AMERICAN COLLEGE OF EMERGENCY PHYSICIANS
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1999

Case Studies in Fluid and Electrolyte Management in the Pediatric Emergency Department Patient

Managing the fluid and electrolyte needs of acutely ill children in the emergency department can be intimidating. Children may present with simple dehydration or more complex fluid and electrolyte derangements. Prompt recognition and treatment may be necessary to prevent a catastrophic outcome. The lecturer will present cases that illustrate the evaluation and initial management of children with dehydration, hyponatremia or hypernatremia, hypoglycemia, DKA, and other acute end metabolic disorders in children.

- Describe the presenting symptoms of children with dehydration, sodium derangements, hypoglycemia, and DKA.
- Describe the emergency management of children with dehydration, sodium derangements, hypoglycemia, and DKA.

MO-51
Monday, October 11, 1999
4:00 PM - 5:55 PM
Room # N251
Las Vegas Convention Center

FACULTY

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American College of Emergency Physicians
SCIENTIFIC ASSEMBLY 1999
Las Vegas, Nevada

Case Studies in Emergency Fluid and Electrolyte Management in the Pediatric Patient

(Part I of II)

Monday - 51
4:00 pm - 5:55 pm

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CASE STUDIES in FLUID MANAGEMENT

SHOCK CASE STUDY

2 year old male is brought to the ED with 1 day history of vomiting and lethargy. She also noted to have a rash on her trunk. She had slight congestion for 2 days. Social history remarkable for being in day care.

Vital signs are BP 65/40 P: 176 RR 36 Wt is 15 kg The child is lethargic, obtunded and responds to painful stimuli only. He has glassy look to his eyes. Extremities are mottled and cool. He has scattered petechiae.

Initial management
100% 02
Peripheral access 18 or 20 gauge antecubital IV
Second catheter placed

Bolus •________________* over 5 minutes

Labs: electrolytes, BUN, Cr, glucose, CBC, blood cultures
ABG, foley

Following bolus, minimal improvement

Repeat *________________• over 10 to 20 minutes

Push antibiotics
Repeat third time if necessary

BURN VICTIM CASE STUDY

A 3 yo pulled a hot pot of water off of a stove and suffered partial and full thickness burns. Abdomen and thigh burns involve 20% of TBSA. Discuss the fluid management of this case. What fluids and how much would you give immediately? In the subsequent hours? In the first 24 hours? Wt 15 kg

- Initiate intravenous fluid therapy immediately. Two large-bore catheters are needed, one immediately. Consider central venous catheter.
- Initial stabilization: *____________________* over 10 to 30 minutes.
- After cardiovascular resuscitation; over the first 24 hours:

Lactated Ringers	4 ml x kg x %TBSA
D5W 0.45%NS	maintenance

- 50% of resuscitation fluid given in the first 8" and the remainder over the next 16"
- Avoid the addition of KCL to IV fluids in ED: hemolysis, possibility of development of renal failure
- Watch for 3% saline ("hypertonic saline") in the future

CASE (continued)
Maintenance rate fluids D5W 0.45% NS
100 ml/kg for the first 10 kg + 50 ml/kg for the next 10 kg = ________ over 24 hours
or ________ml/hr
Resuscitation fluids (lactated Ringers solution)
4 ml x kq x %TBSA = 4 ml x 15 kg x 20 = ml/24 hr

TOTAL FLUIDS (Maintenance and resuscitation)

Maintenance ________ml/hr (D10W 0.45% NS) __________ ml/hr

Resuscitation
First 8° 1200 ÷ 2 = 600; 600 ÷ 8 hrs = __________ml/hr (LR)

2nd/3rd 8 hours:1200 ÷ 2 = 600; 600 ÷ 16 __________ ml/hr (LR)

Total/Actual rate:
First 8° _____ ml/hr *plus* ______ ml/hr = __________ml/hr

2nd/3rd 8° mllhr *plus* ml/hr ml/hr

DIABETIC KETOACIDOSIS CASE STUDY

A 7 year old female presents with 2 days of progressive weakness after having one to two weeks of increased thirst. Mother also reports wt loss, and abdominal pain.

PE: awake and alert, sunken eyes, Kussmaul respirations and tachypneic.
RR: 24 BP: 75/50 P: 138 T: 99.5 Appropriate in behavior and **responds to simple** questions, obviously fatigued, appears dry with decreased skin turgor, dry mucous membranes, sunken eyes. Exam otherwise unremarkable. Wt 30 kq.

1. Fluid Management:
a. *Bolus* *________________*or until vital signs stable and patient not clinically volume depleted

Fluid and electrolyte replacement:
1. **Na+** loss approximately **10 meq/Kg**
2. Serum sodium may be falsely low: (pseudohyponatremia):

$Sodium_{corrected}$ ❑ $Sodium_{measured}$ + 1.6 x (glucose-100)/100

- Give crystalloid infusion of 0.45% normal saline with potassium salts
- If corrected sodium ≤ 140 mEq/L; replace half of the deficit over the first 16 hours and restore total deficit over 36 hours
- If corrected sodium ≥ 140 mEq/L, restore total deficit evenly over 48 hours,

b. *K+* loss approximately 10 meq/Kg
1. Replace K+ as 112 KCI and 1/2 KP04

Serum potassium (mEq/L)	Potassium in infusate (mEq/L)
<3	40-60
3 - 4	3 0
4-5	2 0
5-6	10

c. *Bicarbonate* therapy: indicated only with shock or severe acidemia (pH < 7.0)
- Can give sodium bicarbonate, 1 to 2 mEq/kg, IV over 1 to 2 hours.
- HC03 may be given as slow drip for severe acidosis

note: if one combines 1/2 NS wfth 75 mEq NaHC03, then the solution will have the same concentration of Na+ as NS but only 1/2 the chloride load.

2. **Glucose control:**
a. Insulin-R: __________ unit/kg I.V. bolus
b. Insulin drip __________ unit/kg/hr
c. Add 5% dextrose if glucose <250 mg/dl (or if your really busy, <300 mg/dl) and possibly decrease insulin to 0.05 units/kg/hr

3. Brain swelling

Cerebral edema is a problem in pediatric DKA, possibly related to overaggressive fluid resuscitation but it is controversial.

Total fluid should not exceed 4 liters/meter* in the 1st 24". After initial resuscitation from shock, fluid administration should be carefully individualized and governed by corrected serum sodium and clinical response.

Case (continued)	
LAB DATA: ASG: pH 7.05, pO_2 350 mm Hg, pCO_2 15 mmHg;	
Na^+ 135 mEq/L	glucose 500 mg/dl
K^+ 4.5 meq/L	BUN 20
HCO_3^- 8 mEq/L	Cl 113 mEq/L

Fluid and Electrolytes: 30 kg; 7 yrs old; approximately 1 m^2 BSA		
	Deficit	Maintenance (24 hr)
Water	30 kg x 10% = 3.0 kg (*____* ml)	_____ mL (____ mL/hr x 24°)
Sodium	9 mEq/kg = ______ mEq	3 mEq/100 mL H2O = ____ mEq
Potassium	6 mEq/kg = _______ mEq`	2 mEq/100 mL H2O = ____ mEq

Replacement Procedure	Volume	Solution
STAT if shock	mL/kg and repeat PRN	NS or LR
First 1/2 to 1 hour	mL/kg = mL	N S
Replacement Procedure		
Next 8 hours	112 deficit = ______ **mL** (3000-600 =2400 ÷2) 8-hr maintenance = ______ **mL** (___mL/hr x 6) Total = __ over 8 hrs =______ **mL/hr**	[(0.5 LR or 0.5 NS)] + [(20 mEq KCl/L + 20 mEq KPO4/L) or 40 mEq KCl/L] ± 25 – 50 mEq $NaHCO_3$/L (until pH ≥ 7.1) Add 5% dextrose (when blood glucose ≤ 250-300 mg/dl)

Following a second bolus, the child begins to respond more appropriately HR is down to 120, BP up to 88/56. Fluids should be decreased to maintenance but replacement of deficits over the next 24 hours.

HYPONATREMIC DEHYDRATION CASE STUDY

A 10 kg infant with cystic fibrosis has had profuse diarrhea (7 to 10 stools per day) for Several days. Parents have been doing a great job pushing fluids, particularly Kool-Aid and Gingerale. Today, the infant has become lethargic and arrives in the ED comatose.
Patients pre-illness weight: 10.0 kg Wt. on admission: 9.0 kg

Degree of dehydration: moderate (10%); Na+: 110 mEq/L, K+ 5 mEq/L, Cl- 90 mEq/L, HCO3- 12 mEq/L

Maintenance Fluid Requirements	H20 (ml)	_______	(100 ml/kg)
	Na+ (mEq)	_ _	(3 mEq/kg)
	K+ (mEq)	_____	(2 mEq/kg)

Deficit requirements (100 mL/kg):

H20 (ml)	______	(10% BW); ECF = 60% = 600 cc; ICF = 40%
Na+ (mEq)	_______	= 140 mEq/L x 0.6
K+ (mEq)	_______	= 150 mEq/L x 0.4 x 50% correction

Na+ deficit calculation to correct to 135 mEq/L:
a. 135 mEq/L 110 mEq/L (observed Na+) = 25 **mEq/L**
b. Total body water (TBW) (L/kg) = 0.6 L/kg (pre-illness TBW) - 0.1 Ukg (water loss) = 0.5 **L/kg.**
c. Pre-illness wt = 10 kg

Sodium deficit = A x B x C = 25 mEq/l x 0.5 L/kg x 10 kg = _______ mEq

Total Na+ required (maintenance + deficit): ________mEq (30 + 84 + 125)

Total K+ required (maintenance + deficit): ________mEq

Fluid Schedule:

Phase I: 20 mL/kg = 200 mL NS or LR over 20 minutes (if necessary)
Phase II: To be given over the next 8 hours:

1/2 deficit=	__ mL D5W with	_____ mEq NaCl and	_______mEq KCL
113 maintenance=	__ mL D5W with	_ _ mEq NaCl and	_______ mEq KCL
Total:	= 833 mL D5W with	114 mEq NaCl and	22 mEq KCl

Can be given as 833 mL (______ mL/hr) of D5W 0.9% NS with 27 mEq KCl/L (22 mEq)

Phase Ill: To be given over hours 9-25:

1/2 deficit	= _____ ml D5W with	_ _ mEq NaCl and	_____ mEq KCl
2/3 maintenance	= 667 mL D5W with	20 mEq NaCl and	______mEq KCl
Total:	= mL D5W	124 meq NaCl	29 mEq KCl

Can be given as 0.9% NS with 25 mEq KCl/L (29 mEq KCL) at a rate of 75 cc/hr

HYPERNATREMIC DEHYDRATION CASE

A 7 month old infant has had fever and diarrhea for 1 to 2 days. She took formula well initially but has been vomiting over the last 8 to 10 hours. Mother presents with infant now because vomiting and progressive lethargy.
Physical Exam: Temp 39°C Pulse 150 RR: 48 BP: 80/55 Weight 6.3 kg **(wt** 7.0 **kg last week).** The child is lethargic but irritable when examined. Mucous membranes are somewhat dry, diaper is dry, but she cries tears. Skin is warm and doughy. Initial **Na+ is 165** mEq/L.

