FLUID AND ELECTROLYTE MANAGEMENT

Fluid and Electrolyte Management, Case #1

Written by Edward Clark, M.D.

A six-year-old girl admitted for elective surgery and she is made NPO. She weighs 21 kg and is 135 cm. tall. Write the orders for her IV fluids prior to surgery.

Definitions for Specific Terms:

Total Body Fluid Requirements- The sum of maintenance + deficit + ongoing fluid losses

Maintenance Intravenous Fluids- The quantities of water and electrolytes that must be consumed to replace the amount of water and electrolytes lost each day that occur as a result of normal daily metabolic activities, without requiring any renal compensation.

Deficit Fluids- Pathologic fluid losses in illnesses produce a fluid deficit that may manifest as dehydration.

Ongoing Fluid Losses- Sensible and insensible fluid losses

Sensible Fluid Losses- Measurable forms of fluid loss such as urinary losses and stool losses in the absence of diarrhea.

Insensible Fluid Losses- Less readily measurable forms of fluid loss such as losses from the skin and the respiratory tract.

Replacement Fluid Losses- Term used to denote deficit fluids and/or ongoing losses if they are significant or excessive.

"A child awaiting surgery may need only maintenance fluids, whereas a child with diarrheal dehydration needs maintenance and deficit therapy and also may require replacement fluids if significant diarrhea or vomiting continues."

Review of Important Concepts:

Historical Points

Maintenance implies fluid and calorie requirements at rest in a stable patient. In obtaining history, keep in mind that several factors or pathological conditions may increase or decrease fluid needs.

Clinical Reasoning

1. When is it necessary to begin maintenance fluids?
   a. It is important to recognize when to start maintenance fluids. Healthy children can tolerate variations in intake due to many homeostatic mechanisms that can adjust absorption and excretion of water and electrolytes.
   b. The calculated fluid and electrolyte needs that form the basis of maintenance therapy are not absolute requirements.
      - A normal teenager who is given nothing by mouth (NPO) overnight for a morning procedure does not require maintenance fluids because a healthy adolescent can easily tolerate 12-18 hours without oral intake.
      - In contrast, a 6 month old child waiting for surgery should begin receiving fluids within 8 hours of the last feeding.
      - Infants become dehydrated more quickly than older patients due to differences in body surface area and a decreased ability for the kidney to concentrate and compensate.

2. What factors may alter maintenance fluid or electrolyte requirements?
   a. CNS depression
   b. Sedation
   c. Hyperventilation
   d. Burns
   e. Sepsis
   f. Fever
   g. Environmental heat stress
   h. Major surgery
   i. Cardiac and renal disease
   j. Leakage around a gastric tube
   k. Excessive drooling from a cerebral palsy patient
   l. High humidity
   m. Hypermetabolic states
   n. Hypothermia
   o. Chronic conditions
   p. Normal and abnormal sweat loss as in cystic fibrosis where salt requirements may be increased due to sweat loss

3. What makes up the composition of maintenance fluids?
   a. A solution of water, glucose, sodium chloride, and potassium chloride. For each 100 cc of maintenance fluids, a child needs 3 mEq of sodium chloride and 2 mEq of potassium chloride, as well as, a carbohydrate source.
   b. In general for children greater than 10 kg, one-half normal saline with 5% dextrose and 20 mEq/L KCL meets maintenance glucose and electrolyte needs.
   c. One-fourth normal saline with KCL is often used in children under 10kg due to the high water needs per kilogram. The glucose provides approximately 20% of the normal caloric needs of the patient and prevents protein break down.
   d. It is important that patients do not remain on maintenance therapy indefinitely since maintenance fluids do not provide adequate calories, protein, fat, minerals, or vitamins on a long-term basis.

Diagnosis / Calculation Methods

Different methods are used to estimate maintenance fluid and electrolyte requirements in infants and children. The two most common methods are based on either metabolic rate (the caloric or Holliday-Segar method) or on body surface area (or square meter method).

The body surface area method is based on the assumption that caloric expenditure is related to body surface area. This method requires the use of Mosteller's formula or nomogram found in most textbooks and requires a knowledge of the patient's height. Mosteller's formula is surface area (m^2) = Ht(cm) x Wt(kg) / 3600. Apply body surface area to maintenance fluids = 1500 ml / m^2 / 24hr.

Calculating maintenance fluid requirements for a 21kg child:

1. Using the **Holliday-Segar** or "caloric" method: the amount of fluid needed is 100mL/kg/day for the first 10 kg, plus 50mL/kg/day for the next 10 kg, plus 20mL/kg/day for each additional kg thereafter.

   Daily requirement: (100 mL/kg/day x 10 kg) + (50 mL/kg/day x 10 kg) + (20 mL/kg/day x 1 kg) = 1,520 mL/day.

   Hourly rate: 1,520 mL/day divided by 24 hr/day = 63 mL/hr

2. **Alternative Holliday-Segar** method: This method eliminates one step in the calculations by dividing the above amounts (100, 50, 20) of fluid needed by 24hrs and rounding to equal (4, 2, 1); 4mL/kg/hr for the first 10 kg, plus 2mL/kg/hr for the next 10 kg, plus 1mL/kg/hr for each additional kg thereafter.

   When using this "short cut" method, the daily requirement is automatically calculated to an hourly rate. As in the example: (4 mL/kg/hr x 10 kg) + (2 mL/kg/hr x 10 kg) + (1 mL/kg/hr x 1 kg) = 61 mL/hr.

   *Notice that there is a slight difference in calculations. Also, this method is not preferred if fluid deficits and losses need to be figured into the total body fluid requirements.

   Using the **body surface area** method: Calculate the body surface area using Mosteller's formula: 135cm x 21 kg / 3600 = 0.8 m^2 then enter into 1500 ml/ 0.8 / 24hr = 78 mL/hr

*Note that these are estimates and that we have a 15cc per hour difference between the two methods. Is a tablespoon per hour difference going to cause problems in a 6yo child? A small infant?

