Institute of Medicine, Food and Nutrition Board (2004) Dietary Reference Intakes for Water, Potassium, Sodium, Chloride, and Sulfate. National Academy Press, Washington, D.C., pp. 1-18

Summary

This is one volume in a series of reports that presents dietary reference values for the intake of nutrients by Americans and Canadians. This report provides Dietary Reference Intakes (DRIs) for water, potassium, sodium, chloride, and sulfate.

The development of DRIs expands and replaces the series of reports called *Recommended Dietary Allowances* (RDAs) published in the United States and *Recommended Nutrient Intakes* (RNIs) in Canada. A major impetus for the expansion of this review is the growing recognition of the many uses to which RDAs and RNIs have been applied and the growing awareness that many of these uses require the application of statistically valid methods that depend on reference values other than RDAs or RNIs. This report includes a review of the roles that electrolytes and water are known to play in traditional deficiency states and diseases, as well as discussing their roles in the development of chronic diseases.

The overall project is a comprehensive effort undertaken by the Standing Committee on the Scientific Evaluation of Dietary Reference Intakes (the DRI Committee) of the Food and Nutrition Board, Institute of Medicine, The National Academies, in collaboration with Health Canada (see Appendix B for a description of the overall process and its origins). This study was requested by the Federal Steering Committee for Dietary Reference Intakes, which is coordinated by the Office of Disease Prevention and Health Promotion of the U.S. Department of Health and Human Services, in collaboration with Health Canada.

Major findings in this report include the following:

- The establishment of Adequate Intakes (AIs) for *total* water (drinking water, beverages, and food), potassium, sodium, and chloride.
- The establishment of a Tolerable Upper Intake Level (UL) for sodium and chloride.

BOX S-1 Dietary Reference Intakes: Definitions

Recommended Dietary Allowance (RDA): the average daily dietary nutrient intake level sufficient to meet the nutrient requirement of nearly all (97 to 98 percent) healthy individuals in a particular life stage and gender group.

Adequate Intake (AI): the recommended average daily intake level based on observed or experimentally determined approximations or estimates of nutrient intake by a group (or groups) of apparently healthy people that are assumed to be adequate—used when an RDA cannot be determined.

Tolerable Upper Intake Level (UL): the highest average daily nutrient intake level that is likely to pose no risk of adverse health effects to almost all individuals in the general population. As intake increases above the UL, the potential risk of adverse effects may increase.

Estimated Average Requirement (EAR): the average daily nutrient intake level estimated to meet the requirement of half the healthy individuals in a particular life stage and gender group.

• Research recommendations for information needed to advance the understanding of human requirements for water and electrolytes as well as adverse effects associated with intakes of excessive amounts of water, sodium, chloride, potassium, and sulfate.

APPROACH FOR SETTING DIETARY REFERENCE INTAKES

The scientific data used to develop Dietary Reference Intakes (DRIs) have come primarily from observational and experimental studies conducted in humans. Studies published in peer-reviewed journals were the principal source of data. Life stage and gender were considered to the extent possible. Three of the categories of reference values—the Estimated Average Requirement (EAR), the Recommended Dietary Allowance (RDA), and the Adequate Intake (AI)—are defined by specific criteria of nutrient adequacy; the fourth, the Tolerable Upper Intake Level (UL), is defined by a specific endpoint of adverse effect, when one is available (see Box S-1) (see Chapter 1). In all cases, data were examined closely to determine whether a functional end-point could be used as a criterion of adequacy. The quality of studies was examined by considering study design; methods used for measuring intake and indicators of adequacy; and biases, interactions, and confounding factors.

Although the reference values are based on data, the data were often scanty or drawn from studies that had limitations in addressing the various questions that confronted the panel. Therefore, many of the questions raised about the requirements for and recommended intakes of these electrolytes and of water cannot be answered fully because of inadequacies in the present database. Accordingly, a research agenda is proposed (see Chapter 9). In particular, there was a dearth of large, dose-response trials with clinically relevant biological outcomes (considered indicators of adequacy). The absence of such studies is not unique to water and electrolytes. Rather, there are substantial feasibility considerations that preclude the conduct of such trials, especially when the outcome is a chronic disease. The reasoning used to establish the values is described for each nutrient reviewed in Chapters 4 through 7. While the various recommendations are provided as single rounded numbers for practical considerations, it is acknowledged that these values imply a precision not fully justified by the underlying data from currently available human studies.

