Fluids and Electrolytes

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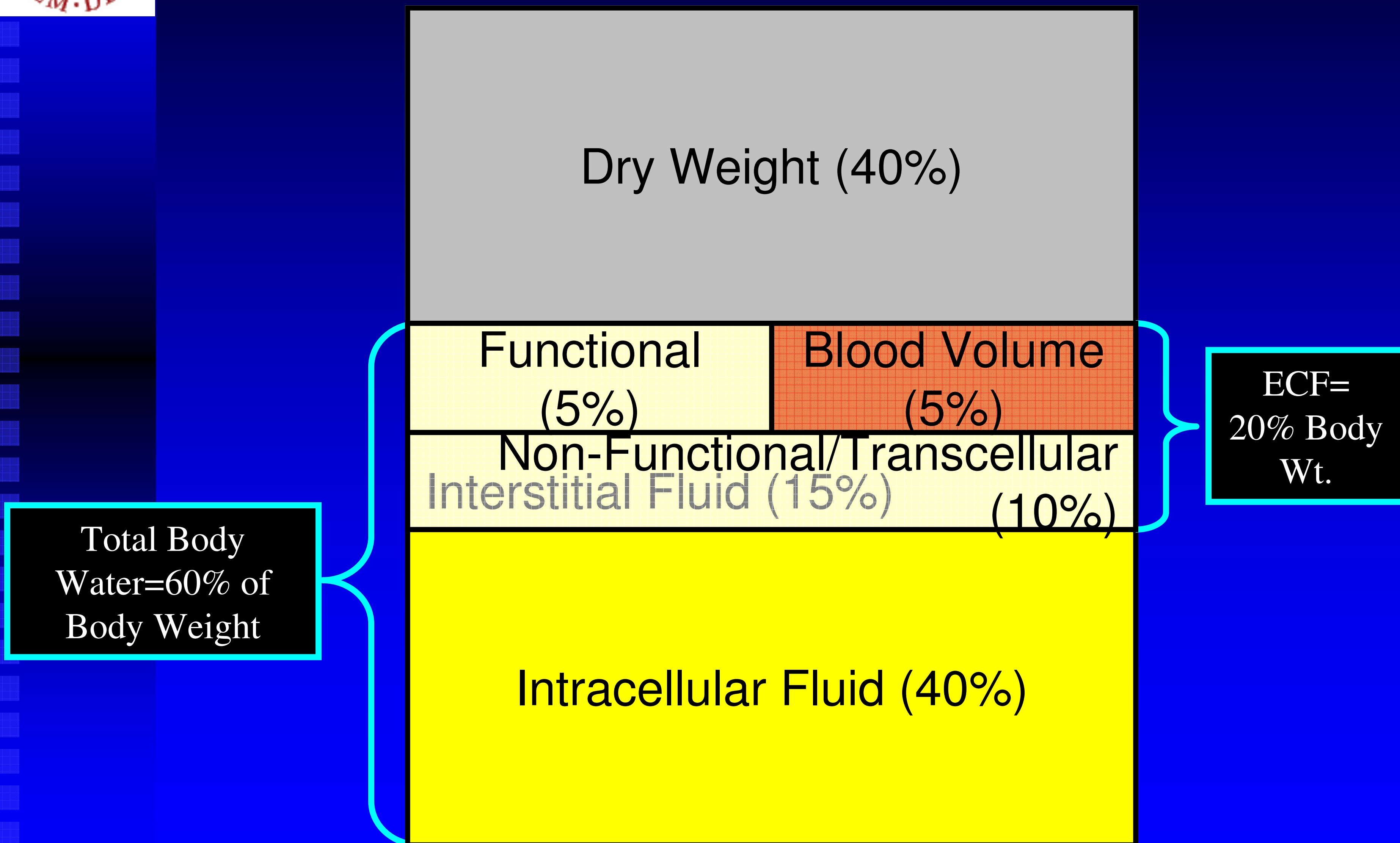
Importance

- Critical aspect in patient management
- Altered in:
  - Major trauma
  - Disease States
  - Operative trauma

