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Turkish Neonatal Society Guideline on fluid and electrolyte balance in the newborn

Türk Neonatoloji Derneği yenidoğanda sıvı ve elektrolit dengesi rehberi

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Abstract

Fluid and electrolyte balance and acid-base homeostasis are essential components of normal cellular and organ functions, both in the intrauterine and postnatal developmental period. Knowledge of physiologic changes and appropriate management are important aspects of neonatal intensive care. The aim is to ensure successful transition from the fetal to neonatal period and maintain a normal fluid-electrolyte and acid-base balance. In this paper, fluid and electrolyte requirements in the neonate, treatment of sodium and acid-base disorders on which some controversy exists, and also perioperative fluid-electrolyte management are reviewed.

Keywords: Acidosis, fluid, electrolyte, hypernatremia, hyponatremia, newborn, perioperative fluid management

Öz

Sıvı-elektrolit ve asit baz dengesinin sağlanması, hem intrauterin dönemde hem de doğum sonrası gelişim sürecinde normal hücre ve organ işlevlerinin sağlanması için gereklidir. Fizyolojik değişikliklerin bilinmesi ve uygun desteğin sağlanması yenidoğan yoğun bakımının önemli konularından birisidir. Amaç fetüsün başarılı bir şekilde yenidoğan dönemine geçişini sağlamak, büyüme devresinde ve hastalıkların seyrinde normal sıvı-elektrolit/asit-baz dengesini devam ettirebilmektir. Bu derlemede yenidoğan döneminde sıvı elektrolit gereksinimleri, tedavi yaklaşımları tartışma konusu olan metabolik asidoz, hipernatremi ve hiponatremi ile perioperatif sıvı-elektrolit yönetimi anlatılmaktadır.

Anahtar sözcükler: Asidoz, elektrolit,sıvı, hipernatremi, hiponatremi, perioperatif sıvı yönetimi, yenidoğan

Introduction

Total body water (TBW) is divided into two compartments, namely intracellular fluid (ICF) and extracellular fluid (ECF).ECF has two primary constituents: intravascular and interstitial. Intrauterine growth rate, pregnancy-related pathologies, delivery type, fluid and electrolyte therapy during labor, renal function of the newborn, and postnatal fluid intakemay affect the fluid distribution in the body (1, 2).

1. Determination of fluid and electrolyte requirements

Determination of fluid and electrolyte requirements is based on maintenance, deficiencies and ongoing losses. Gestational age, renal functions, temperature and humidity of the environment, mechanical ventilation requirement, presence of drainage tubes, and gastrointestinal (GI) losses are critical factors in determining the requirements of the baby (1, 3).

1.1. Fluid requirements

The maintenance fluid requirement is equal to the sum of urine output and insensible water loss (IWL). In the first few days of life, especially in premature infants, fecal fluid loss is very limited. The aim of intravenous infusion therapy is to prevent dehydration while allowing physiologic weight loss. The amount of maintenance fluids can be increased

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Table 1. Insensible fluid losses and maintenance fluid requirements in the first month of life

Body weight (g)	Insensible fluid loss[a] (mL/kg/day)	Total fluid requirement[b] (mL/kg/day)		
		1-2 days	3-7 days	8-30 days
<750	100+	80-140	120-200	120-180
750-1000	50-70	80-120	100-150	120-180
1001-1500	30-65	60-100	80-150	120-180
>1500	15-30	60-80	100-150	120-180

[a]Since transepidermal fluid losses decrease in case of high enviromental humidity, total fluid requirement decreases

[b]Start from the lower limit of there commended fluid volume with a careful approach

or decreased according to the individual requirements of each baby. IWL and maintenance fluid requirements in the first week of life is shown in Table 1 (4). The humidity of the environment significantly affects water loss which is more pronounced in immature babies. Therefore, environmental humidity should be taken into account in the calculation of initial intravenous fluid therapy.

Physical examination findings, body weight, urine output and laboratory studies are used in the evaluation and follow-up of neonatal fluid balance (4).

Physical examination findings: Although loss of the skin turgor or edema, dry or wet oral mucosa, sunkeneyeballs and fontanel may be useful in assessing hydration status, these findings are not reliable for low-birth-weight infants.Tachycardia, hypotension, capillary refill time >3 sec. and metabolic acidosis are indicators of intravascular volume depletion (1).

