I. Overall Principles
   A. Listen for the history.
   B. Examine the Patient.
   C. Don’t forget the ABCs:  
      A – Airway  
      B – Breathing  
      C – Circulation – Requires Volume
   D. The faster you are treating abnormalities (volume or electrolyte), the more often you need to check the patient’s progress to reassess the accuracy of your predictions.
      1. All the calculations made are estimates.
      2. Accuracy of all estimates must be checked by clinical observation of the patient.
   E. Use fluids which are pre-mixed commercially whenever possible.
      1. less expensive  
      2. less opportunity for error  
      3. quicker
   F. Becoming more facile with fluid management will lead to better outcomes.
      1. This does not have to be difficult.

II. Maintenance Fluids
   A. H₂O is generated in the process of metabolism.
      1. Metabolism produces:  
         Heat – regulation requires H₂O  
         Solute – excretion requires H₂O
      2. Metabolic Rate is related to Surface Area and to Weight
      3. Metabolic Rate (kcals/day) approximates Fluid Need (cc/day)
   B. Holliday-Segar Method to calculate metabolic rate for “normal” patients at rate
      1. weight  
      2. caloric expenditure/24 hours
      0-10 kg  
      >10-20 kg  
      >20 kgs
      100 kcals/kg  
      1000 kcals+ 50 kcals/kg for the increment>10kgs  
      1500 kcals+ 20 kcals/kg for the increment> 20kgs

   2. H₂O need = 1 cc H₂O per kcal energy expended.
   C. Maintenance calculation by Holliday-Segar assumes:
      1. fluid losses are “normal” and equal 1 cc/ estimated 1 kcal
         a. insensible losses: respiratory =15% of total skin =30%
         b. urinary losses =55%
   D. Alterations in “maintenance” requirement:
      1. fever – 12% increase for each degree (Celsius) above 38.
      2. activity – 0-30% increase
      3. tachypnea, hyperpnea
      4. anuria
         fixed inability to make urine
5. obligate polyuria
   requires more urine to clear each mOsm of solute
6. VLBW infants
   Decreased skin integrity
   Increased S.A./weight ratio

E. Maintenance Electrolyte Requirements
1. Na 2-4 mEq/100cc H2O (start with 3 mEq/100cc)
2. K  2-3 mEq/100cc H2O (start with 2 mEq/100cc)
3. Cl  5-6 mEq/100cc H2O

EXAMPLE: Maintenance Requirements for 24 hours

<table>
<thead>
<tr>
<th>Weight</th>
<th>H2O</th>
<th>Na</th>
<th>K</th>
<th>IV fluid used</th>
</tr>
</thead>
<tbody>
<tr>
<td>5kg</td>
<td>500cc</td>
<td>15mEq</td>
<td>10mEq</td>
<td>D5/1/4 NS +20 KCl/L</td>
</tr>
<tr>
<td>10kg</td>
<td>1000cc</td>
<td>30mEq</td>
<td>20mEq</td>
<td>&quot;</td>
</tr>
<tr>
<td>20kg</td>
<td>1500cc</td>
<td>45mEq</td>
<td>30mEq</td>
<td>&quot;</td>
</tr>
<tr>
<td>70kg</td>
<td>2500cc</td>
<td>75mEq</td>
<td>50mEq</td>
<td>&quot;</td>
</tr>
</tbody>
</table>

III. ESTIMATING THE DEFICIT
A. History
   Guess the content of the fluid losses
   e.g. Na   K
   diarrheal losses 8mEq/100cc  6mEq/100cc
   vomiting       8mEq/100cc       12mEq/100cc
   NB these are estimates! The ranges are wide.

B. Physical Exam including BP
   Goals: 1. Assess for signs of Shock
      Definition: failure to deliver oxygen and nutrients to tissues
      Sx: decreased alertness – poor brain perfusion
           decreased urine flow – poor renal perfusion
           decreased bowel sounds – poor gut perfusion
           capillary refill time > 2 seconds
           poor peripheral pulses
   2. Estimate degree of dehydration
      See chart next page

NB, BP may not decrease, and may actually increase as volume depletion progresses