Box S-1 provides definitions of each of the categories of dietary reference intakes. In order to establish a recommended dietary allowance (RDA), by definition it is necessary to be able to estimate an intake level that would meet the requirement of half of the individuals the sub-group of the population for whom the recommendation is made; estimating this average requirement (EAR) requires that there is sufficient dose response data relating intake to one or more criteria or functional endpoints that are reasonably sensitive to the presence or absence of the nutrient. None of the nutrients reviewed in this report had sufficient dose response data to be able to set an EAR, and from that derive an RDA. Thus for each nutrient with the exception of sulfate, an AI is set. The indicators used to derive the AIs are described below. For sulfate, the scientific evidence was insufficient to set either an AI or UL. Sulfate needs are covered by the current recommended intake for sulfur amino acids, which provide most of the inorganic sulfate needed for metabolism.

NUTRIENT FUNCTIONS AND THE INDICATORS USED TO ESTIMATE REQUIREMENTS

Water is the largest single constituent of the human body and is essential for cellular homeostasis and life. Water provides the solvent for biochemical reactions, is the medium for material transport, and has unique physical properties (high specific heat) to absorb metabolic heat. Water is essential to maintain vascular volume, to support supply of nutrients, and to remove waste via the cardiovascular system and renal and hepatic clearance. Body water deficits challenge the ability of the body to maintain homeostasis during perturbations (e.g., sickness, physical exercise, and climatic stress) and can impact function and health. *Total* water intake includes drinking water, water in other beverages, and water (moisture) in food. Although a low intake of *total* water has been associated with some chronic diseases, this evidence is

TABLE S-1 Percent of *Total* Water Intake from Beverages (Including Drinking Water) and Food

Life Stage Group	Percent from Beverages[a]	Percent from Foods
Both sexes, 0–6 mo	100	0
Both sexes, 7–12 mo	74	26
Both sexes, 1–3 y	71	29
Both sexes, 4–8 y	70	30
Males, 9–13 y	76	24
Males, 14–18 y	80	20
Males, 19–30 y	81	19
Males, 31–50 y	81	19
Males, 51–70 y	81	19
Males, > 70 y	81	19
Females, 9–13 y	75	25
Females, 14–18 y	80	20
Females, 19–30 y	81	19
Females, 31–50 y	81	19
Females, 51–70 y	81	19
Females, > 70 y	81	19
Females, Pregnant	77	22
Females, Lactating	82	18

[a] Includes drinking water
SOURCE: NHANES III, 1988-94; Appendix D.

insufficient to establish water intake recommendations as a means to reduce the risk of chronic diseases. Instead, an Adequate Intake (AI) for *total* water is set to prevent deleterious, primarily acute, effects of dehydration, which include metabolic and functional abnormalities.

Hydration status, as assessed by plasma or serum osmolality, is the primary indicator used for water. Physical activity and environmental conditions have substantial influences on water needs. Because of homeostatic responses, some degree of over- and under-hydration can readily be compensated over the short-term. While it might appear useful to estimate an average requirement (EAR) for water, it is not possible for a nutrient like water. Given the extreme variability in water needs which are not solely based on differences in metabolism, but also in environmental conditions and activity, there is not a single level of water intake that would ensure adequate hydration and optimal health for half of all apparently healthy persons in all environmental conditions. Hence, an EAR could not be established. Rather, an Adequate Intake (AI) is established instead of an RDA, which must be derived from an EAR. Given that the data on urinary osmolality in the U.S. survey data (NHANES III) indicate few instances of inadequate water intake, the AI for *total* water (from a combination of drinking water, beverages, and food) is set based on the median *total* water intake from the U.S. survey data (Table S-1). The AI for *total* water intake for young men and women (19–30 years) is 3.7 L and 2.7 L per day, respectively (see Table S-

2)[1]. Fluids (drinking water and beverages) provided approximately 3.0 L (101 fluid ounces; ≈13 cups) and 2.2 L (74 fluid ounces; ≈9 cups) per day for 19 to 30 year old men and women, representing ~81 percent of *total* water intake. Water contained in food provided ~19 percent of *total* water intake. Canadian survey data indicated somewhat lower levels of *total* water intake. As with AIs for other nutrients, for a healthy person, daily consumption below the AI may not confer additional risk because a wide range of intakes is compatible with normal hydration. Higher intakes of *total* water will be required for those who are physically active or are exposed to hot environment.