Body weight: Extremely preterm babies and other sick neonates in neonatal intensive care units should be weighed at least once or twice daily. The expected and required weight loss in the first week of life is 5-10% of birth weight in term infants and 10-15% of birth weight in preterm infants, depending on the degree of maturation. Daily weight loss is an important guide in the planning of maintenance fluid therapy and should be 1-2% of body weight in term infants and 2-3% of body weight in preterm infants (1,5).

Urine output and density: Urine output should be 0.5-1 mL/kg/hr in the first day of life, thereafter it should increase up to 2-3 mL/kg/hr (5). Weighing diapers is a common method to determine urinary output. However, it should be kept in mind that this method may lead to erroneous results due to the evaporation of urine and increased density. Urinary output should be continuously monitored and the measured amount should be recorded at 4 to 8 hour intervals. Urine osmolality of 200-400 mOsmol/kg indicates sufficient fluid intake but because of its practicality urine density measurement is more commonly used. However the correlation between urine density measured by urine sticks and osmolality was found to be very poor.It should be kept in mind that the glucose or protein found in the urine of sick preterm babies may falsely lead to high urine density (6, 7).

Laboratory: Serum sodium levels should be between 135-145 mEq/L, potassium level 3.5-5 mEq/L, serum osmolality 275-290 mOsm/kg; (Osm=2x serum sodium level (mEq/L)+ serum glucose (mg/dL)/18+blood urea nitrogen (mg/dL)/2.8). Depending on the gestational age, disease severity and fluid-electrolyte balance, serum electrolytes are assessed at 8-24 hour intervalsusing micro-methods in the first 3-4 days of life until the baby is stabilized (3,5). Blood urea nitrogen, increased creatinine levels, and metabolic acidosis are other laboratory tests indicating decreased ECFvolume (1,8).

1.2. Electrolyte requirements

Sodium: Sodium should not be added to intravenous fluids before postnatal natriuresis / diuresis starts, which is a reflection of physiologic weight loss. It is reported that sodium may be added after the first few days of life or after losing more than 5% of birth weight (9). The maintenance sodium requirement is usually met by the addition of 1-2mEq/kg/day sodium chloride (NaCl) to the fluids. After the first week of life, if the newborn's fluid balance is stable, adding 3-4 mEq/kg/day sodium and chloride will be sufficient for positive sodium balance for growth. Due to renal immaturity, the sodium requirement may increase up to 6-8mEq/kg/day in very small premature infants (1, 8).

Potassium: Potassium supplementation is started only af-

ter adequate urinary output,serum electrolytes and kidney functions have been proven to be normal, with 1-2 mEq/kg/day and increased to 2-3 mEq/kg/day within a few days (1, 10).

1.3. Fluid-electrolyte requirements in special circumstances

In accordance with the basic principles of fluid-electrolyte balance and depending on the nature of the disease, the newborns' fluid and electrolyte treatment of the baby should be individualized.The basic principles of fluid management in the newborn period – common for all frequently seen problems in the newborn such as respiratory distress syndrome, transient tachypnea of the newborn, bronchopulmonary dysplasia, patent ductus arteriosus and perinatal asphyxia – are giving limited amounts of electrolyte free fluids until postnatal diuresis/ natriuresis begins, then individualized treatment according to the urinary output, weight loss, and serum electrolyte levels (5). Detailed information about fluid management in these diseases can be found in the relevant guidelines of the Turkish Neonatal Society.

2. Acid-base balance

The acid-base balance is the balance of hydrogen ion (H+) concentration in body fluids. pH is the negative logarithm of H+ concentration in a solution. Changes in H+ concentration in body fluids affect enzyme activities, electrolyte levels, organ functions, and normal development (11). Similar to adults, the ECF pH level is maintained in a narrow range in newborns. Serum pH below 7.35 is defined as acidosis and above 7.45 as alkalosis.Systems that keep the pH within the normal ranges are the body's buffer systems of the body, respiratory system, and kidneys (4). In the first 24-48 hours of life, factors such as perinatal events, environmental temperature, nutrition and gestational week of the baby affect the acid-base balance. A physiologic mild metabolic acidosis may be seen shortly after birth (4,9).