Suggestions for Learning Activities

- Ask the student(s) the questions listed under "clinical reasoning" to probe their thinking about the above case
- Ask the student(s) to calculate the maintenance fluids on one of their patient's that they are following or the last patient that they have seen.
- Ask the student(s) what patients that are currently on the service may have increased or decreased maintenance fluid requirements? electrolyte requirements? and why?
- How may the following conditions alter a child's maintenance fluid and electrolyte needs?
  - Fever (increased insensible losses)

- Diabetes Insipidus (increased urinary losses)
- Diabetes mellitus (increased urinary losses if hyperglycemia; no change if under control)
- Sedation (decreased insensible losses)
- Renal failure (decreased urinary losses if oligo-anuria type)
- SIADH (decreased urinary losses)

Other Resources

- The Harriet Lane Handbook – chapter on Fluids and Electrolytes and BSA nomogram in Formulary Adjunct

Fluid and Electrolyte Management, Case #3

Written by Pat Patterson, M.D.

A 7-month old with fever, vomiting and diarrhea for the past 24 hours. What are the symptoms and physical findings to help decide if the infant is dehydrated?

Definitions for Specific Terms:

Fever- A rectal temperature above 37.9 degrees C or 100.4 degrees. An oral temperature above 37.4 degrees C or 99.4 degrees F. An axillary temperature above 37.1 degrees C or 98.9 degrees F

Diarrhea- The excessive loss of fluid and electrolytes in stool

Dehydration- Body fluid depletion

Review of Important Concepts:

Teaching Points

- Identify the historical and physical exam findings important in the assessment of the state of hydration/dehydration
- Understand treatment options for patients diagnosed with dehydration

Historical Points

- Age of Child: Infants dehydrate faster than older children and adults Infants have a greater percentage of total body water per weight than do adults. (about 70-75% compared with ~ 50% for adults.)
- Quantify frequency and volume of stools and emesis, bilious vs. non-bilious, to help assess degree of dehydration and possible pathologies.
- Quantify intake: what is being fed the baby, how much, how often. Is it retained? How soon after feeds does the vomiting occur? Clear liquids, particularly the electrolyte solutions commercially available in the US are rapidly absorbed from the GI tract. Administration of free water can contribute to the risk of hyponatremia and the consumption of sugary drinks can contribute to diarrhea.
- Quantify urine output and tear production
- Question last known weight of infant and when it was taken. You may have access to a recent weight that would allow for a direct measurement of the degree of dehydration.
- PMH: any underlying disease that may contribute to dehydration or electrolyte regulation

Physical Exam Findings

The chart below summarizes the important signs and symptoms associated with dehydration

Parameter	Degree of Dehydration		
	Mild	Moderate	Severe
Weight loss (%)	3-5	6-9	10-15
Skin color	Pale	Gray	Mottled
Skin turgor	May be normal	Decreased	Tenting
Anterior Fontanelle	Normal	Depressed	Sunken
Mucous membranes	Slightly dry	Dry	Dry, parched, collapse of sublingual veins
Eyes	Normal	Decreased tears	Sunken, absence of tears
Central nervous system	Alert but thirsty	Irritable	Lethargic, grunting, coma
Pulse	Normal and strong	Rapid and slightly weak	Significantly tachycardic, and very weak to not palpable
Capillary refill*	Normal (< 2 sec)	2–4 sec	> 4 sec
Blood pressure	No change	Orthostatic decrease	Shock
Urine	Normal to mildly reduced	Significantly reduced	Anuria

*Capillary refill: Assessment of capillary refill can be an important tool in determining perfusion. To perform, simply press on the skin with your finger for a couple seconds causing the skin to blanch. Remove your finger and count how many seconds it takes before the capillaries refill and the blanching resolves. The longer the time for capillary refill, the poorer the perfusion.

Clinical Reasoning

1. Does the presence of fever contribute to this infant's dehydration and if so, how?
   Fever contributes to dehydration through increased insensible loss through the skin, sweating, and increases respiratory rates leading to additional fluid loss.

2. What labs, if any, would you consider for this infant?
   In general, no labs are needed unless the patient is assessed to be moderately-to-severely dehydrated. Electrolytes, BUN and creatinine and glucose are helpful.

3. How does your approach to rehydration of a patient with hypernatremia, Na >150 meq/L differ from your approach to the patient with normal sodium?
   If correct serum sodium too rapidly, risk cerebral edema as fluid shifts from the ECF into the CNS in an attempt to equilibrate with the hypernatremic environment of the CNS relative to the ECF provided in the IVF.

4. Why is it ill-advised to use sugary drinks to orally rehydrate patients?
   Juices, soft drinks, and punches usually contain much higher concentrations of sugars and almost no sodium; they are inappropriate for use as an ORS. The higher sugar concentrations in these fluids may exacerbate diarrhea by presenting a large osmotic load to the intestine.

5. If vomiting and diarrhea continue with oral rehydration, should the infant be placed on 'bowel rest' with nothing by mouth in hopes that total rest would stop the vomiting and diarrhea? 'No' Vomiting is not a contraindication to ORT and fluid replacement should continue orally even in the presence of vomiting. Strong evidence suggests that both the volume and duration of diarrhea are reduced when children are fed immediately following rehydration. Key to the successful treatment of dehydration using ORT is the offering of frequent small volumes of liquids; perhaps as little as a tablespoon, 15cc, of solution every 15-20 minutes. A general guideline is to give 50-100 cc/kg of ORS over 2-4 hours.

6. In the moderate to severely dehydrated child, a metabolic acidosis is frequently seen. How would you alter your fluid management if at all?
   In general, there is no need to alter fluid management in the presence of a metabolic acidosis secondary to dehydration. Correcting the underlying dehydration will correct the metabolic acidosis.

Diagnosis and Treatment

Treatment options depend upon degree of dehydration and presence of any underlying conditions that may exacerbate the illness. Severely dehydrated infants and children will need intravenous fluids.