<table>
<thead>
<tr>
<th>% decrease in body weight</th>
<th>Estimating Volume Depletion</th>
</tr>
</thead>
<tbody>
<tr>
<td>(infant and older children)</td>
<td>“mild” “mod” “severe”</td>
</tr>
<tr>
<td>3-5%</td>
<td>alert, normal</td>
</tr>
<tr>
<td>6-10%</td>
<td>irritable, obtunded</td>
</tr>
<tr>
<td>&gt;10%</td>
<td>decreased, very decreased</td>
</tr>
<tr>
<td></td>
<td>sunken</td>
</tr>
<tr>
<td></td>
<td>sunken/pt supine</td>
</tr>
<tr>
<td></td>
<td>high s.g.</td>
</tr>
<tr>
<td></td>
<td>very high s.g.</td>
</tr>
<tr>
<td></td>
<td>dark, muddy</td>
</tr>
<tr>
<td></td>
<td>decreased volume</td>
</tr>
<tr>
<td></td>
<td>scant volume</td>
</tr>
<tr>
<td></td>
<td>little or none</td>
</tr>
</tbody>
</table>
BP/HR  
nml/sl increased nml/very high  v. low/very high

Peripheral pulses  
nml weak not palpable

Estimated deficit (volume)  
30-50cc/kg  
60-100cc/kg  
>100cc/kg

NOTE: These sx will overestimate dehydration if the pt is hyponatremic. These sx will underestimate dehydration if the pt is hypernatremic.

IV. To Prescribe Fluids—
calculate and give:
A. Maintenance fluids – adjusted for individual differences
B. Deficit Replacement fluids – estimated from PE and history type of loss
C. Replacement for any ongoing losses
   1. e.g. continued diarrhea or NG tube drainage
D. Readjustment after lab values are known, and after follow-up confirms or alters your estimates

When the pt is >3-5% dehydrated, always check electrolytes stat

V. Choosing a rate of fluid administration:
A. If the pt is poorly perfused, i.e. there are sx of shock:
   1. give 20cc/kg of isotonic fluid as rapidly as possible
   2. repeat as necessary to establish perfusion

B. Next choose a rate and composition which will:
   1. replace the deficit early in the 24 hour period (4-8 hours)
   2. use available fluids (see chart)
   3. e.g. –
      • ½ the deficit plus ½ the maintenance over 8 hours, then the remaining ½ deficit and ½ maintenance over the next 16 hours, or
      • the whole deficit over 8 hours, then the whole day’s maintenance over 16 hours
   4. NB – plans may need to be changed after the electrolyte values are known

C. Replacement of K+ and HCO₃ may take longer than the replacement of volume
D. Do not start K+ replacement until urine flow is established
### Available IV Fluids

<table>
<thead>
<tr>
<th>Glucose g/L</th>
<th>Na mEq/L</th>
<th>Cl mEq/L</th>
<th>K mEq/L</th>
<th>mOm/L</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Isotonic Fluids:</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Normal Saline</td>
<td>0</td>
<td>154</td>
<td>154</td>
<td>0</td>
</tr>
<tr>
<td>Ringer’s Lactate</td>
<td>0</td>
<td>130</td>
<td>109</td>
<td>4</td>
</tr>
<tr>
<td>5% Albumin</td>
<td>0</td>
<td>100-160</td>
<td>&lt;120</td>
<td>0</td>
</tr>
<tr>
<td><strong>Other Fluids:</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>D$_5$W</td>
<td>50</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>D$_5$W/ ¼ NS</td>
<td>50</td>
<td>34</td>
<td>34</td>
<td>0</td>
</tr>
<tr>
<td>¼ NS</td>
<td>0</td>
<td>38.5</td>
<td>38.5</td>
<td>0</td>
</tr>
<tr>
<td>D$_5$W/ ½ NS</td>
<td>50</td>
<td>77</td>
<td>77</td>
<td>0</td>
</tr>
<tr>
<td>½ NS</td>
<td>0</td>
<td>77</td>
<td>77</td>
<td>0</td>
</tr>
<tr>
<td>25% Albumin</td>
<td>0</td>
<td>100-160</td>
<td>&lt;120</td>
<td>0</td>
</tr>
<tr>
<td>5% NaHCO$_3$</td>
<td>0</td>
<td>595</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>8.4% NaHCO$_3$</td>
<td>0</td>
<td>1000</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td><strong>Hypertonic Saline:</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3% NaCl</td>
<td>0</td>
<td>513</td>
<td>513</td>
<td>0</td>
</tr>
<tr>
<td>5% NaCl</td>
<td>0</td>
<td>855</td>
<td>855</td>
<td>0</td>
</tr>
</tbody>
</table>

