

# Electrolyte & Water Balance In Calves

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## **Introduction**

The importance of administering electrolytes to scouring calves is well recognized. Most calf facilities include electrolytes as a standard item in their arsenal of medications and treatments for calf scours. It is interesting that even though electrolytes are widely used, the method of administration, the amount given, timing, frequency, expected outcomes and actual results are quite variable. That's not surprising considering the misunderstanding, confusion and disagreement surrounding the basic principles of electrolyte and water balance in the body.

The discussions that follow begin with the routine processes of water movement into and out of the digestive tract. This basic

treatment of digestion and absorption sets the stage for discussions of water loss, rehydration therapy and electrolyte formulation that follow in later sections. The second section, Electrolyte and Water Control Mechanisms, provides a more detailed technical look at how the body regulates electrolytes, water balance and works to maintain an electroneutral environment. These principles provide a solid foundation for assessing actual situations and developing successful, cost effective treatment and prevention protocols. The information presented in this text is not unique to baby calves, and accurately describes electrolyte and water movement in other animal species.



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## Digestion, Absorption and Water Movement

*This section describes how water moves into and out of the small intestine relative to ingestion, digestion and absorption of nutrients. An overview of intestinal mucosa structure and function is provided. The role of sodium in water movement and the relationships among sodium, amino acid and glucose absorption are also discussed. These are key concepts necessary for understanding electrolyte function, water loss, rehydration therapy and electrolyte formulation.*

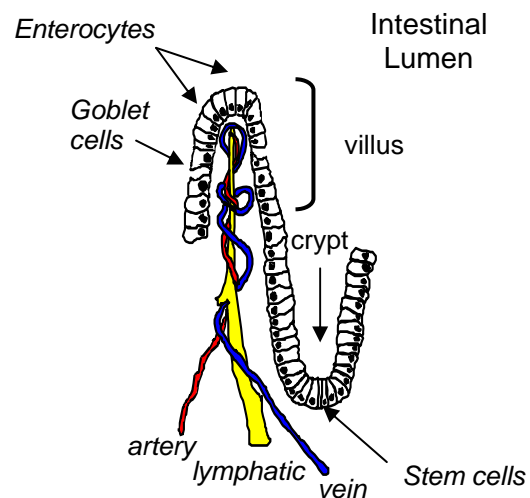
In healthy animals, large amounts of water are regularly secreted into the small intestine to help digest and absorb nutrients. Most of this water is recovered as the nutrients are digested and absorbed. Nearly twice the total volume of water in an animal's body cycles into and out of its digestive tract each day.

The mucosa, or lining of the small intestine, is made up of villi and crypts. Figure 1. Villi project into the open space, or lumen, of the small intestine and are mainly involved in nutrient absorption. Each villus is well supplied with blood and lymph vessels that rapidly move absorbed nutrients away from the digestive tract and into the body. Crypt cells, on the other hand, are primarily concerned with secretion of substances, including water, into the intestinal lumen.

**Water movement into the small intestine.** As food enters the small intestine, water readily "leaks" between the mucosa cells of the upper small intestine into the lumen. During digestion large food particles are broken down to small absorbable nutrients, increasing the concentration of particles inside the intestine. This concentration, referred to as osmotic pressure, is much greater inside the intestine than it is in the cells and fluids of the body surrounding the digestive tract. Since water flows toward areas of high osmotic pressure, water moves from the body into the intestinal lumen. Figure 2.

Water can also be moved into the intestine through specific action of crypt cells. By pumping chloride ions ( $\text{Cl}^-$ ) into the crypt space of the lumen, crypt cells actively draw water into the intestine. Figure 3A. These  $\text{Cl}^-$  ions attract

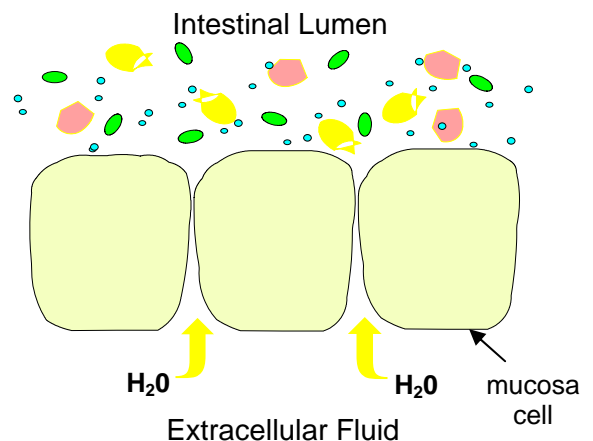
Figure 1.



adapted from Austgen et al

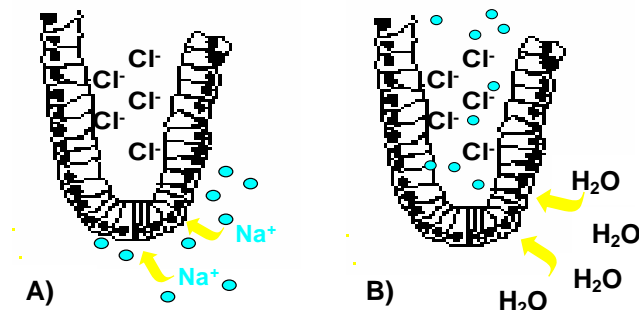
Figure 2.

### Water Movement Into the Small Intestine



sodium ions ( $\text{Na}^+$ ) into the crypt space, increasing the local osmotic pressure. Figure 3B. As the osmotic pressure increases, water is pulled into the intestine.

**Figure 3. Water Secretion Into the Crypt Space**



Some bacteria, such as *E. coli*, produce enterotoxins that trigger this pumping mechanism causing hyper-secretion of water. Cholera, which has resulted in the deaths of millions of humans, is perhaps the most infamous of these organisms that lock this pump system in the “ON” position.

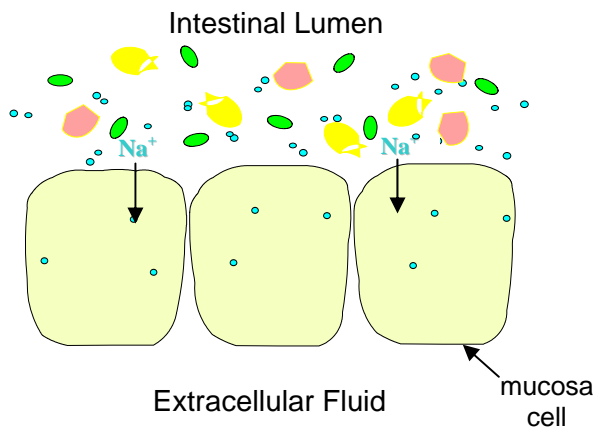
**Water resorption from the small intestine.**

Water is resorbed from the digestive tract as a result of nutrient absorption, with sodium ( $\text{Na}^+$ ) playing an important role in this process. As a rule: **water follows sodium**. Sodium is free to move across mucosa cell membranes in response to osmotic differences, moving from areas of higher osmotic pressure to areas of lower osmotic pressure. Figure 4.

