Electrolytes

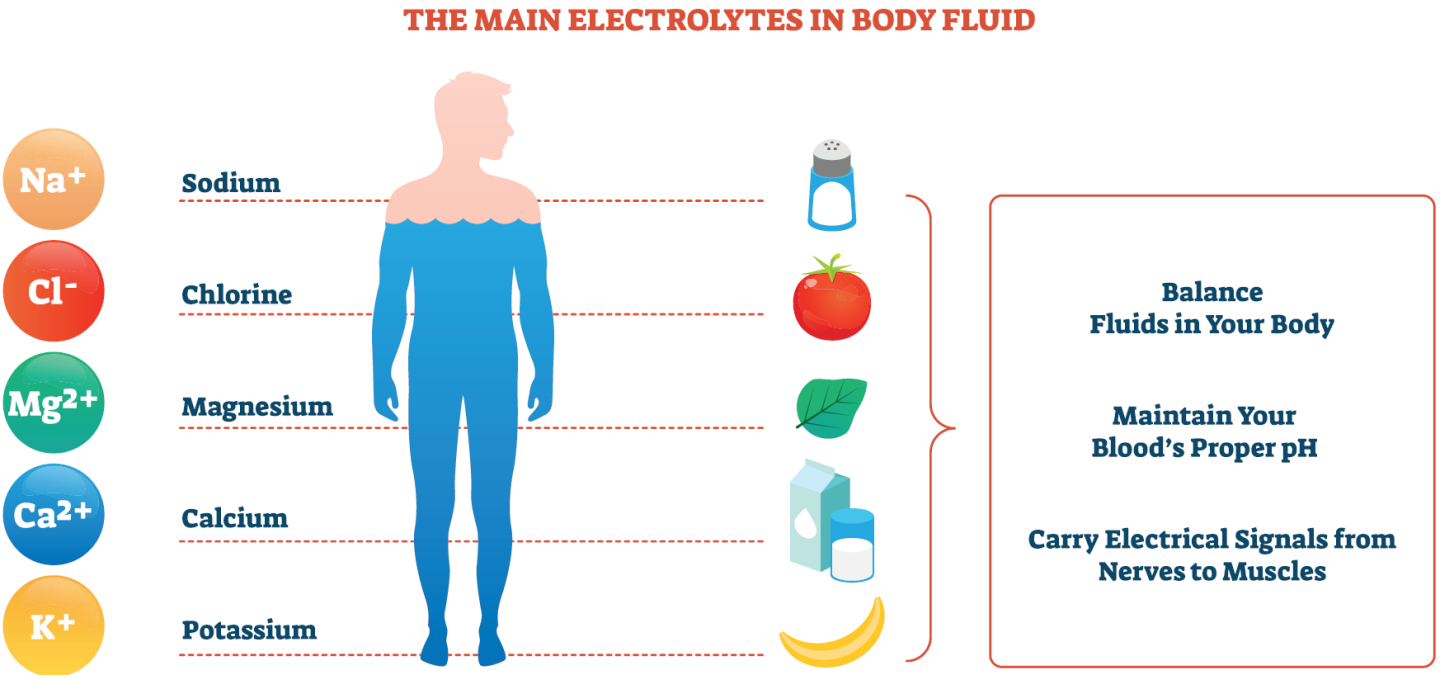
Background

Humans require approximately 35 micronutrients, 15 of which are minerals needed for various metabolic functions. These micronutrients cannot be synthesized in the human body and, therefore, must be obtained from the diet or supplements to meet daily requirements. Minerals exist naturally in the earth's soil and are taken up by various plants, some of which are consumed by animals. Therefore, sources of minerals include fruits, vegetables, grains, nuts, seeds, animal meats, some drinking water, and supplements.

Electrolytes are minerals and compounds containing minerals that allow the body to conduct electricity due to the negative or positive charges they carry in various cells and fluid mediums, such as blood, urine, and sweat. Electrolytes with a positive charge (cations) include calcium (Ca^{2+}), magnesium (Mg^{2+}), sodium (Na^{+}), and potassium (K^{+}). Electrolytes with a negative charge (anions) are bicarbonate (HCO_3^{-}), phosphate (as PO_4^{3-}), and chloride (Cl^{-}).

