Pediatric Sodium Disorders

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Definitions, Physiology, Assessment, and Diagnosis

Definitions

- Normal Serum Sodium Levels – The serum sodium concentration is typically maintained between 135 to 145 mmol/L.[1]
- Dysnatremia – a sodium concentration outside the range of 135 to 145 mmol/L; however, clinically relevant hyponatremia or hypernatremia typically occurs outside the extended normal range of 130 to 150 mmol/L.[1]
- Hyponatremia – a serum sodium level <135 mmol/L.[2] The presence of hyponatremia implies that there is an excess of free water and an electrolyte deficit in the extracellular compartment.[1,3]
- Hypernatremia – a serum sodium level >145 mmol/L.[2]
- Osmolarity – the number of osmoles of solute per liter of solution
- Tonicity (Osmolality) – the total concentration of solutes (impermeable to the cell membrane) that exert an osmotic force across a membrane; for instance, 5% dextrose has the same osmolarity as plasma (286 mosm/L H_2O), but is rapidly metabolized in blood to water; thus, its tonicity is equal to that of free water, as it contains no salt or other active osmole (zero tonicity).[4]
- Isotonic intravenous solution – an intravenous solution that contains osmotically effective solutes that do not cause any net movement of fluid through the cell membrane while infused in the plasma, e.g., 0.9% sodium chloride.[5]
- Hypotonic intravenous solution – an intravenous solution whose osmotically effective solutes result in the net movement of fluid into the cell, e.g., dextrose 5% with 0.45% sodium chloride (D5 1/2 NS).[5]
- Hypertonic intravenous solution – an intravenous solution whose osmotically effective solutes result in the net movement of fluid out of the cell, e.g., 3% sodium chloride.

Physiology of Sodium Homeostasis

- The solute composition of the body is separated into the intracellular and extracellular compartments; the sodium pump (Na^+-K^+-ATPase) maintains sodium primarily in the extracellular space and potassium mainly in the intracellular space.[1]
- Serum sodium levels are controlled by two physiological processes:
  - Maintenance of circulating blood volume
  - Blood osmolality homeostasis.
- Circulating blood volume – changes in blood volume are sensed by receptors in the cardiovascular system, carotid sinuses and aortic arch, and in the kidney.; in turn, these receptors relay information to the sympathetic system to alter vascular resistance, cardiac output, and renal water and salt excretion.[1]
- Blood osmolality – blood osmolality is equal to the sum of the osmolalities of the individual solutes in the blood.
  - Most of the osmoles in the blood are accounted for by sodium.
  - Total blood osmolality can be estimated from the concentrations of serum sodium, glucose, and urea as:

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$$2 \text{ x Sodium} + \frac{\text{Glucose}}{18} + \frac{\text{Urea}}{2.8}$$

- Pseudohyponatremia – In hyperosmotic hyponatremia, an extracellular shift of water occurs secondary to high intravascular solute concentrations.
  - The most common etiology is hyperglycemia, such as during diabetic ketoacidosis.
  - The formula used to determine the “correct” serum sodium level is: Corrected serum sodium = [0.016 x (serum glucose-100)] + serum sodium

Assessment and Diagnosis of Serum Sodium Disorders

- Hyponatremia
  - Mechanism
    - Hyponatremia is generally a result of the administration of hypotonic solutions in the inpatient setting.
    - The body’s main defense against developing hyponatremia is the kidney’s ability to generate a dilute urine and excrete free-water; rarely is either the ingestion of free water alone or the excess renal excretion of sodium the reason for hyponatremia.
    - Renal water balance is primarily under the control of arginine vasopressin [Antidiuretic Hormone (ADH)] that is produced in the hypothalamus and released from the posterior pituitary; ADH increases water absorption by increasing the permeability to water in the collecting tubule.
    - In order to acquire hyponatremia, one needs excess free water along with an impairment that interferes with the kidney’s ability to excrete free water.[2]
  - Assessment – Typical symptoms of hyponatremia can be associated with other common pediatric ailments such as nausea and vomiting,[3] headache, weakness,[6] lethargy, seizures,[3,7] altered mental status, and coma.[2]
  - Diagnosis – A serum sodium level <135 mmol/Liter[2]
- Hypernatremia
  - Mechanism
    - Hypernatremia is generally a condition caused by the insufficient administration of