Although this passive diffusion of  $\text{Na}^+$  results in water movement out of the digestive tract, it is insufficient for adequate water resorption. Sodium is also actively moved across the mucosa cell membrane along with other nutrients.

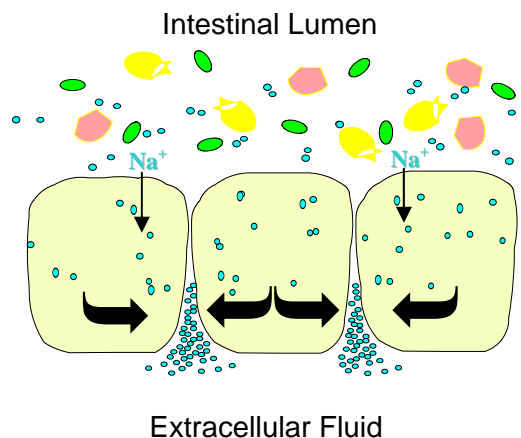
For example, amino acids and carbohydrates are co-transported with  $\text{Na}^+$  out of the lumen and into the mucosa cells of the small intestine.

**Figure 4. Sodium Movement**



Once inside the cell,  $\text{Na}^+$  is rapidly pumped into the extracellular fluid surrounding the cell, away from the intestinal lumen. As a result of these nutrient movements, a series of osmotic gradients are created which move water from the lumen into the cell, and then from the cell into the extracellular fluid. Figure 5. The  $\text{Na}^+$  and water then diffuse into the bloodstream.

**Figure 5.**



The ability to concentrate  $\text{Na}^+$  in the extracellular fluid surrounding mucosa cells, drawing water from the digestive tract, increases as food particles move through the small intestine. By the time food reaches the large intestine, about 80% of the water has been resorbed.

## Electrolyte and Water Control Mechanisms

*This section describes how individual cells, the kidneys and the lungs regulate the body's electrolytes and water. The kidneys and lungs regulate the chemical composition of blood, providing primary control over electrolytes and water in body fluids. A discussion of acid-base balance describes how the concerted efforts of the kidneys and lungs help maintain an electroneutral environment.*

*This elementary exploration of the physical chemistry of biological solutions is the most technical in this publication. Although an understanding of this material is not required before reading the remaining sections, these discussions provide a better understanding of electrolyte and water balance, dehydration, and electrolyte formulation.*

Individual cells work in conjunction with the kidneys and lungs to regulate and maintain normal water and electrolyte balance within the body. The kidneys have the largest responsibility for maintaining blood chemistry, and in concert with the lungs are responsible for regulating the acid-base balance within the blood. These processes involve both electrolytes and water.

Figure 6 shows the typical chemical composition of body fluids. Extracellular fluid makes up about 40% of the body's water and includes the fluid in blood and the space between cells, called the interstitial space. The remaining 60% is intracellular fluid, residing inside of cells. Extracellular fluid provides all of the nutrients, oxygen, waste removal, pH and temperature control for the cell. Cells simply react to conditions in the extracellular fluid.

### Chemical Composition Of Extracellular & Intracellular Fluids

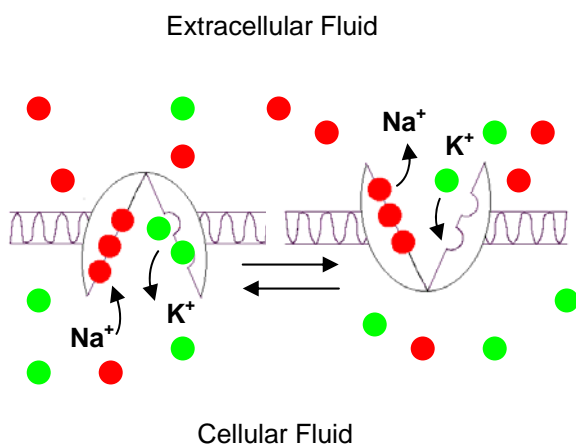
	Extracellular Fluid	Intracellular Fluid
Strong Ions	Na <sup>+</sup>	140 mEq/l
	K <sup>+</sup>	3 mEq/l
	Ca <sup>+2</sup>	1 mEq/l
	Mg <sup>2</sup>	2 mEq/l
	Cl <sup>-</sup>	103 mEq/l
	Other Strong Ions	1 mEq/l
Strong Ion Difference [SID]*	37	131
HCO <sub>3</sub> <sup>-</sup>	28 mEq/l	12 mEq/l
Phosphates	4 mEq/l	75 mEq/l
SO <sub>4</sub>	1 mEq/l	2 mEq/l
Glucose	90 mg %	0 - 2 mg %
Amino Acids	30 mg %	200 mg %
Cholesterol		
Phospholipids	} 0.5 mg %	} 2 - 95 mg%
Neutral fat		
PO <sub>2</sub>	35 mmHg	20 mmHg
PCO <sub>2</sub>	46 mmHg	50 mmHg
pH	7.4	7.0

**Figure 6.**

\*[SID] = [Na<sup>+</sup>]+[K<sup>+</sup>]+[Ca<sup>+</sup>]+[Mg<sup>2+</sup>]-[Cl<sup>-</sup>]-[other strong anions]  
 [ ] means: concentration of

**Cells.** Sodium ( $\text{Na}^+$ ) is the major ion, or electrolyte, outside of the cell. Potassium ( $\text{K}^+$ ) is the major ion inside the cell. Since cell membranes are permeable to  $\text{Na}^+$ , it diffuses into the cell where its concentration is lower. To maintain the low intracellular  $\text{Na}^+$  concentration, the cell quickly pumps  $\text{Na}^+$  back into the extracellular fluid. Sodium pumps located in the cell membrane pump  $\text{Na}^+$  out of and  $\text{K}^+$  into the cell, maintaining normal osmotic gradients.