**EXAMPLE:** A 10kg boy with diarrhea, has 2.5 sec cap refill, decreased skin turgor, sunken fontanel, thready peripheral pulses, scant concentrated urine in the diaper will need:

<table>
<thead>
<tr>
<th>Maintenance</th>
<th>Deficit Replacement (for 10% dehydration)</th>
</tr>
</thead>
<tbody>
<tr>
<td>H$_2$O</td>
<td></td>
</tr>
<tr>
<td>Na</td>
<td></td>
</tr>
<tr>
<td>K</td>
<td></td>
</tr>
</tbody>
</table>

**IV orders:**

D. Whenever IV fluids or oral rehydration fluids are administered for dehydration,
   1. reassess PE, UV and VS to check the accuracy of your predictions
   2. The faster the rehydration, or the more severe the fluid/electrolyte abnormality, the more often the patient needs to be reassessed.
VI. Oral Rehydration -
A. Best used in the absence of shock
   When poor perfusion is present, isotonic fluid bolus can restore perfusion, then oral rehydration can proceed.
B. Glucose is actively absorbed and Na is co-transported across gut mucosa
   1. works even in most forms of diarrhea
   2. optimal glucose transport at concentrations: glucose 2-2.5gm/L
      Na 45-90 mEq/L
   3. higher glucose concentration will exacerbate diarrhea and Na loss

<table>
<thead>
<tr>
<th></th>
<th>Na  mEq/L</th>
<th>K  mEq/L</th>
<th>base mEq/L</th>
<th>glucose gms/dl</th>
<th>Osmolality mOsm/L</th>
</tr>
</thead>
<tbody>
<tr>
<td>WHO-ORS</td>
<td>90</td>
<td>20</td>
<td>30</td>
<td>2.0</td>
<td>310</td>
</tr>
<tr>
<td>Pedialyte</td>
<td>45</td>
<td>20</td>
<td>30</td>
<td>2.5</td>
<td>270</td>
</tr>
<tr>
<td>Ricelyte</td>
<td>50</td>
<td>25</td>
<td>34</td>
<td>3.0</td>
<td>290</td>
</tr>
<tr>
<td>Lytren</td>
<td>50</td>
<td>25</td>
<td>30</td>
<td>2.0</td>
<td></td>
</tr>
<tr>
<td>Ginger ale</td>
<td>3</td>
<td>1</td>
<td>4</td>
<td>5-15</td>
<td>540</td>
</tr>
<tr>
<td>Apple juice</td>
<td>3</td>
<td>28</td>
<td>0</td>
<td>10-15</td>
<td></td>
</tr>
<tr>
<td>Gatorade</td>
<td>20</td>
<td>3</td>
<td>3</td>
<td>4.6</td>
<td>330</td>
</tr>
<tr>
<td>Tea</td>
<td>0</td>
<td>5</td>
<td>0</td>
<td>0</td>
<td>5</td>
</tr>
</tbody>
</table>

C. Instructions for Oral Rehydration
   1. Use WHO-ORS or a commercial preparation for rehydration
      i.e. to replace the deficit over 4-6 hours
   2. Then use breast milk or other lower sodium maintenance fluids for the rest of the day.
   3. Use more ORS to continue to replace ongoing losses.
   4. Restart feedings as soon as possible (?lactose-free)

D. Cautions about Oral Rehydration
   1. Should not start until shock has been treated and reversed.
   2. Some patients (<10%) will need some IV rx due to vomiting or high volume stool.
   3. All patients require monitoring (PE, serial wts) just as with IV rehydration.
   4. Improper mixing of fluids can lead to iatrogenic fluid imbalance.
   5. Some ORS doesn’t taste great.

VII. Hyponatremic Dehydration
A. Hyponatremia is seldom symptomatic unless the serum Na is <120 and occurred quickly.
   1. very rapid correction of very low Na has been associated with CPM in adults
      -central pontine myelinolysis
      -usually seen in malnourished alcoholics, although reported elsewhere.
   2. Hyponatremia can cause seizures when it is severe and sudden.
      -some recommend correction – active discussion persists.
3. Consensus – Correct low S Na quickly only when it is compromising the pt.  
-then, correct it only to 120 mEq/L

B. When there is clear dehydration with low $S_{Na}$ the sx may over-predict the degree of deficit

1. i.e. more severe sx at 5% loss than if normonatremic

C. Calculating the Na deficit

\[
Na\ deficit = (135 - \text{measured Na}) \times \text{TBW in L}
\]