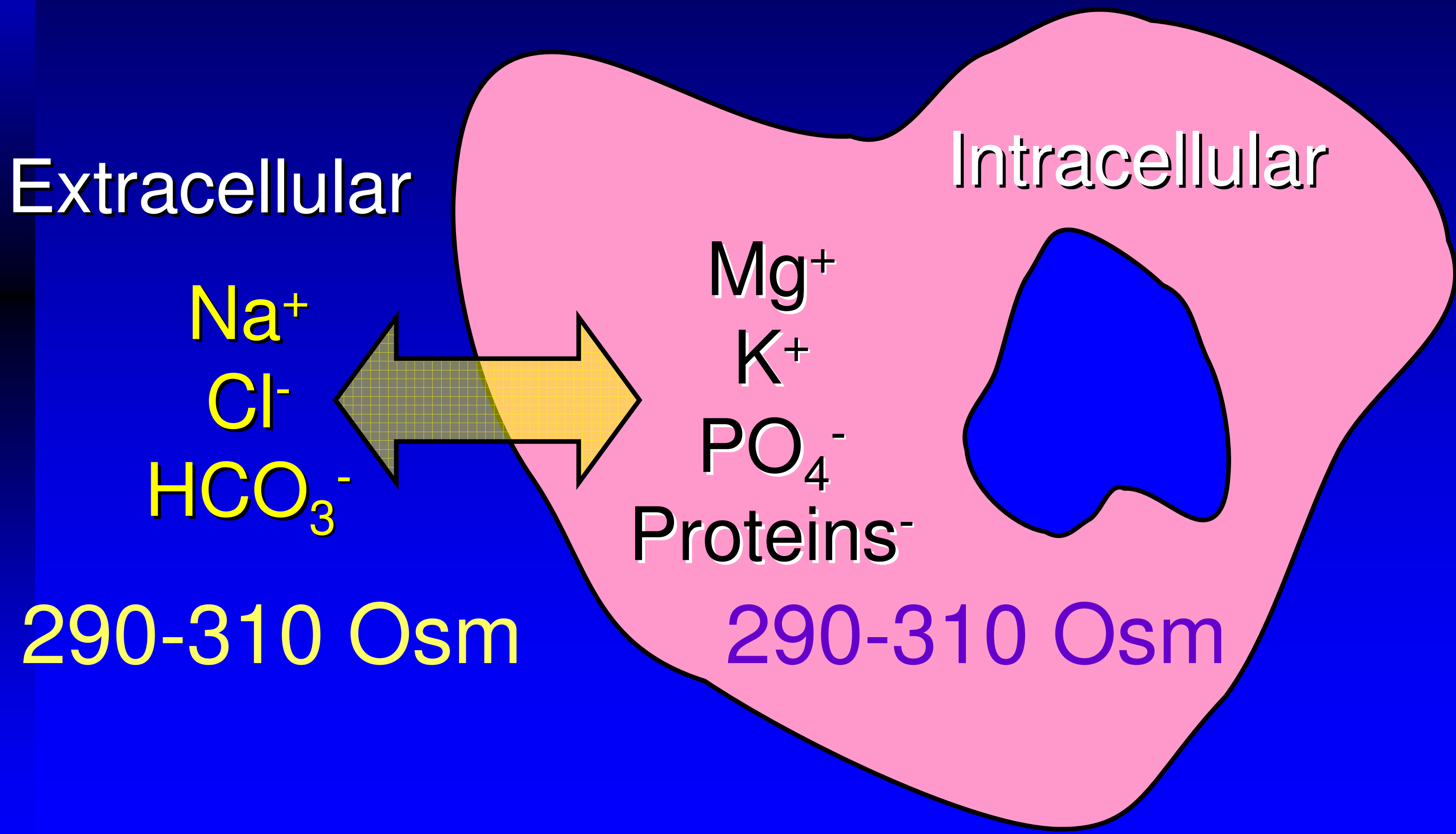
Anatomic Distribution

- Total body water = 50-70% weight
  - Higher in men than women
  - Higher in slim than fat
  - Steadily decreases with age
- Example: 70 kg male: 42 liters of water

Body Fluid Compartments



Osmotic Pressures



Definitions

- Osmosis
  - From the Greek *osmos* (impulse), derived from *otheo* (to push)
  - Refers to the tendency, when 2 solutions of differing concentrations are separated by a semipermeable membrane, for the permeable substance to diffuse through the membrane from its higher to its lower concentration until the pressures across the membrane become equal
  - In most biologic systems, water is freely permeable across membranes
    - Hence, any change in osmotic pressure will lead to shifts in water distribution (since H_2O is usually the only molecule that can move)

Definitions

- Total Osmotic Pressure
  - Sum of all osmotically active particles in the solution
    - $NaCl = 2$
    - $Na_2SO_4 = 3$
    - Glucose = 1