Metabolic acidosis: This is a common problem in critically ill newborns. It can develop secondary to many etiologic factors, though there are usually three fundamental mechanisms:

a. Loss of HCO3- from the body [e.g., diarrhea and proximal renal tubular acidosis (RTA)];

b. Inability to excrete H+ ions from the kidneys (e.g., high protein diet, distal RTA, renal failure);

c. Increase in endogenous (organic / inorganic) or exogenous acids (e.g., inborn errors of metabolism, lactic acidosis, salicylate poisoning).

Calculation of the anion gap helps in the differentiation of metabolic acid caused by exogenous acids (e.g., salicylate) or increased endogenous acids (e.g., lactic acid). It is calculated by subtracting the sum of Cl- and HCO3- ions from serum Na+level (1,4). Normal levels are between 8-16 mEq/L. However it is considered normal up to 18mEq/L in preterm infants weighing <1000g. The most common cause of increased anion deficit in newborns is lactic acidosis secondary to tissue hypoxia (12). The acute effects of acidemia are protein degradation, decreased adenosine triphosphate synthesis, insulin resistance, and hyperkalemia. For compensation, respiration rate increases and tachypnea may be observed in patients. If the serum pH is<7.20, cardiac contraction might be affected, pulmonary vasoconstriction and pulmonary hypertension may develop, followed by lethargy, and coma (12).

The main principle of the correction of metabolic acid is the treatment of the underlying cause. Although it is not proven, sodium bicarbonate should only be used to replace ongoing renal or gastrointestinal losses. In infants with adequate ventilation and hydration together with normal anion gap, intravenous sodium bicarbonate treatment can be given if the serum pH is <7.10 and the plasma bicarbonate level is <10 mEq/L or the base deficit is> -10 mEq/L. The calculation of the bicarbonate amount to be administered can be made according to the following formulas:

HCO_3^- (mEq) = BE (mEq/L) x Body weight (kg) x 0.3

HCO_3^- (mEq) = [Target HCO_3^- - Measured HCO_3^- (mEq/L)] x Body weight (kg) x 0.3

Half of the deficit, calculated according to the severity of acidosis, is given by slow infusion within 1-4 hours and rest of the treatment is completed in the following 8-24 hours directed by repeated blood gas measurements. The aimis to raise the pH level above 7.20. Alternatively, 1-2 mEq/ kg $NaHCO_3$ can also be given by slow intravenous infusion (at least 30 min) in severe acidosis (the amount corresponds to a3-6 mEq/ L increase in bicarbonate level). The 8.4% bicarbonate solution should be diluted in half (4.2% and 0.5 mEq/ mL) before administration (1).

3. Electrolyte imbalances

The most common electrolyte imbalances are sodium, potassium, calcium, and phosphorus imbalances. In this review, only sodium imbalance will be discussed.

Table 2. Etiology of hypernatremia in the newborns

Hypernatremia		
Fluid losses	**Inadequate fluid intake**	**Excessive sodium intake**
Insensible losses (Checktable 1)	• Fluid restriction • Inadequate fluid intake • Lactation problems • Neurological problems • Hypothalamic problems	• Sodium bicarbonate • Hypertonic saline solution • Sodium chloride • Sodium contentin intravenous fluids given for drug perfusion • Blood products • Improperly prepared food • "Salting" • Child abuse
Renal • Diabetes insipidus • Diuretics, mannitol • Tubulopathy • Acute renal failure– recovery phase • Hyperglycemia		
Gastrointestinal • Gastroenteritis • Vomiting • Colostomy/ Ileostomy • Osmotic diarrhea • Malabsorption		

3.1. Hypernatremia

Definition: Although hypernatremia is defined as serum sodium levels 150 mEq/ L and above, if serum sodium levels exceed 145 mEq/ L, fluid-electrolyte treatment should be directed to the etiology (8).

Etiology and Pathophysiology

Hypernatremia in the newborn usually develops as a result of disturbances in water homeostasis rather than sodium homeostasis. Total body sodium may be normal, increased or decreased. The protective mechanisms against hypernatremia are concentrating the urine and a strong sense of thirst. Limited urine concentration capacity and inability to express thirst in the newborn are factors which increase the risk of hypernatremia. The three main causes of hypernatremia are increased water loss, inadequate water intake and excessive sodium intake. Table 2 shows the etiologic factors of hypernatremia according to the physiopathologic mechanisms (12, 13).

