Free Executive Summary

Dietary Reference Intakes for Water, Potassium, Sodium, Chloride, and Sulfate

Panel on Dietary Reference Intakes for Electrolytes and Water, Standing Committee on the Scientific Evaluation of Dietary Reference Intakes

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DRI electrolytes

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 a discussion of their roles in the development of chronic diseases, and provides, where warranted, reference values for use in assessing and planning diets.

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 (which includes drinking water and the water content of beverages and food), potassium, sodium, and chloride.
- The establishment of a Tolerable Upper Intake Level (UL) for sodium and chloride.
- 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 Chapter 1 for an overview of the approach).

In all cases, data were examined closely to determine whether a functional endpoint 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 identified regarding 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 or excess). 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

clinical 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 applicable to electrolytes and water. 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 in the subgroup of the population for whom the recommendation is made; estimating this average requirement (EAR) requires that there be 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 adequate intake (AI) is set. The indicators used to derive the AIs are

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.*

described below. For sulfate, the scientific evidence was insufficient to set an AI. However, sulfate needs are met by the current recommended intakes for sulfur amino acids, which provide most of the inorganic sulfate needed for metabolism.

NUTRIENT FUNCTIONS AND THE INDICATORS USED TO ESTIMATE REQUIREMENTS

Water

The largest single constituent of the human body, water, is essential for cellular homeostasis and life. It 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 the supply of nutrients to tissues, 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, or climatic stress) and can impact function and health. *Total* water intake includes drinking water, water in other beverages, and water (moisture) in food (Table S-1).

Although a low intake of *total* water has been associated with some chronic diseases, this evidence is insufficient to establish water intake recommendations as a means of reducing the risk of chronic diseases. Instead, an 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 underhydration 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 that are not solely based on differences in metabolism, but also on 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 AI is established instead of an RDA, which must be derived from an EAR.

U.S. survey data from the Third National Health and Nutrition

TABLE S-1 Percent of Median *Total* Water Intake in the United States from Beverages (Including Drinking Water) and Food

Life Stage Group[a]	Percent from Beverages[b]	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
M, 9–13 y	76	24
M, 14–18 y	80	20
M, 19–30 y	81	19
M, 31–50 y	81	19
M, 51–70 y	81	19
M, > 70 y	81	19
F, 9–13 y	75	25
F, 14–18 y	80	20
F, 19–30 y	81	19
F, 31–50 y	81	19
F, 51–70 y	81	19
F, > 70 y	81	19
Pregnant	77	22
Lactating	82	18

[a] M = male, F = female.

[b] Includes drinking water.

SOURCE: U.S. Department of Health and Human Services, National Center for Health Statistics, Third National Health and Nutrition Examination Survey, 1988–1994.

Examination Survey (NHANES III) indicate that serum osmolality, an indicator of hydration status, is maintained at a constant level over a wide range of *total* water intakes (i.e., serum osmolality is nearly identical for individuals in the lowest decile of reported intake compared with those in the highest decile of intake). Based on these data, the AI for *total* water (from consuming a combination of drinking water, beverages, and food) is set based on the median *total* water intake from the U.S. NHANES III data (Table S-2). The AI for *total* water intake for young men and women (19 through 30 years) is 3.7 L and 2.7 L per day, respectively (see Table S-2).[1] In the NHANES, fluids (beverages and drinking water) provided approximately 3.0 L (101 fluid ounces; ≈ 13 cups) and 2.2 L (74 fluid

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

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

Life Stage Group	Criterion
0 through 6 mo	Average consumption of water from human milk
7 through 12 mo	Average consumption of water from human milk and complementary foods
1 through 3 y	Median total water intake from NHANES III
4 through 8 y	Median total water intake from NHANES III
9 through 13 y	Median total water intake from NHANES III
14 through 18 y	Median total water intake from NHANES III
> 19 y	Median total water intake from NHANES III
Pregnancy	
14 through 50 y	Same as median intake for nonpregnant women from NHANES III
Lactation	
14 through 50 y	Same as median intake for nonlactating women from NHANES III

[a] No Tolerable Upper Intake Level is established; however, maximal capacity to excrete excess water in individuals with normal kidney function is approximately 0.7 L/hour.