1. <u>Oral rehydration therapy</u>
   - First choice for the conscious child who has mild or moderate dehydration
   - Fluid absorption can be promoted by enteral administration of properly designed fluids, even in the face of ongoing losses.
   - Choice of solution important: An Oral Rehydration Solution, ORS, is specifically formulated to promote water and electrolyte absorption through the co-transport system in the gut. A physiologically appropriate ORS contains: 70–90 mEq/L sodium, ≤ 25 g/L glucose, 20 mEq/L potassium and ~30 mEq/L of base in the form of citrate. Appropriate, commercially available solutions are readily available in the US.

2. <u>Parenteral Therapy for Dehydration</u>:
   - For patients who have severe dehydration (shock) fluids are administered intravenously or intraosseously when access difficult.
   - Rapid boluses of 0.9% sodium chloride, (**not** D5 0.9% NaCl), in initial volumes of 20 mL/kg for ≤ 20 minutes. Take note that parenteral solutions used for bolusing patients generally do not contain dextrose unless glucose testing has demonstrated that the patient is hypoglycemic.

3. <u>Enteral fluid therapy may begin immediately if</u>
   - the patient is conscious
   - airway protective reflexes are intact
   - fluids are given either by mouth or nasogastric tube.

Fluids and Electrolyte Management, Case #4

Written by Lavjay Butani, M.D.

An infant weighing 8 kg is estimated to be 12% dehydrated. What fluids should you start initially? What laboratory tests should be ordered immediately? What is the calculated fluid deficit and how should it be replaced? What IV solution(s) should be used?

Definitions for Specific Terms:

Total Body Fluid Requirements- The sum of maintenance + deficit + ongoing fluid losses.

Maintenance Intravenous Fluids- The quantities of water and electrolytes that must be consumed to replace the amount of water and electrolytes lost each day that occur as a result of normal daily metabolic activities, without requiring any renal compensation.

Deficit Fluids- Pathologic fluid losses in illnesses produce a fluid deficit that may manifest as dehydration.

Ongoing Fluid Losses- Sensible and insensible fluid losses

Sensible Fluid Losses- Measurable forms of fluid loss such as urinary losses and stool losses in the absence of diarrhea

Insensible Fluid Losses- Less readily measurable forms of fluid loss such as losses from the skin and the respiratory tract

Replacement Fluid Losses- Term used to denote deficit fluids and/or ongoing losses if they are significant or excessive.

"A child awaiting surgery may need only maintenance fluids, whereas a child with diarrheal dehydration needs maintenance and deficit therapy and also may require replacement fluids if significant diarrhea or vomiting continues."

Review of Important Concepts:

Historical Points and Physical Exam Findings

- Assessing and estimating the degree of dehydration is the first and most important step in fluid management in a dehydrated child since this will determine how much and in what manner (route and rapidity) fluid resuscitation should occur. The degree of dehydration can be estimated if a recent previous weight of the child when well is known. Often this is not available; in such instances, severity of dehydration can be estimated by looking for a constellation of signs and symptoms (see table in Case 3).
- How alert is the child? What are his/her vital signs? Children with moderate to severe dehydration are at risk of evolving into hypovolemic shock and so their vital signs and sensorium need to be evaluated.

- What have the parents been giving the child at home for rehydration? Infants are especially vulnerable to develop severe electrolyte abnormalities such as hypo or hypernatremia if improper oral rehydration solutions are used (such as water or inappropriately mixed homemade oral rehydration solutions)

Clinical Reasoning

1. What might be some of the common causes of moderate to severe dehydration in a child of this age?
   a. Gastroenteritis (viral or bacterial)
   b. Intractable vomiting (from increased intracranial pressure
   c. Anatomic GI abnormalities
   d. Intoxications
   e. Inborn errors of metabolism)
   f. Acute blood loss from any source, including head injury (accidental or non-accidental trauma)
   g. Urinary losses (salt wasting syndromes such as congenital adrenal hyperplasia)
   h. Excess loss of fluid in sweat (as in children with cystic fibrosis during the summer months)

2. What is the preferred route of rehydration in this child and why?
   a. Children with mild to moderate dehydration can be safely and effectively managed with oral rehydration if their vital signs remain stable, they tolerate oral fluids and their sensorium is normal.
   b. Alternatively other routes of rehydration, including nasogastric and intravenous, can be employed, either exclusively or in combination with oral rehydration.
   c. For children with severe dehydration, rapid repletion of effective circulating volume is desirable and hence this child would benefit from IV rehydration.

3. What laboratory tests should be ordered immediately?
   a. For infants with moderate to severe dehydration, it is important to obtain a blood glucose (finger stick) and electrolytes to evaluate their renal function and for detection of electrolyte abnormalities such as acidosis and dysnatremias.
   b. Other tests should be ordered based on the clinical appearance of the child (e.g. blood gas if child looks lethargic or obtunded), and the clinical scenario obtained on history (e.g. imaging studies and cultures based on suspected differential diagnosis).

Diagnosis / Calculations:

Fluid deficit: Estimated well weight = x kg. Current weight = 8 kg. Weight loss is 12%. Therefore x - 12% x = 8 kg; or x = 9.1 kg (or approximately 9 kg). Fluid deficit is 9 kg - 8 kg= 1 kg (or 1000 ml).

Initial fluid management: Replete effective circulating volume with isotonic saline since a sodium containing solution will stay in the Intravascular extracellular compartment in the most effective manner (since sodium is the predominant cation in the extracellular compartment). Therefore the child should get normal saline as a fluid bolus of 20 ml/kg over 20-30 minutes (or as fast as his/her IV will handle the solution). This should be repeated as needed until vital signs stabilize and the child starts voiding. In addition, the child should be allowed to drink oral rehydration solutions if he/she is alert and does not have a suspected surgical condition.

After the fluid boluses have been administered and the child stabilized, the remainder of the deficit (if any), should be given either continuously over 24 hours (unless he/she is hypernatremic) along with his/her maintenance requirements (900 ml) or half of the deficit should be given over the 1st 8 hours and the remainder over the next 16 hours (along with his maintenance requirement of 900 ml/day).