Phase I: Child is not in shock and is hypernatremic: so slow, steady repletion is indicated rather than boluses. Infant needs IV rehydration due to (1) elevated Na+ requiring 48 hour correction and (2) altered mental status.

Phase II:

1. Determine maintenance fluids and electrolytes:

a. Fluid: ________ ml/kg/d x 7.0 kg = _____ mL/day

b. Nat 3 mEq/L/100 mL of maintenance fluid = _____ mEq/d

c. K+ 2 mEq/L/100 mL of maintenance fluid = ____ mEq/d

2. Calculate the replacement fluids and electrolytes

a. Fluid replacement = (preillness weight – present weight) x 1000 ml/L

= (7.0 kg – 6.3 kg) = 0.7 kg x 1000 ml/L = 700 mL

b. How much of this is free water?

1. Difference between measured serum Na+ and 145 (_____ – 145) = 20 mEq/L

2. Every 1 mEq/L difference in sodium represents a deficit of 4 mL/kg of free water

20 mEq/L x (4 mL x 7 kg) = _______ free water deficit

3. To avoid risk of cerebral edema, calculate to correct halfway to normal serum sodium

= 0.5 (20 mEq/L) x (4 mL x 7 kg) = 280 mL

4. Subtract the free water deficit from the fluid replacement to determine the amount of *electrolyte* containing replacement = 700 mL -- mL = 420 mL

c. Na+ replacement = concentration in ECF x [(fluid replacement containing electrolytes x % lost in ECF) x 1L/1000 mL] =

135 mEq/L x [(______ mL x 60%) x 1 L/1 000 mL] = 34 mEq/L

d. K+ replacement = K+ concentration in ICF x [(fluid replacement containing electrolytes x % lost in ICF) x 1 L/1000 mL] =

150 mEq/L x [(_______mL x 40%) x 1 L/1 000 mL] = 25 mEq/L

3. a. Fluid replacement for 48 hours

= fluid replacement + (fluid maintenance x 2)

= 700 mL + (700 mL x 2) = 2100 mL ÷ 48° = ____ mL/hr

b. Sodium replacement for 48 hours

= sodium replacement + (sodium maintenance x 2)

= 34 mEq/L + (21 mEq/L x 2) = _____ mEq/L

c. Potassium requirement for 48 hours
 = potassium replacement + (potassium maintenance x 2)
 = 25 mEq/L + (14 mEq/L x 2) = ____ mEq/L

d. So, in the next 24 hours, patient needs a rate of 44 ml/hr
 2100 mL of fluid, 76 mEq Na+ = _____ mEq/1000 mL,
 53 mEq/L K+ = 25 mEq/1000 mL)

 i.e readily available as **D5** and **.25%NS**.

4. Repeat electrolytes at a minimum of 12 hours or sooner if mental status not improving.
5. Once Na+ <160 mEq/L, the infant can be given oral maintenance solutions.
6. Advance diet to half-strength, then full strength.

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Case Studies in Emergency Fluid and Electrolyte Management in the Pediatric Patient (Part II of II)

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INTRODUCTION

Understanding fluid and electrolyte management in children does not need to be complicated, Once certain basic principles are understood, an individualized plan for each patient can be devised and instituted: in your head or with a prescription size piece of paper!

Dehydration - common reason for visits to ED:
- 20 million episodes of diarrhea in children aged < 5 annually
- 300 to 400 deaths annually
- 200,000 hospitalizations
- 1.5 million outpatient visits
- **costs** > $1 billion in direct medical costs
- particularly susceptible to shock due to increased metabolic rates and inability to independently replace fluid losses
- 4 million childhood deaths worldwide/year (#2 killer)

ETIOLOGY & PATHOGENESIS OF VOLUME DEPLETION

The loss of fluids and electrolytes results in a state of volume depletion and/or dehydration. The major causes are:

gastroenteritis	viral 70-80%; bacteria 10-20% (e.g.: Shigella. Salmonella, E. Coli, Yersinia, Campylobacter) Giardia, amoebae, antibiotics
other GI	intussusception, duodenal atresia, pyloric stenosis, inflammatory bowel diseases
febrile illnesses	pneumonia, UTI'S, sepsis
burns	
endocrine	DKA, DI, salt losing adrenogenital syndrome, Addison's
renal	medullary disease, nephrogenic DI, diuretic abuse
other	anorexia nervosa, malnutrition, ASA, hemolytic uremic syndrome.

Infants are more susceptible to dehydration. A child's fluid reserve is limited and therefore a small volume deficit makes a large physiologic difference. The initial fluid loss comes from the extracellular fluid (ECF) causing a gradual water shift from the intracellular compartments (ICF) to the ECF. If the dehydration is acute (< 2 days) approximately 80% of fluid loss is from the ECF and 20%

from the ICF. If the losses have continued greater than 3 days the shift is 60% from the ECF, 40% ICF.

The higher proportional water content (expressed as % BW) in a child is NOT a buffer. A child has a greater proportion of extracellular fluid when compared to an adult, but the degree of dehydration is greater in a child. This is due to the fact that the **single most important factor** predisposing infants to dehydration is the high proportional turnover of body fluid, especially **extracellular fluid.** Kooh and Metcoff (J Pediatr. 1963; 62) found that the turnover of fluid (daily fluid intake and outgo), as a proportion of ECF is **twice** that of an adult.

Except in the instance of a fulminant secretory form of diarrhea (e.g. cholera), dehydration usually develops over several days (e.g. rotavirus).

CLINICAL ASSESSMENT

History only suggests etiology and possible presence of hypovolemia
Physical exam best way to determine hydration and shock
1. Vital signs and weight: compare to available charts
 a. Infants — systolic BP at least 60 mm hg
 b. older children — 80 + (2 x age in years)

Weight: may be difficult; may need to approximate with length/weight tape

CLINICAL MANIFESTATIONS

Signs of dehydration develop when the cumulative effect of negative balance ≥ 5% of initial body weight.

Estimate of fluid deficit = % dehydration x wt x 10 = cc of fluid deficit

Clinical Spectrum of Dehydration

Weight Loss (% tot wt)	Mild (<5%)	Moderate (5-10%)	Severe >10%
Approximate deficit	30-50 ml/kg	50-100 ml/kg	>100 ml/kg
Clinical Features			
Heart rate	Normal ± **tilt test**	Rapid ± tilt test	Rapid
Mental status	Alert, restless	Irritable/lethargic	Lethargic, obtunded
Eyes	Normal	Sunken	Glassy
Fontanelle	Normal/Flat	Flat/Depressed	Depressed
Mucous membranes	Normal	Dry	Very Dry
Tears	Normal	Decreased	Absent
Thirst (Drinks)	Normal	Eagerly	Poorly
Skin (Pinch retraction)	Immediate	Slowly	Absent
Skin	Cold, sweaty	Cold, dry	Cool, doughy
Urination(# wet diapers)	Normal	Fewer	None
Systolic BP	Normal	Normal	Decreased
Respirations	Normal	Deep	Deep, rapid
Laboratory			
Urine volume	Small	Oliguria	Oliguria/anuric
Urine Spec grav	1.020	!.025	Maximal
Blood			
Bun	1 O-20	>20	Maximal
pH	7.22-7.4	7.00-7.3	6.8-7.10
HCO3-	> 12-14	8-12	<8-10

Note: Hypematremic dehydration: appear less dehydrated but may manifest earlier CNS signs
Hyponatremic: more dehydrated
Clinical signs and symptoms are not reliable predictors of hydration status in children, e.g. moderately dehydrated children may continue to have tears and moist mucosal membranes. Significant clinical signs associated with dehydration : decreased peripheral perfusion, acidotic breathing, decreased skin turgor, high urea, low pH, large base deficit

Objective Assessment: pre-morbid weight can be used to accurately determine % volume depletion:

$$\frac{\text{Previous Weight} - \text{Present Weight}}{\text{Previous Weight}} \times 100\% = \%\ \text{Dehydration}$$

Laboratory Assessment: Limited utility in determining hydration status. However, indications and usefulness are:
a. R/O DKA
b. Electrolyte abnormalities
c. Osmolar derangement

1. **Serum Na+:** helps determine osmolar classification of dehydration
   No use in calculating fluid deficit
   a. Osmolar Classifications

Isotonic	Na+ 135-l 45 meq/ml
Hypotonic	Na+ < 135 meq/ml
Hypertonic	Na+> 145 meq/ml

2. **Serum potassium:** Does not reflect total body K+ which:
   - is low in most dehydrated states
   directly proportional to length of diarrhea1 illness
   - serum K+ falsely elevated in acidosis
3. **BUN/Creatinine:** little evidence supporting them as valid indicator of dehydration/volume depletion in children
   - severely dehydrated can have low to nl BUN's
   - elevated BUN specific but not sensitive for dehydration
   - Creatinine ≥ 1.2 abnormal in children
4. **Serum Bicarbonate:** moderate degree of acidosis with even moderate dehydration
   Sources of loss: diarrhea1 bicarbonate loss, anaerobic metabolism, starvation ketosis, increased **lactic** acid formation
   More sensitive than other laboratory studies probably most reliable
5. **ABG:** indicated in severely dehydrated and those in shock
   Arterial pH: acidosis?; PC02: adequate ventilation?
6. **Hemoglobin/Hematocrit:** May not be sensitive in acute blood loss;commonly elevated in moderate to severe dehydration

TREATMENT

A. ORAL REHYDRATION

Children with mild dehydration (~5%) may be candidates for purely enteral hydration. The World Health Organization has developed a rehydration formula for enteral hydration of children secondary to gastroenteritis. This formulation takes into account the relationship between sodium and glucose transport to provide a more rapid absorption of electrolytes from the intestines. Most maintenance clear liquid preparations do not contain enough sodium and are not suitable for initial enteral resuscitation efforts (see appendix).

