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Sodium Chloride

Sodium chloride (NaCl), or salt, was one of the first nutrients to be identified as essential to life. In ancient times, city locations were based upon the availability of salt, water, and food.⁵¹¹ Although ocean water contains approximately 2.68% NaCl and animals utilizing this environment face the challenge of coping with excessive salt, most terrestrial animals find it difficult to obtain adequate dietary salt and have developed methods to conserve NaCl.⁵¹²⁻⁵¹⁴ Due to the relative scarcity of salt in typical pastures, thousands of metric tons of NaCl are produced each year for use in mineral supplements.⁵¹¹ Sodium (Na) and chlorine (Cl) are rarely found in elemental form in nature; however, most of the toxic effects of NaCl are due to Na. When appropriate, articles that mention one or the other separately will be cited.

Essentiality

Both Na and Cl are essential elements for practically all forms of life. Sodium (Na⁺) is the major extracellular cation while Cl⁻ is the major extracellular anion; together, they are responsible for maintaining acid-base balance and regulating the osmotic pressure of bodily fluids.^{515,516} Excitable cell membranes (e.g. nerve and muscle cells) depend upon tightly regulated Na⁺ and Cl⁻ concentrations in cells and the extracellular fluid (ECF). Blood, a specialized form of ECF, consists of approximately 0.9% NaCl.⁵¹⁴ Sodium chloride is reportedly the only mineral animals truly crave and will actually seek out.^{514,517} The dietary NaCl requirement of swine is between 0.10 and 0.14%, and 0.18% Na is needed to achieve optimal performance.⁵¹⁸⁻⁵²¹ Similarly, the optimal dietary Na concentration in horses is 0.16-0.18% DM⁵¹⁵ and for cattle is 0.08-0.1%.⁵²² Under extreme conditions, such as high temperatures, lactation, or hard work, these requirements increase due to increased excretion of both Na⁺ and Cl⁻.^{523,524} The clinical signs of sodium chloride deficiency are polydipsia (extreme thirst), polyuria (extreme urination), salt hunger, pica (licking foreign materials), weight loss, and decreased milk production.^{525,526} Chloride deficiencies have been produced by feeding diets with 0.10% Cl or less and present as anorexia, weight loss, lethargy, decreased milk production, polydipsia, polyuria, and cardiopulmonary depression, etc. as clinical signs.⁵²⁷⁻⁵²⁹

Metabolism

Once ingested, 85-95% of Na and Cl are absorbed in the GI tract, particularly the small intestine. Large amounts of Na and Cl are recycled into the intestinal tract via salivary, pancreatic, and intestinal epithelial secretions, as well as bile. The high intestinal Na⁺ concentration is required to transport glucose, amino acids, and other nutrients across the mucosa. Chloride is also secreted into the intestine to aid in creating the low pH environment needed for proteolysis. These secretions must then be reabsorbed further down the GI tract to conserve the elements.⁵¹⁴ It has been suggested that elevated dietary NaCl can increase protein digestion. Hemsley⁵³⁰ discovered that increased NaCl in the diet increased the rate of passage of solid digesta from the rumen, which decreased microbial degradation within the rumen and increased the amount of protein available in the small intestine. Altered ruminal fatty acid concentrations have also been related to dietary NaCl.⁵³¹⁻⁵³³ Dietary Na⁺ and Cl⁻ in excess of physiologic requirements are usually efficiently eliminated from the body via the kidneys.⁵³⁴

Potassium is the main intracellular cation, Na is the main extracellular cation, and Cl⁻ is the main extracellular anion. The relative concentrations of these three elements creates an electrochemical gradient across cell membranes that is essential for nutrient transport, nerve conduction, muscle contraction, and energy generation, and they indirectly aid in maintaining pH balance. Imbalances of these elements result in a variety of disorders from decreased gains to acute death.⁵³⁵⁻⁵³⁷