Roles of Electrolytes in the Body

Electrolytes regulate chemical reactions in various metabolic functions by facilitating the movement of fluids and nutrients in the body. Their functions include fluid balance, muscle contraction, nerve conduction, heart rate, heart rhythm, and blood pressure regulation. They also maintain proper pH levels (acid-base balance) and support nutrient transportation and waste removal. Sodium, chloride, and potassium function primarily to help regulate and maintain fluid balance, whereas calcium and magnesium are needed for optimal muscle function and energy production. Maintaining the proper balance of electrolytes allows the body to function normally, and a disruption in electrolyte levels leads to adverse effects.



Sodium

Sodium (Na+) and chloride (Cl-) are the primary electrolytes outside bodily cells that help maintain fluid balance and regulate blood pressure. Normal sodium levels in the blood are between 135 and 145 mEq/L, and changes in the concentration of extracellular sodium directly impact the amount of total body water. When extracellular sodium concentration increases, as with high salt intake or dehydration, the body attempts to restore homeostasis by 1) stimulating thirst to increase fluid intake, 2) excreting the excess sodium in urine, and 3) retaining fluid. Too little sodium has the opposite effect, moving water from inside the cells to outside the cells, which can lead to low blood pressure, dehydration, and hyponatremia, as indicated by abnormally low sodium levels in the blood (<135 mmol/L).

Recommended & Typical Intakes

Consuming too little or too much sodium can result in health issues, and very little is naturally present in food.[1] Most sources of sodium in the diet are from table salt (sodium chloride) added to foods such as frozen and packaged products, restaurant foods, canned goods, chips, baked goods, and lunch meat. The adequate intake (AI) level for sodium for adults is 1,500 mg, equivalent to 3,800 mg (~2/3 of a teaspoon) of table salt. The typical sodium intake for adults in the U.S. is between 3,300 and 3,800 mg, far exceeding the adequate intake level.[1] Eating patterns rich in fruits, vegetables, and legumes are naturally low in sodium and high in potassium. They reduce fluid retention and improve blood pressure among hypertensive individuals.[2]

Chloride

Chloride is the second most abundant electrolyte outside of cells, with a typical range of 96 to 106 mEq/L in adults. It helps regulate fluid balance and blood pressure and maintain proper pH levels.

Recommended & Typical Intakes

Table salt (sodium chloride) is the main source of chloride in the diet and is also naturally present in meat and seafood. There is no recommended dietary allowance (RDA) for chloride, but the amount determined to ensure nutritional adequacy is 1.8-2.3 grams daily, depending on age and life stage.[3] Because the average American diet is high in salt, deficiency is rare. Low chloride levels, or hypochloremia, can occur when excessive fluid is lost with vomiting due to illness, medications, or diseases.

Potassium

Potassium is the primary electrolyte inside cells, but exists outside cells at 30 times lower levels. Potassium and sodium, the primary extracellular electrolyte, create an electrochemical gradient across cell membranes via the Na+/K+ ATPase pumps to transmit nerve impulses, contract muscles, maintain normal blood pressure and heart rhythms, and regulate fluid balance. A typical range for potassium in blood is 3.8 to 5.0 mEq/L, which the body maintains via the kidneys by balancing the amount consumed with the amount lost in urine, feces, and sweat.

Recommended & Typical Intakes

The adequate intake (AI) for potassium is 2,600 mg/day for women and 3,400 mg/day for men, which can be provided by three to four servings of potassium-rich foods. Fruits and vegetables are rich in potassium, particularly prunes, bananas, potatoes with skin, yams, squash, dark leafy greens, and beans. Most people do not consume enough potassium, which is associated with adverse health effects.[4] As a result, the Dietary Guidelines Committee has identified potassium as a "nutrient of public health concern."[5] The typical American diet is high in sodium and low in potassium, which is widely

recognized as a contributing factor to the high prevalence of hypertension, which impacts approximately 48% of adults in the U.S.[6] An eating pattern low in sodium and high in potassium-rich foods may reduce the risk of high blood pressure and stroke. Therefore, recommendations include eating more fresh fruits and vegetables and fewer low-potassium, high-sodium foods such as processed meat and packaged snack foods.

