes in per capita food-grade salt sales and per capita consumption of carbonated soft drinks (Fig 6B; salt data derived from the Salt Institute,[9] and beverage consumption data from the United States Department of Agriculture[53]). Interestingly, in the United States, the age-adjusted prevalence of obesity remained essentially unchanged from 1960-1962 to 1976-1980. However, the 1988 to 1994 measurements revealed that, in a decade, the prevalence of obesity had increased 61% among men and 52% among women. During 1999 to 2002, the prevalence of obesity was 120% higher among men and 99% higher among women as compared with the prevalence in 1976 to 1980.[11] Between 1977 and 2001, energy intake from sweetened beverages increased on the average by 135% in the United States. During the same period, the energy intake from milk was reduced by 38%. The net effect on energy intake was a 278 total kcal increase per capita a day.[62] To burn the average increase of 278 kcal a day and avoid the development or worsening of obesity, one should walk for approximately 1 hour 10 minutes more or play tennis 40 minutes more, or vacuum 1 hour 10 minutes more each day than in 1977.[56] The increased intake of salt has apparently played an important role in the increase in the consumption of soft drinks and, hence, also in the increase in energy intake. Higher consumption of sweetened beverages was associated with both a greater magnitude of weight gain and an increased risk for development of type 2 diabetes.[63] Both obesity and diabetes sensitize to the hypertensive effect of salt (see above).

Salt Intake and Economics

Both the social and economic burdens of the present high salt intakes are huge, as salt accounts for a big proportion of high blood pressure levels, strokes, and heart attacks in all industrialized communities. On the other hand, the income of beverage, food, and salt companies depends strongly on the level of salt consumption. It is clear that the income of salt manufacturers is directly related to the level of salt use.[9] Many food manufacturers benefit from the salt-induced increased content of water in several food types, such as meat products.[61] However, the connection between the level of salt intake and the level of beverage consumption has the biggest economic implications. In 2004, the per capita consumption of carbonated soft drinks was 52.3 gallons or approximately 198 L,[53] worth $65.9 billion per year in the United States alone.[64] In 1983, in the presence of approximately 30% lower use of salt,[9] the per capita consumption of carbonated soft drinks was approximately 25% lower than in 2004.[53] The available evidence on connections between salt levels in foods, thirst, and beverage intakes suggests that nationwide reduction in salt intake to the currently recommended levels could, at least to some extent, decrease the consumption of beverages. A 25% decrease in the sales of carbonated soft drinks would mean approximately $16 billion a year in the United States. Even if the association between salt intake and consumption of beverages was markedly weaker, the economic effects of the level of salt use are huge. Therefore, the possibility exists that economic factors may play a role in the heavy fight of some beverage, food, and salt companies against initiatives and activities for comprehensive salt reduction.[6-8]

Worldwide Reduction in Salt Intake With Increases in Potassium, Calcium, and Magnesium Intakes is Justified

Comprehensive Reduction in Salt Intake with Increased Intakes of Potassium, Calcium, and Magnesium has an Enormous Population Impact

The main thing that determines the population impact of a blood pressure–lowering factor is the extent to which such factor is implemented in the population. It should be noted that its importance greatly exceeds the importance of the effectiveness of a factor in an individual.[14] Antihypertensive drugs can be used as an example to illustrate the fundamental difference between the effectiveness in individuals and the impact in preventing hypertension problems in the population. Antihypertensive drugs are the most effective agents in lowering blood pressure in the treated individuals. However, their role in the overall control of high blood pressure in the whole population is surprisingly small. The average long-term effect of antihypertensive drugs is an approximately 10–mm Hg fall in systolic blood pressure. A nationwide register kept by the Social Insurance Institution reveals that, in Finland, 8.5% of those aged 35 to 59 years were entitled to special reimbursement of antihypertensive medication at the end of 2004 (Professor Timo Klaukka, personal communication 2005). As approximately 9 of 10 individuals in the population do not receive antihypertensive drug treatment, the average population effect of the present extensive use of antihypertensive drugs is about one tenth of 10 mm Hg, that is, approximately 1 mm Hg only. It is important to note that any measure that can be implemented in all individuals and has an average effect of 1 mm Hg on systolic blood pressure has a population impact that is equal to the effect of current antihypertensive drug therapy.