Clnical findings

As a result of hypertonicity associated with hypernatremia, water passes from the intracellular space to the extracellular space, partially preserving the intravascular volume. Thus,bfindings associated with intravascular volume depletion, such as decreased blood pressure and urine output and also with typical signs of dehydration (restlessness, rapid excitability, malaise, lethargy, high-pitched cry, hyperpnea, fever) are not pronounced until late stages. Hyperglycemia and mild hypocalcemia might be seen. Stroke and other thrombotic complications (dural sinus, peripheral and renovascular thrombosis) may occur due to dehydration and hypercoagulability (12).

Diagnosis

The cause of hypernatremia is usually evident in the patient history. If there are signs of dehydration, the etiology is water loss. If there is no dehydration, sodium intake should be checked. There is no evidence of dehydration in infants with excessive amount of sodium intake. If

Table 3. The cause of hypernatremia according to body weight changes and urine analysis

Hypernatremia etiology	Body weight	Urine analysis		
		Quantity	Osmolality	FeNa
Fluid loss ↑/ Fluid intake↓	Decreases	Decreases	Increases	Decreases
Sodium intake↑	N/Increases	Increases	Decreases	Increases

there is severe sodium overload, there are also signs of hypervolemia (such as weight gain and volume overload. Fractional sodium excretion increases in salt intoxication, whereas it decreases in hypernatremicdehydration (Table 3). If there is both sodium and water deficit, urine examination can differentiate a renal or extrarenal etiology. If the loss is extrarenal, urine output is decreased and urine is more concentrated. Sodium excretion in urine is low (urinary sodium <20 mEq / L, fractional Naexcretion <1%). In renal losses, urine sodium is higher and urine cannot be concentrated (12).

Treatment

The aim is to normalize the serum sodium levels by giving sufficient amounts of free water. The treatment plan should be directed by the presence or absence of shock the underlying etiology should be investigated. In addition to total water deficit, free water/isotonic fluid loss, sodium correction rate, sodium concentration of replacement fluid and ongoing losses should be taken into consideration in the calculation of parenteral fluid (8).

1. Newborn infants with signs of hypovolemic shock

Tachycardia and hypotension are not usually seen in hypernatremic dehydration as intravascular volume is preserved. However, if the baby has symptoms of shock such as lethargy, circulatory collapse, increased capillary refill-time (> 3 sec), oliguria, hypotension, or anuria, 10-20 mL/ kg 0.9% NaCl should be given within 10-20 minutes. If symptoms persist, this dose may be repeated. Subsequent treatment is continued as described in section 3 (12).

2. Newborn infants with mild hypernatremia, feeding enterally and without signs of hypovolemic shock (serum sodium level 146-149 mEq / L)

Mild hypernatremic dehydration due to inadequate breastfeeding/feeding and without hypovolemia, serum sodium levels can be corrected within 24 hours by providing breastmilk by the enteral route (oral/nasogastric tube). Oral rehydration fluids are is usually adequate for babies with gastroenteritis and mild-to-moderate hypernatremia. The total amount is calculated by adding deficits in the maintenance fluid. While calculating the fluid deficits in the first 10 days after birth, physiologic weight loss (average 5% body weight) should be subtracted from the deficit volume; if the baby is> 10 days old, this correction is not needed. Example: in a baby with a weight loss of 15% on the postnatal seventh day, deficit volume should be considered as 10% of body weight (100 mL/ kg), but if the infant is 15 days old, it should be 15% of body weight (150 mL / kg).

3. Newborn infants with moderate –severe dehydration with serum sodium level ≥150 mEq / L

a. Parenteral fluid requirement

If the baby is in shock, 10-20 mL/kg 0.9% NaCl is given initially in 10-20 min. If the baby is not in shock, this treatment is not mandatory, but recommended if the baby is anuric. The total fluid loss is then calculated using the sum of free water loss and isotonic fluid loss. To calculate this, the current weight is substractedfrom the baby's birthweight. However, 5% physiologic weight loss in newborns admitted within the first 10 days should not be included in the total weight loss calculation. The next step is the calculation of free water loss, which is the loss of fluid without electrolytes. There are two formulas used for this:

First formula: The amount of free water required to reduce the serum sodium level by 1 mEq/ L is about 4 mL/ kg. In cases of serious hypernatremia (≥170 mEq/ L) this amount should be lower (3 mL/ kg). The amount of free water that should be given is calculated according to the sodium level becauseserum sodium levels can be reduced to a maximum of 12 mEq/ L in a 24-hour period (1):