Definitions

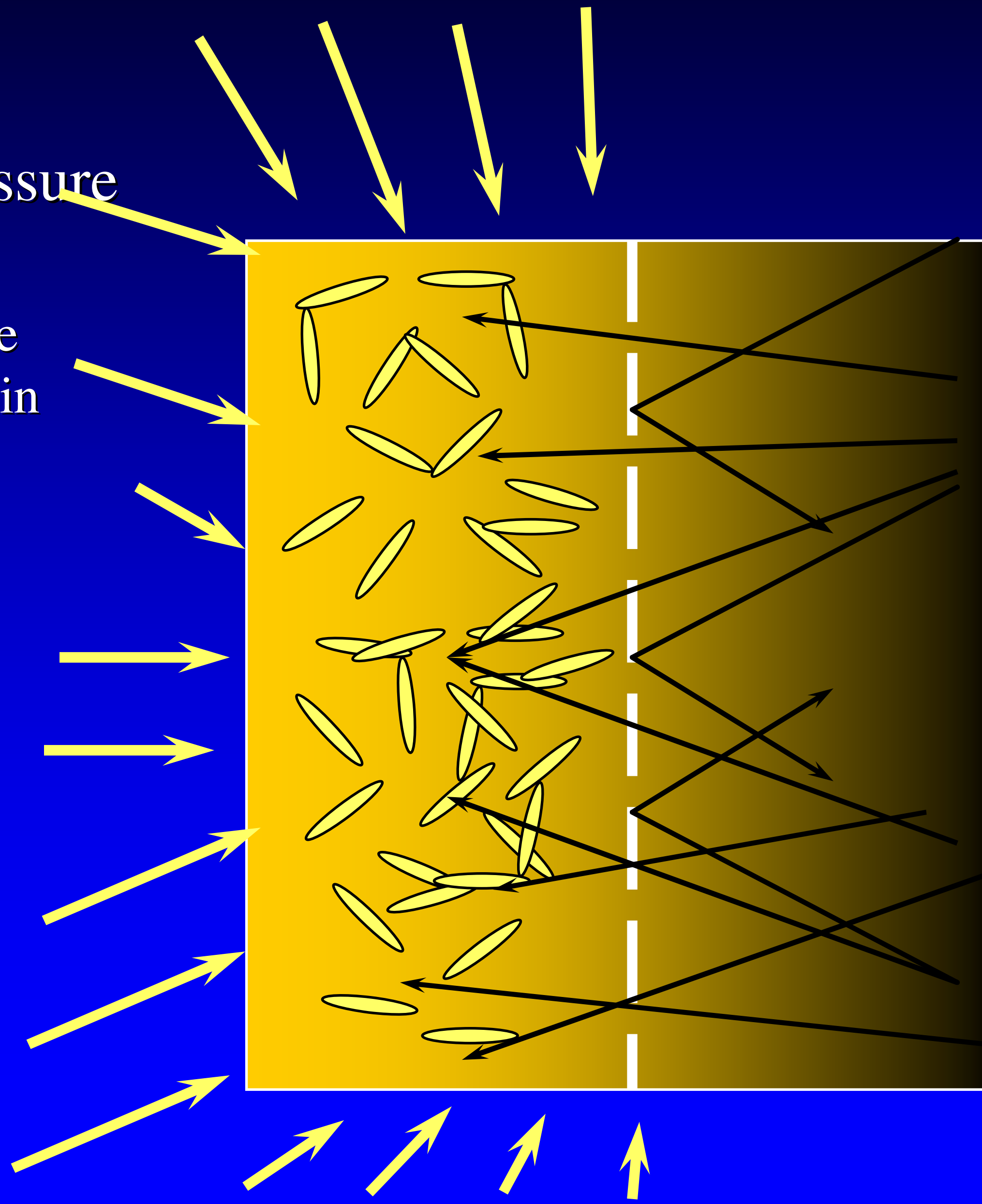
- Oncosis
  - From the Greek, *onkosis* (swelling), derived from *onkos* (bulk, mass)
  - A condition characterized by the formation of one or more neoplasms, tumors, or other swelling
  - i.e., the term "oncology" derives from the same root
- In common usage, "oncosis" and "oncotic" refer to osmotic properties induced by colloids

Definitions

- Colloid
  - From the Greek *kolla* (glue) + *eidos* (appearance)
  - Aggregates of atoms or molecules in a finely divided state dispersed in a gaseous, liquid, or solid medium, and resisting sedimentation, diffusion, and filtration, thus differing from precipitates

Definitions

- Colloid oncotic pressure (COP)
  - the osmotic pressure exerted by colloids in solution
  - designated as π.



Internal Environment

- Homeostasis must be preserved for optimal cellular functioning and viability
  - Balance between input and output must be maintained
  - Maintained by
    - Kidneys
    - Brain
    - Lungs
    - Skin
    - GI tract
  - Compromised by major surgical stress

Why do anything?