The composition of the fluid will depend on his/her serum sodium concentration and his sodium deficit. Assuming a normal serum sodium (140 mEq/L) and assuming that the child has received one fluid bolus of 180 ml (20ml/kg) of isotonic saline, the fluid volume that the child needs over the next day is = 900 ml (maintenance) + 1000 ml (deficit) – 180 ml (bolus volume) = 1720 ml or 72 ml/hour. For the child's sodium requirements, one needs to add his/her maintenance sodium requirement (about 2-3 mEq/kg/day) and his/her sodium deficit.

Sodium (maintenance) = 2-3 mEq/kg/day = 25 mEq/day (approximately)
Sodium deficit = Total body sodium (well state) – Total body sodium (present state)

Total body sodium (well) = Total body water (well) x Serum sodium (well) = 0.7∗ x 9 (weight) x 140 (assuming child has a normal serum sodium) = 6.3 x 140 = 882 mEq

∗ Note: unlike in adults, a greater proportion of body weight is water, in children (ranging from a high of 85% in neonates to 60% in adolescents). For most children using 70% of their weight to calculate total body water will work.

Total body sodium (ill) = Total body water (ill) x Serum sodium (ill) = [Total body water (well)-fluid deficit] x Serum sodium (ill) = (6.3-1.0) x 140 = 5.3 x 140 = 742 mEq

Therefore sodium deficit is 882 – 742 mEq = 140 mEq

And so, the child's total sodium requirement over 24 hours is 140 mEq (sodium deficit) + 25 mEq (maintenance sodium) – sodium already given in isotonic saline bolus (154 mEq/L x 0.18 L=28 mEq) = 165-28=140 mEq/day

The commercially available IV Fluid that most closely matches the child's need of 1720 ml of water and 140 mEq of sodium will be a solution that has a sodium concentration of 140/1.72 mEq/L which is 81 mEq/L. The commercially available IV fluid solution closest to this is ½ NS (which has 77 mEq/L sodium). Therefore this child should get ½ NS at 72 ml/hour. If the child is not eating, most would add some dextrose initially to prevent ketosis and hypoglycemia (hence the best fluid choice would be D5 ½ NS at 72 ml/hour for 24 hours). Avoid using 'home made' IV fluid solutions compounded by the pharmacy-the risk of error is too great to take a chance.

This same basic approach is used in setting of hypo and hypernatremia except that in hypernatremia the deficit should be replaced over 48 hours to prevent significant osmotic shifts.

If patients with hyperosmolar states (such as diabetic ketoacidosis and severe hypernatremia) are rapidly brought to a state of normal osmolality, there is high risk of water moving intracellularly, leading to cerebral edema and herniation of the brain.

Suggestions for Learning Activities:

- Ask the student(s) the questions listed under "clinical reasoning" to probe their thinking about the case
- Have students review the literature on the effectiveness of nasogastric hydration for children with dehydration

Other Resources:

- The Harriet Lane Handbook – chapter on Fluids and Electrolytes and BSA nomogram in Formulary Adjunct
- Alan L. Nager and Vincent J. Wang: Comparison of Nasogastric and Intravenous Methods of Rehydration in Pediatric Patients With Acute Dehydration. Pediatrics 2002; 109; 566

Fluid and Electrolyte Management, Case #5

Written by Adam Weinstein, M.D.

A two-month-old infant is brought to the Emergency Department because of seizures. He has had diarrhea for five days and has been fed only water and diluted apple juice. What might be the cause of the seizures and how should they be treated?

Definitions for Specific Terms:

Total Body Fluid Requirements- The sum of maintenance + deficit + ongoing fluid losses

Maintenance Intravenous Fluids- The quantities of water and electrolytes that must be consumed to replace the amount of water and electrolytes lost each day as a result of normal daily metabolic activities, without requiring any renal compensation.

Deficit Fluids- Pathologic fluid losses in illnesses produce a fluid deficit that may manifest as dehydration.

Ongoing Fluid Losses- Sensible and insensible fluid losses

Sensible Fluid Losses- Measurable forms of fluid loss such as urinary losses and stool losses in the absence of diarrhea

Insensible Fluid Losses- Less readily measurable forms of fluid loss such as losses from the skin and the respiratory tract

Replacement Fluid Losses-Term used to denote ongoing losses if they are significant or excessive.

"A child awaiting surgery may need only maintenance fluids, whereas a child with dehydration due to diarrhea needs maintenance and deficit therapy and also may require replacement fluids if significant diarrhea continues."

Review of Important Concepts:

Historical Points

- Time/course of presentation- How long, acute or chronic. Has this happened before?
- Assess aspects of hydration- Mood, activity, urine output; HR, BP, comparative weights, mental status, skin turgor, mucus membranes, tears, fontanelle, etc…
- Detailed assessment of fluid intake- Volume, content (how much salt, sugar, etc…), and whether any is being kept down vs. how much is being lost.
- Other associated symptoms- e.g. is there a fever? This would influence aspects of hydration status (increased insensible losses), but also have implications on the differential diagnosis, such as meningitis
- Past Medical Hx, Social Hx, Family Hx- Clues with regards to risks of severity and for recurrence, appropriateness of environment, any pertinent co-morbid conditions including those identified on newborn screening.

Clinical Reasoning

1. What might be the cause of the seizures?
   In a child with the above history, an acute electrolyte or metabolic derangement is at the top of the differential, and importantly, these represent immediately reversible causes.
   a. Hyponatremia - high intake of electrolyte free/hypotonic solutions in the setting of dehydration
   b. Hypoglycemia - not keeping anything down? This should be considered.
   c. Hypocalcemia - more a consideration if a chronic history of diarrhea and potentially low intake of calcium. This specifically refers to a low ionized calcium (free calcium) level.