[b] *Total* water represents drinking water, water in other beverages, and water (moisture) from food. See Table S-1 for the median percent of *total* water intake from beverages (including drinking water) and from foods reported in the Third National Health and Nutrition Examination Survey (NHANES III, 1988–1994).

ounces; ≈ 9 cups) per day for 19- through 30-year-old men and women, representing ~ 81 percent of *total* water intake (Table S-1). Water contained in food provided ~ 19 percent of *total* water intake. Canadian survey data indicated somewhat lower levels of *total* water intake (Appendix F).

As with AIs for other nutrients, for a healthy person, daily consumption below the AI may not confer additional risk because wide ranges of intakes are compatible with normal hydration. In this setting, the AI should not be interpreted as a specific requirement. Higher intakes of *total* water will be required for those who are physically active or who are exposed to hot environments.

While over the course of a few hours body water deficits can occur due to reduced intake or increased water (sweat) losses from physi-

AI[c] (L/d)					
Male			Female		
From Foods	From Beverages	***Total* Water**	From Foods	From Beverages	***Total* Water**
0.0	0.7	**0.7**	0.0	0.7	**0.7**
0.2	0.6	**0.8**	0.2	0.6	**0.8**
0.4	0.9	**1.3**	0.4	0.9	**1.3**
0.5	1.2	**1.7**	0.5	1.2	**1.7**
0.6	1.8	**2.4**	0.5	1.6	**2.1**
0.7	2.6	**3.3**	0.5	1.8	**2.3**
0.7	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 Estimated Average Requirement. **The AI is not equivalent to a Recommended Dietary Allowance.**

cal activity and environmental (e.g., heat) exposure, on a day-to-day basis fluid intake, driven by the combination of 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 beverages and water. 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 contribute to *total* water intake.

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, potassium 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 as citrate, that are converted in the body to bicarbonate. Acting as a buffer, bicarbonate neutralizes 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, buffers in the bone matrix neutralize excess acid and in the process bone becomes demineralized. Increased bone turnover and calcium-containing kidney stones are the resulting adverse consequences.

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, this evaluation focuses on research pertaining to non-

[2] 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.

chloride forms of potassium—the forms found naturally in fruits, vegetables, and other potassium-rich foods.

An EAR could not be set for potassium because the data 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 AI is given. The AI for potassium is set at 4.7 g (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 appear 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.

At present, dietary intakes of potassium by all groups in the United States and Canada are 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[3] (74 to 82 mmol)/day for men and 2.1 to 2.3 g (54 to 59 mmol)/day for women; in Canada, the median intakes ranged from 3.2 to 3.4 g (82 to 87 mmol)/day for men and 2.4 to 2.6 g (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 subgroup 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 taking cyclo-oxygenase-2 (COX 2) inhibitors or other nonsteroidal anti-inflammatory (NSAID) drugs, should consume levels of potassium recommended by their health care professional, which may well be lower than the AI.

Sodium Chloride

Sodium and chloride are normally found together in most foods as sodium chloride, also termed salt. For that reason, this report presents data on the requirements for and the effects of sodium and

[3] To convert g of potassium to mmol of potassium, divide g by 39.1 (the molecular weight of potassium) and multiply by 1,000.

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

		AI (g/day)[b]	
Life Stage Group	Criterion	Male	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 in adults	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 in nonpregnant adults		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 in nonlactating adults plus the average amount of potassium estimated in breast milk during the first 6 months (0.4 g/d)		5.1

[a] No Tolerable Upper Intake Level 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 Estimated Average Requirement. **The AI is not equivalent to a Recommended Dietary Allowance.**

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 0.2 g (10 mmol)/day of sodium in the Yanomamo Indians of Brazil to more than 10.3 g (450 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 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 (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 the level of sodium and chloride intake from currently available foods in the United States and Canada at which *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 AI for sodium is set for young adults at 1.5 g (65 mmol)/day (3.8 g of 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 become physically active as recommended in other DRI reports. This AI does not apply to individuals who lose large volumes of sodium in sweat, such as competitive athletes and workers exposed to extreme heat stress (e.g., foundry workers and fire fighters). Sodium intake invariably rises with increased energy intake in physically active individuals, and this increase usually is enough to compensate for sweat sodium losses. However, some individuals in the situations described above can lose excessively large amounts of sodium in sweat, and on those occasions they should ingest a diet that contains sodium in excess of the AI.

The AI for sodium for older adults and 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).

[4] 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 (salt). 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), respectively.