Indications:

- Patient has to be able to tolerate oral intake. Many children who initially are unable to tolerate fluids improve after 20-30 ml/kg of D5W 0.9% NS or D5WLR over 1 hour.
- Patients need careful monitoring of intake, output, and weight
- May be contraindicated in patients with shock, severe dehydration, intractable vomiting, > 10 cc/kg/hr losses, coma, or severe gastric distention
- More than 90% of infants will tolerate ORS if it is given gradually.
- Nasogastric tubes can be used to deliver ORS to patients unable to drink

Technique:

Clear fluids should be pushed

- give 5-10 cc of fluid every 5-10 minutes, increase amount as tolerated.

try administering this fluid with a spoon or small syringe to limit the rate of fluid consumption. Have parents give 1 tsp. every minute, or every 5 minutes if child is vomiting.

stop if severe vomiting occurs. Small amounts of vomiting should not cause one to abandon this mode of rehydration.

- Do NOT use rice water, tea, or boiled milk. Many fruit juices are hyperosmolar (esp. apple juice) and draw water into the intestinal lumen worsening diarrhea.
- In infants, provide adequate electrolytes while minimizing potential errors in formulations of solutions This is the reason for the use of Rehydralyte during initial rehydration followed by Lytren or Pedialyte.
- Once ongoing losses have been stopped, diet may be advanced.

Deficit Replacement:

- Mild dehydration: 60 cc/kg over 2h
- Moderate dehydration: 80 cc/kg over 2h
- In addition, 10 cc/kg of rehydration solution for each diarrhea1 stool seen in the ED

Maintenance Replacement:

- Replace ongoing stool losses with lactose-free formula or ORS on a 1 :1 basis.
- Breast-fed infants: 100 cc/kg of rehydration solution in addition to breast milk ad lib
- Formula-fed infants: lactose-free formula, or half-strength lactose-containing formula at 100-150 cc/kg/24 hrs, alternating with an equal volume of rehydration solution
- Children on regular diet: 100 cc/kg of rehydration solution; continue regular diet. Avoid high carbohydrate content products (e.g. Kool-Aid).
- Rehydrate with 50-100 cc/kg over 24 hours under observation in ED
- If vomiting occurs, decrease to 5-10 cc increments. Small amounts of vomiting are not a contraindication to this method. Add 10 cc/kg for each diarrhea stool seen in the ED.

Discharge Diets:

a. Breast fed infants: continue breast feeding ad lib with supplements of rehydration solution or maintenance solutions

b. Bottle fed infants

If no previous clear liquids resume feeding with lactose-containing formula (112 strength) with rehydration solution, rapidly advancing to full strength within 12 hours and continue to supplement with rehydration solution.

If extended period on clear liquids resume feedings immediately with lactose free formula and supplement with rehydration solution. Advance slowly over the next 2-3 days back to lactose containing formula.

Remember: Following successful rehydration in E.D. child may be discharged with **rapid resumption of normal diet.**

B. PARENTERAL FLUID ADMINISTRATION

ESTIMATION OF PARENTERAL FLUID REQUIREMENTS

Total Body Water (TBW) is approximately 60% of weight (extracellular: 20%; intracellular: 40 %). Parenteral fluid requirements are based on usual losses of water and electrolytes under normal conditions.

Replacement of water and electrolytes estimated from 3 different methods: see appendix.

INDICATIONS:

Oral rehydration therapy is an effective and the preferred therapy for dehydration. Parenteral rehydration in the ambulatory setting is not widely practiced in children but may be feasible and cost-effective.

In addition, there are several indications that remain for parenteral fluid therapy:

1) Evidence of impaired peripheral circulation or overt shock
2) Infant weighing less than 4.5 kg or less than 3 mos. of age
3) Inability to maintain an adequate rate of oral fluid intake because of intractable vomiting, lethargy, or anatomic anomaly.
4) Failure to maintain or gain weight despite fluid intake/excessive fluid losses
5) Hypernatremia: Oral rehydration solutions contain a high level of sodium: Hypernatremia reported in some children who had normal pretreatment serum sodium levels. Seizures reported following oral rehydration of hypernatremia with water.
6) Parenteral limitations: oral rehydration takes time, comprehension of instructions

MAINTENANCE FLUID NEEDS FOR PARENTERAL THERAPY

Maintenance fluid is the amount the body needs for replacement of usual daily losses from the normal functions of the respiratory system, skin, and urinary and GI tract.

A. Insensible Water Loss (IWL) - Water loss through the skin, pulmonary system: in the infant, this is approximately 2/3 skin, 1/3 pulmonary system.

1. Affected by ambient humidity, body clothing, body temperature, respiratory rate, ambient temperature.
2. Fever increases IWL by 7 ml/kg/24° for each degree > 99° F.
3. 1 ml water lost for each calorie metabolized.
4. Evaporative losses: 30 ml/100 calories expended through skin
   15 ml/100 calories through pulmonary system

B. Urinary Water losses: - Kidneys are the final pathway regulating fluid and electrolyte balance of the body. Urine volume is determined by (1) solute load presenting to the kidneys requiring excretion. Solute load is determined by the metabolic rate. If solute load is higher, water allowances for excretion should be higher. (2) urine osmolality

- Average estimate for water excretion is 50-60 ml/kg/day. Urinary loss of water is approximately 50 ml/100 cal expended providing urine osmolality isosmotic (equal to that of ECF). Urinary volume is a function of urinary concentrations for various solute loads and caloric expenditures,

C. Stool water losses: -Approximately 5-10 ml/kg/day in infants and toddlers. In older children, unless there is diarrhea, this volume can be ignored.

Estimation of Maintenance Parenteral Fluid Requirements

First 1 -1 0 kg	100 ml/kg/d	
10-20 kg	1,000 ml	+ 50 ml/kg/d for each kg over 10 kg
After 20 kg	1,500 ml	+ 20 ml/kg/d for each kg over 20 kg
Adult:	2,000.4,000 ml/d	

This is based upon the Holliday Segar Method for calculating fluid requirements and it is quite practical to use in the ED. It is a simple formula which estimates caloric expenditure from weight alone. For each 100 calories metabolized. 100 cc H20 will be required.

Alternative formula for IV rate when in a hurry:

Weight	Hourly rate (ml/hr)
1 - 10 kg	4 X wt (kg)
10 – 20 kg	40 + (2 X wt (kg) for each kg over 10 kg)
> 20 kg	40 + wt (kg)

MAINTENANCE ELECTROLYTE NEEDS FOR PARENTERAL THERAPY

	Water (cc/kg)	Electrolyte (per 100 cc H2O)	
1st 10 kg body weight	100	Na+	3 mEq
2nd 10 kg body weight	50	Cl-	2 mEq
Each additional kg	20	K +	2 mEq

Urine is major source of electrolyte losses in healthy children.

- 0.5 mEq Na+ and K+ per kg lost through skin every 24 hours.
- Usually supplying 3 meq/kg/day of Na+ and 2 meq/kg/day of K+ with 5 mEq of Cl- is sufficient,
  - Human milk has 1 .O to 1.5 mEq/100 calories of Na+ and K+
  - Cow's milk has 2 to 3 mEq/100 calories of Na+ and K+
- Exceptions for maintenance requiring increased electrolyte requirements:
  - sweating
  - vomiting
  - diarrhea
  - burns
  - renal disorders
  - diuretic therapy
  - surgical drainage tubes

Electrolyte requirements

Sodium:	Children: 2-3 meq/kg/d	(adult: 80 meq/d)
Potassium:	Children: 1-2 meq/kg/d Never administer > 4 meq/hr in infancy	(adult: 50 meq/d)
Chloride:	3-5 meq/kg/d	

CALORIC NEEDS FOR SHORT-TERM PARENTERAL THERAPY

For short-term maintenance therapy in a previously well-nourished infant or child, a combination of some parenteral solution and the patients own fat stores is adequate to prevent severe ketosis and tissue catabolism.

- Give glucose = 20% of total caloric expenditure (approximately 5 gms of glucose per 100 calories expended)
- Appropriate solution for average maintenance therapy:

  30 - 35 mEq Na+/liter, 20 mEq KCl/liter, D5W = D5 1/4 NS with 2 meq KCl/100 cc !

As outlined by Barkin, parenteral treatment can be organized into five distinct phases:

Phase	Therapeutic Plan	Pattern of Response
I. Up to 1/2 hr Restoration of vascular volume	20 ml/kg .9%NS or LR over 20 to 30 min; may repeat 10 ml/kg	Improved Vital signs Increased urine flow Improved state of consciousness
II. 1/2 to 9 hr Partial restoration of ECF deficit & acid-base status	1/3 maintenance daily fluids 1/2 deficit fluids	Gain in body weight Improved urine flow Partial resolution of normal acid-base status
III. 9 to 25 hrs	2/3 maintenance daily fluids 1/2 deficit fluids	Sustained gain in body weight Fall in BUN (50% in 24 hours) Sustained urine flow Improved electrolytes
IV. 25 to 48 hrs Total correction of acid-base and K+ status	Ongoing parenteral ± oral hydration Maintenance fluids and replacement of ongoing losses	Sustained gain in body weight Normal electrolytes
V. 2 to 14 days Restoration of caloric and protein deficits	Ongoing oral support	Steady gain in body weight Plasma constituents normal

From Barkin RM, Rosen P: Emergency Pediatrics 3rd ed. C.V. Mosby, St. Louis, 1990

As emergency physicians, we need to primarily concern ourselves wlth Phases I-III

INITIAL MANAGEMENT: PHASE I

1) **IV access** promptly established if there is a hint of circulatory compromise:

- shock with or without hypotension
- mottled appearance
- lethargy
- hypotonicity
- prolonged capillary refill > 3 secs
- cool skin
- irritability

2) **Urgent volume expansion:** up to 20 ml/kg during 15-20 minutes using isotonic crystalloid or isotonic, iso-oncotic colloid-containing solution.

Isotonic "normal" saline is frequently used and effective. However, there is a theoretical disadvantage of a non-physiologic balance of sodium and anion (chloride): dilution acidosis may exacerbate preexisting metabolic acidosis or cause a hyperchloremic acidosis. The extracellular bicarbonate is further diluted.

Preferable solutions:

- 2/3 chloride, 1/3 bicarbonate or lactate (eg. similar to LR).

Saline HC03 ❑ 750 ml D5NS, 225 ml D5W, 25 ml 6.4% NaHC03

3) **Repeat** if a poor therapeutic response is noted, the initial infusion should be repeated over 20 to 30 minutes, assuming nl renal and cardiac function.