2. How should they be treated?
   Immediate/emergent fluid/electrolyte assessment and concurrent resuscitation.
   a. Based on history, the child will likely show signs of acute VOLUME depletion.
      Isotonic Normal Saline infusion (bolus) rapidly over 20 minutes and repeat as needed.
      Usually in 20ml/kg increments.
   b. Stat (I-stat if available) for SODIUM level.
      If critically low (<120-125), would give hypertonic saline with goal to stop seizures and immediately achieve sodium in low-to mid 120s.
      If >125, then hyponatremia unlikely the etiology of the seizures and hypertonic saline not necessary
      In either case once patient is stabilized:
   c. Subsequently provide both deficit and maintenance fluids +/- replacement fluids (if applicable) to complete treatment of the fluid and electrolyte disorder. (see FLUID AND ELECTROLYTE CASE 4 for an example)…
   d. D-stick for immediate blood GLUCOSE.
      Dextrose bolus if low (definitely if <40, some do so if 40-60)
      If >40-60, then can include dextrose as component of maintenance fluid regimen as discussed in previous cases.
   e. Stat (I-stat if available) for CALCIUM level. Replete acutely and with ongoing supplementation if applicable.

3. What makes up the composition of hypertonic saline?
   a. It is an approximately 3% Sodium Chloride solution which specifically, has a sodium concentration of 513 mEq/L.
   b. In comparison, Normal Saline is 0.9% NaCl and has 154 mEq/L of sodium.

4. Once stabilized, henceforward, what is the goal rate of correction of serum sodium and why?
   a. Rapid correction of hyponatremia may result in central pontine myelinolysis
   b. Rapid correction (increase) of extracellular osmolality may result in sudden loss of intracellular volume as water moves extracellularly.
   c. Rapid correction should be reserved for symptomatic patients (e.g. seizures, mental status changes); treatment goal is to stabilize and eliminate the symptoms, then slow down rate of correction.
   d. In asymptomatic patients, or once stabilized, the desired rate of correction is about 0.5 mEq/L correction per hour (or about 10-12 mEq/L per 24 hours).

Calculations:

Volume of Hypertonic (3%) NaCl needed to raise the serum sodium level by "A" mEq/L:
3% NaCl (mL) = "A" mEq/L x body weight (kg) x 0.6L/kg

Example: 5 kg infant with serum sodium 115 mEq/L. Want to raise sodium to 125 mEq/L
So raising level by 10 mEq/L
10 x 5 x 0.6 = 30 mL of 3% NaCl

Dextrose treatment for symptomatic hypoglycemia
IV Glucose bolus of 0.5 to 1 gram/kg
This would be 2-4 mL/kg of D25 (25% Dextrose) if central access
5-10 mL/kg of D10 (10% Dextrose)

Suggestions for Learning Activities:

- Ask the student(s) the questions listed under "clinical reasoning" to probe their thinking about the case.
- Create some sample case scenarios for which the student can practice with hypertonic saline, dextrose, and/or fluid resuscitation calculations.
- Discuss the pathophysiology that places pediatric patients at risk for dehydration with hyponatremia. Emphasize the role of ADH, and distinguish between appropriate stimuli for ADH and the syndrome of inappropriate ADH secretion (SIADH).
- Discuss the pathophysiology that places infants, in particular neonates, at risk for hypoglycemia with acute illness associated with decreased nutritive intake
- Discuss some inborn errors of metabolism that may also present in infancy as hypoglycemia.
- Role play – have the students explain to you (you are the "parent") what is going on during the above resuscitation. In the emergent setting, explain what the cause of the seizure might be and how the resuscitative team is addressing it and will safely and effectively stop the seizure and prevent neurologic morbidity.

Other Resources:

- The Harriet Lane Handbook – chapter on Fluids and Electrolytes
- PALS Provider Guide (American Heart Association)—chapter on Fluid Therapy and Medications in Shock or Arrest (and related "CODE cards")

<u>Fluid and Electrolyte Management, Case #6</u>

Written by Adam Weinstein, M.D.

A nine-month-old infant has diarrhea and signs of moderate dehydration. His electrolytes are Na+ 162, K+ 5.6, Cl- 132, and bicarbonate 12. During IV rehydration the patient has a generalized seizure. What is the probable cause of the seizure? How should it be treated? How could this complication have been avoided?

Definitions for Specific Terms:

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<u>Maintenance Intravenous Fluids</u>-The quantities of water and electrolytes that must be consumed to replace the amount of water and electrolytes lost each day as a result of normal daily metabolic activities, without requiring any renal compensation.

<u>Deficit Fluids</u>- Pathologic fluid losses in illnesses produce a fluid deficit that may manifest as dehydration.

<u>Ongoing Fluid Losses</u>- Sensible and insensible fluid losses

<u>Sensible Fluid Losses</u>- Measurable forms of fluid loss such as urinary losses and stool losses in the absence of diarrhea

<u>Insensible Fluid Losses</u> - Less readily measurable forms of fluid loss such as losses from the skin and the respiratory tract

<u>Replacement Fluid Losses</u>- Term used to denote ongoing losses if they are significant or excessive.

"A child awaiting surgery may need only maintenance fluids, whereas a child with dehydration due to diarrhea needs maintenance and deficit therapy and also may require replacement fluids if significant diarrhea continues."

Review of Important Concepts:

Historical and Physical Exam Points

- Time/course of presentation –how long, acute or chronic.
- Assess aspects of hydration and degree of dehydration—mood, activity, urine output; HR, BP, comparative weights, mental status, skin turgor, mucus membranes, tears, fontanelle, etc…
- Detailed assessment of fluid intake—volume, content (how much salt, sugar, etc…), and at what rate was it administered? Also how much fluid is still being lost (e.g. diarrhea).
- Past Medical Hx, Social Hx, Family Hx—clues with regards to risks of severity and for recurrence, appropriateness of environment, any pertinent co-morbid conditions

Clinical Reasoning

1. What might be the cause of the seizures?
   a. In a child with the above presentation, an acute electrolyte derangement is at the top of the differential.
   b. Overly rapid correction of hypernatremia- This is the most likely etiology. Rapid correction of fluid deficit, in particular with hypotonic fluids, may result in brisk decrease in serum sodium, leading to cerebral edema and CNS disturbance.
   c. Hypoglycemia- This should be considered if there has been no oral intake for awhile and if IV fluids did not contain any dextrose.