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

Life Stage Group	Criterion for AI for Sodium
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 intake
Pregnancy	
14 through 50 y	Same as for nonpregnant women
Lactation	
14 through 50 y	Same as for nonlactating 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 Estimated Average Requirement. **The AI is not equivalent to a Recommended Dietary Allowance.**

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. For example, the AI for chloride for younger adults is 2.3 g (65 mmol)/day of chloride, which is equivalent to 3.8 g/day of sodium chloride.

Sodium AI[a] (g/d)		Chloride AI[b] (g/d)		Sodium UL[c] (g/d)		Chloride UL[b] (g/d)	
Male	Female	Male	Female	Male	Female	Male	Female
0.12	0.12	0.18	0.18	ND[d]	ND	ND	ND
0.37	0.37	0.57	0.57	ND	ND	ND	ND
1.0	1.0	1.5	1.5	1.5	1.5	2.3	2.3
1.2	1.2	1.9	1.9	1.9	1.9	2.9	2.9
1.5	1.5	2.3	2.3	2.2	2.2	3.4	3.4
1.5	1.5	2.3	2.3	2.3	2.3	3.6	3.6
1.5	1.5	2.3	2.3	2.3	2.3	3.6	3.6
1.3	1.3	2.0	2.0	2.3	2.3	3.6	3.6
1.2	1.2	1.8	1.8	2.3	2.3	3.6	3.6
	1.5		2.3		2.3		3.6
	1.5		2.3		2.3		3.6

[b] Chloride determined on molar basis equal to sodium AI or UL.

[c] UL = Tolerable Upper Intake Level. Based on prevention of increased blood pressure.

[d] ND=Not determined. Intake should be from food or formula only.

Sulfate. This nutrient is required by the body for synthesis of 3′-phosphoadenosine-5′-phosphosulfate (PAPS), which in turn is used for synthesis of many important sulfur-containing compounds such as chondroitin sulfate and cerebroside sulfate. While substantial levels of sulfate are found in foods and various sources of drinking water, the major source of inorganic sulfate for humans is from body protein turnover of the sulfur amino acids, methionine and cysteine. Dietary inorganic sulfate in food and water, together with sulfate derived from methionine and cysteine found in dietary protein, as well as the cysteine component of glutathione, provide sulfate for use in PAPS biosynthesis. 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 is 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, underreplacement 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 is no evidence that habitual consumption of a high *total* water intake results in identifiable hazards in apparently healthy people. Because of the ability to self regulate water intake from fluids and foods by healthy people in temperate climates, a Tolerable Upper Intake Level (UL) was not set for water.

Potassium

Gastrointestinal discomfort and ulceration of the gastrointestinal tract have been reported with excess consumption of some forms of potassium supplements but not with potassium from the 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 apparent from electroencephalograms, 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. Therefore, a UL for potassium from foods is not set for healthy adults.

In contrast, excess consumption of 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 individuals with these diseases or clinical conditions, a potassium intake below the AI is often appropriate. For these individuals, salt substitutes (potassium chloride) should be used only 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 nonhypertensive 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 nonlinear in that the blood pressure response to changes in sodium intake is greater at sodium intakes below 2.3 g (100 mmol)/day than above this level.

The strongest dose-response evidence comes from those clinical trials that specifically examined the effects of at least three levels of sodium intake on blood pressure. The range of sodium intakes in these studies varied from 0.23 g (10 mmol)/day to 34.5 g (1,500 mmol)/day. Several trials included sodium intake levels close to 1.5 g (65 mmol)/day and 2.3 g (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. 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 nonhypertensive 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)/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 demonstrated benefit to consuming levels above the AI.

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 well 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.

Summary

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 described briefly in Chapter 8, when a Recommended Dietary Allowance (RDA) is not available for a nutrient, the Adequate Intake (AI) is the appropriate reference intake value 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 at 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 survey data. It is only possible to assume that those whose intakes from food are above the AI are consuming sufficient potassium. It isn't possible to speculate on the extent of inadequacy in those whose intakes are 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 intakes exceeded the UL equals the percent of individuals whose diets would be considered excessive in that particular nutrient. For example, sodium intake data from the NHANES III (Appendix D), which collected 24-hour diet recalls for 1 or 2 days, indicate that:

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.

• The vast majority (between 95 and 99 percent) of men and women in the United States consumed dietary sodium at levels greater than the AI, and thus one would assume that intakes were "adequate," and thus sufficient to cover sodium losses.