**Figure 7. Sodium Pump**



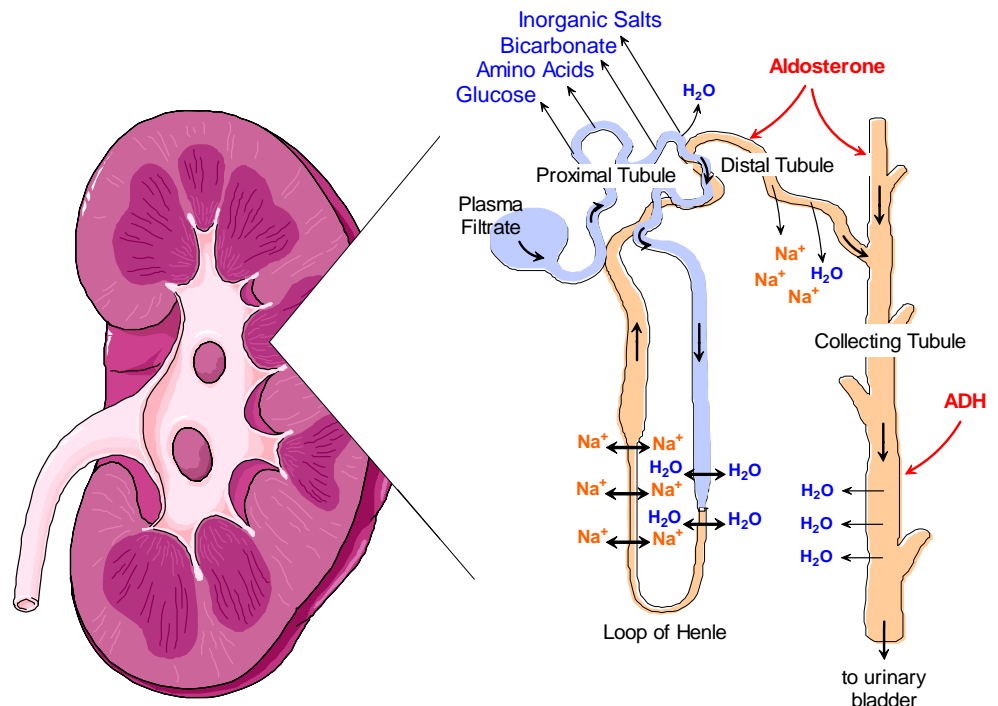
**Kidneys.** The kidneys filter the blood to remove harmful metabolic acids and wastes and reabsorb those substances the body needs. They help control plasma ion concentration and maintain pH by removing strong ions such as  $\text{Na}^+$  and  $\text{Cl}^-$  from plasma into urine. By removing more  $\text{Na}^+$  than  $\text{Cl}^-$ , for example, the kidneys lower the plasma Strong Ion Difference [SID]. SID is simply the difference between the concentrations of positive and negative strong ions. Refer to Figure 6. As  $\text{Na}^+$  is removed, the number of positive ions decreases causing a relative increase in the concentration of negative ions. To offset the increase of negative charges created by  $\text{Na}^+$  removal, the concentration of hydrogen ions,  $[\text{H}^+]$ , increases. As  $[\text{H}^+]$  increases, pH decreases, making plasma more acidic. On the other hand, removing more  $\text{Cl}^-$  than  $\text{Na}^+$  raises plasma [SID], which lowers  $[\text{H}^+]$  and raises pH. The concept of electroneutrality is discussed later in this section.

The kidneys also control blood volume by regulating the amount of water in extracellular fluid. Figure 8. Two hormones, aldosterone and antidiuretic hormone (ADH) help the kidneys control the fluid volume of blood. When water is lost from the body, blood volume decreases. This leads to increased production of aldosterone and ADH. Elevated aldosterone increases  $\text{Na}^+$  pump

**Figure 8. Kidney tubules**

The kidneys contain a vast blood filtering system. Blood cells and proteins are removed, creating a plasma filtrate that passes into the tubules. Glucose, amino acids, bicarbonate and inorganic salts are removed in the proximal tubule. As these solutes are removed from the filtrate, water follows them out of the proximal tubule by osmosis.

Sodium is removed from the filtrate in the Loop of Henle, creating a strong osmotic gradient that draws water out of the tubule. Water can also be removed in the distal and collecting tubules. When additional water needs to be conserved, aldosterone is released, causing increased  $\text{Na}^+$  removal from the distal tubule, which draws out additional water. Antidiuretic hormone (ADH) is released, causing increased permeability of the distal and collecting tubules to water. As a result, urinary output is reduced, conserving more water.



activity in the kidney tubules. As a result, more  $\text{Na}^+$  is removed from the distal tubules and concentrated within the kidney rather than being excreted. This high concentration of  $\text{Na}^+$  in kidney tissue creates an osmotic gradient that pulls water out of the tubules. Elevated ADH works in conjunction with aldosterone by increasing the permeability of the tubules to water, allowing water to follow  $\text{Na}^+$  out of the tubules, thereby reducing urinary water loss.

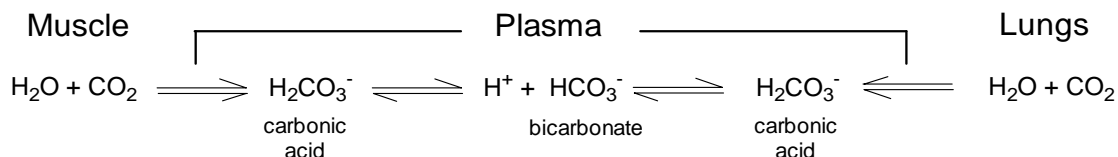
**Lungs.** The lungs play an important role in regulating plasma  $\text{CO}_2$  and pH. Since  $\text{CO}_2$  is a gas, the term partial pressure,  $\text{PCO}_2$ , is used to describe its concentration in liquids. Changes in respiration rate relate to changes in the partial pressure of  $\text{CO}_2$ . For example,  $\text{CO}_2$  is produced during exercise and is removed from muscle tissue by the blood, increasing  $\text{PCO}_2$ . To quickly rid the blood of excess  $\text{CO}_2$ , respiration rate increases. In this process,  $\text{CO}_2$  from the muscle combines with water to form carbonic acid in the blood, which then dissociates to  $\text{H}^+$  and bicarbonate ions ( $\text{HCO}_3^-$ ). Bicarbonate is the primary storage and transportation form of  $\text{CO}_2$  in plasma. In the lungs, this process is reversed with  $\text{CO}_2$  and water being exhaled. Figure 9.

As the rate of  $\text{CO}_2$  production increases,  $\text{PCO}_2$ ,  $[\text{HCO}_3^-]$  and respiration rate increase. If  $\text{CO}_2$  production outstrips the lungs' ability to convert  $\text{HCO}_3^-$  to water and  $\text{CO}_2$ , plasma  $[\text{HCO}_3^-]$  will continue to rise. As a result, plasma  $[\text{H}^+]$  increases to offset the additional negative charges, leading to a decrease in plasma pH.