free water in the inpatient setting in children who are unable to care for themselves.[8]
    - The body's main defenses against developing hypernatremia are the thirst mechanism and the ability to concentrate the urine.
  - Assessment
    - Typical signs and symptoms of hypernatremia include agitation, irritability altered mental status, intracranial hemorrhage, ischemia and venous thrombosis;[8] hypernatremia can lead to hyperglycemia and rhabdomyolysis.
    - Hypernatremia is associated with a mortality rate of 15% in children.[8]
      - Infants with hypernatremic dehydration and end-stage liver disease (along with hypernatremia) are at particular risk.
      - Most neurological morbidities and death related to hypernatremia has resulted from vascular thrombi and intracranial hemorrhage.[9]
  - Diagnosis – A serum sodium level >145 mmol/L[2]

Management

Hyponatremia

- Electrolyte and fluid therapy
  - Effective intravascular volume needs to be rapidly replenished, if depleted, with either isotonic saline and/or a colloid solution in 20 ml/kg increments up to 60 ml/kg within the first hour of fluid resuscitation.
  - Most children with mild to moderate hyponatremic dehydration will respond to isotonic saline (0.9%, 154 mEq/L); it is prudent to avoid hypotonic solutions in treating these children.
  - The sodium deficit is calculated as: [desired serum Na^+ – current serum Na^+ level (mEq/L)].
    - In an emergency, the desired serum sodium level could be 128 if correcting for active seizure activity.
    - On the other hand, the desired serum sodium level could be 135 if trying to slowly correct to normalize the sodium level.
    - To correct the deficit =>Na^+ deficit x total body wate
  - The practical significance of this calculation is not clear in that it assumes an approach to static clinical situation when, in fact, the physiology of fluid and electrolyte shifts is dynamic.
  - A fluid and electrolyte strategy should take into account the clinical assessment of the degree of dehydration (e.g., 5% or 10%) in estimating fluid deficits; furthermore, maintenance fluids and ongoing fluid losses are added to the deficit and replaced over 24 hours.
  - Alternative approach: Worksheet for the non-emergent correction of hyponatremia with 3% hypertonic saline
    - Use this worksheet for patients not exhibiting neurologic symptom
    - Serum sodium should not be corrected faster than 0.5 – 1 mmol/L/hour
    - Decrease infusion rate if serum sodium is increasing >2 mmol/L/hour
    - Worksheet
      Children: 1-18 years
      Ideal body weight (kg) (IBW) = $\frac{(\text{Height in cm})^2 \times 1.65}{1000}$
    - Sodium Correction Factor
      Males 0.6

Females 0.5

Sodium Requirement

- Desired sodium (after 24 hours of treatment)……………_________mmol/L (Physician determined)
- Measured serum sodium…………………………(minus)-________mmol/L
- Sodium Deficit per Liter (desired-measured sodium)…….________mmol/L
- Multiply x Sodium Correction Factor…………………..X________mmol/L
- Sodium correction per kg (Deficit x Correction Factor)…_________mEq/L
- IBW……………………………………………………X_________kg
- Total sodium required (sodium correction/kg x weight)…_________mEq
- Divide by IV concentration of 3% saline…………__0.513__mEq/ml sodium
- Corrected fluid requirement……………………._________ml
- Divided by 24 hours……………………………___24___hours
- Calculated infusion rate………………………______ml/hr over 24 hours

Example

Male – 20kg Height 108cm (IBW) = $\frac{(108)^2 \times 1.65}{1000}$ =19.2kg

Desired sodium level…………………………= 125 mmol/L
Patient serum sodium level…………………..- 115 mmol/L
Sodium deficit……………………………….=   10 mEq/L
Multiply by Correction Factor……………….X 0.6
Sodium correction……………………………= 6 mEq
Multiply by IBW……………………………..X 19.2 kg
Total sodium required……………………….= 115 mEq
Divide by IV concentration of 3%…(divide by) 0.513 mEq/ml sodium
Required volume of 3%…………………………….= 224 ml
Divided by 24 hours…………………………= 9.3 ml/hour over 24 hours