4) If a poor therapeutic response is noted following 40 ml/kg, or if there are ongoing losses or associated renal, cardiac, or pulmonary disease, monitoring with a **central venous or arterial line** may be needed. - Once infant has attained stable hemodynamic status, treatment can proceed to the next phases.

VOLUME REPLETION: PHASES II & III

A multitude of systems for fluid replacement in infants and children exist. All of them are physiologically sound and many of them are similar, in fact almost interchangeable. Simplified, pragmatic approaches are usually based upon the following formula:

Total volume and solute needs = Deficit replacement + maintenance requirement + ongoing losses

1. Deficit replacement: makes up for past losses
2. Maintenance requirements: keeps the patient in balance
3. Replacement therapy: to make up for losses that are ongoing

The following questions should be going through the treating physician's mind. Not all are relevant in all patients and do not all need to be addressed in great detail. However, I think that you probably consciously or subconsciously address each one of these in most volume depleted patients.

Does a Volume Deficit Exist?

History:
- recent weight
- oral/liquid intake
- vomiting
- medications
- fever
- urine output/freq
- fluid loss (diarrhea: # stools/day, frequency, consistency, estimated volume)

Dehydration is a decrease in the volume of body fluid and should be expresses as a percent of **initial** body weight. try to arrive at an approximation of the body fluid deficit in volumetric terms (mls). A clinical estimate of the severiiy of dehydration is inexact and subjective.

$$X = \text{Initial BW} \qquad \frac{X}{\text{BW (admission)}} = \frac{100}{(100 - \%\ \text{estimate dehydration})}$$

Does an Acid-Base Disturbance Exist?
- Acid-base parameters of a venous blood sample suffice
- Causes of commonly seen acute simple metabolic acidosis:
  - Bicarbonate loss in diarrhea1 stool; associated with hyperchloremia
  - Decreased appetite and caloric deprivation cause breakdown of body proteins and fat which causes accumulation of organic acid anions
  - In severe dehydration, **there** is **under-excretion of acids**
- Serum CO2 is highly correlated and may be substituted for the VBG HC03 ($r= .87$, $p=.0001$) (Ryan et al 1998)

Does a Disturbance of Potassium Metabolism Exist?
- K+ deficits in infants with moderate isotonic dehydration range between 8 to 10 mEq/kg; K= is an intracellular ion: therefore parallel declines in ICF and intracellular K+ (eg. rotavirus; however in cholera, which causes a rapid secretory diarrhea, there is less K+ loss)
- K+ deficits enable to the physician to make a crude estimate of the partition of fluid deficit between extracellular and intracellular fluid compartments.
- Serum K+ is of limited value, however:
- Does not always correspond to intracellular concentrations

What Is the State of Renal Function?

If history of oliguria exists, distinguish prerenal azotemia from acute renal failure quickly. In most instances, oliguria reflects prerenal azotemia and is an appropriate physiologic response to dehydration. However, prolonged and profound dehydration and /or shock can cause renal hypoperfusion and consequent ischemic renal tubular cell injury.

BUN has little use practically except in the instance of acute renal failure.

BUN is not a reliable index of renal function. It is affected by: dietary protein load, level of tissue breakdown, variable rates of back diffusion of urea across renal tubular cells.

Serum creatinine is a better index, but concentration is a function of age and muscle mass.
eg. <2 yrs of age, serum Cr is 0.3 to 0.5 mg per dl.

Laboratory Predictors of Fluid Deficit (Teach 1997)

On linear regression analysis, only the BUN/Creatinine ratio and serum uric acid were significantly associated with increasing fluid deficits.

The sensitivity of a BUN/creatinine ratio above 20 for identification of a fluid deficit of more than 5% was 92%, but specifity was low (33%). BUN/Creatinine ratios above 30 to 40 had a lower sensitivity and negative predictive value.

A serum uric acid above 300 mmol/L had a sensitivity and specificity of 85% and 41%, respectively.

The third parameter most strongly related to increasing fluid deficit was the serum anion gap which, if greater than 15 mmol/L, had a sensitivity and specificity of 69% and 52%, respectively.
Conclusions: Laboratory values are not helpful in the asseessment of fluid deficit in children with clinical dehydration, and the authors suggest they be considered only in the context of a history that includes fluid intake and losses and a careful physical exam.

Usefulness of Clinical and Laboratory Parameters (Vega & Avner, 1997)

The physicians's clinical estimate of dehydration compared to percent loss of body weight (PLBW) had a sensitivity of 74% (95% Cl 60-85) for mild dehydration, 33% (95% Cl:17-53) for moderate dehydration, and 70% (95% Cl:44-89) for severe dehydration. There was a significant difference in the mean serum bicarbonate concentrations (HC03) between the PLBW groups (Pc 0.01). The sensitivity of the HC03 < 17 mEq/L in predicting PLBW was 77% (95% Cl:58-90) for PLBW 6-10, and 94% (95% Cl:71-100) for PLBW > 10. The combination of the clinical scale and serum bicarbonate identified all 17 children with PLBW > 10 and 90% (27 of 30) children with PLBW 6-10.
Conclusion: Physicians should not rely solely on clinical assessment to rule out severe dehydration in children, and that obtaining a serum bicrabonate may improve the accuracy of predicting dehydration

	PHYSIOLOGIC OLIGURIA	ACUTE RENAL FAILURE
Urine output	Decreased	Decreased
Urine-specific gravity	>1.020	1.010-1.012
Microscopic examination of sediment	No specific findings	Renal tubular cells
FE (Na) index	<1-2%	>2-3%

$$FE\ (Na) = \frac{U(Na)/P(Na)}{U(Cr)/P(Cr)} \times 100$$

What Kind of Solution Will Be Used?

Assuming that fluid deficit is approximately 10% of body weight, that ongoing losses are minimal, and that the rate of deficit replacement is within the norms of standard practice, then the type of solution used is based on a decision tree proposed by Kallen. The parenteral fluid selected using this schema is a composite of both deficit and maintenance components,

Serum Na+ (mEq/L)	Na+ Concentration Desired (mEq/L)	Fluid Recommended (mEq/L)	Na+ Concentration in Fluid mEq/L)
>150	30-40	D5 .2%NS	34
130-150	50-60	D5 .33%NS	56
120-130	70-80	D5 .45%NS	77
<120	80-l 00	D5 .45%NS + Bicarb	100

From Kallen RJ: The Management of Diarrhea1 Dehydration in Infants Using Parenteral Fluids. In Arnold WC, Kallen RJ (eds):Fluid and Electrolyte Therapy. *Ped Clin N Amer* 1990; 37(2):274.

Potassium administration;
1) should not begin until infant has voided and renal function is adequate
2) should be accomplished gradually during at least 2 days
3) rate should not be greater than 4 meq/kg/day so as not to exceed rate-limited uptake of K+ by cells

Bicarbonate Administration:
1) Is the process causing metabolic acidosis a reversible, self-limited one? Is there a mixed-acid base disorder?
2) Is renal function temporarily impaired (prerenal azotemia), or has acute renal failure supervened?
3) Is the metabolic acidosis of such severity that immediate intervention is warranted?
• Most infants correct acidosis spontaneously as parenteral therapy proceeds. However, metabolic acidosis may need bicarbonate treatment if:
  - post-shock infant with acute renal failure
  - pH <7.20 (reflects 50% increase in hydrogen ion concentration) bicarbonate <8 mEq per liter

As a general principle, the initial dose of sodium bicarbonate, if given as a bolus, is calculated to achieve an increase of the serum bicarbonate concentration of 5 mEq per liter.

The effective volume of distribution of infused bicarbonate is 50% of body weight. Therefore, dosage is:

5 mEq per liter X 0.5 liters per kg = 2.5 mEq per kg
or
near physiologic 2:1 relationship of chloride to bicarbonate

Does an Osmolar Disturbance of Body Fluids Exist?
75% of dehydration states are ISOTONIC
• salt and water are lost in equal proportions

15% of cases are HYPERTONIC (hypernatremic with serum Na >150 mEq/1)
• occurs most often in infants with voluminous hypotonic diarrhea1 losses from viral illnesses, exacerbated by vomiting and early cessation of oral intake

10% of cases are HYPOTONIC (hyponatremic with serum Na+ < 130 mEq/l)
• presents in the child who continues to take hypotonic oral solution in the presence of persistent diarrhea

Clinical Characteristics of Different Osmolal States

Type of Dehydration	Hypotonic	Isotonic	Hypertonic
Serum Na+	<130	130-l 50	z-150
Clinical Features			
Skin			
Color	Gray	Gray	Gray
Temperature	Cold	Cold	Cold
Turgor	Poor	Very poor	Fair
Feel	Dry	Clammy	Thick, doughy
Mucous membranes	Dry	Dry	Parched
Sunken eyeballs	+	+	+
Fontanelle depressed	+	+	+
Mental status	Coma, seizures	Lethargic	Irritable, seizures
Increased Pulse	++	++	+
Decreased B.P.			

It is NOT necessary to measure or estimate serum osmolality. Most instances of dehydration occur without a disturbance of body fluid osmolality. In addition serum Na+ concentration by itself provides no useful information as to the overall state of body fluid balance. However, because the presence or absence of an osmolar disturbance of body fluids influences the type of parenteral fluid used for treatment, serum Na+ must be known. Osmolar disturbances may be suspected based on physical examination.

Typical Fluid and Electrolyte Deficits in Dehydration

	WATER mEq/kg	SODIUM mEq/kg	POTASSIUM mEq/kg
Isonatremic	100-120	8-10	8-10
Hypernatremic	100-120	2-4	o-4
Hyponatremic	100-120	10-12	8-10

Isotonic Dehydration

- 75% of dehydration; serum Na+ 135-145 mEq/L

Fluids are replaced over 24°.

First 8 hours =	112 deficit (emergency fluids)	plus 1/3 maintenance
Next **16** hours =	112 deficit	plus 2/3 maintenance

- Ongoing losses replaced as lost
- Appropriate fluid: D5 .45 NS with 20.30 mEq KCl/L

Examole: A 20 kg, 10% dehydrated patient requires fluid resuscitation in the ED.

Maintenance =	1,500 ml/24 hours =	**62.5 mllhr**
Deficit =	20 kg x 10% = 2 kg =	2 liters (2,000 **ml)**

In the first 8 hours, replete 112 deficit (1,000 ml) minus any fluid given in Phase I [let's say 400 ml in this case (20 ml/kg)]. Therefore, 2,000 ml divided into 2 aliquots: 8 hrs and 16 hours.