Acidosis =  $\uparrow\text{PCO}_2$ ,  $\uparrow\text{HCO}_3^-$ ,  $\downarrow\text{pH}$

Alkalosis =  $\downarrow\text{PCO}_2$ ,  $\downarrow\text{HCO}_3^-$ ,  $\uparrow\text{pH}$

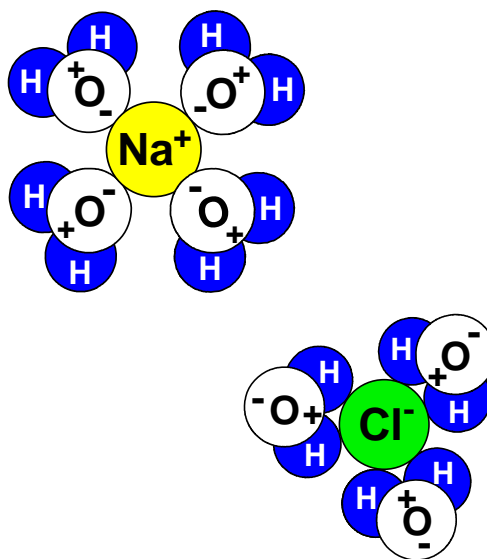
Figure 9. Plasma Carbon Dioxide Transport



**Acid - Base Balance.** By regulating blood chemistry, the kidneys and lungs maintain an electroneutral environment. The processes involved in maintaining electroneutrality are referred to as acid-base balance. The power of the lungs to excrete large quantities of carbon dioxide enables them to compensate rapidly, while the smaller capacity of the kidneys corresponds to a relatively slower rate of compensation through metabolic means. Both must work in concert to maintain an acid-base balance.

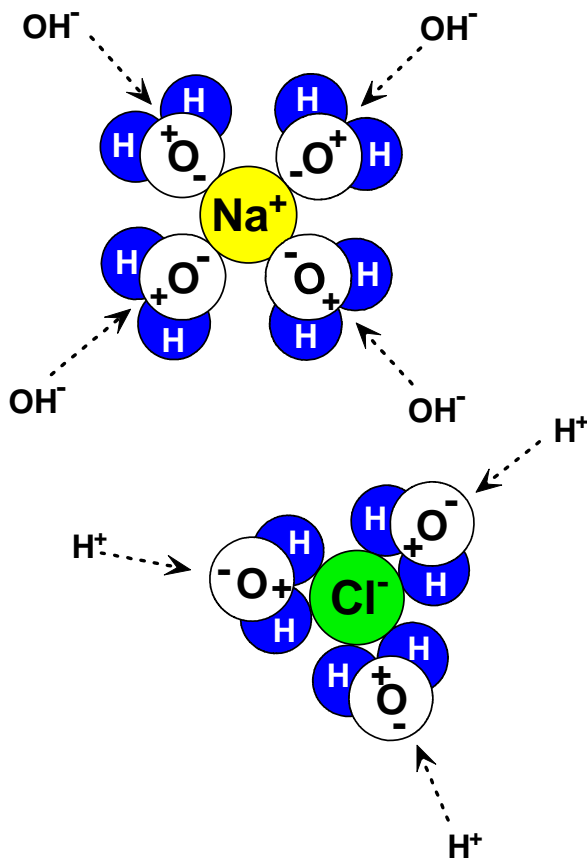
**Metabolic Regulation.** Strong ions are fully dissociated from each other in plasma and form charged water complexes. For example,  $\text{Na}^+$  and  $\text{Cl}^-$  do not associate with each other to form  $\text{NaCl}$  in plasma. Instead,  $\text{Na}^+$  associates with the  $\text{O}^-$  component of water while  $\text{Cl}^-$  associates with the  $\text{H}^+$  component. Figure 10.

Figure 10. Charged Water Complexes



The orientation of water molecules to a strong ion counterbalances and isolates the ion's charge, and exposes either the positive or negative portion of the water molecules. Charged water complexes of  $\text{Na}^+$  have an overall positive charge that attracts  $\text{OH}^-$ , while negative charges associated with  $\text{Cl}^-$  water complexes attract  $\text{H}^+$ . Figure 11.

Figure 11.



$\text{H}^+$  are talked about as if they are separate entities that can be physically grabbed and moved. This approach is a conventional way of explaining  $\text{H}^+$  activity, but somewhat misrepresents their actual nature. For example, the attractive force between water molecules is such that hydrogen ions of one water molecule are strongly drawn to the oxygen of another. As a result, hydrogen ions readily “jump” to adjacent water molecules causing water to dissociate, forming hydronium ions ( $\text{H}_3\text{O}^+$ ) and hydroxyl ions ( $\text{OH}^-$ ).

In acidic solutions,  $[\text{H}_3\text{O}^+] > [\text{OH}^-]$ , while  $[\text{OH}^-] > [\text{H}_3\text{O}^+]$  in basic solutions. Although  $[\text{H}_3\text{O}^+]$  may better represent the hydrogen ion status of biological solutions than  $[\text{H}^+]$ , the term  $[\text{H}^+]$  is more commonly used and is the terminology used in this text.

By selective removal of  $\text{Na}^+$  or  $\text{Cl}^-$ , the kidneys adjust the relative proportion of  $\text{H}^+$  to  $\text{OH}^-$  in plasma. As  $\text{Na}^+$  is removed, the amount of  $\text{OH}^-$  required to offset positive charged water complexes decreases. Consequently, the amount of  $\text{OH}^-$  in the solution decreases. As  $\text{OH}^-$  decreases, the relative amount of  $\text{H}^+$  increases, bringing about a reduction in pH. On the other hand, removal of negative charged water complexes reduces the amount of  $\text{H}^+$  needed in the solution to offset negative charges. As the relative amount of  $\text{OH}^-$  increases, the solution becomes more basic and pH rises. These processes are summarized below.

Figure 12.

#### Kidney Action to Maintain Electroneutrality

$\downarrow \text{Na}^+, \downarrow [\text{OH}^-], \uparrow [\text{H}^+], \downarrow \text{pH}$

$\downarrow \text{Cl}^-, \downarrow [\text{H}^+], \uparrow [\text{OH}^-], \uparrow \text{pH}$

In a nutshell, that's how the kidneys help maintain electroneutrality. Obviously there has to be some biological reason for the kidney to remove  $\text{Na}^+$  or  $\text{Cl}^-$ .

**Respiratory Regulation.** Since bicarbonate ( $\text{HCO}_3^-$ ) is the plasma transport form of  $\text{CO}_2$ , its regulation falls under the jurisdiction of the lungs, not the kidneys. As previously discussed, the lungs quickly adjust the partial pressure of carbon dioxide in plasma ( $\text{PCO}_2$ ) by either increasing or decreasing respiration rate. As a result, plasma bicarbonate either decreases or increases.