Magnesium

Magnesium is widespread throughout the body, and every organ requires it, especially muscles, kidneys, and the heart. It is present inside cells and is involved in over 300 metabolic reactions, including energy production, protein synthesis, nerve transmission, blood sugar control, blood pressure regulation, pH balance, bone and teeth formation, and muscle function. DNA, RNA, and glutathione synthesis also involve magnesium. Approximately half of the body's magnesium is in bone and teeth, while the remaining is in muscle and soft tissue. Only about 1% is in blood, which the kidneys tightly regulate between 0.75 and 0.95 millimoles (mmol/L) by modifying magnesium excretion through urine depending on dietary intake.[7] Bones act as a magnesium reservoir, and inadequate dietary intake results in magnesium stores in bone being reduced to nearly one-half over the course of a lifetime.[8]

Recommended & Typical Intakes

The recommended dietary allowance (RDA) for magnesium is 400-420 mg for adult males, 300-310 mg/day for non-pregnant females, and 340-350 mg/day during pregnancy. Due to losses in sweat and urine, individuals who exercise intensely require 10-20% more magnesium, and consuming less than 260 mg/day for male athletes and 220 mg/day for female athletes and exercisers increases the risk for deficiency.[9]

Magnesium is naturally present in plant and animal foods and is sometimes added to foods like bread, cereal, and oatmeal. Bottled and tap water may also contain magnesium. The richest sources of magnesium include nuts and seeds, leafy green vegetables, beans, yogurt, soymilk, potatoes, and whole grains such as whole wheat products, oats, brown rice, and barley. Refined grains have the least amount of magnesium unless it is added through fortification.

Approximately half of Americans do not consume enough magnesium from food alone to meet daily requirements but eat enough to prevent overt deficiency.[10] However, recommended amounts are reached when dietary supplements are consumed. The average total magnesium intake increases from 350 mg to 449 mg in males and 267 mg to 387 mg in females with supplementation.[11] Chronic inadequate intakes may increase the risk of chronic disease and is inversely associated with osteoporosis, hypertension, cardiovascular disease, type 2 diabetes, migraines, and colorectal cancer.[12,13]

There is no upper limit for naturally occurring magnesium in food and beverages. However, the upper limit for magnesium in supplements and medications is 350 mg/day, owing to the laxative effect often used in clinical or therapeutic settings.[14]

Assessing deficiency is difficult due to the body's ability to retain more magnesium with low intakes and draw upon the stores in the bone to maintain normal blood levels. Individuals at risk of deficiency are those with chronic low magnesium intakes coupled with losses due to heavy sweating, alcoholism, medication use, ongoing diarrhea or malabsorption due to digestive diseases, Type 2 diabetes, and reduced absorption in older adults.[15] [16]

Calcium

Calcium is a vital mineral in the human body. Ninety-nine percent is stored in bones and teeth, and the remaining one percent is in blood, muscle, and other tissues. It is essential for muscle contraction, nerve impulse transmission, blood

pressure regulation, blood clotting, hormone secretion, and enzyme activation. Calcium levels in the blood are tightly regulated by several hormones, primarily parathyroid hormone, calcitonin, and vitamin D, to maintain the proper function of these essential processes.

Calcium (Ca^{2+}) carries a positive electrical charge in bodily fluids, allowing it to conduct electrical currents across cell membranes and facilitate ion exchange across cellular barriers. It exists in extracellular fluids between 8.8 and 10.4 mg/dL bound mainly to albumin and in free (ionized) form at 4.6 to 5.3 mg/dL. Blood levels may not accurately reflect nutritional adequacy, whereas a bone mineral density test assesses overall calcium status since most of the body's calcium stores are in bone.