	1,000 ml- 400 ml = 600 ml/8hrs =	**75 ml/hr.**
Replete second half of deficit (1,000 ml) over 16 hours =		**62.5 mllhr.**

Therefore, patient receives:	62.5 mllhr + 75 ml/hr =	**137.5 mllhr** for first 8 hours
	62.5 ml/hr + 62.5 mllhr =	**125 mllhr** for the next 16 hours.

Hypotonlc Dehydratlon:

- **10% of cases;** serum Na+ < 130 mEq/L
- If Na+ is less than 130. Na+ and K+ losses exceed water losses causing ECF contraction secondary to osmotic gradient, i.e. water moves into the ICF with signs of circulatory insufficiency.
- Usually associated with intake of hypotonic fluids with concomitant GI losses

Na+ deficit:
(135 mEq/L - measured Na+) x total body water (0.6 L/kg) x body weight in kg

- Deficit fluid, electrolytes replaced evenly over 24 hours
- Appropriate solution: D5.9NS with 20-30 mEq KCl/L
- If severe hyponatremia is present in symptomatic patients (seizures, altered mental status), hypertonic 3% saline may be given to raise sodium to 125 mEq/L. Dose: 4 **ml/kg IV over 10 minutes.**
  CAUTION: rapid complete correction associated with *pontine myelinolysis*

Hypertonic Dehydration

- 15% of cases of dehydration; serum Na+ > 150 mEq/L; severely contracted intracellular volume
- Patients have deficit of free water, most often associated with ingestion of high solute fluid (boiled skim milk. broth); voluminous hypotonic stool losses with decreased po intake

- Degree of dehydration is difficult to assess and often underestimated.
- Fluid deficit 50 ml/kg if Na+ = 150; 90 ml/kg if Na+ = 160: 140 ml/kg if Na+ = 170
  2-4 mEq/kg Na+ O-4 mEq/kg K+
- Clinical: irritability, seizures
- Laboratory hyperglycemia, hypocalcemia
- The child must be rehydrated slowly: gradual, continuous replacement to replace deficit over 48”
  If Na+ is 175 mEq/L, decrease by 15 mEq/L per 24 hours
- Volume of free water to lower serum Na+ above 145mEq/L is approximately 4 cc/kg evenly over 48 hours
- Solutions: D5.2NS; D5.33NS D5.45 NS

Phase I: 20 cc/kg of NS or LR
Phase II, III: Hypotonic fluid D5W 0.20 0.45% NS over 48” at a constant rate of maintenance plus hydration
- If Na+ ≥ 175 mEq/L, decrease level by 15 mEq/L/24°
- If Na+ ≤ 175 mEq/L, decrease the level halfway to normal (145 mEq/L) during the first 24°

How Rapidly Should the Deficit Be Replaced?
- Depends on whether or not osmolar disturbance is present
- Full repletion is safe within the first 8 to 24 hours in infants with hypotonic and isotonic dehydration
- Hypertonic dehydration: replacement should be more gradual to prevent undue fluid shifts into cells of the CNS (relative water intoxication) if the extracellular sodium concentration declines to rapidly.
  1) Aim for a rate of decline of serum sodium of 0.5 mEq per liter /hour, or 12-15 mEq per liter per day.
  2) Aim for fluid correction over 24-48 hours

How Long Should Parenteral fluid Therapy continue?
Closely monitor infant receiving parenteral fluids: change of hemodynamic vital signs, body weight, urinary output and specific gravity, serum electrolytes.
Indications of successful fluid therapy:
- steady weight gain, esp. if diarrhea continues
- stable vital signs and resolution of physical signs of dehydration
- progressive decline of urine spec gravity to 1.010 or less, and concomitant increase in urine output
- improvement in metabolic acidosis
- progressive improvement in azotemia

Rate of Deficit Repletion as a Cumulative Percent

	0-12 Hours	12-24 Hours	24-48 Hours
Isonatremic	50	100	
Hypernatremic	25	50	100
Hyponatremic	75	100	

From Kallen RJ: The Management of Diarrhea1 Dehydration in Infants Using Parenteral Fluids. In Arnold WC, Kallen PJ (eds):Fluid and Electrolyte Therapy. fed *Clin* N *Amer* 1990; 37(2):276.

Disposition

Admission or discharge of a dehydrated child is determined by the entire clinical picture

A. Relative Indications for Admission
1. Unstable patient
2. Failure to respond to E.D. management
3. Insufficient parental/guardian supervision
4. Ongoing disease process

5. Disease process requiring:
    a. Parenteral medications/fluids
    b. Skilled nursing care
    c. Close monitoring
    d. Potential for unstable relapse

B. Relative Indications for Discharge

1. Response to E.D. Management
2. Successful E.D. Observation Period
3. Appropriate parenteral/guardian supervision
4. Adequate follow-up mechanism
5. Disease process with:
    a. Low-risk for unstable relapse
    b. Oral medications

FLUID RESUSCITATION OF SHOCK

HYPOVOLEMIC SHOCK

State of multisystem organ perfusion insufficiency resulting from the escape of fluid (blood or plasma) from the intravascular compartment.
whole blood (trauma or surgery)
-plasma: dehydration from vomiting or diarrhea

▪ Most common cause of shock in children is hemorrhagic blood loss due to trauma. Traumatic injury is the most common cause of morbidity and mortality in childhood; 0.1% of 20 million pediatric ED visits per year.

Signs of hemorrhagic shock develop in direct proportion to the loss of blood volume.
Shock may be classified in 3 levels:
1) early: <25% blood volume loss
2) prehypotensive: >25% to 40% blood volume: associated with delayed capillary refill
3) hypotensive: >40% blood volume

Acceptable Upper Limits of Normal Respiratory Rates and Pulse

Age	Respiratory Rate	Pulse
Infant	50	160
Toddler	45	140
School-age child	25	120
Adolescent	16	110

From American Academy of Pediatrics/American College of Emergency Physicians. *Manual of* Advanced Pediatric Life support.1 993

Circulatory shock- hypovolemia
a. impaired oxygen delivery
b. hypotension when cardiac output falls 30%. Lactate production reflects oxygen debt and is a better marker of cellular hypoxia

“Shock” is not synonymous with hypotension. Compensating mechanisms in the face of progressive hypovolemia are able to maintain blood pressure up to the point of decompensation despite hypoperfusion of certain organs. BP can actually be above normal in children with volume depletion! Blood and heart perfusion are maintained at the expense of the kidneys, lungs, intestines, skin, and muscle.

• Hypotension may be a late occurrence (according to ATLS, after 40% blood volume loss). Shock becomes irreversible if intravascular volume not corrected within a critical period.

• Cumulative blood loss at multiple sites of injury can reach a critical level quickly:

pelvic ring fracture	10% EBV (est. blood volume)
femur fracture	**20%** EBV
multiple fractures(e.g. 2-femurs, 2 of the pelvis)	60% EBV

Therapeutic Classification of Hemorrhagic Shock in the Pediatric patient

Blood loss % blood volume*	'UP to 15%	15–30%	30–40	40% or more
Pulse rate	normal	mild tachycardia	mod tachycardia	severe tachycardia
Pulse Pressure	normal	decreased	decreased	decreased
Blood pressure	normal/increased	decreased	decreased	decreased
Capillary refill	normal	positive (>3)	positive (>5)	positive (>5)
Respiratory rate	normal	mild tachypnea	moderate tachypnea	severe tachypnea
Urinary output	1-2 ml/kg/hr	0.5-l .O ml/kg/hr	0.25-0.5 ml/kg/hr	Negligible
Mental status	slightly anxious	mildly anxious, irritable	anxious/confused, lethargy, obtundation	confused lethargic
Fluid replacement (3:1 rule)	Crystalloid	Crystalloid	Crystalloid + blood	Crystalloid + blood

* Assume blood volume to be 8–9% of body weight (80-90 ml/kg)

• Lactate?: Lactate levels are a better prognosticator for hospital admission than are standard vital signs; they improve triage and allow for ealier recognitionof critically ill pediatric **patients.** (Milzman 1996)

IV ACCESS:

. urgent and difficult in child with poor peripheral perfusion
• central venous lines do not ensure flow rate greater than that of peripheral vein unless catheter diameter is greater. Sheath sizing:

4Fr: up **to 15** kg; 5 **Fr: 15-20** kg: **6 Fr:** > **20** kg

• Problems encountered in obtaining IV access
(1) increased subcutaneous fat (2)smaller vessels (3) vasoconstriction (sympathomimetic & heat loss control (4) anxious and uncooperative

1. Primary sites:
Peripheral: dorsal hand, antecubiial, saphenous veins, foot

2. Intermediate sites: percutaneous cannulation of external jugular vein; probably underutilized (Mom or Dad should perhaps not be present for this stick)
Central: percutaneous femoral vein cannulation is preferred central approach in infants or children
Intraosseous: No access within 2 minutes or cardiac arrest: Intraosseous; excellent in volume depleted patients due to noncollapsible sinusoids (AAP Guidleines 1992)
Surgical cut-downs on the femoral vein and percutaneous or internal jugular

COLLOID VS. CRYSTALLOID:

Colloid. contains plasma protein at concentration iso-oncotic to plasma (approx. 5%)

achieves volume expansion equipotent (i.e. isovolemic) with that of plasma due to its being confined to the intravascular compartment.

Crystalloid eg. 0.9% NS; LR

distributes and equilibrates in a large volume of distribution, i.e. ECF (approx 3X larger than blood volume)

Fluids for resuscitation

Choices: L.R., N.S., Dextran, Hetastarch, Albumin, plasma, plasmanate, blood

Goals of therapy

a. keep pa02 > 80 mm Hg
b. maintain red cell mass(> 7gm/dl Hgb)
c. remember that asanguinous fluid may boost C.O. initially but eventually reduces 02 delivery
d. replace losses as needed
e. new studies with traumatic shock: is aggressive fluid replacement harmful?

