Artykuł przeglądowy *Review*

Calves with diarrhea and a water-electrolyte balance*)

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Summary

Excessive water and electrolyte loss through the gastrointestinal (GI) tract during diarrhea is the most common cause of dehydration, which in acute cases can lead to death. Causes of diarrhea include environmental, nutritional and infective factors. During the course of diarrhea, electrolytes responsible for decreased water absorption accumulate in the GI tract. Together with an increasing degree of dehydration in calves the following are observed: hyponatremia, hyperkalemia and hypochloremia. Water and electrolyte imbalance implicates haematological and metabolic changes: decrease in glucose concentration, increase in urea and creatinine concentration in blood, loss of carbohydrates and accumulation of organic acid, which conduce to the appearance of metabolic acidosis. The kidneys are mainly responsible for maintaining a water and electrolyte balance. Water and electrolyte imbalance is relatively easily achieved in neonatal calves during diarrhea as a result of a limited renal function and lower than in adults efficiency of renal hormonal regulation.

Keywords: calves, diarrhea, water and electrolyte balance

Excessive water and electrolyte loss through gastrointestinal (GI) tract during diarrhea is the most common cause of dehydration, which in acute cases can lead to death. The process of dehydration is accompanied by reduction of: extracellular fluid and/or intracellular fluid and circulating blood volume, water and electrolyte imbalance (4, 36). Acute diarrhea is often accompanied by a high rate of mortality, which in Poland accounts for 50%, during the first 3 weeks of life (37).

Etiology of diarrhea

Causes of diarrhea include different factors: environmental (e.g. improper animal hygiene), nutritional (e.g. excessive amounts of milk or milk replacer) and infective (rotaviruses, coronaviruses, enterotoxigenic *E. coli*) (15, 21). These factors often interplay in the pathogenesis of diarrhea. Research conducted in the North-West area of Poland showed that cryptosporidia and rotaviruses were the main cause of diarrhea in calves (during the first two weeks of their life). Moreover, a great percentage of the cases of diarrhea in these calves resulted from human negligence: improper temperature of administrated colostrum, improper hygiene etc. During the course of diarrhea, caused by various types of factors, disturbed intestinal sodium and potassium absorption is observed. Moreover, electrolytes accumulated in the gastrointestinal tract hamper water absorption. As a consequence an organism losses both water and electrolytes. Undigested disaccharides (e.g. lactose) that are accumulated in the GI tract are another factor responsible for disturbed water absorption. It is reported that a high content of lactose (over 55%) in milk replacer significantly increases the possibility of diarrhea occurrence (10).

The excessive colonization of gastrointestinal tract by pathogens results in enterocyte damage and/or dysfunctions of brush border membrane. Secretion of water, sodium and chloride ions from the enterocytes is enhanced by bacterial enterotoxins. Electrolytes along with water, accumulated in the gut lumen, are excreted with feces (24). When *Salmonella* crosses the gut barrier, it enters into M cells in Peyer's patches. The interaction of these pathogens with the intestinal

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epithelial cells induce an inflammatory state which is the direct cause of diarrhea (3). Rotaviruses are responsible for impairment of the mature enterocytes of the villi (primarily in the middle and terminal segment) of the small intestine and enhance its exfoliation. As a result disturbed water and electrolyte absorption is observed, which, in turn, causes its accumulation in the gut lumen (22). Cryptosporidium primarily infects the small intestine, but it can also colonize the blind gut and the colon. These pathogens elicit moderate atrophy, villus conglomeration, and changes in superficial epithelial cells (11).

Factors that induce diarrhea in calves in the early neonatal period are low blood immunoglobulin G (IgG) concentration and low body mass of an animal (2). However, Gutzwiller (12) did not observe the intensification of diarrhea symptoms in calves with lower plasma IgG concentration. Moreover, the author did not show seasonal fluctuations in the concentration of immunoglobulin G both in cows colostrum and calves plasma. According to Gutzwiller (12) the above phenomenon cannot be explained by insufficiency of colostral IgG transfer through calves gastrointestinal tract.