*Combined Effect of Respiratory & Metabolic Regulation.* Although the lungs and the kidneys have their own regulatory processes, they work together to maintain plasma electroneutrality. As an example, consider a baby calf that is undergoing the common summertime problem of heat stress. In an attempt to get rid of extra heat, the calf's respiration rate increases. Although rapid breathing rids the body of some excess heat, it also causes a loss of  $\text{CO}_2$ , which lowers plasma  $\text{PCO}_2$  and  $\text{HCO}_3^-$ . Reducing  $\text{HCO}_3^-$  also reduces the  $[\text{H}^+]$  required to neutralize the negative charges associated with bicarbonate. As plasma  $[\text{H}^+]$  decreases, the relative  $[\text{OH}^-]$  increases, causing plasma to become more alkaline. Plasma pH rises. This situation is generally referred to as respiratory alkalosis. Figure 13 summarizes the changes that occur in the calf as a result of increased respiration rate due to heat stress.

**Figure 13.**

**Effect of Increased Respiration Rate  
In Response To Heat Stress**

$\downarrow \text{CO}_2, \downarrow \text{PCO}_2, \downarrow \text{HCO}_3^-, \downarrow [\text{H}^+], \uparrow [\text{OH}^-], \uparrow \text{pH}$

To compensate, the kidneys remove  $\text{Na}^+$ . As  $\text{Na}^+$  is removed, the  $[\text{OH}^-]$  required to offset the positive charge associated with sodium is reduced. This reduction in plasma  $[\text{OH}^-]$  increases the relative  $[\text{H}^+]$ , bringing plasma pH down to normal. Figure 14 summarizes the kidney response to the calf's respiratory alkalosis caused by heat stress.

**Figure 14.**

**Kidney Metabolic Response To  
Respiratory Alkalosis**

$\downarrow \text{Na}^+, \downarrow [\text{OH}^-], \uparrow [\text{H}^+], \downarrow \text{pH}$

Through their combined actions the lungs and kidneys may have averted a couple of potentially life-threatening situations. Nevertheless, the calf has lost body water during the heat stress and the removal of  $\text{Na}^+$  has lowered the plasma [SID] below normal to maintain electroneutrality. Oral electrolyte therapy is an obvious remedy for both the water and electrolyte loss. If administered early enough, the electrolyte treatment could avert or at least lessen the heat stress and resulting physiological changes in the calf.

*pH.* The pH of intracellular fluid is about 7.0 and about 7.4 for extracellular fluid. At normal body temperature, the pH of a solution is 6.8. Therefore, body fluids are actually maintained at a slightly alkaline pH. The pH range of physiological solutions is small, with a pH change of 1.0 being fatal.

Ion movements in body fluids cause changes in pH, making it a dependant variable. As demonstrated above, significant changes can occur in plasma chemistry that result in virtually no change in pH. Furthermore, equal changes in  $[\text{H}^+]$  and  $[\text{OH}^-]$  in physiological solutions do not bring about equal changes in pH. To summarize, a change in pH indicates a problem. It does not, however, indicate what is causing the problem or what needs to be corrected. pH is not a very sensitive measure for evaluating the acid-base status or changes in status of body fluids.

Pathogens, feed characteristics and management influence digestive function and can result in water loss through the digestive tract. There are four types of digestive water loss. Each is defined in this section. A diarrheic animal may actually suffer from more than one type of water loss at the same time. The process of dehydration and the clinical signs associated with progressive water loss in calves are also discussed.

### Types of Water Loss Associated With Diarrhea

**Increased Permeability.** Microbes cause inflammation and damage to the intestinal mucosa resulting in increased water movement into the intestine. This type of water loss is commonly caused by viruses (rotavirus, coronavirus) and protozoa (coccidia, cryptosporidia). Inflammation may also lead to hypersecretion.

**Hypersecretion.** This type of water loss is similar to increased permeability in that large amounts of water move into the intestine, but there is no tissue damage. Bacterial enterotoxins stimulate cellular pumps in the crypt cells of the intestinal mucosa to secrete large amounts of ions into the intestinal lumen. These ions draw water into the small intestine. These mechanisms were previously described in Figure 4. Hypersecretion in calves is most commonly caused by *E. coli*.

**Malabsorption.** Epithelial damage in the small intestine reduces nutrient absorption. Viruses and protozoa damage the villi in the small intestine leading to villous atrophy, and can damage the large intestinal mucosa as well. Normal amounts of water may be secreted into the digestive tract, but tissue damage results in poor nutrient and water absorption. Malabsorption causes nutrients to bypass absorption in the small intestine. As these nutrients reach the large intestine, they can cause bacterial overgrowth and excessive production of volatile fatty acids (VFAs). As a result, osmotic changes occur that worsen fluid loss.

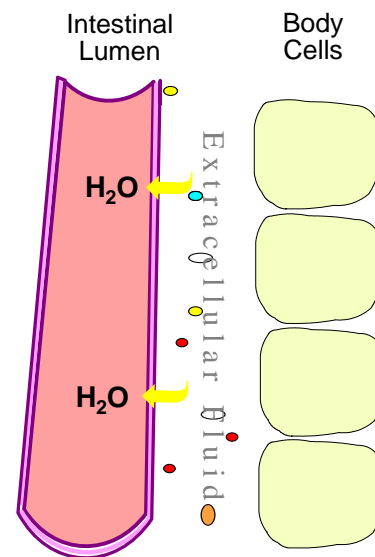
**Maldigestion.** Changes in feed management may lead to maldigestion. A sudden change in feed, use of poor quality ingredients, the presence of feed allergens or other detrimental feed factors

and digestive disorders can lead to maldigestion. Maldigestion usually results in malabsorption.

### Dehydration

During diarrhea, large amounts of water and electrolytes are lost from the body. Water moves from the extracellular fluid (the blood and the interstitial space between cells) into the intestinal lumen. Figure 14A.

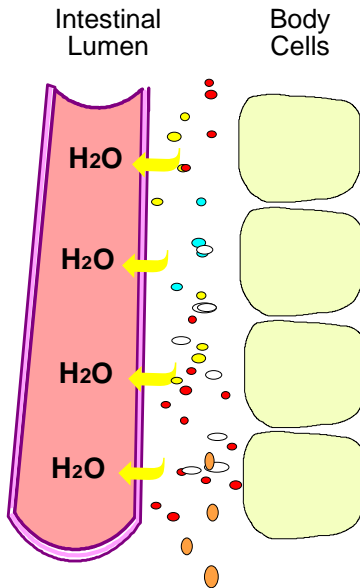
**Figure 14A. Process of Dehydration Due To Scours**



**14-A**

As more and more water moves into the intestine, the concentrations of ions and other substances in the extracellular fluid rises resulting in a hypertonic solution. Figure 14-B. (See Figure 14- D for more information on hypertonic solutions.)