- Why bother with “ins” and “outs”?
  - That is, if we did nothing, couldn’t we achieve balance by letting it all stay in?
- Answer: No
  - The body produces metabolites that are eliminated in the urine:
    - Urea
    - Creatinine
    - Acid
  - You must excrete 500 - 800 ml of urine a day to excrete products of metabolism

"Ins"

- Normal person: Oral intake
  - 1 to 2.5 liters per day
    - 100 to 1,500 ml liquid
    - 400 - 1000 ml's
      - extracted from solid food
      - oxidative metabolism (~400 ml/day)

"Outs"

- Urine
  - ~800 - 1500 ml daily
- Stool
  - ~250 ml daily
- Insensible loss
  - 600 ml daily
    - 75% lungs
    - 25% skin
  - Increased due to fever, hyperventilation, hypermetabolism, arid environment, evaporation (i.e., from exposed viscera)

Fundamental Concepts

- Electrolytes are measured in terms of their ***concentration*** within a fluid, not their content

Normal Concentrations of Plasma Electrolytes

Electrolyte	Normal plasma concentration (mEq/L)
Na^+	135 – 145
K^+	3.5 – 4.8
Cl^-	95 – 106
HCO_3^-	22 – 32
Mg^{++}	1.7 – 2.3

Normal Volume and Composition of Body Fluids

Source	Daily loss (ml)	$[Na^+]$ (mEq/L)	$[K^+]$ (mEq/L)	$[Cl^-]$ (mEq/L)	$[HCO_3^-]$ (mEq/L)
Saliva	~1,000	20-80	10-20	20-40	20-160
Gastric juice	1,000 – 2,000	20-100	5-10	120-160	0
Bile	~1,000	150-250	5-10	40-60	20-60
Pancreatic juice	1,000 – 2,000	120	5-10	10-60	80-120
Succus entericus	1,000 – 2,000	140	5	Variable	Variable
Colon	200-1,500	75	30	30	0
Sweat	200-1,000	20-70	5-10	40-60	0

Volume Disorders

- Occur due to adding or subtracting an **ISO**tonic fluid
  - Primarily affects extracellular fluid volume
  - No impact on intracellular fluid volume
  - No fluid shifts between compartments
    - (unless volume deficit is so severe than cell membrane pumps fail to maintain transcellular balance)

Causes of Extracellular Volume Deficits

- Loss of both sodium and water
  - not necessarily in the same proportion
- Acute or chronic GI fluid losses
  - Diarrhea
  - Vomiting
  - Fistulae
  - NG suction
- Fluid sequestration ("third spacing")
  - Postinjury
    - Burns
    - Multiple trauma
  - Postsurgical
- Excessive urinary sodium losses
  - Renal disease
  - Adrenal disease
  - Diuretic administration

Extracellular Volume Deficits:
Signs and Symptoms

- Orthostatic hypotension
- Narrowed pulse pressure
- Tachycardia
- Evidence of reduced venous filling
- Oliguria
  - Concentrated urine
- Drowsiness
- Mild decrease in body temperature
- Small, soft tongue
- Reduced skin turgor
- More severe volume deficits eventually lead to stupor or coma
  - reduced deep tendon reflexes
  - muscle atony

Extracellular Volume Deficits: Management

- Replacement with parenteral fluids
  - Crystalloids
  - Colloids
- Rapidity of replacement depends upon severity of deficit and underlying general health of the patient
  - Severe deficits: 500 ml to 1,000 ml boluses
  - Lesser volumes with the elderly and infirm
- Monitor clinical response
  - Blood pressure, urine output, correction of other signs that initially signalled volume deficit
- Set a volume administration threshold
  - If administered volume is exceeded, a more specific indication of nature and degree of volume status is required
    - Typically a central venous pressure monitor or, more precisely, pulmonary artery catheter

Extracellular Volume Deficits: Maintenance

- Volume
  - Determine total quantity of fluid volume loss over 24 hour period
  - Add constant for insensible losses
    - ~ 500 ml at sea level
    - ~ 1,000 ml at elevations, in arid environments
    - Higher insensible losses with fevers, hypermetabolism
- Concentration
  - Determine sodium concentration of each fluid
    - Measure concentrations if necessary
  - Divide total by the total fluid volume to arrive at the required sodium concentration
  - Same process can be used for other specific electrolytes when necessary
- Rate
  - Divide the total volume by 24 (hours) to calculate the total fluid rate

Example Case #1

- You are providing care for a 32 year-old male who was involved in a motor vehicle collision, sustaining a left pneumohemothorax, a retroperitoneal hematoma, and a pancreatic transection.
- He is now 6 days post-injury and has a paralytic ileus and what appears to be an antibiotic-associated enterocolitis
  - He cannot eat and he has diarrhea

Extracellular Volume Deficits:
Maintenance

Source	Volume (L)
Urine	1.240
Insensible	0.600
Diarrhea	0.400
Chest tube	0.560
JP drain	0.180
Total	**2.980**

What happens if these losses continue without replacement?