Toxicity

The toxicity of NaCl is intimately related to the availability of water and is sometimes referred to as “sodium ion toxicity-water deprivation syndrome;” however, if the dose of Na⁺ is high enough, Na is toxic regardless of water intake.⁵³⁸ If adequate water is present, most animals can tolerate relatively large doses by increasing Na⁺ excretion.^{534,539-542} If sufficient water is not available, acute toxicosis results in dehydration, blindness, incoordination, convulsions, recumbency, and death.^{205,538,543,544} The

normal physiological response to elevated dietary NaCl is increased water intake; however, if the water contains high NaCl concentrations, drinking results in even more NaCl intake and increases the risk of receiving a toxic dose.⁵⁴² Even when sufficient potable water is available to eliminate excess dietary Na, every gram of NaCl excreted requires producing at least 5 ml of urine⁵⁴⁵ at a finite metabolic cost. Thus, slight to moderately elevated Na⁺ may impact growth and performance.^{542,546,547}

The mechanisms underlying acute toxicity are related to cellular dehydration, or “tissue shrinking,” and edema. When extracellular Na⁺ concentrations become elevated, water is drawn out of the cell down the concentration gradient, resulting in shrinking.^{514,548} Eventually intracellular Na⁺ concentrations adjust to a new equilibrium with the extracellular fluid (ECF), and cells return to their normal volume. By two to three days of exposure to elevated Na⁺, neurons have replaced the increased intracellular Na⁺ with “idiogenic osmoles,” hydrophilic, organic molecules that compensate for the attraction of extracellular Na⁺ for water.⁵⁴⁹ Tissue shrinkage due to elevated ECF Na⁺ results in damage to the small blood vessels that supply the superficial portions of the brain. Later, after animals have adapted to elevated extracellular Na⁺ concentrations (whether from excessive dietary Na intake or water deprivation) and are allowed free access to water, the extracellular fluid becomes diluted and water is drawn back toward the elevated osmolarity inside the neurons, resulting in cellular swelling and damage. In either case, clinical signs result from cerebrocortical (brain) damage.

Acute toxicity has been observed in cattle, pigs, dogs, and rats after ingestion of extreme concentrations of NaCl. Ninety-one cattle developed muscular weakness, muscle fasciculations, and sternal and lateral recumbency, and they subsequently died, as a result of drinking water from a tank and lagoon that contained 4,370 and 21,160 mg Na⁺/L, respectively.²⁰⁵ Cattle consuming water containing 5,850 mg Na⁺/L experienced a 13.7% reduction in body weight, with corresponding reductions in feed and water intakes.⁵⁵⁰ Water containing 6,726-6,826 mg Na⁺/L resulted in a loss of condition, scouring, and death in 15 of 220 cattle.⁵⁵¹ Six cattle began showing signs of CNS disruption four hours after consuming 50 kg of a supplement containing 50,000 ppm NaCl (19,500 ppm Na), despite drinking water immediately afterward.⁵³⁸ A pig owner replaced free-choice NaCl as a salt block with two “handfuls” of loose trace mineral salt in 30 gallons of water. Within six days, four pigs began champing jaws, frothing at the mouth, and convulsing, and two ulti-

mately died.⁵⁵² Abruptly switching gilts to a diet containing 13,600 ppm NaCl resulted in feed refusal and watery diarrhea lasting several days.⁵⁵³ Dosing an 11.3-15.9 kg (25-35 lb) pig with approximately 178.6 g NaCl (69.6 g Na⁺) in 500 ml water resulted in death within 15 minutes.⁵⁵⁴ A female dog became blind, convulsed, and eventually died after consuming seawater (26,800 mg NaCl/L) on a hot summer day.⁵⁴⁴ Three female Boston terriers became ataxic, convulsed, and later died after drinking water contaminated with brine and containing approximately 100,000 mg NaCl/L.⁵⁵⁵ A male Airedale terrier began having seizures and eventually died after ingesting a bolus of a salt-mixture clay. The concentration of NaCl in the clay was not reported; however, it was stated a minimum of 20 g NaCl still remained in the dog’s stomach.⁵⁴⁸ The minimum toxic dose in canines was estimated at 2,000 mg NaCl/kg BW (780 mg Na/kg BW).⁵⁵⁶ Rats refused to drink water containing 25,000 mg NaCl/L; death occurred after several days of water refusal were followed by gorging on water.⁵⁵⁷