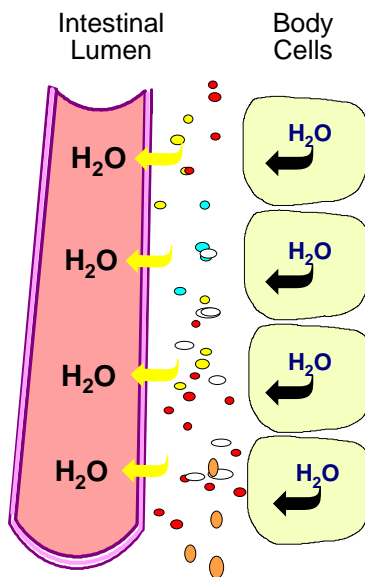
Figure 14 B.



14-B

As a result, osmotic pressure within the extracellular fluid increases. Since water moves toward areas of high osmotic pressure, water leaves the surrounding cells and moves into the extracellular fluid. Figure 14C.

Figure 14 C.



14-C

This movement of water out of the cells increases the volume of the extracellular fluid and lowers its osmotic pressure. As body cells lose water they become dehydrated. This process of cellular dehydration helps maintain blood volume.

**Figure 14-D. Hypertonic, Hypotonic and Isotonic**

“Tonic” refers to the concentration of substances in a liquid relative to that found in normal plasma. Hypertonic describes a liquid that contains more solutes and less water than plasma. Hypotonic means a solution with fewer solutes and more water than plasma, and an isotonic solution has similar concentrations of solutes and water to those found in normal plasma.

The hypertonic situation is described above for water lost through the digestive tract. It is also an appropriate description of dehydration resulting from sensible water loss through respiration and body temperature regulating mechanisms during periods of heat stress and reduced water intake.

A hypotonic situation can arise when large amounts of electrolytes etc. are lost from the extracellular fluid into the intestinal lumen relative to water loss. This results in an increasing proportion of water remaining in the extracellular fluid, thereby reducing its osmotic pressure. Since the osmotic pressure within the cells is now greater than the surrounding fluid, cells retain their water. Additional water may actually be drawn from the extracellular fluid into the cells during hypotonic water loss.

Isotonic water loss occurs when the same relative proportions of water, electrolytes and other solutes are lost from the extracellular fluid into the digestive tract as are normally found in plasma. Since there are no osmotic gradients created in this situation, water would not tend to flow from one body compartment in response to osmotic changes.

Practically speaking, it is difficult to ascertain the specific tonicity involved in an episode of diarrhea without analytical equipment.

As dehydration progresses, tissues tend to shrink, skin becomes dry and wrinkled, and eyes become shrunken and soft. Fever develops as

dehydration worsens. If water loss continues and plasma volume falls, the kidneys reduce urine output in order to conserve water. As urine output decreases, waste products accumulate in the blood.

Reduced kidney function causes changes in plasma ion concentrations and a reduction in plasma pH. As pH is reduced, acidosis occurs. Both dehydration and acidosis interfere with the animal's ability to maintain its body temperature and lead to hypothermia. The animal's attitude and posture are related to the severity of these factors. Table 1.

Acidosis is more severe in older calves and may contribute more to depression and weakness than in younger calves. As shown in Table 1, the plasma ion deficit of older calves is more severe than younger calves showing the same clinical signs. *E coli* infections are most common in calves under one week of age and tend to cause hypersecretion diarrhea with rapid and severe water loss. The speed with which dehydration occurs during these infections may not provide

enough time for the lungs to compensate for the rapid onset of acidosis. As a result, dehydration rather than acidosis may be more related to attitude and posture in younger calves. Respiratory compensation is consistent with prolonged metabolic acidosis, and could be the reason older calves present a more severe acidosis in each category (Naylor, 1987)

As water loss reaches about 8 - 10% of body weight, blood viscosity increases causing a decrease in cardiac output and a rise in pulse rate.

As water loss continues, acidosis progresses, lowering plasma pH to the point that cell membranes start to depolarize. Potassium begins to leave the cells and increases in the extracellular fluids. The reduced membrane potential interferes with muscular contractions, causing the heart to beat irregularly. Blood pressure decreases resulting in circulatory failure and reduced blood flow to the lungs. The pulse weakens and the calf goes into an irreversible shock and becomes comatose. Death results from heart failure.

**Table 1. Relationship Between Metabolic Acidosis And Clinical Signs In Calves**

<u>Category</u>	<u>Weight Loss</u>	<u>Clinical Signs</u>	<u>Severity of Acidosis By Age (mmol/l)*</u>	
			<u>&lt;8 days</u>	<u>&gt;8 days</u>
1	4-6%	no clinical signs, stands without assistance strong suckling reflex	0	5
2	6-8%	weak but able to stand, weak suckling reflex, dry mouth and nose, tight skin, sunken eyes and depression	5	10
3	8-10%	calf resting on its sternum, above signs more pronounced, depression more severe	12	16
4	10-14%	calf in lateral recumbency, cool extremities, poor peripheral pulse, comatose	13	20

\*This is the plasma base deficit and represents how far away a calf is from the normal acid base balance of zero

Source: adapted from J.M. Naylor, Can Vet J. 1989; 30:577-580



## Oral Rehydration Therapy

**Overview.** *The amount and timing of electrolyte replacement therapy is critical for rapid recovery from dehydration. This section describes the relationship between the degree of water loss and the amount of electrolyte solution required to offset the loss. An overview of the effect of different pathogens on water loss and rehydration therapy, regulation of voluntary intake and effects of tube-feeding are presented. The importance of regular milk replacer feedings on the hydration status of the animal and in maintaining nutrient intake is also explored.*

The timing of electrolyte replacement therapy is critical. A common mistake is waiting too long before administering electrolyte solutions to affected calves. Table 2 shows that calves can lose as much as 6% of their body weight before showing visible signs of dehydration. Giving fluids too little, too late allows progressive fluid loss. As a result, the calf's condition continues to deteriorate. Most calves that die of scours usually die from loss of water and electrolytes, not from direct action of pathogenic organisms. The focus of any treatment plan should be on replacing lost fluids and restoring acid base balance.

Good candidates for oral rehydration therapy are those calves that can stand and suckle. Weak calves with a poor suckle reflex may need to be

tube-fed. Calves that have lost the suckle reflex and are recumbent and unable to rise, are poor candidates for oral rehydration therapy. Subcutaneous and/or intravenous infusions are indicated in more advanced stages of dehydration and acidosis. The calf's ability to recover declines as the severity of dehydration and acidosis increases.