• More than 95 percent of men and 75 percent of women in the United States had sodium intakes that exceeded the UL, even when the amount of sodium added to foods during meals (table salt) 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

Type of Use	*For an Individual*[a]	*For a Group*[b]
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 Intake Level

[a] Evaluation of true status requires clinical, biochemical, and anthropometric data.
[b] Requires statistically valid approximation of distribution of usual intakes.
[c] For the nutrients in this report, AIs are set for all age groups for water, potassium, and sodium (and chloride on an equimolar 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. The use of other DRIs (the Estimated Energy Requirement [EER] and the Acceptable Macronutrient Distribution Range [AMDR]) are described in another report in this series (IOM, 2002/2005).

hypertension—while a multifactoral diagnosis, hypertension is causally related to increased sodium intake.

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 multidose 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 and increase potassium intake in the general population.

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DIETARY REFERENCE INTAKES

FOR

Water, Potassium, Sodium, Chloride, and Sulfate

Panel on Dietary Reference Intakes for Electrolytes and Water

Standing Committee on the Scientific Evaluation of Dietary Reference Intakes

Food and Nutrition Board

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Willing is not enough; we must do."
—Goethe

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Preface

This report is one in a series that presents a comprehensive set of reference values for nutrient intakes for healthy U.S. and Canadian individuals and populations. It is a product of the Food and Nutrition Board (FNB) of the Institute of Medicine, working in cooperation with Canadian scientists.

The report establishes a set of reference values for dietary electrolytes and water to expand and replace previously published Recommended Dietary Allowances (RDAs) and Recommended Nutrient Intakes (RNIs) for the United States and Canada, respectively. Close attention was given to the evidence relating electrolyte intake to the risk of high blood pressure and hypertension, as well as other diseases, and the amounts of water from beverages and foods needed to maintain hydration. In addition, since requirements for sulfur can be met by inorganic sulfate in the diets of animals, a review of the role in inorganic sulfur in the form of sulfate is included.

The group responsible for developing this report, the Panel on Dietary Reference Intakes for Electrolytes and Water, under the oversight and assistance of the Standing Committee on the Scientific Evaluation of Dietary Reference Intakes (the DRI Committee), has analyzed the evidence on risks and beneficial effects of nutrients included in this review.

Although all reference values are based on data, available data were often sparse or drawn from studies with significant limitations in addressing various questions confronted by the panel. Thus, although governed by scientific rationales, informed judgments were often required in setting these reference values. The reasoning used

in evaluating each nutrient is described in Chapters 4 through 7. Chapter 3 outlines the risk assessment approach used to establish the reference values for upper intake levels as developed and further modified by the DRI Subcommittee on Upper Reference Levels. Chapter 8 addresses major conceptual issues related to the uses of the DRIs that were included in the early stages of the DRI process and have been developed further as described in reports from the Subcommittee on Interpretation and Uses of Dietary Reference Intakes.

While the quantity of research reports relating sodium and potassium intake to blood pressure is quite large, the quality of the research useful to the panel for setting requirements of sodium and potassium was limited. In particular, there was a dearth of large, dose-response studies with clinically relevant biological outcomes carried out in normal, apparently healthy individuals.

Given the ability of many humans to adapt to varying amounts of electrolyte intake and the impact of temperature and activity level on needs of electrolytes and water, it was not possible to determine Estimated Average Requirements (EAR) for these nutrients. Instead, Adequate Intakes (AIs) were set for sodium, potassium, and water. No AI was set for sulfate as there is sufficient sulfur in the human diet from foods (derived from sulfur amino acids) and water to meet the needs of healthy individuals. No specific Tolerable Upper Intake Levels (ULs) were set for water, potassium, or sulfate as healthy persons can adapt to higher intakes from foods and beverages. In contrast, a UL was set for sodium based upon the increased risk of cardiovascular outcomes, particularly cardiovascular disease and stroke.

Readers are urged to recognize that the DRI process is iterative in character. The FNB and the DRI Committee and its subcommittees and panels fully expect that the DRI conceptual framework will evolve and be improved as novel information becomes available and is applied to an expanding list of nutrients and other food components. Thus because the DRI activity is ongoing, comments have been solicited widely and received on the published reports of this series. Refinements that resulted from this iterative process were included in the general information regarding approaches used (Chapters 1 and 2 and in the discussion of uses of DRIs in Chapter 8). With more experience, the proposed models for establishing reference intakes of nutrients and other food components that play significant roles in promoting and sustaining health and optimal functioning will be refined. Also, as new information or new meth-

ods of analysis are adopted, these reference values undoubtedly will be reassessed.