Recommended & Typical Intakes

The recommended calcium intake for adults varies by age, sex, and life stage.[17] General recommendations are 1,000 mg/day for men 19 to 70 and women 19-50. The recommendation increases to 1,200 mg for men once they reach 71 and for women once they reach 51 or post-menopausal status. The daily recommendation for pregnant and breastfeeding women and teenagers is 1,000 and 1,300 mg, respectively.

Natural food sources of calcium include dairy products such as milk, yogurt, and cheese; leafy greens such as kale, Bok choy, collard greens, and spinach; nuts and seeds; canned fish with bones; and most grains. Calcium is also added to plant milks, tofu, orange juice, and breakfast cereal via fortification.

Approximately half (49.8%) of the U.S. population does not meet calcium recommendations, with particularly concerning trends in key vulnerable groups, including women, children, adults over 60 years old, Hispanic Americans, and Black Americans.[18]

Post-menopausal women are at risk for calcium inadequacy and bone loss due to lower estrogen production, which reduces calcium absorption and increases bone breakdown. Vegans, individuals with a milk allergy or lactose intolerance, and others who avoid dairy products may also be at risk for deficiency and may need to supplement calcium to meet daily recommendations.[19]

Hypocalcemia, blood calcium levels below 8.8 mg/dL is generally caused by health conditions such as low parathyroid hormone levels resulting from thyroid removal or genetic disorders, vitamin D deficiency due to insufficient sunlight exposure or low intakes, or kidney failure. Symptoms depend on the severity and include muscle cramps, dry skin, brittle nails, confusion, irritability, and, in severe cases, muscle spasms, seizures, and abnormal heart rhythms.

Vitamin C

Vitamin C (ascorbic acid) is a water-soluble essential nutrient that is vital to various aspects of metabolism, including as a cofactor in the synthesis of collagen, neurotransmitters serotonin and norepinephrine, and as a potent antioxidant, which are substances that prevent and reduce cellular damage caused by free radicals and reactive oxygen species generated through normal metabolism and from outside sources such as cigarette smoke and pollutants. Vitamin C is present in fruit and vegetables and is identical to the vitamin C in supplements.

Recommended Intakes

Adult men and women require 90 mg/day and 75 md/day, respectively, but studies suggest more (400 mg/day) is ideal for maximizing immune function and reducing risk for chronic disease.[20] Vitamin C supports immune system defense by impacting various functions in the innate and adaptive immune system, and by preventing and reducing the duration and

severity of symptoms of respiratory and systemic infections.[21] The tolerable upper intake level (UL) for adults 19 and older is 2,000 mg/day and is considered safe for most adults.[22] Common side effects with high intakes include diarrhea and gastrointestinal disturbances.

Vitamin C supplements can reduce some immediate markers of oxidative stress and inflammation after exercise and may be particularly beneficial for endurance athletes and those with high training loads, since prolonged or intense exercise can lead to a temporary decrease in immune function.[23,24]

Vitamin B12

Vitamin B-12 is a water-soluble vitamin needed to prevent neurological disorders, anemia, and other blood disorders. It supports the maintenance of healthy nerve cells and the production of red blood cells and acts as a cofactor for enzymes involved in energy production, including the methylation of homocysteine to methionine. It is also needed for DNA synthesis, repair, and methylation, which helps maintain genetic stability.

Vitamin B12 contains the mineral cobalt, and the various forms are referred to as cobalamins. Methylcobalamin is the biologically active form of B12 in animal foods such as meat, poultry, fish, seafood, eggs, and dairy. Plants do not contain vitamin B12 unless added through fortification of cereals and grain products. The bioavailability of vitamin B12 is higher for dairy foods than fish, meat, or poultry, and approximately 50% higher from supplements than food sources.[25]

Recommended Intakes

The recommended daily amount for adults is 2.4 mcg and increases to 2.6 mcg and 2.98 mcg in pregnancy and during breastfeeding, respectively. Individuals who avoid animal products, those with gastrointestinal disorders, and the elderly are at risk for deficiency, due to malabsorption from food.[26]

Vitamin B12 helps with red blood cell formation, supports oxygen delivery to muscles, and potentially reduces muscle fatigue during exercise. Supplementation with B vitamins may benefit exercise performance and reduce fatigue, particularly in those with low or marginal B12 status.[27] Maintaining adequate B12 intake is important for active individuals to support optimal performance and recovery.