It has been argued that the magnitude of the effect in whites with normal blood pressure does not warrant general recommendation to reduce sodium intake.[65] The authors found that reduced intake of sodium lowers systolic blood pressure by 1.27 mm Hg in whites with normal blood pressure. In individuals with elevated blood pressure, the fall in systolic blood pressure was remarkably greater, 4.18 mm Hg. As elevated blood pressure is present in approximately half of the population (blood pressure, >130/85 mm Hg), the data of the authors actually suggest an average population effect, which is (1.27 + 4.18 mm Hg)/2, that is, a fall of approximately 2.7 mm Hg. This compares very favorably with the population impact of the antihypertensive drug treatment, which is less than half of the impact of a population-wide sodium reduction. Therefore, the reasoning of the authors is not correct. It should also be underlined that salt reduction effectively enhances the effectiveness of antihypertensive drug therapy.

Diets with Decreased Levels of Sodium and Increased Levels of Potassium, Calcium, and Magnesium are Safe

It would, a priori, appear logical that the natural diet[12,13] and the nutrients that such a diet provides are both useful and safe. In a recent evaluation of the safety of the nutrient amounts that can be derived from a diet composed of unprocessed foods, it was also concluded that such amounts are safe, although they are, in some cases, markedly different from the current average levels.[16] Hence, a marked decrease in salt and moderate supplementation of the current diets with potassium, calcium, and magnesium can be considered safe for the population. In Finland, the long-term progressive fall in the average salt intake has been accompanied by an impressive decrease in blood pressure, decrease in cardiovascular diseases, and increase in life expectancy. This long-term nationwide experience provides convincing evidence for both the benefits and safety of marked, comprehensive salt reduction.

Two recent reports from one group have raised concerns about the possible harms that might be caused by lower than average current intakes of sodium.[21,60] Alderman et al[60] reported that all-cause and cardiovascular mortality increase progressively with decreasing sodium intakes. However, it has become apparent that one severe shortcoming of the study led to bias and misinterpretations. The authors used single dietary recall and postulated that the result reflected the long-term food and nutrient intake, characteristic of each individual. Unfortunately, in these studies, energy intakes measured by dietary recall at baseline were strikingly different; energy intake in women with the lowest salt intake was only 989 kcal/d (normal energy requirement, 1900-2200 kcal/d by recommended dietary allowance), and in women with the highest salt intake energy intake was 1976 kcal/d. Surprisingly and paradoxically, individuals with the lowest energy intake were heaviest at the end of the follow-up period. These findings clearly indicate that the dietary recall used in these studies[21,60] was strongly underestimating the real energy intake and, thus, also the intake of dietary salt in individuals with the lowest salt intake. Our interpretation is supported by the fact that the authors found a very close correlation between intakes of energy and dietary salt. It should also be underlined that the treatment groups at baseline were to some extent different in age, race, sex, and education, which also might have led to unexpected and contradictory findings. Therefore, the conclusion from these studies, if any, should be drawn with caution. In striking discrepancy with the abovementioned studies, Tuomilehto et al[66] showed recently in a comprehensive prospective study from Finland that high sodium intake predicted mortality and risk of coronary heart disease, independent of other cardiovascular risk factors, including blood pressure.

How to Meet the Challenge of Comprehensive Salt Reduction

The population-wide salt reduction recommendations of several authoritative organizations have not been able to decrease the average intakes of salt. In fact, despite the recommendations, a remarkable increase in the use of salt has taken place in the United States and probably also in many other countries. Little, if any, progress can be made in the battle against the huge health problems caused by the high use of salt, unless the United States and other nations are able to cope appropriately with the powerful factors that operate toward high salt intakes.