2. How should it be treated?
   Immediate/emergent fluid/electrolyte assessment and concurrent resuscitation.
   a. If due to overly rapid correction of hypernatremia, should reverse it and acutely elevate serum osmolality with hypertonic saline.
   b. Hypertonic saline is an approximately 3% Sodium Chloride solution which specifically, has a sodium concentration of 513 mEq/L. In comparison, Normal Saline is 0.9% NaCl and has 154 mEq/L of sodium.
   c. Administration will acutely increase serum sodium, and reverse cerebral edema and the CNS disturbance.
   d. Sometimes administered empirically at a rate of 0.5 to 2mL/kg/hr until seizures stopped/target sodium level reached, though protocols vary widely from institution to institution.
   e. Could also calculate rate of correction by administering a specified volume for a desired sodium level (see Calculation below)

3. Essential components of management would then include
   a. Continuing hypertonic saline until seizures and CNS concerns resolve
   b. Close and frequent monitoring of serum sodium and electrolytes, osmolality to achieve target level
   c. Maintain at this level and once patient is stabilized:
      - Subsequently provide both deficit and maintenance fluids +/- replacement fluids (if applicable) to complete treatment of the fluid and electrolyte disorder.
      - This should be provided cautiously with goal to complete treatment in 48-72hours or such that rate of correction of hypernatremia does not exceed 0.5 mEq/L/hr (or 10-12 mEq/L/day).

4. How could this complication have been avoided?
   a. Avoiding a rapid correction of hypernatremia as noted above
   b. Rapid correction should be reserved for symptomatic patients (e.g. seizures, mental status changes); treatment goal is to stabilize and eliminate the symptoms, then slow down rate of correction.
   c. In asymptomatic patients, or once stabilized, the desired rate of correction is about 0.5 mEq/L correction per hour (or about 10-12 mEq/L per 24 hours).

Calculations:

Volume of Hypertonic (3%) NaCl needed to raise the serum sodium level by "A" mEq/L:
3% NaCl (mL) = "A" mEq/L x body weight (kg) x 0.6L/kg

Example: 10 kg infant with serum sodium that fell from 162 mEq/L to 147 mEq/L. Want to raise sodium to 152 mEq/L.
So raising level by 5 mEq/L
5 x 10 x 0.6 = 30 mL of 3% NaCl

Suggestions for Learning Activities:

- Ask the student(s) the questions listed under "clinical reasoning" to probe their thinking about the case.
- Create some sample case scenarios for which the student can practice with hypertonic saline and fluid resuscitation calculations.
- Discuss the pathophysiology that places pediatric patients at risk for overly rapid correction of hyperosmolality. Emphasize the role of ADH. Consider, alternative hyperosmolar states such as DKA, uremia, and toxic ingestions (e.g. ethylene glycol).
- Role play – have the students explain to you (you are the "parent") what is going on during the above resuscitation. In the emergent setting, explain what the cause of the seizure might be and how the resuscitative team is addressing it and will safely and effectively stop the seizure and prevent neurologic morbidity.

Other Resources:

- The Harriet Lane Handbook – chapter on Fluids and Electrolytes
- PALS Provider Guide (American Heart Association)—chapter on Fluid Therapy and Medications in Shock or Arrest (and related "CODE cards")

Fluid and Electrolyte Management, Case #7

Written by Adam Weinstein, M.D.

An 8kg nine-month-old infant has vomiting and diarrhea. He has dry mucous membranes and decreased tearing and urination. After your assessment, you would like to try oral rehydration. What liquids, what quantity, and how often should the mother give the fluids to the infant?

Definitions for Specific Terms:

Total Body Fluid Requirements - The sum of maintenance + deficit + ongoing fluid losses

Maintenance Intravenous Fluids -The quantities of water and electrolytes that must be consumed to replace the amount of water and electrolytes lost each day as a result of normal daily metabolic activities, without requiring any renal compensation.

Deficit Fluids - Pathologic fluid losses in illnesses produce a fluid deficit that may manifest as dehydration.

Ongoing Fluid Losses - Sensible and insensible fluid losses

Sensible Fluid Losses - Measurable forms of fluid loss such as urinary losses and stool losses in the absence of diarrhea

Insensible Fluid Losses -Less readily measurable forms of fluid loss such as losses from the skin and the respiratory tract

Replacement Fluid Losses -Term used to denote ongoing losses if they are significant or excessive.

"A child awaiting surgery may need only maintenance fluids, whereas a child with dehydration due to diarrhea needs maintenance and deficit therapy and also may require replacement fluids if significant diarrhea continues."

Review of Important Concepts:

Historical and Physical Exam Points

- Time/course of presentation
  - How long?
  - Acute or chronic?
- Assess aspects of hydration
  - Mood
  - Activity
  - Urine output
  - HR, BP
  - Comparative weights
  - Mental status
  - Skin turgor

  - Mucus membranes
  - Tears
  - Fontanelle, etc…
  - How severe is the dehydration?
- Detailed assessment of fluid intake
  - Volume
  - Content (how much salt, sugar, etc…)
  - Determine whether any is being kept down vs. how much is being lost.
  - Any risks for hypo- or hyperosmolar abnormality?
- Past Medical Hx, Social Hx, Family Hx
  - Clues with regards to risks of severity and osmolar abnormalities, appropriateness of environment, any pertinent co-morbid conditions?

Clinical Reasoning

1. What liquids should the mother give the infant?
   a. In a child with dehydration from GI losses, the infant will need to have both fluid and electrolyte replacements. The ideal solution will be an electrolyte containing solution.
   b. Oral solutions in this regard include solutions like WHO formula or Rehydralyte (which have ~75 mEq/L Na) or Pedialyte (which has ~45 mEq/L Na)
   c. These solutions should also contain some sugar (glucose), ideally in 1:1 molar ratio with sodium, to enhance GI absorption of the fluid via the Na-Glucose co-transporter. Pedialyte adjusts this to a 3:1 ratio to make it more palatable. This is still much closer to 1:1 than sports drinks. These fluids also contain potassium 20 mEq/L and citrate (as a base equivalent) 10 mEq/L.
   d. Solutions that contain excess free water without electrolytes will create risk for development of hyponatremia or other electrolyte disorders. For severely dehydrated patients, even Pedialyte may be too hypotonic in this regard, and a fluid with 75 mEq/L of sodium or more is preferred.