Electrolytes and Exercise

Electrolytes play a vital role in athletic performance, recovery, and overall health during exercise. Despite the biological significance of these nutrients, the current recommended amounts are not achieved by portions of the population with respect to magnesium, potassium, and calcium as noted previously. Although the body tightly regulates blood levels of electrolytes to maintain key aspects of metabolism, imbalances can result from dehydration, overhydration, excessive sweating, dietary intake, vomiting, diarrhea, medications, and medical conditions. Dehydration is a common issue among athletes across various sports and occurs when fluid and electrolyte losses exceed intake. The loss of 2% of body mass can impair performance through increased cardiovascular strain, elevated core temperature, reduced cognitive function, and decreased endurance capacity.[28]

The most common exercise-associated electrolyte imbalance involves sodium, one of the primary electrolytes lost in sweat (Table 1).[29,30,31]

Table 1 - The Composition of Sweat

Sodium	460-1840 mg/L
Chloride	710-2840 mg/L
Potassium	160-390 mg/L
Magnesium	0-36 mg/L
Calcium	0-120 mg/L

Sodium Imbalances

Exercise-associated hyponatremia (EAH), a low blood sodium concentration that develops during or after exercise, was first observed in endurance athletes in the 1980s and, more recently, in team sports, hot yoga, cyclists, rowers, military personnel, half marathons, marathons, and Ironman events.[32] The most common cause is overdrinking hypotonic fluids beyond thirst and the retention of body fluid, which has been referred to as water intoxication.[33,34] EAH symptoms include bloating, nausea with and without vomiting, and severe headaches.[32] Hence, to prevent EAH, individual sweat rates are determined, and proper hydration and sodium replenishment strategies are utilized for endurance athletes.

High sodium levels, or hypernatremia (<145 mmol/L), can occur during exercise with inadequate fluid intake coupled with fluid loss from heavy sweating and vomiting, as seen in ultramarathon runners.[35] Weight-conscious athletes such as boxers, wrestlers, bodybuilders, and mixed martial artists who adopt weight-cutting strategies are at risk of hypernatremia due to induced dehydration, particularly with the rapid loss of 10% of body weight and little to no food and fluid intake.[36] Severe dehydration and hypernatremia result in nausea, vomiting, altered mental status, seizures, coma, and acute kidney damage.[37]

Potassium Imbalances

Imbalances in potassium levels are far less common than sodium imbalances among healthy individuals since the kidneys maintain normal levels and less is lost through sweat. Low blood potassium (< 3.5 mmol/L), called hypokalemia, may occur after prolonged endurance exercise with heavy sweating and insufficient replenishment.[36] It can also result from ongoing diarrhea and vomiting, the use of diuretics and laxatives, eating disorders, and magnesium depletion, and may cause muscle cramps, fatigue, numbness or tingling sensations, heart palpitations, and gastrointestinal stress. Proper potassium replenishment with fruit and vegetable intake or proper supplementation after endurance exercise and heavy sweating can prevent exercise-associated hypokalemia.[36]

Overusing potassium supplements may lead to abnormally high potassium levels, called hyperkalemia, in individuals with kidney disease. Supplements typically contain small amounts of potassium (80-99 mg) to reduce the risk of hyperkalemia and to prevent interactions with various medications, such as those used to treat high blood pressure. Although rare, the rupture in muscle cells from unaccustomed or extreme exercise damage induced by maximal exercise can result in hyperkalemia since 70-80% of potassium is stored in muscle cells.[38]

