Fluid and Electrolyte Replacement Therapy in Children
Cases for Discussion

Case 1.

A 2½ month old female presented with a four-day history of diarrhea and a two-day history of progressive fever, rapid respirations, lethargy, irritability and decreased urine output. The product of a normal pregnancy, delivery and neonatal period, she had been well until four days prior to admission when she developed initially soft and finally liquid yellow-green stools without blood or mucous. Due to their increased frequency, a physician was consulted. All formula and solid foods were discontinued and sugar-water feedings were begun. Although the frequency of stools decreased, diarrhea continued.

Approximately two days prior to admission, the patient’s urine became dark yellow and of progressively smaller quantity. She became lethargic and irritable. Over the 24 hours prior to admission, her respirations became rapid and urine output ceased. She was seen and admitted.

On admission, the patient was a well-nourished, irritable, semi-stuporous infant with rapid, deep respirations. Vital signs included a heart rate of 180/min, respirations 36/min, blood pressure 60/40 mm Hg, and a temperature of 101.5°F. Height was 58 cm, weight was 3.6 kg. The anterior fontanelle was depressed and non-pulsatile. The eyes were sunken into their orbits and were of poor turgor. The corneas did not reflect light, and there were no tears. The mucous membranes were dry. The skin was dry and turgor was poor. Extremities were cool and modestly cyanotic. There was prolonged pallor of the nail beds following pressure, and the pulse was of poor volume.

Questions

1. In this patient, were the $U_{Na}$ and $U_{Osm}$ obtained, which of the following sets of values would you expect? Which results are most compatible with congenital adrenal hyperplasia?

<table>
<thead>
<tr>
<th></th>
<th>$U_{Na}$ (mEq/L)</th>
<th>$U_{Osm}$ (mOsm/kg H$_2$O)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A.</td>
<td>&lt; 10</td>
<td>300</td>
</tr>
<tr>
<td>B.</td>
<td>&lt; 10</td>
<td>800</td>
</tr>
<tr>
<td>C.</td>
<td>&lt; 10</td>
<td>150</td>
</tr>
<tr>
<td>D.</td>
<td>&gt; 25</td>
<td>300</td>
</tr>
<tr>
<td>E.</td>
<td>&gt; 25</td>
<td>600</td>
</tr>
</tbody>
</table>

2. What would you estimate stool water sodium concentration to be?
   A. 20-30 mEq/L
   B. 60-80 mEq/L
   C. 100-120 mEq/L
   D. 140 mEq/L or greater

3. What would you estimate his serum Na$^{+}$ concentration to be?
   A. 122
   B. 138
   C. 161

4. Should you consider this patient’s condition to merit immediate therapy, which of the following fluids would you select for rapid intravenous administration?
   A. Isotonic saline
   B. ¼ normal saline
   C. ½ normal saline
   D. 5% saline
5. On clinical grounds, what would you estimate this patient’s degree of “dehydration” (expressed as a percent of wet body weight) to be?
   A. 0-5%
   B. 5-10%
   C. 10-15%
   D. greater than 15%

Laboratory studies included a hematocrit of 43% and a white blood cell count of 12.5 thousand. Urinalysis revealed dark yellow, clear urine. There was 1+ protein (30 mg/dl) but no acetone or sugar. The sediment contained 3-5 WBC, 0-2 RBC and numerous hyaline casts. Serum sodium was 122, potassium 5.6, CO₂ 12, and chloride 100 mEq/L. The serum creatinine was 0.4 and the BUN 40 mg/dl. Blood sugar was 90 mg.

6. Calculate the patient’s effective osmolality.
   A. 244 mOsm/kg H₂O
   B. 254 mOsm/kg H₂O
   C. 263 mOsm/kg H₂O
   D. 285 mOsm/kg H₂O

Would the osmolality recorded on an osmometer, when compared with your calculation above, be
   A. Higher?
   B. Lower?
   C. Approximately the same?

7. In view of the laboratory results, would you revise your estimate of this patient’s dehydration?
   A. Original estimate correctly assessed losses.
   B. Original estimate underestimated losses.
   C. Original estimate overestimated losses.