Over the course of a few hours, body water deficits can occur due to reduced intake or increased water losses from physical activity and environmental (e.g., heat) exposure. However, on a day to day basis, fluid intake, driven by thirst and the consumption of beverages at meals, allows maintenance of hydration status and total body water at normal levels.

Approximately 80 percent of *total* water intake comes from drinking water and beverages. While consumption of beverages containing caffeine and alcohol have been shown in some studies to have diuretic effects, available information indicates that this may be transient in nature, and that such beverages can contribute to *total* water intake and thus can be used in meeting recommendations for dietary intake of *total* water. While the AI is given in terms of *total* water, there are multiple sources of such water, including moisture content of foods, beverages such as juices and milk, and drinking water. While all of these can contribute to meeting the adequate intake, no one source is essential for normal physiological function and health.

Potassium, the major intracellular cation in the body, is required for normal cellular function. Severe potassium deficiency is characterized by hypokalemia—a serum potassium concentration of less than 3.5 mmol/L. The adverse consequences of hypokalemia include cardiac arrhythmias, muscle weakness, and glucose intolerance. Moderate potassium deficiency, which typically occurs without hypokalemia, is characterized by increased blood pressure, increased salt sensitivity[2], an increased risk of kidney stones, and increased bone turnover (as indicated by greater urinary calcium excretion and biochemical evidence of reduced bone formation and increased bone resorption). An inadequate intake of dietary potassium may also increase the risk of cardiovascular disease, particularly stroke.

The adverse effects of inadequate potassium intake can result from a deficiency of potassium *per se*, a deficiency of its conjugate anion, or both. In unprocessed foods, the conjugate anions of potassium are organic anions, such

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[1] Conversion factors: 1 L = 33.8 fluid oz; 1 L = 1.06 qt; 1 cup = 8 fluid oz.

[2] In general terms, salt sensitivity is expressed as either the reduction in blood pressure in response to a lower salt intake or the rise in blood pressure in response to sodium loading.

TABLE S-2 Criteria and Dietary Reference Intake Values[a] for *Total* Water[b]

Life Stage Group	Criterion	AI[c] (L/d) Male From Foods
0 through 6 mo	Average consumption of water from human milk	0
7 through 12 mo	Average consumption of water from human milk and complementary foods	0.2
1 through 3 y	Median total water intake from NHANES III	0.4
4 through 8 y	Median total water intake from NHANES III	0.5
9 through 13 y	Median total water intake from NHANES III	0.6
14 through 18 y	Median total water intake from NHANES III	0.7
> 19 y	Median total water intake from NHANES III	0.7
Pregnancy		
14 through 50 y	Median total water intake from NHANES III	
Lactation		
14 through 50 y	Median total water intake from NHANES III	

[a] No UL established; however, maximal capacity to excrete excess water in individuals with normal kidney function approximately 0.7 L/hour.
[b] *Total* water represents drinking water, other beverages, and water from food. See the Table S-1 for the median percent of *total* water intake from beverages (including drinking water) and foods in most recent national survey (NHANES III, 1988-94).

as citrate, that are converted in the body to bicarbonate. Acting as a buffer, the bicarbonate-yielding organic anions found in fruits and vegetables neutralize diet-derived acids, such as sulfuric acid generated from sulfur-containing amino acids commonly found in meats and other high protein foods. In the setting of an inadequate intake of bicarbonate precursors, bone titrates excess acid and in the process becomes demineralized. Increased bone turnover and kidney stones are adverse consequences that result from bone titration of excess diet-derived acids. In processed foods to which potassium has been added and in supplements, the conjugate anion is typically chloride, which does not act as a buffer. Because the demonstrated effects of potassium often depend on the accompanying anion and because it is difficult to separate the effects of potassium from the effects of its accompanying anion, the evaluation focuses on research pertaining to non-chloride forms of potassium—the forms found naturally in foods. An EAR could not be set for potassium because the data.