Other Electrolyte Imbalances

Acute chloride, calcium, and magnesium imbalances that lead to adverse health effects rarely occur in healthy individuals.[36] Restrictive dietary practices, such as omitting or severely limiting food groups and extreme exercise (~10 hours a day), have been shown to result in magnesium deficiency, which was subsequently reversed with supplementation.[36]

Exercise can increase magnesium loss through urine and sweat, raising the need for magnesium by 10-20%.[9] Exercising in the heat and humidity, regular sauna use, and athletes in weight-focused sports like boxing, wrestling, and gymnastics are especially at risk for magnesium-deficient status. Replacing magnesium with electrolyte supplements and meeting daily requirements by eating more magnesium-rich foods or a complete multivitamin and mineral can prevent deficiency.

Calcium is essential for overall health and plays a supportive role in maintaining fluid balance. Although calcium is lost in sweat, the amount is relatively small compared to other electrolytes, typically 20-60mg/day and up to 100-200mg/day with heavy sweating. Additionally, the body's homeostatic mechanisms effectively maintain blood calcium levels by drawing upon bone stores when dietary intake is inadequate. Therefore, exercise-associated calcium imbalances are rare, but chronic insufficient intakes can lead to significant health issues as the body tries to maintain critical blood calcium levels by drawing from bone reserves.

Electrolyte Supplements

Electrolyte supplements are designed to help maintain fluid balance during exercise and in hot and humid conditions, replenish fluid and essential minerals lost in sweat and utilized during exercise, and, in some cases, make up for insufficient amounts from the diet. Therefore, the primary goals of their use are to prevent excessive dehydration (the loss of $\geq$2% body weight) and electrolyte imbalances, which can lead to performance decrements and health issues, and to aid in recovery.[29,39]

Key Findings in the Research

Although sweat rates and compositions vary between individuals, electrolyte requirements are based on multiple factors, including:

1. **Sweat rate and composition**: Sweat rates and sodium concentrations range from 20 to 80 mmol/L (460 to 1840 mg/L), with considerable individual variation.[40]
2. **Exercise duration and intensity**: Higher workloads increase both fluid and electrolyte losses.
3. **Environmental conditions**: Heat and humidity significantly increase sweat losses.
4. **Individual physiology**: Some people are naturally "salty sweaters."

Effects on Exercise Performance

Electrolyte-containing beverages can improve exercise capacity, especially under heat stress, energy restriction, and prolonged or intense activity, compared to placebo or water alone.[41] When consumed before and after prolonged and exhaustive exercise and in hot or humid conditions, electrolytes improve the body's capacity to retain water and reduce exercise-related fatigue compared to water alone.[42,43]

Consuming carbohydrate-electrolyte drinks before and during play in sports like soccer with intermittent prolonged activity, increased self-paced exercise performance, sprinting speed, and technical skills, and improves endurance performance, allowing individuals to exercise longer and at higher intensities compared to water or placebo.[44,45,46,47]

Effects on Muscle Cramps

Electrolyte supplementation is often recommended to prevent exercise-associated muscle cramps (EAMC), but human research shows mixed results. Although it can delay the onset, allow longer exercise duration, and reduce the

susceptibility to muscle cramps in some situations, it does not completely prevent EAMC for all individuals.[48] Among half-marathon runners self-reporting the incidence of muscle cramps, a magnesium-rich electrolyte mix with 100 mg of elemental magnesium reduced muscle cramps from 46% to 21% compared to water.[49] In men who became dehydrated from performing downhill running, consuming an electrolyte drink afterwards decreased muscle cramp susceptibility compared to water. Water alone after dehydration increased the risk of cramping, likely due to dilution of blood electrolytes.[50]

Effects on Recovery

Electrolyte drinks with and without carbohydrates are more effective than water alone at retaining body fluids and restoring fluid balance after exercise, which are crucial for recovery and subsequent performance. They have been shown to more effectively restore hydration status after exercising when compared to water alone.[43,51,52]

Evidence-Based Hydration and Electrolyte Strategies

Hydration guidelines were set forth by the American College of Sports Medicine in 2007 in their Position Stand on Exercise and Fluid Replacement and by the National Athletic Training Association in 2017 in their Position Paper in their Position Statement: Fluid Replacement for the Physically Active.[39,53] These guidelines are outlined below unless noted otherwise.