Chronic toxicity has been investigated under both field and experimental conditions. Cattle consuming water containing 12,000 mg NaCl/L (4,680 mg Na⁺/L) throughout the summer months did not become clinically dehydrated, but they did exhibit diarrhea, a 28.2% reduction in feed intake, and a 69% increase in water intake.⁵⁵⁸ Cattle ingesting water containing 2,500 mg NaCl/L (975 mg Na⁺/L) for 28 days showed increased water intake, decreased milk production, and diarrhea.⁵⁴⁷ Steers fed diets containing 50,000 ppm NaCl (19,500 ppm Na) for up to 175 days gained less weight and utilized organic matter less efficiently than controls.⁵³¹ Steers fed high grain diets containing 70,000 ppm NaCl (27,300 ppm Na) for 126 days showed increased water intake, decreased feed intakes, and altered digestion patterns.⁵⁵⁹ Feeding lactating cows low fiber diets in conjunction with concentrate containing 60,000 ppm NaCl resulted in a 6.9% decrease in organic matter consumption and a 22% increase in water intake, but these diets had no effect on milk production.⁵⁶⁰ Lactating heifers supplemented with 136 g NaCl/day, beginning 42 days prepartum and continuing until 10 days postpartum, showed an increased incidence of udder edema.⁵⁶¹ Water containing 15,000 mg NaCl/L resulted in decreased feed consumption, decreased body weight, and increased water intake in sheep.⁵⁴⁶ Drinking water containing 10,000-13,000 mg NaCl/L resulted in neonatal mortality and distress at parturition when given to twin-bearing pregnant ewes.⁵⁶² Sheep drinking water

containing 15,000 mg NaCl/L for 21 days consumed less feed and more water than controls.⁵⁴² Sheep consuming water containing 20,000 mg NaCl/L for three days experienced a sharp decline in feed intake. After five days drinking the water, the animals' feed consumption eventually recovered, suggesting an adaptive response.⁵⁶³ Lambs given 2 g NaCl/kg BW from an early age had significantly lower growth rates, reduced feed intakes, and diarrhea in comparison to controls.⁵⁶⁴ Pigs consuming 15,000 mg NaCl/L water for 30 days became stiff legged and nervous, and they had reduced water intakes.⁵⁶⁵ Hypertension has been produced in rats by offering water containing 10,000-25,000 mg NaCl/L for six months or longer.⁵⁶⁶⁻⁵⁶⁸ Feeding trials determined the chronic oral LD₅₀ of NaCl fed to rats for 100 days was 2.69 g/kg BW.⁵⁶⁹

Toxicity has also been shown to occur when elevated dietary NaCl is coupled with water restriction. Feeding 60 3-year-old steers a supplement containing 4.5 kg NaCl one day prior to withholding feed and water (to obtain fasting body weights) resulted in blindness, incoordination, knuckling of fetlocks, and recumbency in five animals.⁵⁴³ Goats offered diets containing 30,000 ppm NaCl for 30 days showed a 20% decrease in feed intake when water was freely available and a 43% reduction when water was restricted.⁵⁷⁰ Pigs fed NaCl at the rate of 2.4 g/kg BW with restricted water showed "extreme signs" of NaCl toxicity and ultimately died.⁵⁷¹ Sodium chloride poisoning was diagnosed in a herd of pigs that exhibited convulsions, an unsteady gait and muscle-twitching, blindness, and rapid breathing. The pigs had been without water for an undetermined amount of time, and no levels of dietary NaCl were given.⁵⁷² Swine began having convulsions and were exhibiting head pressing within three days of being purchased at an auction. It was determined the clinical signs developed as a result of the pigs receiving a high salt diet prior to the sale and then receiving no water during the auction.⁵⁷³

There are several reports that indicate at least some Na can be tolerated. Offering cattle water containing 4,110 mg NaCl/L resulted in increased water intake and diuresis; however, no other effects on animal health were noticed.⁵⁷⁴ Cattle consuming water with 5,000 mg NaCl/L (2,000 mg Na⁺/L) appeared clinically normal throughout the course of two 30-day experiments.⁵³⁹ Steers consuming 192-193 g NaCl/day for 84 days showed no observable negative effects when ingesting a roughage diet; however, when fed a corn silage diet, the animals consuming the high Na diet had reduced weight gains

and feed efficiencies. Roughage diets tend to increase water intake, potentially diluting NaCl and decreasing its effects.⁵³² Sheep consuming water containing 13,000 mg NaCl/L for up to 16 months increased their water intake, but they exhibited no other adverse health effects.^{540,575-580} Rations with a NaCl concentration of 91,000 ppm fed to sheep caused no significant effects on breeding, gestation, lambing, or wool production.⁵⁸¹ Swine consuming 5,150 mg NaCl/L water had a drastic increase in water intake; however, no other adverse effects were noticed.⁵⁸²