2. What quantity of fluids should the mother give to the infant and how often?
   a. Given the ongoing vomiting, small volumes more frequently may be more easily tolerated.
   b. Ideally, the provider will assess the degree of dehydration (if any).
      - If infant is well-hydrated, then mother should provide the infant the fluid to achieve a daily maintenance volume plus replacement of any diarrheal losses
      - If infant is dehydrated, then mother should provide both deficit and maintenance fluids +/- replacement fluids to rehydrate the infant and maintain euvolemia.
   c. With oral fluids and for home intake, estimates may be adequate, provided infant is:
      - Tolerating fluids, not vomiting them. Giving small volumes hourly, or sips every 15 to 30 minutes may be needed in this regard
      - Showing signs of maintaining or improving hydration based on mood, activity, and urine output

Calculations:

The infant in this case weighs 8 kg, and based on the above description has mild to moderate dehydration. Calculate and prescribe a fluid replacement regimen using oral rehydration.

Theoretical example:

- Daily Maintenance needs are 800 mL/day (8 x 100mL/kg/day)
- Diarrheal losses need to be replaced—could consider 1.5 X maintenance rate with aim of estimating this target = 1200mL/day for this infant
- Deficit needs to be replaced as well.
    - Mild dehydration is 5% volume deficit = 400 mL
        - (5% x 8kg = 8L = 8000 mL x 0.05)
    - Moderate dehydration is 10% deficit = 800 mL
        - (10% x 8kg= 8L = 8000mL x 0.10)
- So could replace 600mL in addition to 1.5X maintenance rate = 1200mL + 600mL = 1800mL/day or (1800mL/day ÷ 24hr/day = 75ml/hr)
- If replacing orally with Pedialyte or Rehydralyte, could encourage parents to achieve this by giving:
    - 75 mL/hr (2.5 ounces each hour, on average)

Instruct parent(s) to call M.D. if not tolerating (ongoing emesis) or hydration status not improving due to higher volume diarrhea, and worsening mood, activity, urine output

Suggestions for Learning Activities:

- Ask the student(s) the questions listed under "clinical reasoning" to probe their thinking about the case.
- Create some sample case scenarios for which the student can practice with fluid calculations. Can use the above theoretical calculation in this regard.
- Discuss the pathophysiology that would preclude the use of an oral rehydration regimen.
- Role play – have the students explain to you (you are the "parent") how to rehydrate and maintain hydration of your infant with gastroenteritis and dehydration using oral fluids, noting the above (which fluids to use, how much, how often, and how to know it is not working and therefore, to seek care).

Other Resources:

- The Harriet Lane Handbook – chapter on Fluids and Electrolytes
- Rudolph's Pediatrics (or other standard pediatrics textbook) Chapter on Fluid, Electrolytes, and Acid Base, subsection on Oral Hydration.

Fluid and Electrolyte Management, Case #8

Written by Adam Weinstein, M.D.

A nine-year-old child with diabetic ketoacidosis has the following electrolytes: Na+ 132, K+ 5.4, Cl- 103 and Bicarb 9. What is the anion gap? As the fluid deficit is corrected what is likely to happen to the serum K? How should this be managed?

Definitions for Specific Terms:

Total Body Fluid Requirements- The sum of maintenance + deficit + ongoing fluid losses

Maintenance Intravenous Fluids-The quantities of water and electrolytes that must be consumed to replace the amount of water and electrolytes lost each day as a result of normal daily metabolic activities, without requiring any renal compensation.

Deficit Fluids-Pathologic fluid losses in illnesses produce a fluid deficit that may manifest as dehydration.

Ongoing Fluid Losses- Sensible and insensible fluid losses

Sensible Fluid Losses-Measurable forms of fluid loss such as urinary losses and stool losses in the absence of diarrhea

Insensible Fluid Losses-Less readily measurable forms of fluid loss such as losses from the skin and the respiratory tract

Replacement Fluid Losses-Term used to denote ongoing losses if they are significant or excessive.

Anion Gap- The difference between the measured cations (Sodium) and measured anions (Chloride, Bicarbonate) in the serum. Potassium is not included as it is "negligible" in quantity. When there is an "elevated" anion gap, it suggests there is are unmeasured anions in the serum (such as lactic acid or ketoacids, for example)

"A child awaiting surgery may need only maintenance fluids, whereas a child with dehydration due to diarrhea needs maintenance and deficit therapy and also may require replacement fluids if significant diarrhea continues."

Clinical Reasoning:

1. What is the anion gap?
   Sodium – (Chloride + Bicarbonate) concentrations. 132 mEq/L - 112 mEq/L = 20 mEq/L

2. As the fluid deficit is corrected what is likely to happen to the serum K?
   a. The serum potassium concentration will decrease
   b. Based on history and experience with DKA, these patients are moderately to severely dehydrated
   c. Therefore renin-angiotensin-aldosterone system is active

d. Once renal perfusion is improved, then aldosterone activity will facilitate renal tubular K excretion
e. Incidentally, the patient in DKA may have some K losses via vomiting as well
f. As patients with DKA are rehydrated, the kidney is better able to excrete ketoacids and start to correct the acidosis
g. As acidosis corrects, hydrogen ions will shift out of cells and extracellular potassium will shift back intracellularly, lowering serum K
h. A similar effect will be observed as hyperosmolality corrects as well
i. Presumably, the patient with DKA will also be treated with insulin
j. Insulin will also directly shift potassium intracellularly, lowering serum K.

3. How should this be managed?
   a. As soon as rehydration is begun, there should be a low threshold to add potassium to the IVF
   b. Since the decrease in serum potassium will be anticipated, once renal function is established and serum K reaches or approaches 5 mEq/L, potassium should be added
   c. Can be adjusted with concentrations of 20 to 40 mEq/L in the fluids, often as potassium phosphate or combination of potassium chloride plus potassium phosphate.