Crystalloid

Pros	Cons
Inexpensive Readily available Extensive experience No disease transmission Rapid expansion of vascular volume	Large volumes needed (3:1 rule) Dilutes serum proteins Lowers oncotic pressure Expands interstitial space Prolonged recovery

Colloid

Pros	Cons
Less volume Better and more rapid expansion of vascular space Increase 02 consumption due to increased C.O. Increased cardiac work	Expensive Some risk of infectious transmission in some products Not readily available ± Pulmonary edema ± Impaired renal function ± negative inotropic effect

Hemorrhagic shock:

Average blood volume in children is 80 mL/kg

- e.g. blood loss Of Only 200 ml in a 10 kg (total blood volume 800 mL) represents a 25% decrease in blood volume.
- whole blood should be replaced with whole blood
- **LR** may be used for Class I or II (BV loss 25% or less)

How to rapidly estimate volume of blood to be infused: wt (kg) = (Age[years] x 2) + 10 **Blood volume (ml) = 80 ml per kg x body wt (kg)** Then calculate % blood loss (e.g. clinical signs, Class I-IV, etc.): **% x baseline blood volume = blood needed**

Dose: 20 ml/kg rapidly as possible (probably need to use syringe connected to 3-way stopcock or positive pressure)

Repeat dose as necessary (inadequate multisystem perfusion)

If 40 ml /kg crystalloid (equivalent to plasma volume) does not restore adequate peripheral circulatory status, give whole blood.

- In desperate situations:
  1) non-crossmatched **type 0, Rh-negative** PRBC's reconstituted with 150 ml of 0.9% NS; administered 10 ml/kg.
  2) Type-specific whole blood: 20 ml/kg
- Reassess after each infusion

Blood
- Hgb value < 8 gm/dl on arrival carries higher risk of mortality
- Hgb value < 7 gm/dl overwhelms the compensatory increase in C.O, and impairs oxygen transport and delivery
- Blood indicated in any trauma patient of
  - failure to stabilize after crystalloid infusion
  - signs of continued tissue hypoxia not due to pulmonary injury
  initial hemoglobin value < 7 gm/dl

- **Whole blood** is indicated at the outset if patient with post-traumatic hemorrhage is assessed as having Class Ill shock or greater than 30-40% loss of blood volume.

If whole blood is not immediately available, isotonic, iso-oncotic solution (5% albumin). ▪ If blood or plasma not available, crystalloid using 3 for 1 rule (3,000 ml for 1,000 ml of EBL) is indicated.
- If hemodynamic monitoring available, endpoint for sufficient volume expansion is a restoration of central venous pressure to at least 5-8 mm hg, PCWP (pulm capillary wedge pressure) to at least 10 mm hg.

Shock due to Dehydration:
- Shock may develop after losses equivalent to 10-15% of initial body weight.
- Hypotension is a late sign of hypovolemia and must be urgently corrected.
- Crystalloid is a less effective volume expander than iso-oncotic solutions.
  - twice as much crystalloid fluid as compared to colloid required for comparable effect, eg.:

bolus of LR 20 ml/kg gives a pulse of expansion of intravascular space equivalent to 25% of EBV (80 ml/kg). It is rapidly dissipated to ECF. Since interstitial fluid is 3X larger than plasma volume, 20 ml/kg is partitioned as follows:
- 5 ml/kg intravascular compartment
- 15 ml/kg into extravascular fluid

1. Immediate resuscitation: Phase I: 20 cc/kg bolus. Reassess the patient
- Some improvement: repeat 10 cc/kg bolus
  No improvement: repeat bolus 20 cc/kg, foley catheter, CXR

Reassess
- Improved: decrease fluids to maintenance and calculate deficits for continued treatment
- No improvement: repeat bolus 10 cc/kg
- If no improvement: repeat bolus 10 cc/kg; 20 cc/kg in sepsis or trauma
- If no urine output, repeat CXR to r/o renal failure and possible CHF
- ABG: assess acid base status, watch for signs of respiratory failure; intubate art first evidence of increasing pCO_2 or BP not responding to fluid challenges
- If CXR clear: consider Albumin 25%-10cc/kg if Hct>30%
- Consider blood 10cc/kg if Hct<30%

Reassess:
- Improved: decrease fluids to maintenance and calculate deficits for continued treatment
- No improvement consider CVP; Consider Inotrope only if certain volume has been restored; dopamine 5-10 ucg/kg/min

Hemodynamic support in fluid-refractory pediatric septic shock: unlike adults, children with fluid-refractory shock are frequently hypodynamic and respond to inotrope and vasodilator therapy.

Because hemodynamic states are heterogenous and change with time, an incorrect cardiovascular therapeutic regimen shoudl be suspected in any child with persistent shock.

Ceneviva (1998) After fluid resuscitation:

Group I: 58% children had low CI and responded to inotropic therapy with or without vasodilator

Group II: 20% had a high CI and low SVR and responded to vasopressor therapy alone

Group III: 22% had both vascular and cardiac dysfunction and responded to combined vasopresor and inotropic therapy.

Shock persisted in 36% of the children.

Group I: 50% needed addition of vasodilator

Group II: 50% needed addition of an inotrope for evolving myocradial dysfunction

2. Initial Replacement Phase: If normal perfusion is restored with the initial fluid bolus or the degree of dehydration is less severe, early replacement can be initiated. The child's fluid deficit is calculated and 50% of the deficit is replaced in the first 8 hours.
In hypertonic dehydration, a slower rate may be indicated.

3. Late Replacement Phase: This portion of the resuscitation is generally performed as part of the inpatient management. The remaining fluid deficit is replaced over the next 16 hours and feedings are restarted. Depending upon the oral intake, complete parenteral replacement of the entire deficit may not be necessary.

SPECIFIC ETIOLOGIES & SHOCK STATES

Numerous disease states besides dehydration can produce clinical shock and/or volume depletion. These disease states exhibit a clinical continua from mild dehydration to shock. The emergency physician must be able to recognize and manage patients at any point along this continua. Since initial stabilization is the first priority, determination of the exact cause of the dehydration or shock may be delayed. In the interim before definitive diagnosis, no harm must be done. Once the etiology for the patient's problem is uncovered, the resuscitative approach can be tailored to more specifically treat the patient's problem.

A. HYPOVOLEMIC SHOCK: secondary to decrease in circulating volume

1. Phases

a. Compensated

Normal blood pressure	Peripheral vasoconstriction
Increased heart rate	Normal CNS
Reduced urine output	Increased myocardial contractility

b. Uncompensated

Decreased blood pressure	Decreased CNS
Anuria	Decreasing cardiac output

c. Irreversible

Major organ failure	Cellular death imminent

2. Etiologies

a. Hemorrhagic: trauma, GI bleed, CNS Bleed (neonate), Hemolysis

b. Fluid and electrolyte losses, gastroenteritis, DKA, polyuric states, adrenal Insufficiency, cystic fibrosis

c. Plasma/protein loss: burns, nephrosis, peritonitis

3. Management

a. Airway & Breathing: 100% oxygen, intubation if any question

b Fluid replacement (20 cc/kg)

c. Address specific etiology: pressure dressing, insulin and NS, etc

d. Foley catheter

e. Nasogastric tube

f. CVP

g. Dopamine only if intravascular compartment full

B. CARDIOGENIC SHOCK: The source of this problem is 1° pathology of the cardiovascular system

1. Phases

a. early

dyspnea on exertion	orthopnea	
increasing fatigue	mild tachycardia	top normal of heart

b. late

cyanosis	hypotension	tachycardia
cardiomegaly	gallop rhythm	rales

2. Etiology

a. Congenital Heart defects

hypoplastic left heart	aortic coarctation	aortic stenosis
anomalous coronary artery		

b Dysrhythmia

tachycardia	bradycardia	AV block

c. Infectious

myocarditis	pericarditis	endocarditis

d. Obstructive

tamponade	pulmonary embolism	pneumothorax

3. Management

a. Airway& Breathing : 100% oxygen; intubation if any question

b. Fluid replacement (20 cc/kg)

If etiology is known and no evidence of hypovolemia then skip bolus. If the etiology is unknown and patient is given single bolus no harm will usually result

c. Inotropes: dooamine

d. Afterload reduction: nitroprusside

e. Foley catheter

f. Nasogastric tube

g. CVP

C. **DISTRIBUTIVE** SHOCK: This is generally caused by loss of peripheral vascular resistance

1. Phases (Septic)

a. Early

Febrile	Tachypnea	Warm extremities
Decreased SVR	Increased cardiac output	Normal CNS
Polyuria	Bounding Pulse	Respiratory alkalosis

b. Late

Hypothermic	Bradypnea	Cold, mottled extremities
Obtunded	Metabolic acidosis	Hypotension

2. Etlologies

a. Sepsis: Gram negative sepsis, meningococcemia

b. Neurogenic

c. Drugs

d. Anaphylaxis

3. Management

a. Airway & Breathing:

b. Fluid replacement (20 cc/kg) bolus

c. Inotropes: Dopamine

d. Antibiotics

e. Foley catheter

f. Nasogastric tube

g. CVP

Appendix

FORMULAS FOR WEIGHT, BLOOD PRESSURE, AND BLOOD VOLUME

Weight estimate	8 + (2 X [age, yr]) = weight kg	
Blood pressure minimum	70 + (2 x [age, yr]) = 2/3 X (systolic blood pressure =	Systolic blood pressure Diastolic blood pressure
Blood volume	< 2 y = 100 mL/kg > 2 y = 80 mL/kg	

THREE METHODS FOR ESTIMATION OF
PARENTERAL FLUID REQUIREMENTS

I. Metabolic Requirements (caloric expenditure): water and electrolyte requirements parallel caloric expenditure but not body weight. Its advantage is that it is effective for all ages, shapes, and clinical states. Determine child's standard basal caloric expenditure(SBC):

Age	Weight (kg)	Caloric Expenditure (cal/kg/24 hr)
Newborn	2.5-4	50
1 week-6 months	3-8	65-70
6-l 2 months	8-12	50-60
l-2 years	10-15	45-50
2-5 years	15-20	45
5-1 0 years	20-35	40-45
10-l 6 years	35-60	25-40
Adult	7 0	15-20

Add 12% of SBC for each degree that patient's rectal temperature is above 37.8°C.
Add 0-30% of SBC to account for activity level.
For each 100 cals metabolized in 24°: the patient needs 100-120 cc H_2O, 2-4 mEq Na^+, and 2-3 mEq K^+.

II. Holllday - Segar Method: simple formula which estimates caloric expenditure from weight alone For each 100 calories metabolized, 100 cc H_2O will be required.

Water (cc/kg)		Electrolyte (per 100 cc H2O)	
1st 10 kg body weight	100	Na+	3 mEq
2nd 10 kg body weight	50	Cl-	2 mEq
Each additional kg	20	K+	2 mEq

Ill. Body Surface Area: based upon the assumption that caloric expenditure is proportional to the surface area. It provides no convenient method of taking into account changes in metabolic rate.