TBW = total body water

Varies from 0.75 x weight in newborns to 0.5 in adults

Safe bet is to use 0.5 in all children to avoid overload

D. Note: Na deficit does not always exist when there is hyponatremia

Assess total body volume status first

If low - there is Na and H$_2$O deficit, with Na > H$_2$O

If high - there is H$_2$O excess, and probably Na excess as well

EXAMPLE: A 10 kg infant with a serum Na of 120 and 10% dehydration due to diarrhea

24 hour fluid/electrolyte needs:

<table>
<thead>
<tr>
<th></th>
<th>H$_2$O</th>
<th>Na</th>
<th>K</th>
</tr>
</thead>
<tbody>
<tr>
<td>&quot;Maintenance&quot;</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Diarrhea deficit

Extra Na deficit

VIII. Hypernatremic Dehydration – Management when Serum Na is >150 mEq/L

A. First establish perfusion (reverse shock if it is present)

1. Initial treatment of poor perfusion/shock is done as always

- rapid bolus normal saline or colloid 10-20 cc/kg, repeated if necessary

- usually in progress before electrolytes are known

B. Subsequent replacement of the deficit is done slowly

1. Goal – decrease the $S_{Na}$ no faster than 0.5-1.0 mEq/L every hour.

   A. Check to make sure there are no other factors elevating Serum somolality

   - can measure serum osm directly

   - or estimate: serum osmolality = 2 (Na) + glucose/18 +BUN/2.8

   - if other factors are elevating $S_{OSM}$ they must be treated slowly as well.

2. Even though the deficit is predominantly H$_2$O, it is safer to use fluids no more dilute than 34 mEq/L Na (1/4 NS) to replace the deficit

3. Rationale:

   - H$_2$O moves freely across all cell membranes, including blood-brain barrier.

   - when $S_{Na}$ is elevated for more than a few hours, the brain cells generate

     “idiogenic osmoles” (AA) to maintain intracellular tonicity and size

   - “idiogenic osmoles” are not diffuseable or transportable out of the cells
- sudden decrease of extracellular Na concentration will cause H₂O to enter the CNS cells suddenly, causing cerebral edema.

C. Calculating the Water deficit
3. assume that the deficit is all free water (i.e. there is no Na deficit)
4. assume that Total Body Water (TBW) is approximately 0.5 x weight (kg)
5. the H₂O deficit (in Liters) = TBW x [(measured S_{Na}/ 140) – 1]

EXAMPLE: A 10k child who has a serum Na measured at 180, and has a hx of diarrhea, vomiting and rehydration with a home brew containing table salt and water, of unknown composition, boiled.

TBW=0.5 x 10 kg = 5 kg = 5L

H₂O deficit = 5 L x (180/ 140 – 1)
= 5 L x (1.3 – 1)
= 5 L x 0.3
= 1.5 L

D. Planning the fluid resuscitation:
1. Re-establish perfusion
2. Give maintenance fluids
3. Spread the H₂O deficit replacement out over 48-72 hours, given as ¼ NS.
4. Check electrolytes frequently at first, then regularly until S_{Na} is back to <150.

IX. Abnormalities of Potassium
A. K⁺ is mainly intracellular – 90% of total body K⁺ is intracellular
- intracellular fluid K⁺ concentration is 150mEq/L
- intravascular K⁺ accounts for only about 5% of total body K⁺

B. K⁺ Balance
1. Intake – nutritional or IV
2. Internal shifts
   a. anabolism: K⁺ taken up into cells
      1) cellular uptake regulated by insulin, aldosterone, beta-agonists
      2) 3 mEq/L K⁺ required for each 1 gm N(protein)
   b. catabolism: K⁺ released into extracellular space
   c. cell injury: Na- K ATPase is slowed – K⁺ is released into extracellular space
   d. pH shifts: K⁺ for H⁺ balance changes
      1) acidosis $\rightarrow$ K⁺ leaves cells
      2) alkalosis $\rightarrow$ K⁺ enters cells
3. Excretion
   a. Renal – depends on GFR, but is mainly a secretory function
   b. Extrarenal – GI and sweat
4. Total Body K⁺ and Serum K⁺ are not closely correlated

**It is impossible to predict accurately the size of a K⁺ deficit.**
1 mEq/L decrease may reflect 10-30% loss of total body K⁺
C. Relationship of Serum K+ to ECG changes
   1. depends on total body K+ deficit or overload
   2. Serum K+  ECG changes
      <3.0  Flat T waves, prominent U waves, S↓depression
      7.0  Peaked T waves
      7.0-8.0  Prolonged P-R interval
      8.0-9.0  Widened QRS, absent P wave
      > 9.0  Wider QRS, V Fib, arrest
   NOTE: these changes can occur at lower S↓k+ if intracellular K+ is low.