Calculations:

1. Practice calculating anion gap in a number of settings
   Practice assessing whether a given metabolic acid-base disturbance is an isolated single abnormality versus a combined metabolic disturbance using delta-delta formula

2. The change in Anion Gap should equal the change in serum bicarbonate.
   a. If change (delta) in Anion gap equals the change (delta) in serum bicarbonate, then there is a pure Anion Gap metabolic acidosis
   b. If change in Anion gap is less than change in serum bicarbonate: Then this suggests there is a combined metabolic acidosis with both an anion gap and non-anion gap component
   c. This is because there is something "worsening" the acidosis in addition to the acid that is causing the gap
   d. If change in Anion gap is greater than the change in serum bicarbonate:
      - then this suggests there is a metabolic alkalosis in addition to an anion gap metabolic acidosis
      - this is because there is something "normalizing" the serum bicarbonate—the serum bicarbonate is "better" than it would be if it were just a "pure" anion gap metabolic acidosis.

3. In the question above:
   Anion Gap = 20. Delta gap = 20-12 = 8
   Bicarbonate = 9. Delta bicarb= 24-9= 15
   Anion gap delta is less than bicarbonate delta
   Therefore there is a combined anion gap acidosis with a non-anion gap component
   potentially diarrhea and/or renal tubular loss

Suggestions for Learning Activities:

- Ask the student(s) the questions listed under “clinical reasoning” to probe their thinking about the case.
- Create some sample case scenarios for which the student can practice understanding the concept of anion gap and mixed metabolic disturbances using the delta delta formula.
- Discuss the physiology of potassium ions and what environments will cause it to move intracellularly versus extracellularly
- Discuss in the context of the differential diagnosis for hyperkalemia
- Discuss in the context of the emergent management of symptomatic or life-threatening hyperkalemia
- Discuss the pathophysiology of diabetic ketoacidosis and its resulting fluid and electrolyte disturbances, including those of osmolarity, hypo- vs. iso- vs. hypernatremia, potassium, and phosphate.

Other Resources:

- The Harriet Lane Handbook – chapter on Fluids and Electrolytes
- Rudolph’s Pediatrics (or other standard pediatrics textbook) Chapter on Fluids, Electrolytes, and Acid-Base and Chapter on Diabetic Ketoacidosis.

<u>Fluids and Electrolyte Management, Case #9</u>

Written by Lavjay Butani, M.D.

A nine-month-old girl presents with two days of vomiting and diarrhea. She is listless and her heart rate is 210. What is the most appropriate initial management of this child?

Review of Important Concepts:

Historical Points

Assessing and estimating the degree of dehydration is the first and most important step in fluid management in a dehydrated child since this will determine how much and in what manner (route and rapidity) fluid resuscitation should occur. The degree of dehydration can be estimated if a recent previous weight when the child was well is known. Often this is not available; in such instances, severity of dehydration can be estimated by looking for a constellation of signs and symptoms (see table in Case 3).

Physical Exam Findings

1. Can the degree of dehydration explain her clinical picture?
   a. If this child appears mild or moderately dehydrated based on her previous weight or physical signs, one has to evaluate her for other causes for her listlessness and high heart rate, such as septic shock or cardiogenic shock.
   b. One also needs to keep in mind that this child could have more than one process going on at the same time (such as sepsis and hypovolemia).

2. What have the parents been giving the child at home for rehydration?
   a. Infants are especially vulnerable to develop severe electrolyte abnormalities such as hypo or hypernatremia if improper oral rehydration solutions are used (such as water or inappropriately mixed homemade oral rehydration solutions)

3. Are there sick contacts?
   A family history of similar illness may indicate an infectious etiology such as viral gastroenteritis.

4. Dietary history and exposures?
   A history of exposure to cattle, pets (such as turtles), well water or unpasteurized milk may indicate specific bacterial or parasitic pathogens (Salmonella for turtles, Giardia or E. coli for well water use), enterohemorrhagic E. coli with unpasteurized milk and cattle exposure.

5. Has she been immunized? Parental refusal to immunize or other barriers to immunization increase likelihood of infectious causes for her symptoms and concerning vital signs.

6. What are the rest of her vital signs and her examination?
   a. Fever may indicate sepsis.
   b. If she has meningeal signs (which are often not present in young infants and children), meningitis would be high on the list.

Clinical Reasoning

1. What might be some possibilities that would explain this child's clinical appearance? Severe gastroenteritis (viral or bacterial)
   a. Inborn errors of metabolism
   b. Bacteremia
   c. Meningitis
   d. Pneumonia
   e. Urosepsis.

2. How would you manage this child acutely?
   a. Stabilize the airway, breathing and circulation.
   b. Check blood glucose. For circulation, administer an IVF bolus of 20 ml/kg with normal saline (to expand her intravascular volume) over 20-30 minutes. Repeat as needed until clinical signs of dehydration have improved and vital signs have stabilized.
   c. Further management and investigations will depend on the clinical history and examination.
   d. For serious bacterial infections, a 'sepsis work up' including an LP should be seriously considered and IV antibiotics presumptively started.
   e. Frequent monitoring of her vital signs is important as is watching her neurologic status.
   f. Further enteral and/or parental rehydration and its rate and content would likely be incorporated based on the child's evaluation, including the estimated degree of dehydration and lab results (e.g. any dysnatremia).
   g. If vomiting and diarrhea persists, replacement fluids may be needed to prevent the child from going into hypovolemic shock.

Suggestions for Learning Activities:

- Ask the student(s) the questions listed under "clinical reasoning" to probe their thinking about the case
- Have students think about options for hydration if IV access cannot be obtained easily.
- EBM project- have students review risks and benefits of the new rotavirus vaccine in preventing morbidity and mortality in children from gastroenteritis.

Other Resources:

- The Harriet Lane Handbook – chapter on Fluids and Electrolytes and BSA nomogram in Formulary Adjunct