Na<170 mEq / L: Current bodyweight (kg) x4 mLx12 or 48 mL/ kg/ day
Na≥170 mEq / L: Current bodyweight (kg) x3 mLx12 or 36 mL/ kg/ day

Second formula: Free water loss (liter) = 0.6*x kg x [1- (target Na** / measured Na)]
*The value 0.6 in the formula refers to the percentage of water in the body; although this ratio is 70-75% in the

Table 4. Free water contents of intravenous fluids

Intravenous fluid	Sodium (mEq/L)	Free water (%)
%5 dextrose	0	100
%0.2 saline	34	75
%0.45 saline	77	50
%0.9 saline	154	0

newborn, it is appropriate to use 60% to minimize the risk of rapid decrease of serum sodium levels.

**If the measured serum Na level is <170 mEq/ L, the target serum Na level should be 145 mEq/ L, and if the measured Na is ≥170 mEq/ L, the target serum Na level should be 150 mEq/ L.

b. Correction rate of serum sodium levels

Thismay vary from 24 to 96 hours depending on the serum sodium level of the patient. In an acute event, rapid correction can be performed, but in long-term hypernatremia, serum Na levels should not be reduced more than 0.5 mEq/ L per hour and 12 mEq/ L per day (10 mEq/ L/ day decreaserate is safer). Rapid changes ofserumsodium levels in hypernatremic infants may cause both central pontine and extrapontin miyelinosis.

c. The sodium concentration of the intravenous fluids

The sodium and free water contents of frequently used intravenous fluids are shown in Table 4 (1). According to these contents, 100 mL 0.2% saline solution contains 75 mL and 100 mL 0.45% saline contains 50 mL free water. It is appropriate to use one of these two solutions in therehydration phase of most infants with mild-to-moderate hypernatremic dehydration. However, if the serum sodium level is 165-175 mEq/ L, i 0.9% saline should be given initially to prevent a sudden decrease in serum sodium level. If sodium is >175 mEq/ L, even 0.9% saline will remain hypotonic compared with serum sodium. In this case 3% saline (513 mEq /L) should be added to make the Na concentration of the fluid 10-15 mEq/ L lower than the serum Na, and target Na levels should not be lower than 150 mEq/ L (Table 5). No matter which method is used, the serum sodium level should be monitored very closely and either the flowrate of the fluid or Na concentration should be changed. Serum sodium should be monitored frequently if serum Na level is >170 mEq / L, once every hour in the first 4 hours, at 2-4 hour intervalsin the first day, and if serum Na level is<170 mEq / L, 4 hours after starting fluid treatment, and at 4-6 hour intervals within the first day (sodium level should be monitorized by capillary method if possible). If the sodium decrease rate is>0.5mEq/ L / h, the infusion rate should be reduced or the sodium content of the liquid should be increased. When enteral feeding is started, the amount of oral intake should be subtracted from the intravenous fluid volume. Hyperglycemia, which may develop in hypernatremic dehydration but insulin should not be used in this case. Ongoing losses should be replaced by adding appropriate amounts of Na/K according to the content of the fluid. The underlying cause (e.g. infection, diabetesinsipidus, insensible loss) should be investigated and treated accordingly (1, 4-6, 8, 12).

Table 5. Recommendations for intravenous fluid treatment according to serum sodium levels

Serum Na^+ level (mEq/L)	Intravenous fluid (sodium content)	Notes	Time for Na^+ decrease (day)
150-160	%0.2 saline (34 mEq/L)	Incase of enteral feeding, the amount of enteral feeds is subtracted from the total amount of fluid.	1-2
160-175	%0.45 saline (77 mEq/L)	When the serum Na level is> 165 mEq/L, start with 0.9% saline solution, the Na content of the fluid is regulated according to the rate of drop in serum Na level	2-3
>175	Sodium content of the fluid should be 10-15 mEq/L lower than the patient actual sodium level	eg, In case of a baby with serum Na level of 180 mEq/L, starting fluid is added 3% NaCl to increase Na content of the fluid 170 mEq/L	3-4

If serum Na level is > 200 mEq/L,peritoneal dialysis may be considered

(Caution! This procedure may drop serum Na too fast therefore close monitoring is essential, consider increasing the content of peritoneal fluid Na content)