H_2O	1500 cc/m^2/24h
Na	30-50 meq/m^2/24h
K	20-40 meq/m^2/24h

Insensible water loss from skin and respiratory tract depend on metabolic rate. Metabolic rate is dependent on age, body size (represented by body weight). Urine volume relates to metabolic rate, osmolar load presented to the kidney for excretion, and kidney concentrating ability,

Estimates Of Body Surface Area

AGE	WEIGHT(KG)	SURFACE AREA
Newborn	3	0.2
1 year	10	0.5
3 years	15	0.6
5 years	20	0.7
9 years	30	1.0
14 years	50	1.5
Adult	70	1.7

Correlation Between Growth and Body Fluids

	PREMATURE	NEWBORN	1 YEAR	3 YEARS	ADULT
Body weight (kg)	1.5	3	10	15	70
Body surface area (m^2)	0.15	o r	0.5	0.6	1.7
BSA/body weight	0.1	0.07	0.05	0.04	0.02
Total body water (% BW)	75-80	70-78	60-65	62	60
Extracellular fluid (% BW)	50	45	25	21	20
Intracellular fluid (% BW	30	33	40-45	41	40

From Holliday MA: Body Fluid Physiology During Growth. In Maxwell MH, Kleeman CR (eds): Clinical Disorders of *Fluid* and Electrolyte ***Metabolism,*** ed 2. New York, McGraw-Hill, 1972, p 544.

Oral Rehydration Solutions

Composition of Oral Rehydration Solutions

Solution	Glucose (g/dl)	Na+ (mEq/L)	K+ (mEq/L)	Cl- (mEq/L)	Base (mEq/L)
WHO solution	2.0	90	20	80	30 (HC03)
Rehydralyte Pedialyte RS	2.5	75	20	65	30 (citrate)
Pedialyte	2.5	45	20	35	30 (citrate)
Lytren	2.0	50	25	45	30 (citrate)
Resol	2.0	50	20	50	[illegible]
Infalyte	2.0	50	20	40	30 (citrate)
Human milk		7	14	12	

Composition of Clear Liquid Beverages

FLUID	SODIUM (mmol/L)	POTASSIUM (mmol/L)	CARBOHYDRATE (gm/100 mL)	OSMOLARITY (mmol/L)
Apple juice	0.1-3.5	24-32	12	650-734
Grape juice	0.8-2.8	31-44	15	170-1190
Colas	1.3-t .7	0.1	10.4-l 1.3	390-750
Gingerale	0.8-5.5	0.1-1.5	5.3	520-560
Kool-Aid	0.5-l .2	0.1-1.8	10.6	250-590
Gatorade	20	3	4.6	330
Tea	0	5	0	330
Chicken broths	140-251	1.5-8.3		

Composition of Common Parenteral Fluids

Fluid	Na+	K+	Cl-	HCO3-
D5W	n	0	0	0
0.9% NaCl	154	0	154	0
1/2 NS	77	0	77	0
3% Saline	513	0	513	0
8.4% NaHCO3	1000	0	1000	0
Ringer's Lactate	130	4	109	28*
25% Albumin	140	0	110	0
Plasmanate	110	2	50	2

*Contained as citrate but converts to bicarbonate when it circulates through the liver. This may assist in the correction of metabolic acidosis and limit the patient's chloride load.

DEACONS (Detection of Electrolyte Abnormalities in Children Observational National Study)
Rothrock SG, et al: 1997

Of 715 eligible patient visits, 488 (66%) electrolyte panels contained a laboratory abnormality, with 182 (25%) Clinical Significant Electrolyte Abnormalities (CSEAs). A decision rule requiring 1 of 6 clinical criteria was 100% sensitive (95% Cl 96100%) and 24% specific (95% Cl 21-28%) in detecting CSEAs with positive and negative predictive values of 31% (95% Cl 28.34%) and 100% (95% Cl 97-100%), respectively. If these criteria had been used to screen patients for whom electrolyte panels were ordered, 128 patients (18%) would have had electrolyte panels obtainedand CSEAswoudl have been missed.

Odds Ratios for Single and Combined C eria

Clinical Criterion	Odds Ratio	95% Confidence Interval
Any of 6 high-yield criteria	115	7.1 - 1,860
* Dry mucous membranes	5.2	3.6-7.5
* Vomiting	4.9	3.3-7.1
Poor skin turgor	4.4	2.7 -7.1
Sunken orbits	4.0	2.5-6.5
Diarrhea	3.8	2.6-5.4
Poor oral intake	3.7	2.6-5.4
History of weight loss	3.3	1.9-5.7
Depressed fontanelle	3.1	1.3-7.4
Poor urine output	3.1	2.1-4.4
* Capillary refill > 2 sec	3.0	1.8-4.9
* Age < 6 months	2.8	1.9-3.9
Failure to thrive	2.8	1.3-6.3
Prior abnormal electrolytes	2.7	1.1-6.8
Tachycardia	2.0	1.4-2.8
* Diabetes	2.0	0.5-7.0
Major head truma	0.1	0.02-l .1
Trauma necessitating resuscitation	0.1	0.006-l .7

* High-yield criteria

CASE STUDIES

SHOCK CASE STUDY

2 year old male is brought to the ED with 1 day history of vomiting and lethargy. She also noted to have a rash on her trunk. She had slight congestion for 2 days. Social history remarkable for being in day care.

Vital signs are BP 65/40 P: 176 **RR 36** Wt is 15 kg The child is lethargic, obtunded and responds to painful stimuli only. He has glassy look to his eyes. Extremities are mottled and cool. He has scattered petechiae.

Initial management:
100% 02
Peripheral access 18 or 20 gauge antecubital IV
Second catheter placed
Bolus 300 cc NS over 5 minutes
Labs: electrolytes, BUN, Cr, glucose, CBC, blood cultures
ABG, foley

Following bolus, minimal improvement.
Repeat 300 cc NS over 10 to 20 minutes
Push antibiotics
Repeat third time if necessary

BURN VICTIM CASE STUDY

A 3 yo pulled a hot pot of water off of a stove and suffered partial and full thickness burns. Abdomen and thigh burns involve 20% of TBSA. Discuss the fluid management of this case. What fluids and how much would you give immediately? In the subsequent hours? In the first 24 hours? Wt 15 kg

- Initiate intravenous fluid therapy immediately. Two large-bore catheters are needed, one immediately. Consider central venous catheter.
- Initial stabilization: 20 ml/kg of 0.9%NS or LR over 10 to 30 minutes.

Burn Resuscitation Formula

- After cardiovascular resuscitation; over the first 24 hours:

Lactated Ringer's	4 ml x kg x %TBSA
D_5W 0.45%NS	maintenance

Shrlners Burns Institute-Galveston Unit Resuscitation Formula

FLUID ADMINISTRATION- RINGER'S LACTATE

1. First 24 hours:
   a. 5000ml/m^2 burn + 2000 ml/total BSA m^2
   b. Administer 112 in 8 hours and the remaining half in 16 hours
2. Second 24 hours:
   a. 3750 ml/m^2 + 1500 ml/total BSA m2
   b. Administer 112 in 8 hours and remaining half in 16 hours
3. Adjust the above rates to maintain a urine output of 1 ml/kg/h.

- 50% of resuscitation fluid given in the first 8° and the remainder over the next 16°
- Avoid the addition of KCL to IV fluids in ED: hemolysis, possibility of development of renal failure
- Watch for 3% saline ("hypertonic saline") in the future
- Successful resuscitation: normotensive, warm patient with urine output of > 1 ml/kg/24°
- All children with greater than 20% burns should remain NPO for the first 24 to 48 ° to avoid complications of ileus

Note: recent study suggests rapid fluid resuscitation in burns may result in a safe and more effective resuscitation (Puffinberger 1994):
44 children: 22 received 1/2 volume over ≤4 hours; 22 received standard 1/2 volume over 8 hours.
Results: 20 in rapid group but only 8 in standard group had stable vital signs at 24 hours.
urine output in 22/22 rapid group, 19/22 standard group at 1 .O ml/kg/hr in first 24 hours.
mechanical ventilation: 5/22 rapid group versus 13/22 in standard group despite inhalation injury requiring intubation higher in rapid group (7 vs 4).
Rapid group received more fluid overall ((5.1 vs 3.86 ml/kg/hr) and more sodium: no significant increase in tissue edema or need for escharotomy.

CASE(continued)
Maintenance rate fluids D5W 0.45% NS
100 ml/kg for the first 10 kg + 50 ml/kg for the next 10 kg = 1,250 ml over 24 hours or 52 mllhr
Resuscitation fluids (lactated Ringer's solution)
4 ml x kg x %TBSA = 4 ml x 15 kg x 20 = 1,200 ml/24 hr

TOTAL FLUIDS (Maintenance and resuscitation)
Maintenance 52 mllhr (D10W 0.45% NS) = 52 ml/hr
Resuscitation
2nd/3rd 8 hours 1200 ÷ 2 = 600; 600 ÷ 8 16 hrs = 75 ml/hr (LR)
= 37.5 ml/hr (LR)
Total/Actual rate:
First 8° 52 ml/hr *plus* 75 ml/hr = 127 mllhr
2nd/3rd 8° 52 ml/hr *plus* 37.5 mllhr = 90 ml/hr

DIABETIC KETOACIDOSIS CASE STUDY

A 7 year old female presents with 2 days of progressive weakness after having one to two weeks of increased thirst. Mother also reports wt lo&and abdominal pain.
PE: awake and alert, sunken eyes, Kussmaul respirations and tachypneic.
RR: 24 BP: 75/50 P: 138 T: 99.5 Appropriate in behavior and responds to simple questions, obviously fatigued, appears dry with decreased skin turgor, dry mucous membranes, sunken eyes. Exam otherwise unremarkable. Wt 30 kq.

A few notes on DKA:
Dehydration with metabolic acidosis is common. Hyperglycemia invokes an osmotic diuresfs. Electrolyte losses accompany this diuresis resulting in greater hyperglycemia and hypertonicity. Measured serum osmolality is elevated. Fluid losses accelerate with increased glucose concentration.
- Because of the osmotic gradient created by the hyperglycemia and resultant fluid shift from the intracellular to extracellular compartment, the severity of clinical dehydration may be underestimated.
- Net free water losses nay be as high as 100 to 150 ml/kg.