8. Assuming a wet weight of 4.0 kg and a serum sodium of 145 mEq/L when normally hydrated, calculate the following. (Assume hydrated ECF and ICF to be 30 and 40% of body weight.)
   A. Total water loss or gain (ANS 0.4 L lost)
   B. Total sodium loss of gain (ANS 113 mEq lost)

9. Considering the patient’s surface area (or other method) what would be the value you would expect for normal losses of water and Na⁺/24 hours from each of the following sources during the period of fluid replacement?
   A. Insensible losses from skin
   B. Insensible losses from lung
   C. Normal urinary water loss

In view of this patient’s clinical situation, would you revise any of the above estimates? If so, indicate your revised estimates.

10. Which of the following statements most accurately reflects this patient’s total potassium balance?
   A. Since the serum potassium is increased, total body potassium is increased.
   B. Although the patient’s serum potassium is increased, total body potassium is decreased.
   C. Despite the increased serum potassium, total body potassium is normal.

11. If this were your patient, what would be the composition of the fluid you would choose (exclude acid-base requirements) and what would be your plan of rehydration?

BONUS QUESTION

12. Since this patient’s stool, urine, and insensible losses are hypotonic, explain his hyponatremia.
Case 2.
An 18-year-old college freshman acutely developed severe nausea, vomiting and water diarrhea six hours after a fraternity party. He recalls eating potato salad, sandwiches and draft beer. His symptoms persisted for 18 hours, during which his oral intake was limited to small amounts of water and soft drinks. He had not voided for six hours. On examination, he was mildly lethargic. His weight was 63 kg, blood pressure 110/70 mm Hg supine and 60/40 mm Hg sitting. His pulse was 110/min and his tongue was dry. Skin turgor was reduced and his extremities were pale and cool.

Questions
1. What would you estimate stool water sodium concentration to be?
   A. 20-30 mEq/L
   B. 60-80 mEq/L
   C. 100-120 mEq/L
   D. 140 mEq/L or greater

2. What would you estimate gastric sodium concentration to be?
   A. 20 mEq/L
   B. 40 mEq/L
   C. 80 mEq/L
   D. 100 mEq/L

3. What would you estimate his serum Na\(^+\) concentration to be?
   A. 122
   B. 138
   C. 161

4. Should you consider this patient’s condition to merit immediate therapy, which of the following fluids would you select for rapid intravenous administration?
   A. Isotonic saline
   B. ¼ normal saline
   C. ½ normal saline
   D. 5% saline

5. On clinical grounds, what would you estimate this patient’s degree of dehydration (expressed as a percent of wet body weight) to be?
   A. 0-5%
   B. 5-10%
   C. 10-15%
   D. greater than 15%

   Laboratory data included hematocrit of 50%, creatinine 1.4 and BUN 25 mg/dl, sodium 138, potassium 3.8, CO\(_2\) 29, and chloride 96. Urine specific gravity was 1.030 and the sediment was normal.

6. In view of the laboratory results, would you revise your estimate of this patient’s dehydration?
   A. Original estimate correctly assessed losses
   B. Original estimate underestimated losses
   C. Original estimate overestimated losses
Case 3
A three-month-old male was well until three days prior to admission when he began to regurgitate two to five minutes after each feeding of cereal and Enfamil. His stools remained yellow and formed at a frequency of two each day. His symptoms persisted over 36 hours and he became irritable. Over the last 18 hours, he became progressive lethargic.

The patient was acutely ill, irritable, lethargic and intermittently experienced myoclonic jerks. The weight was 3.5 kg, height 58.5 cm, heart rate 190/min, respirations 48/min, and blood pressure 100 (flush). Skin turgor was moderately diminished and “doughy.” The mucous membranes were parched and the fontanelle was depressed. The extremities were warm but mottled.

Questions
1. What would you estimate his serum Na\textsuperscript+ concentration to be?
   A. 122  
   B. 138  
   C. 151  

2. On clinical grounds, what would you estimate this patient’s degree of dehydration (expressed as a percent of body weight) to be?
   A. 0-5%  
   B. 5-10%  
   C. 10-15%  
   D. greater than 15%

3. Should you consider this patient’s condition to merit immediate therapy, which of the following fluids would you select for rapid intravenous administration?
   A. Isotonic saline  
   B. \(\frac{1}{4}\) normal saline  
   C. \(\frac{1}{2}\) normal saline  
   D. 5% saline

Laboratory data included a hematocrit of 31%. Urinalysis revealed 3+ protein and a normal sediment. Creatinine was 1.8 and BUN 41 mg/dl. Sodium was 178, potassium 4.2, CO\textsubscript{2} 24 and chloride 108 mEq/L. Calcium was 6.2 mg/dl.