In Finland, which has made an exception, the decrease in the average intake of salt has been brought about by a huge publicity campaign about the harmful effects of high salt intakes, accompanied by some legislative measures, and various activities aimed at decreasing salt additions in the food industry. Counseling of individuals has proved to have a very small population impact. The only factor that would be effective in decreasing the overall salt intake in the population is a marked reduction in the amount of salt added in the industrial manufacturing of foods. In the United States, for example, the practical question therefore is how to decrease the overall additions of salt to the foods of the nation from the current level of 1500 million kg per year to 1000 kg or, preferentially, to 750 million kg per year. The latter amount would mean that, on the average, US citizens would consume less than 7 g of salt a day. Taking into consideration the wasted amounts of food and salt, the reduction in sales and additions of food-grade salt to 750 million kg a year would decrease the average salt intake to the level of approximately 5 to 6 g per person a day.

It is self-evident, however, that no recommendations can convince the companies, which would suffer huge economic losses from reduced use of salt, to take any voluntary actions toward comprehensive reduction in salt use. The public health challenge therefore is to find new innovative methods for effective salt reduction. The experience from Finland and Great Britain[67] suggests that no comprehensive salt reduction may be possible without effective governmental interventions. For example, use of appropriate taxation policies could be a powerful method to influence the levels of salt in foods. Legislation on food labeling, such as mandatory warnings of a high salt content, has proved to be very effective in reducing the salt levels of many foods in Finland.

Replacement of the use of processed food items with the use of unprocessed natural foods would have dramatic effects on the intake of sodium and healthy mineral nutrients (see Figs 1 and 2). Complete replacement of the processed foods would result in intakes, which are believed to be in agreement with our genetic programs and therefore best compatible with good health. The use of the currently recommended DASH diet instead of the usual diet is a step toward this direction. This approach has proved to be effective in carefully designed research settings. However, one should realize that the changes that the population ought to do when switching from the usual diet to the DASH diet are remarkable. The use of processed food items is not decreasing. A continuously increasing proportion of the daily diet in industrialized countries consists of processed foods. It is hardly possible to change this trend to any marked extent at present.[14]

As the average taste is accustomed to high salt levels, consumers may be reluctant to accept products with remarkably less salty taste. It is not tempting for the food industry to manufacture low-salt products that are unacceptable for the consumers. Ions (sodium and chloride) also have good water binding and other useful technological effects on the structure of several food items. Therefore, rather than focusing on salt (sodium) only, it may be wise to use also other measures that have proved effective and may be more acceptable for both consumers and industry. The best scientifically based and technically suitable possibility that has already been shown to be useful is offered by the known beneficial effects of increased intakes of potassium, calcium, and magnesium. Appropriate use of potassium, magnesium, and calcium makes it possible to decrease the level of sodium considerably without adverse effects on taste.[68] The "functional food" approach, which corrects the composition of extensively used processed foods, is likely to be particularly effective in producing immediate beneficial effects. The types of food items that are most suitable for such composition improvements may be different in various communities with different food traditions.

It has proved to be easy to lower sodium and increase potassium and magnesium levels by using potassium- and magnesium-enriched salt.[52,69,70] Replacement of common salt with such sodium-reduced, potassium-, and magnesium-enriched salts lowers blood pressure[52,69,70] and also produces other beneficial effects, such as improvement in glucose tolerance.[69] Such a "healthy food/function food" approach, together with claims of their health benefits in comparison with traditional products, would increase the competitiveness of such foods. Such an approach would be beneficial for the population and economically worthwhile particularly for food companies and corporations that are not active in the beverage business. To further increase the competitiveness, such foods could be made even more health promoting by concomitant enrichment with other healthy compounds, such as plant sterols. Such composition changes result in foods that affect beneficially both blood pressure and serum cholesterol, the 2 major causative factors of heart diseases and stroke.[68,71,72] In the United States, the Food and Drug Administration encourages the production and use of foods that have a low content of sodium and/or a high content of potassium or calcium, and that are enriched with cholesterol-lowering plant sterols. Such products are eligible for health claims, which help in health education and are tempting for consumers. Other national governments should also promote healthier food choices by allowing, on good scientific basis, various nutrition and health claims that help consumers choose healthier alternatives, and make the production of healthier products tempting for food manufacturers.

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