Changes of blood parameters in calves during diarrhea

According to the calves' age, "the amount" and reciprocal proportions of water and electrolyte loss through the gastrointestinal tract, different changes in plasma electrolyte concentration are observed. In one-week old calves with experimentally induced diarrhea no changes in serum sodium concentration were reported, but an increase in serum potassium and decrease in serum chloride concentration were observed (36). Similar results were obtained by Seifi et al. (33). These authors did not observe any changes in serum sodium concentration in two-week old calves with diarrhea, but they did show a significantly higher concentration of serum potassium and lower concentration of serum chlorides when compared with healthy animals. In older calves (between 1^{st} and 5^{th} months of age), decreased blood plasma sodium and increased blood plasma potassium concentration were reported during the diarrhea (13, 20). However, decrease in blood plasma chloride concentration in these calves were observed only when the animals were highly dehydrated (13). Lorenz et al. (20) indicated that increased hyponatraemia in older calves suffered from diarrhea is to a lesser extent assigned to sodium losses with feces and urine. However, an increase in blood plasma potassium concentration in calves during diarrhea results from its movement from intracellular to the extracellular fluid in response to the acidosis (29).

Diarrhea is often accompanied by a metabolic acidosis which is a result of the loss of carbohydrates and also from organic acid accumulation (18). Guzelbektes et al. (13) showed both lower blood pH values and blood plasma carbohydrates concentration in calves with diarrhea when compared with healthy animals. Moreover, Schlerka et al. (32) reported that pH values of blood and urine decreased during acidosis. Increased concentration of D-lactic acid in calves blood plasma is also observed (19). In a healthy organism, lactic acid is easily excreted by the kidneys. During dehydration of an organism its excretion is impaired due to limited water losses through kidneys.

In calves that suffered from diarrhea changes in blood plasma concentration of various electrolytes are observed electrolytes are observed, that are vital for proper organism functions. Ranjan et al. (28) reported significantly lower blood plasma zinc concentration and significantly higher blood plasma copper concentration in calves with diarrhea, aged between 15 and 30 days, when compared with healthy calves. These authors suggested that low plasma zinc concentration was associated with: lower resorption, losses of this electrolyte through the digestive tract, increased zinc requirements for immune system and also utilization of its stores in tissues for synthesis of antioxidative enzymes. Ranjan et al. (28) also state that a high copper concentration in blood plasma can be caused by acute phase reaction and also by antioxidant synthesis, which contain copper in its composition, e.g. ceruloplasmin or erythrocyte antioxidant enzymes.

Walker et al. (36) reported higher blood plasma phosphate values in 3-7-day-old calves with diarrhea. Guzelbektes et al. (13) showed that blood serum phosphate concentration increased along with the increase of calves' degree of dehydration. Moreover, hyperphosphatemia observed in 3-7-day-old calves was accompanied by a lower blood plasma ionized calcium concentration (36).

Diarrhea also influences the plasma protein profile changes. During diarrhea higher values of total serum protein, serum albumin and lower serum globulin concentration were observed when compared with healthy animals (13, 33, 36).

Calves that suffered from diarrhea at an age of less than 14-days-of-life showed significantly a higher serum concentration of urea nitrogen and a significantly lower serum glucose concentration in comparison to the healthy animals (33). Guzelbektes et al. (13) reported increased blood plasma urea and glucose concentration along with the increase of dehydration degree in older calves (above 45^{th}-day-of-life) with diarrhea. In dehydrated calves high blood plasma concentration of hemoglobin, urea and creatine were observed (33, 36). Moreover, it was demonstrated that white blood cell concentration and haematocrit values rose along with the increase of dehydration degree of an organism (13). In calves with osmotic diarrhea an increase in alkaline phosphatase and gamma-glutamyl transferase activity are observed (17).

The regulation of water and electrolyte renal handling

Disturbed homeostatic mechanisms which result from limited regulation of water and electrolyte renal handling were frequently observed in newborn calves with diarrhea (8). Kidney functions in calves show differences in comparison to adult individuals, e.g. lower renal blood flow (RBF) and glomerular filtration rate (GFR) (7). Moreover, calves' kidneys in the early postnatal period demonstrate significantly lower efficiency of urine concentration. In calves during the first week of life mean urine osmotic pressure does not exceed the limit of 650 mmol/kg H_2O. This functional immaturity of calves' kidneys results in the relatively greater susceptibility of the newborn to dehydration during diarrhea in comparison to adult cattle. Dehydration induces a decrease in blood hydrostatic pressure and urine volume, whereas the osmotic pressure of the blood and urine increases (1). Walker et al. (36) reported that calves with diarrhea (3-7-days-old) showed a 26% plasma volume decrease which was accompanied by a significant drop of the following: stroke volume and cardiac output, mean central venous pressure and blood volume. Hypovolaemia and low GFR values observed in these calves were the main factors responsible for the increase of haematocrit values. Brooks et al. (4) observed a 4% decrease in extracellular fluid volume and a 9.5% decrease in GFR values in two week old calves suffering from diarrhea in comparison to healthy animals. In calves with diarrhea, aged between the 1st to the 30th days of life, Ulutas and Sahal (35) demonstrated lower renal sodium and potassium excretion in comparison to healthy individuals.