Many of the questions that were raised about requirements and recommended intakes could not be answered satisfactorily for the reasons given above. Thus among the panel's major tasks was to outline a research agenda addressing information gaps uncovered in its review (Chapter 9). The research agenda is anticipated to help future policy decisions related to these and future recommendations. This agenda and the critical, comprehensive analyses of available information are intended to assist the private sector, foundations, universities, governmental and international agencies and laboratories, and other institutions in the development of their respective research priorities for the next decade.

This report has been reviewed in draft form by individuals chosen for their diverse perspectives and technical expertise in accordance with procedures approved by the National Research Council's Report Review Committee. The purpose of this independent review is to provide candid and critical comments that will assist the institution in making its published report as sound as possible and to ensure that the report meets institutional standards for objectivity, evidence, and responsiveness to the study charge. The review comments and draft manuscript remain confidential to protect the integrity of the deliberative process. We wish to thank the following individuals for their review of this report:

> Michael Alderman, Albert Einstein College of Medicine; John R. Claybaugh, Tripler Army Medical Center; David Cole, University of Toronto; Gary Curhan, Harvard University; Johanna T. Dwyer, Tufts New England Medical Center; Shiriki K. Kumanyika, University of Pennsylvania; Gary W. Mack, Yale University; Melinda Manore, Oregon State University; Timothy Noakes, Sports Science Institute of South Africa; Suzanne Oparil, University of Alabama at Birmingham; Frank Sacks, Harvard University; Judith Stern, University of California at Davis.

Although the reviewers listed above have provided many constructive comments and suggestions, they were not asked to endorse the conclusions or recommendations nor did they see the final draft of the report before its release. The review of this report was overseen by John W. Suttie, University of Wisconsin, appointed by the Institute of Medicine, who was responsible for making certain that an independent examination of this report was carried out in accordance with institutional procedures and that all review comments were carefully considered. Responsibility for the final

content of this report rests entirely with the authoring panel and the institution.

The support of the Canadian government and Canadian scientists' participation in this initiative are gratefully acknowledged. This close collaboration represents a pioneering first step in the harmonization of nutrient reference intakes in North America. A description of the overall DRI project and of the panel's task is given in Appendix B.

The DRI Committee and the Panel on DRIs for Electrolytes and Water extend sincere appreciation to the many experts who assisted with this report by giving presentations to the panel, providing written materials, participating in the groups' open discussions, analyzing data, reviewing the report, and other means. Many, but far from all, of these individuals are named in Appendix L. Special gratitude is extended to the staff at ENVIRON International Corporation for providing national survey data.

The Panel on DRIs for Electrolytes and Water performed their work under great time pressure. Their dedication made the report's completion possible. All gave their time and hard work willingly and without financial reward; the public and the science and practice of nutrition are among the major beneficiaries of their dedication. Special thanks go to DRI Committee members Robert Russell, Joseph Rodricks, and Susan Barr for assisting the Panel in its review. In addition, the DRI Committee thanks the staff responsible for its development—in particular Paula Trumbo who served as a program officer for the study through June 2003, Allison A. Yates, who stepped in as Paula's replacement, and Crystal Rasnake, research assistant on the project in the later phases of its completion and key to organizing the many references and tables. The intellectual and managerial contributions made by these individuals to the report's comprehensiveness and scientific base were critical to fulfilling the project's mandate. Sincere thanks also go to other FNB staff, including Carrie Holloway, Mary Poos, Gail Spears, and Sandra Amamoo-Kakra, who also contributed their efforts over the years to complete this document.

And last, but certainly not least, the DRI Committee wishes to extend special thanks to panel chair Larry Appel, who oversaw the entire report development process, to Vernon Young, past chair of the DRI Committee, and to Cutberto Garza, former Chair of the Food and Nutrition Board, under whom this study was initiated.

John Erdman
Chair, DRI Committee

Postscript:

Following release of the report in pre-publication copy form, the Panel and DRI Committee were saddened to learn of two untimely events: the deaths of both Lawrence M. Resnick, M.D., a member of the Panel who was steadfast in his views while congenial in his search for approaches that were scientifically supportable; and Vernon R. Young, Ph.D., who, as the first chair of the DRI Committee, led the pursuit of integrating good science into nutrient-based reference values while challenging all those involved to think past old axioms as the term "nutrient" was redefined; he was a true scholar.

Contents

DIETARY REFERENCE INTAKES

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