1. Fluid Management:
a. *Bolus 10 -20 cc/kg of NS* or until vital signs stable and patient not clinically volume depleted
Fluid and electrolyte replacement:
1. **Na+** loss approximately **10** meq/Kg
2. Serum sodium may be falsely low: (pseudohyponatremia):

Sodiumcorrected = **Sodium**,,,,,,, + 1.6 x (glucose-100)/100

- Give crystalloid infusion of 0.45% normal saline with potassium salts
- If corrected sodium ≤ 140 mEq/L; replace half of the deficit over the first 16 hours and restore total deficit over 36 hours
- If corrected sodium ≥ 140 mEq/L, restore total deficit evenly over 48 hours

b. *K+ loss* approximately 10 meq/Kg
1. Replace K+ as 1/2 KCl and 1/2 KP04

Serum potassium (mEq/L)	Potassium in infusate (mEq/L)
<3	40-60
3-4	30
4-5	20

c. Bicarbonate *therapy:* indicated only with shock or severe acidemia (pH < 7.0)
- Can give sodium bicarbonate, 1 to 2 mEq/kg, IV over 1 to 2 hours.
- HC03 may be given as slow drip for severe acidosis
  note: if one combines 1/2 NS with 75 mEq NaHC03, then the solution will have the same concentration of Na+ as NS but only 112 the chloride load. A child must be adequately ventilating prior to giving bicarbonate.
- Tobias: 1998 study: Venous pH monitor continuously measured pH with clinically applicable correlation between the venous measurement of pH by the Paratrend & and the arterial pH measured using convential technology.

2. Glucose control:
a. Insulin-R: 0.1-0.2 unit/kg I.V. bolus
b. Insulin drip 0.1 unit/kg/hr
c. Add 5% dextrose if glucose <250 mg/dl (or if your really busy, <300 mg/dl) and possibly decrease insulin to 0.05 units/kg/hr
d. Monitor glucose hourly

3. Brain swelling
Cerebral edema is a problem in pediatric DKA, possibly related to overaggressive fluid resuscitation but it is controversial. Cerebral edema is unpredictable in onset and usually without warning signs. It usually occurs 8 to 12 hours after initiation of treatment. There are two reports in 1991 which describe extremely early onset of cerebral edema in DKA, one before treatment and one about 2 hours after treatment had begun.

It is manifested as abrupt onset of changes in mental status, pupillary changes, and posturing progressing to coma with mortality rate of up to 90%. Specific treatment variables that predispose to the development of cerebral edema have not been identified. However, rapid rates of fluid administration and total fluid dose > $4L/m^2$ have correlated for increased risk.

Total fluid should not exceed 4 liters/meter^2 in the 1st 24". After initial resuscitation from shock, fluid administration should be carefully individualized and governed by corrected serum sodium and clinical response.

If neurologic deterioration occurs, the patient should be administered mannitol 1-2 gm/kg and intubated for hyperventilation.

Case (continued)
Na+ 135 mEq/L, K+ 4.0 meq/L, HCO3- n Hg, pCO2 15 mmHg;
8 mEq/L, Cl 113 mEq/L, glucose 500 mg/dl, BUN 20

Fluid and Electrolytes: 30 kg; 7 yrs old: approximately 1 m^2 BSA		
	Deficit	Maintenance (24 hr)
Water	30 kg x 10% = 3.0 kg (3000 ml)	1700 mL (70 mL/hr x 24°)
Sodium	9 mEq/kg = 270 mEq	3 mEq/100 mL H20 = 51 mEq
Potassium	6 mEq/kg = 180 mEq`	2 mEq/100 mL H20 = 34 mEq

Replacement Procedure		
	Volume	Solution
STAT if shock	20 mL/kg and repeat PRN	NS or LR
First 1/2 to 1 hour	20 mL/kg = 600 mL	NS
Replacement Procedure		
Next 8 hours	1/2 deficit = 1200 mL (3000-600 =2400 ÷2) 8-hr maintenance = 560 mL (70 mL/hr x 8) Total = 1760 mL over 8 hrs = 225 mL/hr	[(0.5 LR or 0.5 NS)] + [(20 mEq KCl/L + 20 mEq KPO4/L) *or* 40 mEq KCl/L] ± 25 – 50 mEq $NaHCO_3$/L (until pH ≥ 7.1) Add 5% dextrose (when blood glucose ≤ 250-300 mg/dl)

Following a second bolus, the child begins to respond more appropriately HR is down to 120, BP up to 88/56. Fluids should be decreased to maintenance but replacement of deficits over the next 24 hours.

HYPONATREMIC DEHYDRATION CASE STUDY

A 10 kg infant with cystic fibrosis has had profuse diarrhea (7 to 10 stools per day) for several days. Parents have been doing a great job pushing fluids, particularly Kool-Aid and Gingerale. Today, the infant has become lethargic and arrives in the ED comatose.
Patient's pre-illness weight: 10.0 kg Wt. on admission: 9.0 kg

Degree of dehydration: moderate (10%); Na+: 110 mEq/L, K+ 5 mEq/L, Cl- 90 mEq/L, HCO3-12 mEq/L

Maintenance Fluid Requirements	H20 (ml)	1,000	(100 ml/kg)
	Na+ (mEq)	30	(3 mEq/kg)
	K+ (mEq)	20	(2 mEq/kg)
Deficit requirements (100 mL/kg):	H20 (ml)	1,000	(10% BW); ECF = 60% = 600 cc; ICF = 40%
	Na+ (mEq)	84	= 140 mEq/L x 0.6
	K+ (mEq)	30	= 150 mEq/L x 0.4 x 50% correction

Na+ deficit calculation to correct to 135 mEq/L:
a. 135 mEq/L - 110 mEq/L (observed Na+) = 25 mEq/L
b. Total body water (TBW) (Ukg) = 0.6 Ukg (pre-illness TBW) - 0.1 L/kg (water loss) = 0.5 Ukg.
c. Pre-illness wt = 10 kg

Sodium deficit = A x B x C = 25 mEq/l x 0.5 L/kg x 10 kg = 125 mEq
Total Na+ Deficit = 84 mEq + 125 mEq: 209 mEq
Total Na+ required (maintenance + deficit): 239 mEq (30 + 209)
Total K+ required (maintenance + deficit): 50 mEq

Fluid Schedule:
Phase I: 20 mL/kg = 200 mL NS or LR over 20 minutes (if necessary)
Phase II: To be given over the next 8 hours:

1/2 deficit=	500 mL D5W with	104 mEq NaCl and	15 mEq KCL
1/3 maintenance=	333 mL D5W with	10 mEq NaCl and	7 mEq KCL
Total:	= 833 mL D5W with	114 mEq NaCl and	22 mEq KCl

Can be given as 833 mL (100 mL/hr) of D5W 0.9% NS with 27 mEq KCl/L (22 mEq)

Phase III: To be given over hours 9-25:

1/2 deficit	= 500 ml D5W with	104 mEq NaCl and	15 mEq KCl
2/3 maintenance	= **667** mL D5W with	20 mEq NaCl and	14 mEq KCl
Total:	= **1167** mL D5W	124 meq NaCl	29 mEq KCl

Can be given as 0.9% NS with 25 mEq KCl/L (29 mEq KCl) at a rate of 75 cc/hr

Adapted from Barkin RM, Rosen P. Emergency Pediatrics: Guide To Ambulatory Care. 3rd ed. St. Louis, Mo. CV Mosby; 1990.

HYPERNATREMIC DEHYDRATION CASE

A 7 month old infant has had fever and diarrhea for 1 to 2 days. She took formula well initially but has been vomiting over the last 8 to 10 hours. Mother presents with infant now because vomiting and progressive lethargy.

Physical Exam: Temp 39°C Pulse 150 RR: 48 BP: 80/55 Weight 6.3 kg (wt 7.0 kg last week). The child is lethargic but irritable when examined. Mucous membranes *are* somewhat dry, diaper is dry, but she cries tears. Skin is warm and doughy. Initial **Na+ is 165 mEq/L.**

Phase I: Child is not in shock and is hypernatremic: so slow, steady repletion is indicated rather than boluses. Infant needs IV rehydration **due** to (1) elevated Na+ requiring 48 hour correction and (2) altered mental status.

Phase II:

1. Determine maintenance fluids and electrolytes:

a. Fluid:	100 ml/kg/d x 7.0 kg	= 700 mL/day
b. Na+	3 mEq/L/100 mL of maintenance fluid	= 21 mEq/d
c. K+	2 mEq/L/100 mL of maintenance fluid	= 4 mEq/d

2. Calculate the replacement fluids and electrolytes

a. Fluid replacement = (preillness weight – present weight) x 1000 ml/L
= (7.0 kg – 6.3 kg) = 0.7 kg x 1000 ml/L **= 700** mL

b. How much of this is free water?

1. Difference between measured serum Na+ and 145 (165 – 145) = 20 mEq/L
2. Every 1 mEq/L difference in sodium represents a deficit of 4 mL/kg of free water
20 mEq/L x (4 mL x 7 kg) = 560 mL free water deficit
3. To avoid risk of cerebral edema, calculate **to** correct halfway to normal serum sodium
= 0.5 (20 mEq/L) x (4 mL x 7 kg) = **280** mL
4. Subtract the free water deficit from the fluid replacement to determine the amount of *electrolyte containing* replacement = 700 mL – 280 mL = **420** mL

c. Na+ replacement = concentration in ECF x [(fluid replacement containing electrolytes x % lost in ECF) x 1L/1000 mL] = 135 mEq/L x [(420 mL x 60%) x 1L/1000 mL] = 34 mEq/L

d. K+ replacement = K+ concentration in ICF x [(fluid replacement containing electrolytes x % lost in ICF) x 1L/1000 mL] = 150 mEq/L x [(420 mL x 40%) x 1L/1000 mL] = 25 mEq/L

3. a. Fluid replacement for 48 hours
= fluid replacement + (fluid maintenance x 2)
= **700** mL + (700 mL x 2) = 2100 mL ÷ 48° = 44 mL/hr

b. Sodium replacement for 48 hours
= sodium replacement + (sodium maintenance x 2)
= 34 mEq/L + (21 mEq/L x 2) = 76 mEq/L

c. Potassium requirement for 48 hours
= potassium replacement + (potassium maintenance x 2)
= 25 mEq/L + (14 mEq/L x 2) = 53 mEq/L

d. So, in the next 24 hours, patient needs a rate of 44 ml/hr
2100 mL of fluid, 76 mEq Na+ = 36 mEq/1000 mL, 53 mEq/L K+= 25 mEq/1000 mL)
i.e readily available as D5.25NS.

4. Repeat electrolytes at a minimum of 12 hours or sooner if mental status not improving
5. Once Na+ <160 mEq/L, the infant can be given oral maintenance solutions.
6. Advance diet to half-strength, then full strength.

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