- Severe hyponatremia with signs and symptoms of encephalopathy, mental status changes, and seizure
  - Prompt steps should be taken to secure the airway if indicated and restore effective perfusion.
  - Fluid restriction is not appropriate during medical emergencies.
  - Patients should be treated with hypertonic saline (3%, 513 mEq/L); the rate of infusion should raise the serum sodium level by 1 mEq/L per hour until
    - The patient's symptoms improve
    - A serum sodium level of 125-130mEq/L has been achieved
    - The optimal rate of sodium corrections is 15-20mEq/L in 48 hours.[1]
    - The amount of 3% hypertonic saline to use is:
      - Sodium dose = TBW x Na^+ deficit
      - Volume of 3% saline = sodium dose x 2 ml/ mEq of Na^+
      - The volume of 3% saline should be delivered over 3 hours.

Hypernatremia

Electrolyte and fluid therapy

- Effective intravascular volume needs to be rapidly replenished with either isotonic saline and/or a colloid solution in 20 ml/kg increments up to 60 ml/kg within the first hour of fluid resuscitation.
- It is important to provide free water in correcting hypernatremia.
- One method of estimating the amount of fluid needed to correct the free water deficit is:
  - Free water deficit (ml) = 4 ml x lean body weight (kg) x [Desired change in serum Na mEq/L]
  - This assumes the total body water to 50% of body weight.
  - This calculation deficit does not account for insensible losses or ongoing urinary or gastrointestinal losses; maintenance fluids are given in addition to the deficit replacement.[2]
- In regard to the rate of fluid replenishment there are no well-designed studies.
  - One approach is not to exceed 1 mEq/hour or 15 mEq/24 hours.
  - In severe hypernatremia (Na^+ greater than 170 mEq/L), serum sodium should not be corrected below 150 mEq/L in the first 48 to 72 hours.[11]
- Electrolytes need to be measured every hour for 4 hours in order to gauge the rate of serum sodium concentration change. Adjustments in the electrolyte solution and rate of infusion are made accordingly.
- Case vignette- Gastroenteritis (Hypernatremic Dehydration)
  - A 9-month old child (weight = 8 kg) with a 2-day history of URI symptoms, vomiting, diarrhea and low grade fever presents to your office. On exam, he appears to be 10% dehydrated. His laboratory work reveals a serum sodium of 152 mEq/L, potassium 4.1 mEq/L and a total carbon dioxide of 12 mEq/L. Urine chemistries reveal a specific gravity of 1.030, sodium < 5 mEq/L, potassium of 18 mEq/L and an osmolality of 700 mOsm/kg/H_2O.
  - In calculating the estimated volume deficit in hypernatremia, the equation is:

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$$\text{Water deficit} = (\text{Total Body Water}) \times \left(\frac{\text{Serum Na}^+}{140} - 1\right)$$

Total Body Water = Weight (kg) x percentage of body water

⇨ Child (less than 1 year of age) = 0.8 , children (1 to 12 years) = 0.6 , adults = 0.4

$$\text{Thus, the water deficit} = (8\text{ kg} \times 0.8) \times \left(\frac{152}{140} - 1\right) = 0.64 \text{ Liters or } 640 \text{ ml}$$

The overall volume deficit would be 640 ml with a composition of sodium of 152 mEq/L (or essentially 0.9% NaCl (154 mEq/L)]

  - The rate of sodium correction is important in order to avoid cerebral edema; one approach is to lower the sodium by no more than 10 mEq/L/day.[12]
  - Thus, in our vignette the correction would occur: 152-140 = 12 mEq / 10 mEq per day = 1.2 days or close to 29 hours.
  - The free water deficit would be replaced over 29 hours or 640 ml/29 hours for 22 ml/hr; however, one must add maintenance requirements to this rate as well as ongoing losses.
  - The purpose of the volume deficit formula is to serve as a guide to initial therapy, since there are a number of factors that must be considered when replacing fluids including
    - Ongoing water losses (e.g., insensible and urinary losses)
    - Electrolyte shifts that may occur with gastrointestinal losses

- Central nervous system disease
- Endocrine disorders

This guideline was developed to improve health care access in Arkansas and to aid health care providers in making decisions about appropriate patient care. The needs of the individual patient, resources available, and limitations unique to the institution or type of practice may warrant variations.

References

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