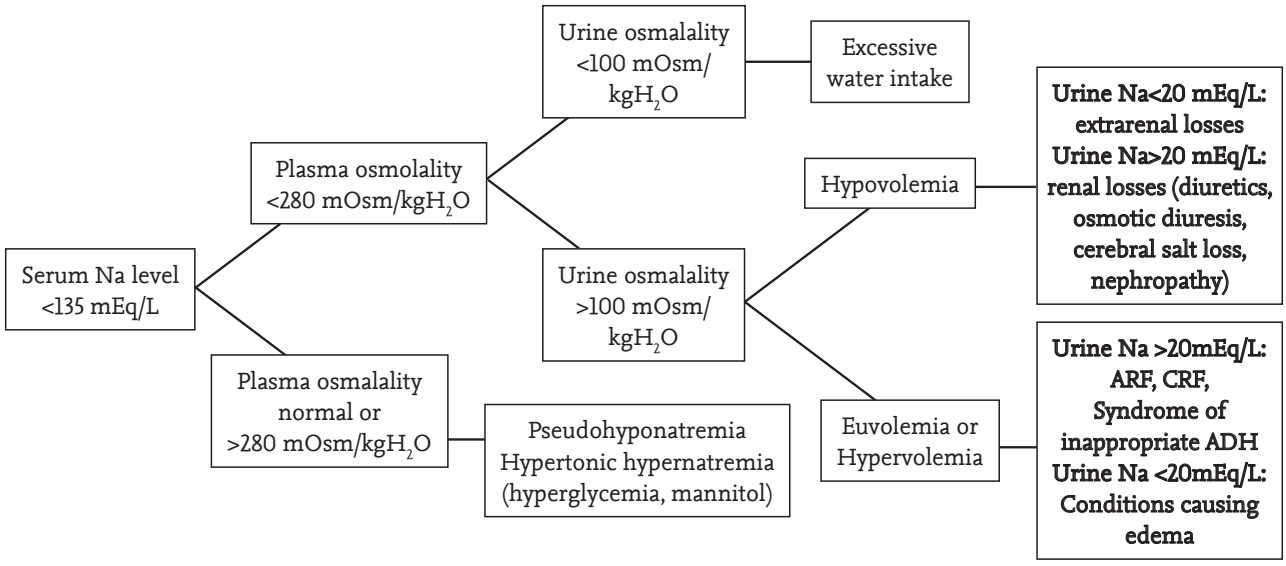


Figure 1. Algorithm for differential diagnosis of neonatal hyponatremia (13)

3.2. Hyponatremia

Definition

Hyponatremia is a condition in which serum sodium level is <135 mEq/ L. Although hyponatremia is usually defined as a serum sodium level of <130 mEq/ L, it will be more accurate to accept the 135 mEq/ L limit becausestudies in neonates show that hyponatremia is an independent predictor of adverse neuromotor development (8, 12).

Etiology and pathophysiology

The two most important factors determining the serum sodium level are the amount of total body water and the total amount of salt. If the water/salt ratio increases, hyponatremia develops. Hyponatremia in the neonatal period can be classified as early (within the first week of life) and late (within the first monthof life, after the first week). The hyponatremia that develops in the early period is usually due to water excess, whereas the cause of late hyponatremia is usually negative sodium balance.

Clinical findings

As osmolality is reduced in hyponatremia, water passes from the ECF compartment to the ICF compartment and the cells begin to swell. The clinical manifestations of hyponatremia are primarily neurological and depend on hypoosmolality-induced brain edema. Common findings are feeding difficulties, vomiting, lethargy, irritability, convulsions, and coma followed by brain stem herniation and respiratory arrest. Clinical findings depend on both the development rate and the duration of hyponatremia. A baby with chronic hyponatremia whose serum sodium level is 110 mEq/ L may be asymptomatic, whereas in another patient, convulsions may develop when serum sodium falls abruptly from 140 mEq/ L to 125 mEq/ L (12).

Diagnosis

Clinical information about fluid balance, weight changes, drugs (especially diuretics) and underlying diseases together with plasma and urinary osmolality lead to a differential diagnosis (Figure 1).

Treatment

The presence of convulsions, the administered amount of free water and sodium, the hypovolemic or hypervolemic nature of the dehydration, the amount of urine and the use of natriureticdrugs should be considered in the treatment plan.