4. In this patient, were the U\textsubscript{Na} and U\textsubscript{Osm} obtained, which condition would you suspect with each U\textsubscript{Na} and U\textsubscript{Osm} given? (Match)

<table>
<thead>
<tr>
<th>Volume depletion</th>
<th>U\textsubscript{Na} (mEq/L)</th>
<th>U\textsubscript{Osm} (mOsm/kg H\textsubscript{2}O)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acute renal failure</td>
<td>8</td>
<td>880</td>
</tr>
<tr>
<td>Diabetes insipidus</td>
<td>38</td>
<td>295</td>
</tr>
</tbody>
</table>

5. In view of the laboratory results, would you revise your estimate of this patient’s dehydration?
   A. Original estimate correctly assessed losses  
   B. Original estimate underestimated losses  
   C. Original estimate overestimated losses

BONUS QUESTIONS
6. Assuming that no electrolytes were lost from vomiting and urine losses were negligible (due to ECF contraction), calculate the water deficit (assume TBW=0.7 and ICF is 35% of wet body weight).
   Ans: 0.62 L
Fluid and Electrolyte Replacement Therapy in Children

Answer Sheet

Case 1.
1. values anticipated with volume depletion: B; values compatible with CAH: E
2. A
3. A
4. A
5. C
6. A, A
7. C
8. (a) 0.4 L (400 ml); (b) 10 mEq
9. H₂O Na
   (a) ~500 ml/m² X 0.25 m² = 125 ml/24 hr 0
   (b) ~ 250 ml/m² X 0.25 m² = 64 ml/24 hr 0
   (c) ~ 750 ml/m² X 0.25 m² = 188 ml/24 hr < 10 mEq/24 hr
10. B
11. For discussion
12. For discussion

Case 2.
1. A
2. B
3. B
4. A
5. B
6. A

Case 3.
1. C
2. C
3. A
4. |       | U_Na | U_Osm |
   |——-|------|------|
   | volume depletion | 8    | 880  |
   | acute renal failure | 38   | 295  |
   | diabetes insipidus | 5    | 330  |
5. B
6. For discussion
Fluid and Electrolyte Replacement Therapy in Children

I Maintenance fluid and electrolyte therapy
a) Sources of water and electrolyte loss
   i) Insensible losses are fixed (not homeostatically controlled) and account for 50% of normal water losses
      (1) Skin: transdermal loss is responsible for 2/3 of total insensible loss and average 500 ml/m²/24 hours. Fever increases skin loss by 12% for each degree Centigrade. Environmental humidity does not change skin loss. Electrolyte (sodium [Na] and potassium [K]) losses are negligible.
      (2) Lungs: pulmonary loss changes with metabolic rate and ventilation. Normal losses average 300 ml/m²/24 hours. Hyperventilation increases losses by 20-80% depending on intensity. Hyperpyrexia increases losses by 12% for each degree Centigrade. High humidity (e.g. humidified, mechanical ventilation) decreases losses by 50-80%. Electrolyte losses are negligible.
   ii) Renal losses
      (1) Water losses. Obligatory renal water loss (i.e. non-homeostatically controlled water loss necessary to maintain solute balance) is determined by solute excretion and renal concentrating capacity.
         a) Solute (urea and electrolyte excretion). Urea excretion is dictated by protein intake. Thirty-five percent of dietary protein is converted to urea. The molecular weight of dietary protein is 60 grams, and the molecule does not dissociate osmotically. Thus, the contribution of urea to solute excretion can be estimated:

         \[
         \text{Milliosmoles of urea} = \frac{\text{protein intake (mg/day)} \times 0.35}{60 \text{ mg/milliosmole}}
         \]

         Electrolyte excretion must equal dietary intake. Sodium chloride is the major urinary electrolyte contributing to osmolality. The molecular weight of NaCl is 58 grams. The osmolar weight is one-half the molecular weight (NaCl dissociates into two osmotically active particles). Thus:

         \[
         \text{Milliosmoles of NaCl} = \frac{\text{NaCl intake (mg/day)}}{29 \text{ mg/milliosmole}}
         \]