The limited data available regarding Cl⁻ in water seems to indicate it is primarily a palatability factor. The EPA's secondary water standard for human consumption suggests that more than 250 mg Cl⁻/L imparts a "salty" taste.⁵⁸³ Water containing 5,000 mg CaCl₂/L offered to cattle resulted in water refusal despite lack of any other water sources. Water containing 3,000 mg/L resulted in increased water consumption and urinary acidification but no measurable effects on performance or health.⁵⁸⁴ The SO₄²⁻ ion was less palatable to beef heifers than the Cl⁻ on an equimolar basis.⁵⁸⁵ Rats drinking water containing 10,000 mg CaCl₂/L were unable to produce normal litters, and 15,000 mg CaCl₂/L reduced growth rates.⁵⁸⁶ Conversely, in another study, rats consuming 15,000 mg CaCl₂/L adapted, grew normally, reproduced, and were able to suckle their young.⁵⁵⁷

Summary

The effects of Na and Cl are difficult to separate since neither exists in its pure state in nature, and the elements usually occur together in water. It is also difficult to separate the chronic effects of NaCl from those attributed to TDS in the literature, as the Na⁺ and Cl⁻ ions are major constituents of salinity under natural conditions. Nevertheless, it is the Na⁺ ion that seems to be responsible for most of the recognized effects of "salt" poisoning.⁵⁸³ At present, there is not sufficient data to make any specific recommendations regarding Cl⁻ in drinking water for livestock or wildlife.

The toxic effects of Na are very dependent upon the availability of fresh water. If abundant, good quality drinking water is available, animals can tolerate large doses of Na. This fact notwithstanding, at some point excess dietary Na exceeds the ability of the organism to excrete Na⁺, and acute poisoning results, regardless of water intake. The threshold for acute toxicity seems to be approximately 1g Na/kg BW for swine, with cattle equal or slightly less sensitive and sheep considerably less sensitive (roughly

2.5 g Na/kg BW). Most animals will limit their consumption of NaCl to approximately 400 mg Na/kg BW/day, if possible. Beyond this dose, feed intake, water consumption, and productivity decline. We couldn't find sufficient equine-specific data to nominate a toxic dose, but most reviewers indicate horses are roughly similar in sensitivity to cattle and swine. Similarly, there is virtually no quantitative data on wild ungulates, but there is no reason to suspect wild ruminants are significantly more sensitive than cattle.

If the only water available is also the major source of dietary Na, long-term impacts will occur at lower dosages. Chronic health effects, mainly decreased production, have been reported at water concentrations as low as 1,000 mg Na⁺/L in dairy cows; however, other studies with beef heifers in cooler climates reported only minimal effects at 1,600-2,000 mg Na⁺/L. Interestingly, the actual *doses* of Na consumed by the cattle in all of these studies (250-400 mg Na⁺/kg BW) were similar. Dosages greater than 800 mg Na/kg BW resulted in effects ranging from weight loss and diarrhea to death.

It is theoretically possible animals maintained on high-Na⁺ water for prolonged periods will, if suddenly exposed to low-Na⁺ water, develop acute Na⁺ ion intoxication, and anecdotal reports suggest that such has happened under field conditions. We were unable, however, to discover sufficient quantitative information to make any recommendations other than animals should be transitioned from high to low Na⁺ water sources gradually.

Assuming water consumption typical of a rapidly growing steer (see Introduction) and only background feed Na concentrations, the no-effect level would be about 1,000 mg Na⁺/L or 2,500 mg NaCl/L. Serious effects, including death, become likely at 5,000 mg Na⁺/L. We recommend keeping drinking water Na concentrations at less than 1,000 mg/L, although short-term exposure to concentrations up to 4,000 mg/L should be well-tolerated.