1) Patients with a serum Na level <120 mEq/ L without hyponatremic convulsions: Irrespective of volume status, 3% NaCl is given in 4-6 hours to increase serum Na level to 120 mEq/ L (Na content 513 mEq/ L or approximately 0.5 mEq/ mL). 1 mEq / L increase in serum sodium level is expected with 1 mL/ kg 3% NaCl administration; the increase rate should not exceed 1mEq/ L per hour. After the serum sodium level reaches 120 mEq/ L, total correction should be continued more slowly (up to 12 mEq / L per day or 0.5 mEq / L per hour).

2) Patients with CNS signs or seizures related to acute hyponatremia: The seizures are usually resistant to anticonvulsants and is caused by brain edema. In order to recover the brain edema quickly, 3% NaCl 2 mL/ kg is given

in 10-15 minutes, and if the symptoms persist, it may be repeated for asecond or third time. After the symptoms have disappeared, correction should be continued more slowly (up to 12 mEq/ L per day).

3) Hypervolemic hyponatremia: Water excess in cases of inappropriate ADH secretionsyndrome, renal insufficiency, and conditions with edema,there is both water and sodium excess, but water excess is higher than sodium excess which requires water and sodium restriction. To achieve this, the fluid supply is reduced by at least 20 mL/ kg/day; the amount of fluid is adjusted according to the serum sodium increase rate. In order to prevent central pontine demyelination, serum sodium levels should be increased slowly and should not exceed 12 mEq/ L per day. The risk of brain edema is higher than the risk of central pontine demyelination in cases of rapidly progressing acute hyponatremiabecause adaptation responses are not yet developed (1, 4-6, 8, 12).

4) Hypovolemic hyponatremia/ real sodium deficit: In hypovolemichyponatremia, both water and Na are deficient. These infants are usually dehydrated and if there is concomitant circulatory collapse, intravascular space should be expanded initially by infusing 20 mL/ kg saline in 20 minutes. Thereafter, deficit and maintenance fluid treatment should be given.

Calculation of sodium deficit

If hyponatremia is asymptomatic and serum sodium level is> 120 mEq/ L, hypertonic NaCl infusion is not required. Sodium deficit is calculated by using the formula: [Target Na level (135 mEq / L) –current Na level] x 0.6 x body weight (kg). The calculated amount is given in addition to the 24 hours maintenance electrolytes and fluids. The serum Na level increase should not exceed 12 mEq/ L in 24 hours.Even if the measured sodium value requires more than 12 mEq/ L correction, the correction should be limited up to 12 mEq/ L.

Calculation of sodium deficiency

If hyponatremia is asymptomatic and serum sodium level is> 120 mEq/ L, hypertonic Na Clinfusion is not required. Sodium deficit is calculated using the formula and it is given in addition to 24-hour maintenance electrolyte and fluid requirements. Sodium level increase should be limited to 12 mEq/ L in 24 hours. If the measured serum sodium level requires more than 12 mEq/ L correction, the 24-hour deficit treatment should be limited to 12 mEq/ L.

4. Fluid and electrolyte management in neonatal surgery

Surgical interventions in neonates, especially in preterm infants, have significant impacts such as catabolic response development, the passage of fluid into the interstitial areas space a result of increased capillary permeability, sodium and free water retention. Perioperative fluid management, which may seriously affect the prognosis of the baby, should be designed to protect intravascular volume, and renal and cardiovascular functions (1).

4.1. Preoperative fluid management

The aim is to ensure normal fluid electrolyte balance and cardiovascular stability. If there is a loss of fluid into the third space, as in the case of dehydration or bowel obstruction, the intravascular volume will also decrease and these deficits should be replaced by normotonic and normoosmolar solutions. A crystalloid (0.9% NaCl) or a colloid solution (albumin) can be used for this purpose (14, 15). It is recommended that the preoperative fasting time for elective surgery should be 4 hours for breast-fed infants and 6 hours for formula-fed infants. However, it has been reported that 4-hour fasting time is also sufficient for formula fed babies (16).

4.2. Intraoperative fluid management

The aim is to replace preoperative fasting deficits and the losses from the surgical site, and to prevent development of hyponatremia, hypo-and hyperglycemia while supplying maintenance requirements. The target should be normovolemia at the end of surgical intervention.