         For practical purposes, an average dietary solute load is 600 mOsm/m²/day. This would decrease with anorexia, nausea or vomiting. The solute load from endogenous catabolism during starvation is 200 mOsm/m²/day.

         b) Renal concentrating capacity. Maximum urine osmolality is 1400 mOsm/L. On a usual water intake, average osmolality is 800 mOsm/L. Total obligatory water loss of the mature kidney averages 600-800 ml/m²/day. Maximum renal concentrating capacity decreases in the newborn (700 mOsm/L), during renal failure (300 mOsm/L) and in diabetes insipidus (100 mOsm/L). Thus, obligatory daily renal water losses vary widely.

         For the normal child with an average solute and water intake:

         \[
         \frac{600 \text{ mOsm/m²}}{800 \text{ mOsm/L}} = 0.75 \text{ L/m²}
         \]

         For the child with chronic renal failure (urine SG 1.010 or 300 mOsm/L) (or during an osmotic diuresis) who receives an average solute intake:

         \[
         \frac{600 \text{ mOsm/m²}}{300 \text{ mOsm/L}} = 2.0 \text{ L/m²}
         \]
For the child with diabetes insipidus on an average solute intake:

\[
\begin{align*}
600 \text{ mOsm/m}^2 \\
100 \text{ mOsm/L} &= 6.0 \text{ L/m}^2
\end{align*}
\]

For the normal child on IV D5W with post-op SIADH:

\[
\begin{align*}
200 \text{ mOsm/m}^2 \\
800 \text{ mOsm/L} &= 0.25 \text{ L/m}^2
\end{align*}
\]

For the normal child on no solute and a restricted water intake:

\[
\begin{align*}
200 \text{ mOsm/m}^2 \\
1400 \text{ mOsm/L} &= 0.14 \text{ L/m}^2
\end{align*}
\]

These are consequential when managing the normal child with SIADH or the child with abnormal renal concentrating capacity.

(2) Electrolyte losses. Renal electrolyte excretion must balance electrolyte intake to maintain body balance. There is essentially no requirement for sodium intake, since sodium excretion becomes negligible 24-48 hours after dietary restriction. Potassium reabsorption, however, is less complete, and excretion averages 40-60 mEq/m²/24 hours (2-3 mEq/kg/24 hours) despite dietary potassium restriction

iii) Stool losses

(1) Water losses. Normal stool losses average 50 ml/m²/24 hours. When diarrhea occurs, stool water losses increase. Stool weights provide useful guides to stool water loss.

(2) Electrolyte losses. Normal sodium losses are negligible. Stool water sodium concentration seldom exceeds 20 mEq/L. With viral diarrhea, concentrations average 20-30 mEq/L; they approach 60 mEq/L with bacterial diarrhea. In secretory diarrhea (e.g. cholera) sodium concentration approaches 140 mEq/L. Potassium losses are usually negligible. Concentrations are normally < 10 mEq/L.

iv) Sweat. Under usual hospital environmental temperature, this abnormal loss does not occur.

(1) Water and electrolyte replacement

(a) Water. The volume of water necessary to maintain hydration may be estimated from the normal sources of water loss adjusted for the influences of metabolic rate, ambient temperature and humidity, ventilatory rate and osmotic load. Average losses per square meter:

<table>
<thead>
<tr>
<th>Sources of Water Loss</th>
<th>ml/m²/24 hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>Insensible losses</td>
<td></td>
</tr>
<tr>
<td>Skin</td>
<td>500</td>
</tr>
<tr>
<td>Lungs</td>
<td>300</td>
</tr>
<tr>
<td>Stool</td>
<td>50</td>
</tr>
<tr>
<td>Renal</td>
<td>800</td>
</tr>
<tr>
<td>Sweat</td>
<td>0</td>
</tr>
<tr>
<td>Total losses</td>
<td>1650</td>
</tr>
<tr>
<td>Water oxidation</td>
<td>-150</td>
</tr>
<tr>
<td>Maintenance requirement</td>
<td>1500 ml/m²/24 hours</td>
</tr>
</tbody>
</table>

(b) Electrolytes

(i) Sodium. Normal extrarenal losses of water contain virtually no sodium. When renal function is normal, urinary conservation of sodium is complete. Traditionally, small amounts are given, but this should be considered with each patient.