		Female		
From Beverages	***Total* Water**	From Foods	From Beverages	***Total* Water**
0.7	**0.7**	0	0.7	**0.7**
0.6	**0.8**	0.2	0.6	**0.8**
0.9	**1.3**	0.4	0.9	**1.3**
1.2	**1.7**	0.5	1.2	**1.7**
1.8	**2.4**	0.5	1.6	**2.1**
2.6	**3.3**	0.5	1.8	**2.3**
3.0	**3.7**	0.5	2.2	**2.7**
		0.7	2.3	**3.0**
		0.7	3.1	**3.8**

[c]AI = Adequate Intake. The observed average or experimentally determined intake by a defined population or subgroup that appears to sustain a defined nutritional status, such as growth rate, normal circulating nutrient values, or other functional indicators of health. The AI is used if sufficient scientific evidence is not available to derive an EAR. **The AI is not equivalent to an RDA.**

currently available do not provide multiple dose levels within the range to determine the point at which the diet of approximately half of those evaluated would be inadequate for potassium. Thus an Adequate Intake (AI) is given. The AI for potassium is set at 4.7g (120 mmol) per day for adults (see Table S-3). Available evidence indicates that this level of potassium intake should lower blood pressure, blunt the adverse effects of sodium chloride on blood pressure, reduce the risk of kidney stones, and possibly reduce bone loss. It is important to note that the beneficial effects of potassium in these studies appears to be mainly from the forms of potassium that are associated with bicarbonate precursors—the forms found naturally in foods such as fruits and vegetables.

TABLE S-3 Criteria and Dietary Reference Intake Values[a] for Potassium by Life Stage Group

Life Stage Group	Criterion	AI (g/day)[b] Male	AI (g/day)[b] Female
0 through 6 mo	Average consumption of potassium from human milk	0.4	0.4
7 through 12 mo	Average consumption of potassium from human milk and complementary foods	0.7	0.7
1 through 3 y	Extrapolation of Adult AI based on energy intake	3.0	3.0
4 through 8 y	Extrapolation of Adult AI based on energy intake	3.8	3.8
9 through 13 y	Extrapolation of Adult AI based on energy intake	4.5	4.5
14 through 18 y	Extrapolation of Adult AI based on energy intake	4.7	4.7
> 18 y	Intake level to lower blood pressure, reduce the extent of salt sensitivity, and to minimize the risk of kidney stones	4.7	4.7
Pregnancy			
14 through 50 y	Intake level to lower blood pressure, reduce the extent of salt sensitivity, and to minimize the risk of kidney stones		4.7
Lactation			
14 through 50 y	Intake level to lower blood pressure, reduce the extent of salt sensitivity, and to minimize the risk of kidney stones plus the amount of potassium in breast milk (0.4 g/d)		5.1

[a] No UL is established; however, caution is warranted given concerns about adverse effects when consuming excess amounts of potassium from potassium supplements while on drug therapy or in the presence of undiagnosed chronic disease.
[b] AI = Adequate Intake. The observed average or experimentally determined intake by a defined population or subgroup that appears to sustain a defined nutritional status, such as growth rate, normal circulating nutrient values, or other functional indicators of health. The AI is used if sufficient scientific evidence is not available to derive an EAR. **The AI is not equivalent to an RDA.**

At present, dietary intake of potassium by all groups in the United States and Canada is considerably lower than the AI. In recent surveys, the median intake of potassium by adults in the United States was approximately 2.9 to 3.2 g/day[3]

[3] To convert mmol of potassium to mg of potassium, multiply mmol by 39.1 (the molecular weight of potassium).

(74 to 82 mmol/day) for men and 2.1 to 2.3 g/day (54 to 59 mmol/day) for women; in Canada, the median intakes ranged from 3.2 to 3.4 g/day (82 to 87 mmol/day) for men and 2.4 to 2.6 g/day (62 to 67 mmol/day) for women. Because African Americans have lower intakes of potassium and a higher prevalence of elevated blood pressure and salt sensitivity, this sub-group of the population would especially benefit from an increased intake of potassium.

It should be noted that individuals with chronic renal insufficiency, who may be taking angiotensin-converting enzyme (ACE) inhibitors, certain diuretics, individuals with type 1 diabetes, and those on cyclo-oxygenase-2 (COX 2) inhibitors or other non-steroidal anti-inflammatory (NSAID) drugs, should consume levels of potassium recommended by their health care professional, which may well be lower than the AI.

Sodium and *chloride* are normally found in most foods together as sodium chloride, also termed salt. For this reason, this report presents data on the requirements for and the effects of sodium and chloride together[4]. Sodium and chloride are required to maintain extracellular fluid volume and serum osmolality. Human populations have demonstrated the capacity to survive at extremes of sodium intake from less than 0.05 g of sodium in the Yanomamo Indians of Brazil to over 13.8 g (600 mmol)/day in Northern Japan. The ability to survive at extremely low levels of sodium intake reflects the capacity of the normal human body to conserve sodium by markedly reducing losses of sodium in the urine and sweat. Under conditions of maximal adaptation and without sweating, the minimal amount of sodium required to replace losses is estimated to be no more than 0.18 g/day (8 mmol/day). Still, it is unlikely that a diet providing this level of sodium intake is sufficient to meet dietary requirements for other nutrients. Given that dose response data are lacking regarding at what level half of the individuals in a group would have their needs met for other essential nutrients, which would be necessary to develop an EAR, an AI was developed instead.