D. Hypokalemia
   1. Causes
      a. Decreased intake
      b. Renal losses
         1) intrinsic defects – e.g. Bartter’s syndrome
         2) Diuretics – thiazides and loop diuretics
         3) Renal response to GI Cl-losses and volume depletion
         4) Hyperaldosteronism
   2. Consequences
      a. muscular weakness/paralysis/respiratory failure
      b. loss of renal concentrating ability
         1) vacuolization of tubular cells
      c. myocardial conduction abnormalities
         1) exacerbation of digoxin toxicity
   3. Treatment
      a. Replacement of K+ may take longer than volume replacement
         -care should be taken not to allow worsening of hypoK during volume
          resuscitation and during correction of academia
      b. Total amount of K+ deficit will not be known until:
         1) acid-base abnormalities are fixed
         -N.B. correction of acidosis may/usually will worsen
          hypokalemia
         2) results of attempts at replacement are known

EXAMPLE: A 7 y.o. boy with Type I diabetes presents with vomiting and diarrhea for several
days. His laboratory values are as follows: Gluc-450, Na 134, K 3.2, CO₂ 8, Cl 89, BUN 75. WT
on arrival 20 kg. Weight in your office 3 weeks ago was 22 kg.

How would you calculate a:

1. Water deficit?
2. Na, K+ maintenance and CO₂ deficit?

\[
\begin{array}{c|c|c|c|c}
\text{H₂O/Vol} & \text{Na} & \text{K} & \text{Base} \\
\hline
\text{Maint} & & & \\
\text{Deficit} & & & \\
\end{array}
\]

IV Fluid Treatment Plan
E. Hyperkalemia

1. Causes
   a. increased load: 1) catabolism
      2) dietary or iatrogenic
   b. decreased excretion 1) renal failure
      2) adrenal insufficiency
      3) “K-sparing” diuretics
      4) other renal abnormalities without adrenal abn
         s/p transplantation
         obstructive uropathy
         sickle cell disease
         pseudohypoaldosteronism
   c. internal shifts 1) acidosis/ acidemia
      2) rhabdomyolysis, very vigorous exercise
      3) familial hyperkalemic paralysis
      4) drugs: succinylcholine, digoxin overdose

2. Consequences - cardiac and neuromuscular
   - severity depends on extracellular K+ level and intra-/ extra-cellular K ratio
   - more severe at lower serum levels if the intracellular K+ level is lower

3. Treatment – a 3 phase approach
   a. Stabilize the membrane effects
      1) Ca gluconate 10% 0.5-1.0 ml/kg IV slow push or
      2) Ca Cl 100mg/ml 0.2cc/ kg/ dose IV into a central or large vein
         (has been reported to burn skin on contact)
      3) effect – immediate, duration – 10 – 15 minutes
      4) may need to be repeated during the episode
   b. Shift K+ into the cells
      1) NaHCO₃ 1-2 mEq/kg (may need more if there is a big deficit)
         effect within 5-15 min, duration up to 2 hours
         do not mix with Ca-containing solutions/ flush the line
         if the pt is hypocalcemic, may cause tetany
         contributes to Na overload
      2) Glucose (to induce an endogenous insulin surge) .5-1.0 gm/kg IV over 15 min
         effect in 15-30 min, duration 4-6 hours
         if insulin is needed, use .3 units regular per gram glucose given over 2hrs
      3) Beta agonists – Albuterol inhaler by nebulizer or MDI
         effect with 1-5 min, duration 1-2 hours
         doesn’t require access, but may increase HR
   c. Remove K+ from the body
      1) increase the GFR and tubular flow rate- volume expansion
      2) diuretics – furosemide 1 mg/kg IV
-useful only if renal function is demonstrable
-**onset varies from minutes to never, duration permanent**

3) **Kayexelate enema** – 1 gm/kg mixed in sorbitol 5%
   -**onset over 2 hours, duration permanent**
   -if used PO, the effect takes much longer – up to 6-12 hours
   -exchanges 1 mEq K for 1 mEq Na
   -has caused bowel perforations in some immediately post-operative pts

4) **Dialysis**