(ii) Potassium. Potassium losses are confined to renal excretion. Potassium conservation is incomplete despite dietary potassium restriction, and 40-60 mEq/m²/24 hours (2-3 mEq/kg/24 hours) must be replaced
II Fluid and electrolyte deficits in “dehydration”
Two conditions with different pathological physiologies, different clinical presentations and different specific treatments are both frequently referred to as “dehydration.” The two pure entities are (1) loss of sodium chloride with contraction of ECF volume and (2) primary water loss. Both entities occur clinically, but they are uncommon. The term “dehydration” in the usual clinical vernacular refers to a combined loss of water and sodium chloride. Fluid and electrolyte replacement depends on recognition and replacement of both losses.

a) Estimation of water deficit
i) Based on documented weight loss. When accurate body weight prior to dehydration is known, acute weight changes are assumed due to water loss and can be translated into water deficit assuming that 1 gram of weight lost equals 1 ml of water lost. Thus, for a 4.0 kg child who presents with a dehydrated weight of 3.6 kg:

\[ \text{H}_2\text{O deficit} = \text{hydrated weight} - \text{dehydrated weight} \]
\[ = 4.0 \text{ kg} - 3.6 \text{ kg} \]
\[ = 0.4 \text{ kg, or} \]
\[ = 400 \text{ ml} \]
This calculation is seldom possible, and water loss must be estimated on the basis of physical signs.

ii) Based on clinically estimated weight loss
(1) Signs of clinically estimated weight loss
(a) Mild dehydration (3-5%). The sensorium is clear, blood pressure and pulse are normal, skin and ocular turgor are normal or only mildly decreased, and mucous membranes are dry. Historically, the urine output has been normal.
(b) Moderate dehydration (6-10%). The patient is lethargic but irritable on mild stimulation. The pulse may be elevated, but the blood pressure is normal until 10% lost when orthostatic hypotension occurs. As the water loss increases, skin turgor progressively decreases and mucous membranes progress from “tacky” to dry. Ocular turgor is diminished, and the eyes and fontanelles appear “sunken.” Extremity hypoperfusion is progressive, and increasing capillary refill time, pallor and “coolness” occur as losses approach 10%. Historically, urine output is diminished. If present, anion gap metabolic acidosis is mild (CO\(_2\) > 15 mEq/L).
(c) Severe dehydration (11-15%). The patient is responsive only to painful stimuli. Tachycardia, supine hypotension, and decreased central venous pressure are invariable. Urine output has not been observed for 8-10 hours. Acidosis is severe (CO\(_2\) < 15 mEq/L). There is an abnormal anion gap.
(d) Extreme dehydration (> 15%). The patient is unresponsive to painful stimuli and there is cardiovascular collapse, anuria (estimated clinically) and severe acidosis (total CO\(_2\) < 10 mEq/L).

b) Estimation of intracellular (ICF) water losses. The physical signs of “dehydration” reflect decreases in ECF. ICF losses cannot be estimated from the clinical findings, but decreases or increases in the ICF water are essential in your estimation of total body water losses. Changes in ICF water are reflected by the serum sodium concentration. The cell membrane is freely permeable to water, and water movement across this membrane is determined by transient differences in the osmolalities of the extracellular and intracellular fluids. Water movement continues until the osmolalities of the two compartments are again equal. Since the major component of osmolality in the ECF is sodium, the serum sodium concentration is an accurate index of osmolality (and of ICF water content). Water moves down its concentration gradient. Water “concentration” is inferred from the concentration of sodium (i.e. when the sodium concentration is low, water concentration is high). The following figures illustrate the distribution of total body water in isotonic (a) hypotonic (b) hypertonic (c) volume depletion where the ECF water loss is identical (~10% indicated by crosshatch).
Estimating ICF volume from the plasma Na$^+$

EWL   ECF             ICF

A

<table>
<thead>
<tr>
<th>Na 140</th>
</tr>
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<tbody>
<tr>
<td>Osm 280</td>
</tr>
</tbody>
</table>

B

<table>
<thead>
<tr>
<th>Na 120</th>
</tr>
</thead>
<tbody>
<tr>
<td>Osm 240</td>
</tr>
</tbody>
</table>