Duration of Activity

- **For sessions under 60 minutes**: Plain water is typically sufficient for most individuals during shorter exercise sessions, unless exercising in extreme heat or for heavy or salty sweaters.
- **For sessions 60-90 minutes**: Consider electrolyte replacement, especially sodium.
- **For sessions over two hours**: Scientific evidence strongly supports dedicated glucose and electrolyte replacement strategies to improve time to exhaustion, power output, and muscle soreness and fatigue.[54]

Before Exercise

- Begin exercise in a euhydrated state by consuming fluids and meals several hours before activity. This allows for proper urine absorption and elimination.
- Drink approximately 17 ounces (500 ml) of fluid approximately two hours before exercise.

During Exercise

- For exercise longer than an hour, or in the heat or humidity:
    - Fluid replacement should be individualized based on sweat rate, which can be estimated by measuring body weight before and after exercise.
    - Beverages containing both carbohydrates (4–8%) and sodium (0.5–0.7 g/L) are recommended, as they help maintain plasma volume, enhance palatability, promote fluid retention, and may prevent hyponatremia.
- For exercise under one hour, water is generally sufficient, as there is little evidence of performance differences between water and carbohydrate-electrolyte drinks in this context.

After Exercise

- The goal is to replace fluid and electrolytes lost during exercise to restore balance and prepare for the next exercise session.
- Drink 16-24 ounces of fluid, including electrolytes, particularly sodium, for every pound lost during exercise.
- Beverages with 0-3.9% and 4-9% carbohydrate-electrolyte solutions may restore hydration status when whole foods are not available.[51]
- Consider milk-based recovery drinks that combine electrolytes, carbohydrates, and protein for rapid glycogen replenishment, particularly if exercising on the same or the next day.

Ultra Endurance Events

For events lasting more than hours, more aggressive electrolyte replacement strategies may be necessary, including the following:

- Scheduled sodium intake (300-600 mg/hour)
- Alternating between electrolyte solutions and water
- Monitoring for symptoms of both dehydration and overhydration

Youth Athletes

Special considerations for younger athletes include:

- Reduced sweating efficiency
- Lower overall sweat rates
- Potentially greater susceptibility to heat illness
- Need for flavor enhancement to encourage adequate hydration
- Scheduled hydration breaks with monitoring

Considerations

Population-Specific Needs

Athletes, especially endurance athletes and fitness enthusiasts who participate in high-intensity, prolonged activities in the heat or humidity, and those who participate in regular sauna use, may benefit more from supplementation than the general population.

Safety and Dosage

Generally considered safe when used as directed. Excessive intake can lead to imbalances and health issues like hypernatremia or hyperkalemia. Consult your physician prior to use if taking medications.

Conclusion

Electrolyte supplements with and without carbohydrates reliably improve exercise performance and hydration compared to water alone, particularly during prolonged, high-intensity activity in hot or humid conditions. They help maintain fluid

balance, reduce fatigue, and support better recovery, making them a valuable tool for athletes and active individuals. They should be used thoughtfully, considering individual requirements and existing dietary intake.

Supplement Facts

Supplement Facts

Serving Size: 1 Stick Pack (7g)
Servings Per Container: 30

	Amount Per Serving	% Daily Value
Calories	10	
Total Carbohydrates	2 g	1%*
Vitamin C (as calcium ascorbate)	400 mg	444%
Vitamin B12 (as methylcobalamin)	50 mcg	2083%
Calcium (from calcium ascorbate)	50 mg	4%
Magnesium (from magnesium citrate)	100 mg	24%
Chloride (from sea salt)	900 mg	39%
Sodium (from sea salt)	600 mg	26%
Potassium (from potassium citrate)	300 mg	6%

*Percent Daily Values are based on a 2,000 calorie diet

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