4.3. Intraoperative fluid volume

This is the sum of maintenance and replacement fluids. Accordingly, two different amounts and rates of fluid will need to be adjusted during surgery. While the maintenance fluid is administered at a constant rate, the rate of the replacement fluids, which may vary depending on the amount of losses, must be adjusted separately. Fasting fluid deficit is very low in healthy infants who undergo elective surgery due to the short fasting times before surgery. Because parenteral nutrition/ intravenous fluids are given to sick infants before surgery, their hydration conditions are accepted as normal. Third space losses might be 1 mL/ kg/ hr in minor surgical procedures, 15-20 mL/ kg/ hr in major surgical procedures, and as high as 50 mL/ kg/ hr in necrotizing enterocolitis surgery in preterm infants. These losses must be replaced with a crystalloid solution, blood losses with either 1: 1 ratio

blood or colloid solution (5% albumin). Heart rate, blood pressure, and capillary refill time should be closely monitored (14).

4.4. Content of intraoperative fluids

It is now well known that hyponatremia due toperioperative hypotonic fluid administration may cause permanent neurologicsequela or death. Two important factors in the development of perioperative hyponatremia are reduced free water excretion due to the release of stress-induced antidiuretic hormoneand administration of hypotonic fluids. As a result, brain edema, brain stem herniation, and death may occur.

The glucose content of intraoperative fluids has also been re-evaluated in recent years. It is understood that not only long-term hypoglycemia but temporary hypoglycemia may cause neurologic damage during surgery. However the risks of perioperative hyperglycemia are also well known. Stress-induced insulin resistance is a contributing factor to the development of hyperglycemia during surgery. Hyperglycemia may cause dehydration, electrolyte disorders, and lactate increase by osmotic diuresis. However, it is suggested that mildly elevated blood glucose levels may protect the neonatal brain against ischemic damage and they are protected from lactic acidosis because of their high lactate clearance rate. A glucose perfusion rate of 2-4 mg/ kg/ min is sufficient to keep blood glucose in acceptable limits and to prevent hypohyperglycemia and lipolysis during surgery. A glucose infusion rate at 2.5 mg/ kg/ min during cardiac surgery prevents hypoglycemia without increasing the incidence of hyperglycaemia. Blood glucose should be closely monitored during surgical interventions regardless of which fluid is used (14, 16).

It is recommended that the sodium content of intraoperative fluids in neonates should be within physiologic limits (120-140 mEq/ L) in order to preventhyponatremia and should contain 1-2.5% glucose for the prevention of hypo-hyperglycemia. This fluid can be used both for maintenance and to replace third-space losses. However, thesefluids exist in only a few countries of Europe. In the European Consensus Report, attention was brought to the necessity for widespread production of these solutions (17, 18).

4.5. Indications for volume replacement and fluid choices

Crystalloid solutions: In order to replace the intravascular losses which are frequently observed during surgical interventions, crystalline solutions are given initially. Studies in hypotensive preterm babies have shown that saline administration is as effective as albumin infusioncauses less fluid retention than 5% albumin in the first 48 hours. However, in the presence of a previously known capillary leak syndrome, replacement with colloids is less effective on edema.

Albumin: This is the most frequently used colloid in the neonatal period. In hypotensive preterm infants, 5% albumin was reported to be as effective as fresh frozen plasma but less effective than 20% albumin. This indicates that the volume rather than the concentration of albumin is more important in establishing cardiovascular stability.

HES "(hydroxyethylstarch)"preparations: Although the use of new-generation preparation in children seemsto be safe, it is not recommendedfor routine use in newborn infants because there are not enough safety studies.
Fresh frozen plasma: This should only be used if there is a clotting disorder.

The delivery rate of the selected fluid: The rate depends on the cardiovascular stability. Initially, 15-20 mL/ kg of saline is given within 15-20 min. If cardiovascular stability is not achieved, it is repeated once more. After administration of a total of 30-50 mL/ kg of a crystalloid solution, a colloid solution should be given (eg, albumin) to protect the intravascular osmotic pressure (14, 16).

4.6. Postoperative fluid management

In order to achieve cardiovascular stability, sufficient amounts of fluid and vasopressor drugs should be given, also ongoing fluid and electrolyte losses must be replaced. However, free water retention may continue due to increased ADH release in the postoperative period. In this case, 50-80% reduction of maintenance fluids should be considered (19). The most frequent postoperative losses are due to nasogastric drainage. These and other losses should be measured on an hourly basis, replaced by every 4 hours (may vary from 2 to 6 hours), the sodium content should be adjusted according to the estimated sodium content of the fluid losses.

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