C

<table>
<thead>
<tr>
<th>Na 160</th>
</tr>
</thead>
<tbody>
<tr>
<td>Osm 320</td>
</tr>
</tbody>
</table>

WL: 10% ECF volume water loss as judged by clinical examination
IWF: gain in water by the ICF
IWL: loss of water by the ICF

i) Isotonic (isonatremic) dehydration. The serum sodium concentration (equivalent to osmolality) is normal, water concentration is normal, no water movement occurs, and the ICF volume is unchanged (normal). The water deficit is confined to the ECF, and total body water loss is accurately estimated from the physical findings.

ii) Hypotonic (hyponatremic) dehydration. The serum sodium concentration is low (< 132 mEq/L), water concentration is high, and water concentration moves down its concentration gradient from the extracellular to the intracellular fluid compartment. Thus, the “% dehydration” determined by physical findings reflects a decrease in ECF water due to both the loss of water to the outside (e.g. from diarrheal losses) and the loss of water to the ICF. Thus, the physical findings “overestimate” true losses of today body water, and the deficit is less than the estimate based on physical findings.

iii) Hypertonic (hypernatremic) dehydration. The serum sodium concentration is high (> 145 mEq/L), water concentration is low, and water moves down its concentration gradient from the intracellular to the extracellular fluid compartments. The “% dehydration” estimated by examination reflects ECF losses to the outside, but these have been partially mitigated by the movement of water into the ECF from ICF. Losses from the ICF are large (actually twice those of the ECF). This “underestimates” the true loss of water, and the deficit is more than the estimate suggests.

c) Estimation of total body water loss. Using the percent weight loss and the weight of the dehydrated patient at presentation, the absolute water loss can be calculated:

\[
\text{Hydrated weight (kg)} = \frac{\text{dehydrated body weight (kg)}}{1 - \text{weight loss}^*}
\]

\[
\text{Water loss (L)} = \text{hydrated} - \text{dehydrated weight (kg)}
\]

*% weight loss expressed as a decimal (e.g. 10% = 0.10)

For example, were the dehydrated weight 3.6 kg and the % weight loss determined by examination to be 10%,

\[
\text{Hydrated weight} = 3.6 \text{ kg} = \frac{3.6 \text{ kg}}{1 - 0.1*} = 4.0 \text{ kg}
\]

\[
\text{Water loss} = 4.0 - 3.6 = 0.4 \text{ kg (L) = 400 ml}
\]
d) Estimation of sodium deficits. The sodium deficit must be estimated from both the loss of body water and the change in serum sodium concentration. Specifically, the total body sodium and the estimated normal total body water) minus the total body sodium dehydrated (calculated from the plasma sodium during dehydration and the total body water minus the water loss sustained during dehydration.

i) Isotonic (isonatremic) dehydration. When the serum sodium concentration is normal, no water movement has occurred, and all fluid lost from the body has been sustained by the ECF. The sodium loss is the product of the estimated volume of water lost at the normal serum sodium concentration. Thus, the water deficit can be replaced quantitatively by normal saline.

ii) Hypo- and hypertonic (natremic) dehydration. In either of these states, the sodium deficit is the consequence of a change in both the ECF volume and sodium concentration. Sodium loss equals the difference in sodium contents of the normal ECF and of the dehydrated ECF. Fortunately this estimate is made easily based on valid assumptions.

1) The number of particle (osmoles) in the ICF does not change. This is true unless the sodium-potassium pump fails to keep these ions distributed normally (i.e. the cell dies). Thus, the decrease in total body osmoles is confined to the ECF. Since ECF osmoles are primarily sodium, the osmolar loss equals the sodium loss.

2) The normal serum sodium concentration can be estimated between 135-145 mEq/L.

3) The normal total body water can be estimated in the normally hydrated state (see table). Changes in volume of total body water and extracellular space with growth as a function of body weight (from B. Friis-Hansen and I.S. Edelman et al.)