The Adequate Intake (AI) for sodium is set for young adults at 1.5 g/day (65 mmol/day) (3.8 g sodium chloride) to ensure that the overall diet provides an adequate intake of other important nutrients and to cover sodium sweat losses in unacclimatized individuals who are exposed to high temperatures or who are moderately physically active as recommended in other DRI reports. This AI does not apply to highly active individuals, such as endurance athletes who lose large amounts of sweat on a daily basis. The AI for sodium for older adults and

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[4] In this report, the terms 'salt', 'sodium chloride', and 'sodium' are used interchangeably. In view of the format of published data, this report presents intake data primarily as g (mmol)/day of sodium and of chloride, rather than g (mmol)/day of sodium chloride. To convert mmol to mg of sodium, chloride, or of sodium chloride, multiply mmol by 23, 35.5, or 58.5 (the molecular weights of sodium, chloride, and sodium chloride).

TABLE S-4 Criteria and Dietary Reference Intake Values for Sodium

Life Stage Group	Criterion for AI
0 through 6 mo	Average consumption of sodium from human milk
7 through 12 mo	Average consumption of sodium from human milk and complementary foods
1 through 3 y	Extrapolation of Adult AI based on energy intake
4 through 8 y	Extrapolation of Adult AI based on energy intake
9 through 13 y	Extrapolation of Adult AI based on energy intake
14 through 18 y	Extrapolation of Adult AI based on energy intake
19 through 50 y	Intake level to cover possible daily losses, provide adequate intakes of other nutrients, and maintain normal function
51 though 70 y	Extrapolated from younger adults based on energy intake
> 70 y	Extrapolated from younger adults based on energy
Pregnancy	
14 through 50 y	Same as non-pregnant women
Lactation	
14 through 50 y	Same as non-lactating women

[a] AI = Adequate Intake. The observed average or experimentally determined intake by a defined population or subgroup that appears to sustain a defined nutritional status, such as growth rate, normal circulating nutrient values, or other functional indicators of health. The AI is used if sufficient scientific evidence is not available to derive an EAR. **The AI is not equivalent to an RDA.**

the elderly is somewhat less, based on lower energy intakes, and is set at 1.3 g (55 mmol)/day for men and women 50 through 70 years of age, and at 1.2 g (50 mmol)/day for those 71 years of age and older (see Table S-4).

Concerns have been raised that a low level of sodium intake adversely affects blood lipids, insulin resistance, and cardiovascular disease risk. However, at the level selected for the AI, the preponderance of evidence does not support this contention. A potential indicator of an adverse effect of inadequate sodium is an increase in plasma renin activity. However, in contrast to the well-accepted benefits of blood pressure reduction, the clinical relevance of modest rises in plasma renin activity as a result of sodium reduction is uncertain. The AI for chloride is set at a level equivalent on a molar basis to that of sodium, since almost all dietary chloride comes with the sodium added during processing or consumption of foods; thus the AI for chloride for younger adults is 2.3 g/day (65 mmol/day) of chloride, which is equivalent to 3.8 g/day sodium chloride.

Sulfate is required by the body for synthesis of 3'-phosphoadenosine-5'-phosphosulfate (PAPS); this compound, in turn, is used for synthesis of many important sulfur-containing compounds such as chondroitin sulfate and cerebroside sulfate. While significant levels of sulfate are found in foods and various sources of drinking water, the major source of inorganic sulfate for humans is from bio-degradation due to body protein turnover of the sulfur amino acids, methionine and cysteine. Dietary sulfate in food and water, together with

AI[a] (g/d)		UL[b] (g/d)	
Male	Female	Male	Female
0.12	0.12	ND[c]	ND
0.37	0.37	ND	ND
1.0	1.0	1.5	1.5
1.2	1.2	1.9	1.9
1.5	1.5	2.2	2.2
1.5	1.5	2.3	2.3
1.5	1.5	2.3	2.3
1.3	1.3	2.3	2.3
1.2	1.2	2.3	2.3
	1.5		2.3
	1.5		2.3

[b] UL = Tolerable Upper Intake Level. Based on prevention of increased blood pressure.
[c] ND=Not determined. Intake should be from food or formula only.

sulfate derived from methionine and cysteine found in dietary protein, as well as the cysteine component of glutathione, provide sulfate for use in PAPS bio synthesis. Sulfate requirements are thus met when intakes include recommended levels of sulfur amino acids. For this reason, neither an Estimated Average Requirement (and thus a Recommended Dietary Allowance) nor an Adequate Intake of sulfate are established.