The amount of supplemental fluids a calf needs each day depends on its rate of dehydration. Table 2 shows the minimum amount of electrolyte solution required daily by a 100# calf. The amount of fluid indicated at each level is the amount of electrolyte solution that needs to be fed in addition to regular milk replacer feedings. Substituting electrolyte feeding for milk replacer feeding does nothing to correct the fluid loss.

**Table 2. Electrolyte Solution Requirements For Rehydration Therapy (100 lb calf)**

<u>Weight Loss</u>	<u>Clinical Signs</u>	<u>Minimum Electrolyte Solution Required</u>
4-6%	no clinical signs, stands without assistance strong suckling reflex	3 qt
6-8%	weak but able to stand, weak suckling reflex, dry mouth and nose, tight skin, sunken eyes and depression	4 qt
8-10%	calf resting on its sternum, above signs more pronounced, depression more severe	5 qt
10-14%	calf in lateral recumbency, cool extremities, poor peripheral pulse, comatose	6-7 qt

Consider a 100 lb calf that is scouring, but shows no other clinical signs. The calf is alert and attentive and has a strong suckle reflex. We can assume the calf has lost about 5% of its body weight due to diarrhea. For this calf, a 5% weight loss equals 5 pounds. If a gallon of water weighs 8 lb, each quart weighs 2 lb and each pint weighs 1 pound. Therefore, this calf has lost 5 pints or 2½ qt of water. Since absorption is not likely to be 100%, the calf should receive at least 3 qt of electrolyte solution daily while scouring.

Table 3 shows the electrolyte solution requirements of 60 and 80 lb calves. A 5% weight loss is about 3 lb and 4 lb respectively. In this case the 60 lb calf requires a minimum of 1½ quarts while the 80 lb calf needs a minimum to 2 quarts of electrolyte solution to replace the water lost through diarrhea.

Electrolyte solutions should be fed between milk replacer feedings at least two hours after the milk replacer. This routine provides a more even distribution of liquid consumption throughout the day. A properly formulated electrolyte solution is designed to maximize the absorption and utilization of both the ingredients and water.

**Efficacy of Treatment.** Enterotoxigenic *E. coli* causes a hypersecretion type of water loss. In this situation only about 60% of the electrolyte solution is absorbed, so the frequency of administration needs to be increased. In this case, 40% of the electrolyte solution will pass through the calf’s digestive tract, adding to the calf’s fecal water loss. This makes the diarrhea appear to be worsening with electrolyte therapy even though the treatment is effective.

Rotavirus, coronavirus and cryptosporidia invade and damage the intestinal villi causing an increased permeability type of water loss. These organisms tend to affect calves over a week old causing a somewhat slower rate of water loss and a more prolonged infection than with Enterotoxigenic *E. coli*. Electrolyte therapy reduces the metabolic acidosis associated with these infections. As a result, the suckling reflex increases, helping the animal to recover without other treatments.

**Voluntary Intake.** Mammals regulate their sodium intake. As sodium loss increases, calves preferentially consume sodium-containing fluids.

**Table 3. Electrolyte Solution Requirements For Rehydration Therapy (60 and 80 lb calves)**

<b>Weight Loss</b>	<b>Clinical Signs</b>	<b>Minimum Electrolyte Solution Required</b>	
		<b>60 lb</b>	<b>80 lb</b>
4-6%	no clinical signs, stands without assistance strong suckling reflex	1.5 qt	2 qt
6-8%	weak but able to stand, weak suckling reflex, dry mouth and nose, tight skin, sunken eyes and depression	2.5 qt	3+ qt
8-10%	calf resting on its sternum, above signs more pronounced, depression more severe	3 qt	4 qt
10-14%	calf in lateral recumbency, cool extremities, poor peripheral pulse, comatose	4 qt	6 qt

This is one reason why sodium is such an important component of an effective electrolyte solution. The solution should be made available at the onset of infection since calves that become acidotic cannot effectively regulate sodium intake. Free-choice electrolyte solutions have been shown to decrease mortality in baby pigs from 20% to 7% under naturally occurring diarrhea conditions.

**Tube feeding.** It may be necessary to tube-feed calves with a weak suckle reflex. In this situation, there is little or no stimulation for closure of the esophageal groove causing the electrolyte solution to enter the rumen rather than the abomasum. Some solution overflows into the abomasum and is absorbed as efficiently as nursed solutions, but rumen bacteria may be washed away.

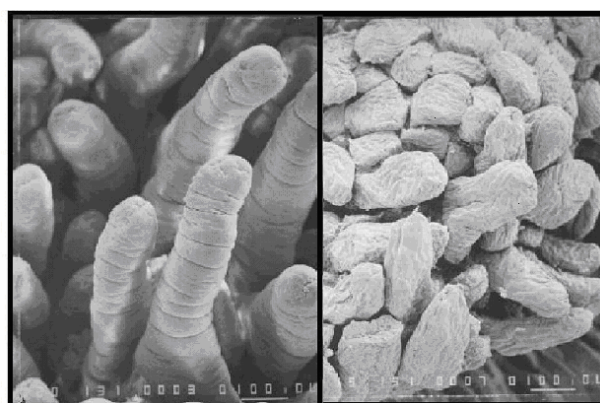
Although it is critical to rehydrate scouring calves, the possibility of negative effects of tube feeding on rumen microflora does exist. These effects depend on the calf's age and degree of rumen development. Most electrolyte solutions, for example, contain glucose. In the developing rumen glucose is fermented to volatile fatty acids and lactate causing a decrease in rumen pH. This lower pH can destroy certain rumen bacteria, slowing the calf's return to normal feed digestion and absorption.

**Milk/Milk Replacer Feeding.** Dehydration is reported as the primary reason that scouring calves die. Second place goes to starvation. When normal digestive and absorptive functions of the intestine are impaired, calves cannot absorb adequate nutrients from the diet. Since young calves have precious little in the form of stored nutrients to sustain them, digestive and absorptive problems can progressively lead to

rapid weight loss, weakness and death. This situation is made worse when milk replacer is withheld during the treatment process.

Withholding milk replacer does reduce nutrients available for gut pathogens, but also reduces nutrients for the calf. This reduction in nutrients not only compromises the normal gut flora, it also reduces nutrients available for immune function and contributes to intestinal villi atrophy. The villi on the left of Figure 15 are healthy intestinal villi of a pig at weaning. The picture on the right shows villi two days later before the pig has adjusted to the new diet, and clearly shows the severe effects of withholding nutrients.