<table>
<thead>
<tr>
<th>Age</th>
<th>Total Body Water (as a % of body weight)</th>
<th>Extracellular Space (as a % of body weight)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-1 days</td>
<td>77</td>
<td>42</td>
</tr>
<tr>
<td>11-120 days</td>
<td>73</td>
<td>34</td>
</tr>
<tr>
<td>½ - 2 years</td>
<td>62</td>
<td>27</td>
</tr>
<tr>
<td>2-7 years</td>
<td>63</td>
<td>25</td>
</tr>
<tr>
<td>10-15 years (male)</td>
<td>59</td>
<td>20</td>
</tr>
<tr>
<td>12-15 year (female)</td>
<td>56</td>
<td>20</td>
</tr>
<tr>
<td>17-34 years (male)</td>
<td>61</td>
<td>18</td>
</tr>
</tbody>
</table>

4) The dehydrated total body water can be determined by subtracting the estimated water loss (see above) from the normal today body water. Sodium deficit (in either hyper- or hyponatremia) can be estimated using the equation:

\[
\text{Osmolar (Na) loss} = \text{TBS}_H - \text{TBS}_D = [\text{TBW}_H \times P\ Na_H] - [(\text{TBW}_H - \text{TBW}_D) \times P\ Na_D]
\]

Where: TBS is total body solute (expressed here for convenience as mEq Na)

TBW is total body water

P Na is plasma sodium concentration

H indicates the hydrated state

D indicates the dehydrated state

For example, were the 3.6 kg infant described above to present with a plasma sodium of 122 mEq/L, his sodium loss could be estimated using your estimates of hydrated weight (HW) (4.0 kg) and weight loss (WL) (0.4 L) and normal (hydrated) values for total body water (73% of HW) (from table) and serum sodium (140 mEq/L):

\[
\begin{align*}
\text{TBS}_H &= \text{TBW}_H \times P\ Na_H = (\text{HW} \times 0.73) \times P\ Na_H \\
&= (4.0\ \text{kg} \times 0.73) \times 140\ \text{mEq/L} = 408.8\ \text{mEq} \\

\text{TBS}_D &= [\text{TBW}_H - \text{TBW}_D] \times P\ Na_D = [(\text{HW} \times 0.73 - \text{WL}) \times P\ Na_D] \\
&= (2.02\ \text{L} - 0.4\ \text{L}) \times 122\ \text{mEq/L} = 307.4\ \text{mEq} \\
\text{Na loss} &= \text{TBS}_H - \text{TBS}_D = 408.8 - 307.4 = 101.4\ \text{mEq}
\end{align*}
\]
e) Estimation of potassium (K) deficit. The deficit of total body potassium is impossible to calculate. The ECF concentration represents only 10% of total body K and only grossly reflects changes in total body K. Further, it is disproportionately increased or decreased with ECF acidosis or alkalosis, respectively. In the absence of an acid-base disorder, a 1 mEq/L reduction in serum potassium reflects a total body deficit of 100-200 mEq of K for an average adult. Further decrements reflect greater total body losses (200-400 mEq) per each additional 1 mEq/L decrease in serum K. Similar estimates do not exist for children, an extrapolation based on weight or surface area are of unknown validity.

III Abnormal “ongoing” losses.” One must always consider the possibility that the losses of fluid and solute that generated the state of dehydration will continue.

a) Gastrointestinal losses. In most diarrhea, the defect is one of decreased absorption, and diarrhea ceases once oral intake ceases. Secretory diarrhea, however, produces losses which continue during the period of rehydration. These must be replaced quantitatively. Usually, the water content can be determined using diaper weights, and the sodium and potassium content of stool water can be measured directly. Similar measurements can be made from gastric or intestinal drains.

b) Urinary losses. Abnormal urinary losses are inconspicuous, and nursing or maternal observations virtually never direct attention to them. These losses usually continue during the period of rehydration, and they can be responsible for unexpected failures in volume expansion or in the correction of electrolyte abnormalities. Osmotic diureses, complicating diabetes mellitus or relief of urinary obstruction, are usually expected. Those due to previously unrecognized diabetes insipidus or poor concentrating capacity in the child with chronic renal failure (particularly due to developmental obstructive uropathy or renal dysplasia) may be very occult. Once recognized, they should be replaced quantitatively by measuring urine volume and urinary electrolyte concentrations. Since these children often undergo surgical procedures requiring parenteral fluids, preoperative measurements of urine volume and electrolytes permits prospective placement during the pre- and postoperative period.