CRITERIA AND PROPOSED VALUES FOR TOLERABLE UPPER INTAKE LEVELS

A risk assessment model is used to derive Tolerable Upper Intake Levels (ULs). The model consists of a systematic series of scientific considerations and judgments (see Chapter 3). The hallmark of the risk assessment model is the requirement to be explicit in all of the evaluations and judgments made.

Water. Water intoxication can lead to life-threatening hyponatremia, which can result in central nervous system edema, lung congestion, and muscle weakness. Hyponatremia occurs occasionally in psychiatric patients (psychogenic polydipsia). In unusual circumstances, hyponatremia can also occur from excessive fluid intake, under-replacement of sodium, or both during or after prolonged endurance athletic events. The symptomatic hyponatremia of exercise is typically associated with greater than 6 hours of prolonged stressful exercise. Acute water toxicity has been reported due to rapid consumption of large quantities of fluids that greatly exceeded the kidney's maximal excretion rate of from 0.7 to 1.0 L/hour. Hyponatremia does not occur in healthy populations consuming the average North American diet.

Thus, while hazards associated with overconsumption of fluid can be identified, there are not data on habitual consumption of elevated water intakes resulting in identifiable hazards in apparently healthy people. Because of the ability to self regulate excessive consumption of water from fluids and foods by healthy people in temperate climates, a Tolerable Upper Intake Level was not set for water.

Potassium. Gastrointestinal discomfort and ulceration of the gastrointestinal tract have been reported with some forms of potassium supplements but not with potassium from diet. Cardiac arrhythmias from hyperkalemia are the most serious consequence of excessive potassium intake. The typical sequence of findings is hyperkalemia, followed by conduction abnormalities on ECG and then cardiac arrhythmias which can be life-threatening. Such consequences result from either a high plasma concentration of potassium or from rapid and extreme changes in its concentration. In individuals whose urinary potassium excretion is impaired by a medical condition, drug therapy, or both, instances of life-threatening hyperkalemia have been reported. However, in otherwise healthy individuals (that is, individuals without impaired urinary potassium excretion from a medical condition or drug therapy), there have been no reports of hyperkalemia resulting from acute or chronic ingestion of potassium naturally occurring in food.

In otherwise healthy individuals (that is, individuals without impaired urinary potassium excretion from a medical condition or drug therapy), there is no evidence that a high level of potassium from foods has adverse effects. Therefore, a UL for potassium based on foods is not set for healthy adults.

In contrast, supplemental potassium can lead to acute toxicity in healthy individuals. Also, chronic consumption of a high level of potassium can lead to hyperkalemia in individuals with impaired urinary potassium excretion. Hence, supplemental potassium should only be provided under medical supervision because of the well-documented potential for toxicity. Clinical settings in which high intakes of potassium could pose a serious risk include type 1 diabetes, chronic renal insufficiency, end stage renal disease, severe heart failure, and adrenal insufficiency. In these individuals, a potassium intake below the AI is often appropriate. For individuals with these diseases or clinical conditions, salt substitutes (potassium chloride) should only be used under medical supervision.

Sodium chloride. The main adverse effect of increased sodium chloride in the diet is increased blood pressure, which is a major risk factor for cardiovascular-renal diseases. Results from the most rigorous dose-response trials have documented a progressive, direct effect of dietary sodium intake on blood pressure in non-hypertensive as well as hypertensive individuals. The dose-dependent rise in blood pressure appears to occur throughout the spectrum of sodium intake. However, the relationship is non-linear in that the blood pressure response to changes in sodium intake is greater at sodium intakes below 2.3 g (100 mmol) per day than above this level. The strongest dose-response evidence comes from those clinical trials that specifically examined the effects of at least 3 levels of sodium intake on blood pressure. The range of sodium intake in these studies varied from 0.23 g (10 mmol) per day to 34.5 g (1,500 mmol) per day. Several trials included sodium intake levels close to 1.5 g (65 mmol) per day and 2.3 g/day (100 mmol/day).