Hormones are responsible for regulation of renal functions. On the one hand there are antinatriuretic and antidiuretic factors, mainly renin-angiotensin-aldosterone system (RAAS) and vasopressin (AVP); on the other hand there are natriuretic and diuretic factors such as the natriuretic peptide family (NPF): atrial natriuretic peptide (ANP), brain natriuretic peptide (BNP), urodilatin and also prostaglandins.

A gradual maturation of the hormonal system is observed in calves in the early postnatal period (8, 25, 26). Results reported by Ożgo (25) indicate that RAAS is active in newborn calves. Moreover, the authoress pointed out that plasma renin activity (PRA) is high during the first month of calves' lives (especially immediately after birth) and its values are higher than in dams. However, plasma aldosterone concentration in neonatal calves is relatively low. Plasma aldosterone concentration shows dynamic changes during the first days of life. A significant decrease in plasma concentration of this hormone during the first 24 hours of calves' lives may be partially related to mineralocorticoids reserve expenditure obtained during the fetal life. Plasma aldosterone concentration showed an increase with age, probably in response to water volume decrease, whereas a decrease in plasma sodium concentration was observed. Moreover, the authoress demonstrated that changes in plasma aldosterone concentration were not correlated with PRA changes. A high vasopressin concentration during the first week of calves' lives is observed (26). However in newborn calves both vasopressin and aldosterone are ineffective in the prevention of water and electrolyte excretion, because this antidiuretic and antinatriuretic action of these hormones is surpassed by factors which are known to act antagonistically. One of the most significant hormones is ANP. The plasma concentration of this peptide is low immediately after birth and significantly increases till the 7th day of calves' lives (7). During the first three days of calves' lives the predominance of natriuretic and diuretic action of ANP is observed. In the following days of calves' lives the regulation of water and electrolyte balance results from an interaction of natriuretic (diuretic) and antinatriuretic (antidiuretic) hormones.

Dehydration and salt loss stimulate the hormonal system which regulates the water and electrolyte balance of an organism. Hayashi et al. (14) demonstrated that released vasopressin in dehydrated animals favors a decrease of circulating blood volume, but to a lesser extent an increase of plasma osmotic pressure. Consumption of water by previously dehydrated animals contributes to the inhibition of vasopressin secretion (34). During limited access to water, blood plasma volume and hydrostatic pressure decrease, whereas urine osmotic pressure increases. This leads to an increase in RAAS hormone concentrations which are involved in water and electrolyte retaining (31). In dehydrated animals plasma angiotensin II and vasopressin concentration increase; however, plasma ANP concentration decreases (1). The direction of an action of angiotensin II and vasopressin is convergent (5). Decrease at plasma ANP concentration in dehydrated animals effectively protects them from further water and electrolyte loss with urine. It was demonstrated that atrial natriuretic peptide not only inhibits vasopressin and angiotensin II secretion, but it also limits AQP2 incorporation (which mediates antidiuretic action of AVP) into the renal collective duct cells (16, 27). It was previously shown that diarrhea in calves caused a 10-15 fold increase in PRA, plasma aldosterone and arginine vasopressin concentration when compared to healthy calves (30).

Vasopressin and atrial natriuretic peptide regulate the water and electrolyte balance through regulation of renal functions. Moreover, both hormones are involved in intestinal water and electrolyte resorption. Vasopressin, through AQP2, stimulates water resorption in the colon, whereas atrial natriuretic peptide regulates salt and water resorption in the intestinal epithelium (6, 9, 23).

The gastrointestinal water loss leads to loss of electrolytes. Together with an increasing degree of dehydration in calves the following are observed: hyponatremia, hyperkalemia and hypochloremia. Water and electrolyte imbalance implicates metabolic changes: decrease in glucose concentration, increase in urea and creatinine concentration in blood, loss of carbohydrates and accumulation of organic acid, which conduce to appearance of metabolic acidosis. The kidneys are mainly responsible for maintaining a water and electrolyte balance. Water and electrolyte imbalance is relatively easily achieved in neonatal calves during diarrhea as a result of limited renal function and lower than in adults efficiency of renal hormonal regulation.

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