**Figure 15. Intestinal Villi**



University of Missouri

The digestive tract requires more energy to keep it going than any other organ in the body. If the inflow of nutrients is greatly reduced, the digestive tract begins to shut down, conserving energy by reducing functions. Villus atrophy reduces nutrient absorption and compromises the protective barrier function they provide against pathogens. There is strong evidence that withholding nutrients also prolongs the duration of diarrhea and slows recovery.



## Components of Electrolyte Solutions

**Overview.** *Electrolyte solutions should be formulated for their ability to enhance water absorption, water retention and to reduce acidosis. Since diarrhea can have a serious effect on bacterial populations in the digestive tract, inclusion of specific direct-fed microbials favors conditions for growth of beneficial bacteria and reestablishment of a normal intestinal environment.*

**Water** is the most important nutrient for sustaining life. Water corrects dehydration and acts as a solvent for electrolytes.

**Sodium ( $Na^+$ )** is the major extracellular ion in the body. Water follows the movement of  $Na^+$ , making it the major electrolyte component as well. As  $Na^+$  is absorbed from the digestive tract into the blood and into cells, it causes water to move along with it. Cells absorb sodium through simple diffusion. It is also co-transported into cells along with glucose and amino acids. Sodium can also play a role in voluntary uptake of electrolyte solutions. Since mammals regulate sodium intake, calves will preferentially drink sodium-containing solutions as sodium loss increases.

**Glucose** is a sugar, or carbohydrate, that facilitates sodium absorption. Glucose is co-transported with  $Na^+$  from the digestive tract. This enhances  $Na^+$  absorption and water uptake from the small intestine.

Glucose also provides a minor energy source for the calf. However, an electrolyte solution should not be looked at as a replacement for energy provided by milk replacer.

High glucose electrolyte solutions are sometimes presented and used as a replacement for milk or milk replacer during diarrhea. Six quarts of such a solution provides about 75% of the daily energy needed by a baby calf for maintenance, while providing none of the protein required by the calf. Glucose, which is absorbed more quickly than lactose (milk sugar), causes a rapid increase in plasma glucose. Insulin is released into the calf's bloodstream to lower the elevated plasma glucose level. This insulin response is excessive in young calves. Within three hours after administration of

the high glucose electrolyte solution, plasma glucose is lower than the pretreatment level.

**Glycine** is an amino acid that is co-transported with  $Na^+$  and works along with glucose to facilitate sodium and water absorption. Glycine is the most easily synthesized amino acid and is most often included in electrolyte solutions.

**Potassium ( $K^+$ )** is the major intracellular ion. Potassium helps maintain the integrity of the cell membrane and is involved in neural function and muscular contraction. Advanced dehydration leads to acidosis and severe electrolyte imbalance, causing a loss of cell membrane potential and cell death. A high supplemental level of  $K^+$  can be lethal.

**Chloride ( $Cl^-$ )** is the major negative ion (electrolyte) involved in acid-base and water balance in the body. The kidneys use  $Cl^-$  to adjust and maintain equilibrium. Potassium chloride and sodium chloride are excellent  $Cl^-$  sources.

**Ascorbic Acid** (vitamin C) cannot be synthesized by calves until they are about 3 weeks old, and is therefore considered an essential nutrient for calves less than three weeks of age. Ascorbic acid is an antioxidant and is found in high concentrations in steroid secreting cells. The concentration of ascorbic acid in plasma is lower in stressed calves than non-stressed calves. Oral supplementation of ascorbic acid elevates the ascorbic acid level in plasma of preruminant calves.

**Direct-Fed Microbials (DFMs)** are specific, genetically superior species of bacteria that support conditions in the intestinal tract that are favorable to the growth of beneficial

microorganisms and are unfavorable for pathogens. DFMs help prevent intestinal colonization by pathogens through production of antimicrobial compounds such as lactic acid, hydrogen peroxide, modified bile acids, and bacteriocins, which are effective bactericidal/bacteriostatic compounds. DFMs compete with pathogens for attachment sites for growth, compete for nutrients, neutralize toxins and stimulate the host immune system.

*Bacillus* bacteria are lumen organisms and do not attach to intestinal cells before providing their beneficial effects. This characteristic makes *Bacillus* an excellent microbial additive during diarrhea. Water moves rapidly into the digestive tract during diarrhea, making bacterial attachment and colonization more difficult. Attachment is first required for most other lactic acid bacteria. *Bacillus* produce an abundant array of enzymes and antimicrobial compounds with activity against pathogens. *Bacillus* are very hardy organisms and survive under harsh conditions.

*Lactobacillus* bacteria rapidly colonize the newborn intestinal tract and are the predominate microorganisms in the small intestine. They survive the digestive process and attach to the

epithelial lining, making them an excellent complement to *Bacillus*. They grow best at a pH of 5.5 and are very effective against *E. coli*.

*Bifidobacteria* are primary colonizers of the large intestine, growing best at a pH between 6.5 and 7.0. Bifidobacteria are antagonistic toward *E. coli* and Clostridium.

*Fructo-oligosaccharides (FOS)*. FOS are naturally occurring plant sugars. When fed to animals, they travel intact to the large intestine where they provide a source of nutrients for beneficial bacteria such as Bifidobacteria. FOS have been shown to increase volatile fatty acid production in the large intestine and improve calcium and magnesium absorption. FOS cannot be digested by the animal or by pathogenic bacteria, and are an excellent complement to direct-fed microbials containing bifidobacteria.

*Glutamine/Glutamate* are amino acids that have been shown to improve villi height and overall intestinal morphology during periods of stress and following injury. Both glutamine and glutamate provide a local fuel source for enterocytes, the absorptive cells of intestinal villi.



## Summary

Maintaining a calf's electrolyte and water balance is key to optimizing digestive function and minimizing the impact of intestinal pathogens. The presence of pathogens in the digestive tract can lead to changes in the normal processes of nutrient digestion, absorption and water movement. Diarrhea, or scours, occurs when normal movement of water into and out of the digestive tract is disrupted, resulting in water loss and dehydration.

The kidneys and lungs work in concert with cellular mechanisms to control electrolytes and water in body fluids. Loss of fluids through diarrhea is accompanied by loss of body salts. The kidneys and lungs attempt to control the chemical composition of blood and maintain an electroneutral environment. As dehydration progresses, they begin to lose control. This fluid

and electrolyte loss produces a change in body chemistry that can lead to severe depression in the calf and eventual death.

Rehydration therapy with an effective electrolyte solution can help alleviate effects of dehydration and help restore a normal electrolyte balance. Timing and amount are critical. To be effective, an electrolyte solution must be properly formulated with the primary purpose of enhancing water absorption. The secondary purpose is to provide a source of major extracellular and intracellular ions to help replenish key electrolytes lost during dehydration. And finally, an electrolyte solution should provide ingredients that help rebuild and maintain a healthy intestinal environment.

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