While blood pressure, on average, rises with increased sodium intake, there is well-recognized heterogeneity in the blood pressure response to changes in sodium chloride intake. Individuals with hypertension, diabetes, and chronic kidney disease, as well as older-age persons and African Americans, tend to be more sensitive to the blood pressure raising effects of sodium chloride intake than their counterparts[5]. Genetic factors also influence the blood pressure response to sodium chloride.

There is considerable evidence that salt sensitivity is modifiable. The rise in blood pressure from increased sodium chloride intake is blunted in the setting of a diet high in potassium or a low fat, mineral rich diet; nonetheless, a dose-response relationship between sodium intake and blood pressure still persists. In non-hypertensive individuals, a reduced salt intake can decrease the risk of developing hypertension.

The adverse effects of higher levels of sodium intake on blood pressure provide the scientific rationale for setting the UL. Because the relationship between sodium intake and blood pressure is progressive and continuous without an apparent threshold, it is difficult to precisely set a UL, especially because other environmental factors (weight, exercise, potassium intake, dietary pattern, and alcohol intake) and genetic factors also affect blood pressure. For adults, a UL for sodium of 2.3 g (100 mmol) per day is set, equivalent to a total of 5.8 g/day of sodium chloride. In dose-response trials, this level was commonly the next level above the AI that was tested. The equivalent UL for chloride is 3.5 g. It should be noted that the UL is not a recommended intake and, as with other ULs, there is no benefit to consuming levels above the AI.

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[5] In research studies, different techniques and quantitative criteria have been used to define salt sensitivity. In general terms, salt sensitivity is the extent of blood pressure change in response to a change in salt intake. Salt sensitivity differs among subgroups of the population and among individuals within a subgroup. The term 'salt sensitive blood pressure' applies to those individuals or subgroups that experience the greatest change in blood pressure from a given change in salt intake—that is, the greatest reduction in blood pressure when salt intake is reduced.

Among certain groups of individuals who are most sensitive to the blood pressure effects of increased sodium intake (e.g., older persons, African Americans, and individuals with hypertension, diabetes, or chronic kidney disease), their UL for sodium may be lower. These groups also experience an especially high incidence of blood pressure-related cardiovascular disease. In contrast, for individuals who are unacclimatized to prolonged physical activity in a hot environment, their needs may exceed the UL because of sodium sweat losses.

Sulfate. While diarrhea can occur from a high sulfate intake, this condition usually results from ingestion of water with high sulfate content. Overall, there were insufficient data to use the model of risk assessment to set a UL for sulfate.

Although a specific UL was not set for water, potassium, or sulfate, the absence of definitive data does not indicate that all people can tolerate chronic intakes of these substances at high levels. Like all chemical agents, nutrients and other food components can produce adverse effects if intakes are excessive. Therefore, when data are extremely limited or conflicting, extra caution may be warranted in consuming levels significantly above that found in typical food-based diets.

USING DIETARY REFERENCE INTAKES TO ASSESS NUTRIENT INTAKES OF INDIVIDUALS

Suggested uses of Dietary Reference Intakes (DRIs) appear in Box S-2. For statistical reasons that were addressed in the reports, *Dietary Reference Intakes: Applications in Dietary Assessment* (IOM, 2000) and *Dietary Reference Intakes: Applications in Dietary Planning* (IOM, 2003) and briefly in Chapter 8, when a Recommended Dietary Allowance (RDA) is not available, the Adequate Intake (AI) is the appropriate reference intake to use in assessing and planning the nutrient intake of individuals. Usual intake at or above the AI has a low probability of inadequacy.

When the median intake of a population group is equal to or exceeds the AI, the prevalence of inadequacy is likely to be low, especially when the AI is set as the median intake of a healthy group. This is the case for *total* water, in which the AI was based on median intakes of a population with little evidence of chronic dehydration. In the case of potassium, where the AI is set at a level much higher than the median intake, it is not possible to estimate the prevalence of inadequacy from comparison to survey data. It is only possible to assume that those whose intake is above the AI have sufficient intake. It isn't possible to speculate on the extent of inadequacy in those whose intake is below the AI for potassium.