IV Plan of therapy

a) Volume and composition of fluids

i) Isotonic dehydration. Fluid deficit must be considered isotonic saline while maintenance fluids should be considered essentially sodium free. Calculation would determine the appropriate sodium concentration. Unless K depletion is significant at presentation, K should not be added until urine output is assured. With a history of anorexia, prolonged diarrhea and documentation of marked acidosis, K supplementation should be given at the outset, despite a “normal” serum K concentration. Replacement of severe K depletion requires 60-80 mEq/m²/day (3-4 mEq/kg/day). Except in unusual circumstances, IV fluid concentrations should not exceed 40 mEq/L. If a deficit is not suspected, maintenance K averages 40-60 mEq/m²/day (1-2 mEq/kg/day). Oral replacement is safer than intravenous if it can be tolerated.

ii) Hypotonic dehydration. The primary defect in this type of dehydration is sodium depletion. Once sodium depletion (and volume replacement) has been corrected, renal water excretion will return the plasma sodium to normal. The deficit of sodium and water and maintenance fluids (free of sodium) should be added, and the final calculation will dictate the sodium concentration. The same considerations apply with regard to potassium.

iii) Hypertonic dehydration. The deficits and maintenance fluids should be added as for hypotonic dehydration. The potential for CNS complications (e.g. seizures) necessitates special consideration (see below).

b) Rate of administration

i) Immediate resuscitation. When peripheral vascular collapse occurs due to ECF constriction, normal saline should be given IV “push” at a dose of 10-20 ml/kg. Blood pressure, heart rate and, if available, central venous pressure measurements should be monitored during
administration to determine both rate and final dose. This approach is necessary before the serum sodium is known, and is appropriate for iso-, hypo-, and hypertonic dehydration.

ii) Rehydration

(1) Isotonic and hypotonic dehydration. Unless dehydration is severe, the rate of administration is determined by the volume of fluid to be replaced each 24 hours. Conventionally, in mild and moderate dehydration, two-thirds of deficit fluids (plus daily maintenance) are replaced during the first 24 hours and one-third of deficit fluid (plus daily maintenance) are replaced during the second 24 hours. In severe dehydration, fluid may be administered at a rate of 6-8 ml/m² for the first 2 hours and at 3-4 ml/m² for the next 2-6 hours. Thereafter, the rate should insure administration of the remaining fluid over the next 18 hours.

(2) Hypertonic dehydration. Rapid correction of hypernatremia in this setting often induces central nervous system irritability, and replacement requires special consideration. The lowest frequency of seizures occurs when the serum sodium falls by < 0.5 mEq/L/hr (12 mEq/24 hr), and the water deficit should be replaced over a period of time calculated to insure less than this rate of change. (Obviously, maintenance fluids will be repeated each 24 hours during the period of water deficit replacement.) The serum sodium should be determined within 4-6 hours of rehydration, and the rate of deficit water replacement should be adjusted as necessary.

c) Evaluation of therapy. It should be reemphasized that there is no laboratory value that may be used to estimate sodium or water deficit or surfeit. Determinations are ultimately based on clinical estimations of weight loss. All subsequent calculations must be considered appropriate as guidelines for therapy. Consequently, the evaluation of fluid therapy depends on serial re-estimations of clinical parameters of salt and water balance as therapy progresses.

i) Parameters for regular assessment:

(1) Serial, accurate measurements of body weight
(2) Blood pressure, heart rate and CVP (if available)
(3) Hydration (skin turgor, cap refill, etc.)
(4) Urine output (Adequate output should be achieved by 6-8 hours. Absence of output in excess of 12 hours suggests acute renal failure.)
(5) Serum electrolytes, creatinine, and BUN.

ii) Recommendations

(1) During the first day of rehydration, orders should not be written for more than 6 hours in advance

(2) After 6 hours of rehydration, reevaluation of clinical parameters is essential. If improvement is not consonant with expectations, calculation of maintenance fluid requirements and of the fluid deficit should be reviewed and sources of “ongoing” losses should be sought. If gross differences between anticipated and actual improvement are found, severe metabolic, renal, adrenal or posterior pituitary dysfunction should be suspected.

(3) Fluid orders for the next 6-12 hours should be written based on calculations for maintenance fluid and deficit fluid corrected for the experience gained over the first 6 hours of observations.