Chronic consumption above the UL may place an individual or group at risk of adverse effects. Therefore, the percent of survey individuals whose intake

BOX S-2 Uses of Dietary Reference Intakes for Healthy Individuals and Groups

Type of Use	*For an Individual*[a]	*For a Group*[b]
Assessment	**EAR:** use to examine the probability that usual intake is inadequate (if individual's usual intake is at the EAR, then 50% probability that intake is inadequate).	**EAR**: use to estimate the prevalence of inadequate intakes within a group (% in a group whose intakes are inadequate = % whose intakes are below the EAR).
	RDA: usual intake at or above this level has a low probability of inadequacy.	**RDA:** do not use to assess intakes of groups.
	AI[c]**:** usual intake at or above this level has a low probability of inadequacy.	**AI**[c]**:** mean usual intake at or above this level implies a low prevalence of inadequate intakes.
	UL: usual intake above this level may place an individual at risk of adverse effects from excessive nutrient intake.	**UL:** use to estimate the percentage of the population at potential risk of adverse effects from excess nutrient intake.
Planning	**RDA:** aim for this intake.	**EAR:** use to plan an intake distribution with a low prevalence of inadequate intakes.
	AI[c]**:** aim for this intake.	**AI**[c]**:** use to plan mean intakes.
	UL: use as a guide to limit intake; chronic intake of higher amounts may increase the potential risk of adverse effects.	**UL:** use to plan intake distributions with a low prevalence of intakes potentially at risk of adverse effects.

RDA = Recommended Dietary Allowance
EAR = Estimated Average Requirement
AI = Adequate Intake
UL = Tolerable Upper Level

[a] Evaluation of true status requires clinical, biochemical, and anthropometric data.
[b] Requires statistically valid approximation of distribution of usual intakes.

continued

BOX S-2 Continued

[c] For the nutrients in this report, AIs are set for all age groups for water, potassium and sodium (and chloride on an equi-molar basis to sodium). The AI may be used as a guide for infants as it reflects the average intake from human milk. Infants consuming formulas with the same nutrient composition as human milk are consuming an adequate amount after adjustments are made for differences in bioavailability. In the context of assessing groups, when the AI for a nutrient is not based on mean intakes of a healthy population, this assessment is made with less confidence.

In the case of energy, an Estimated Energy Requirement (EER) is provided: it is the dietary energy intake that is predicted (with variance) to maintain energy balance in a healthy adult of defined age, gender, weight, height and level of physical activity, consistent with good health. In children and pregnant and lactating women, the EER is taken to include the needs associated with the deposition of tissues or the secretion of milk at rates consistent with good health.

For individuals, the EER represents the midpoint of a range within which an individual's energy requirements are likely to vary. As such, it is below the needs of half the individuals with specified characteristics, and exceeds the needs of the other half. Body weight should be monitored and energy intake adjusted accordingly.

exceed the UL equals the percent of individuals whose diets are considered excessive in that particular nutrient.

For example, sodium intake data from the third National Health and Nutrition Examination Survey (NHANES III) (Appendix D), which collected 24-hour diet recalls for 1 or 2 days, indicate that:

- The vast majority (between 95 and 99 percent) of men and women consume dietary sodium at levels greater than the AI, and thus one would assume that intakes were 'adequate', which would mean that the prevalence in the population of hyponatremia resulting from inadequate sodium intake is very low.
- More than 95 percent of men and 75 percent of women had sodium intakes that exceeded the UL in the United States, even when the amount of sodium added to foods during meals was excluded. In phase I of the same survey (NHANES III), 24.7 percent of men and 24.3 percent of women 18 years and older had hypertension, meaning that a substantial number of individuals appear to experience this adverse effect identified in the risk assessment related to sodium.

RESEARCH RECOMMENDATIONS

Three major types of information gaps were noted: (1) a paucity of data for estimating average requirements for electrolytes and water in presumably healthy humans, (2) an even greater dearth of evidence on the electrolyte and water needs in infants, children, adolescents, the elderly, and pregnant and lactating women, and (3) a lack of multi-dose trials to determine the effects of electrolyte and water intake on chronic diseases. There is also a need for research on public health strategies that effectively reduce sodium intake as well as increase potassium intake in the general population.

REFERENCES

IOM (Institute of Medicine). 2000. *Dietary Reference Intakes: Applications in Dietary Assessment*. Washington, DC: National Academy Press.

IOM (Institute of Medicine). 2003. *Dietary Reference Intakes: Applications in Dietary Planning*. Washington, DC: National Academy Press.