Cumulative Fluid Balance without Replacement

	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7
Daily fluid losses	2,980	2,980	2,980	2,980	2,980	2,980	2,980
Net balance	-2,980	-5,960	-8,940	-11,920	-14,900	-17,880	-20,860

Extracellular Volume Deficits: Maintenance

Source	Volume (L)	$[Na^+]$ (mEq/L)	Total Na^+ lost (mEq)
Urine	1.240	30	37
Insensible	0.600	20	12
Diarrhea	0.400	140	56
Chest tube	0.560	140	78
JP drain	0.180	140	25
Total	**2.980**		**209**

Extracellular Volume Deficits: Maintenance

Source	Volume (L)	$[Na^+]$ (mEq/L)	Total Na^+ lost (mEq)
Urine	1.240	30	37
Insensible	0.600	20	12
Diarrhea	0.400	140	56
Chest tube	0.560	140	78
JP drain	0.180	140	25
Total	**2.980**		**209**
Average [Na+] (mEq/L) = 209/2.98 =		**70**	

Electrolyte Content of Parenteral Fluids (mEq/L)

Solution	Cations					Anions		
	Na^+	K^+	Ca^{2+}	Mg^{2+}	NH_4^+	Cl^-	HCO_3^-	HPO_4^-
Extracellular fluid	142	4	5	3	0.3	103	27	3
Lactated Ringer's solution	130	4	2.7			109	28*	
0.9% sodium chloride (saline)	154					154		
M/6 sodium lactate	167						167*	
M (molar) sodium lactate	1,000						1,000*	
3% sodium chloride	513					513		
5% sodium chloride	855					855		
0.9% ammonium chloride					168	168		

*Present in solution as lactate, which is converted to bicarbonate.

Extracellular Volume Deficits:
Maintenance

Source	Volume (L)	[Na⁺] (mEq/L)	Total Na⁺ lost (mEq)
Urine	1.240	30	37
Insens			2
Diarrh			6
Chest tube	0.560	140	78
JP drain	0.180	140	25
Total	**2.980**		**209**
Average [Na+] (mEq/L) = 209/2.98 =		**70**	

= D$_5$½ NS at 2,980 ml/24 hours

= D$_5$½ NS at 125 ml/hr

Example Case #2

- You are caring for a patient on his 2nd day following an open cholecystectomy and a common bile duct exploration for acute suppurative cholangitis
- He has a nasogastric tube and a Jackson-Pratt drain in place

Extracellular Volume Deficits: Maintenance

Source	Volume (L)	$[Na^+]$ (mEq/L)	Total Na^+ lost (mEq)
Urine	2.3	30	69
NG losses	0.400	60	24
Insensible	0.200	140	28
JP drain	0.180	140	25
Total	**3.080**		**146**

Extracellular Volume Deficits:
Maintenance

Source	Volume (L)	$[Na^+]$ (mEq/L)	Total Na^+ lost (mEq)
Urine	2.3	30	69

General Rule: Replace no more than 1,500 ml of daily urine output

—or you'll be chasing your own volume infusions as the urine output cumulatively increases

Average [Na+] (mEq/L) = 146/3.08 =		**47**	

Extracellular Volume Deficits: Maintenance

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Total	**3.080**		**146**
Average [Na+] (mEq/L) = 146/3.08 =		**47**	

Extracellular Volume Deficits: Maintenance

Source	Volume (L)	[Na^+] (mEq/L)	Total Na^+ lost (mEq)
Urine	1.5	30	45
NG lo			4
Inser			8
JP drain	0.180	140	25
Total	2.280		122
Average [Na+] (mEq/L) = 146/3.08 =		54	

= $D_5{}^1/_3$ NS at 2,280 ml/24 hours

= $D_5{}^1/_3$ NS at 100 ml/hr

Volume Excess

- Causes:
  - Iatrogenic
  - Renal Insufficiency
  - Cirrhosis
  - CHF

Fluid & Electrolyte Abnormalities

- Hypernatremia (ICD-9 code 276.0)
- Hyponatremia (ICD-9 code 276.1)
- Hyperkalemia (ICD-9 code 276.7)
- Hypokalemia (ICD-9 code 276.8)
- Hypercalcemia (ICD-9 code 275.42)
- Hypocalcemia (ICD-9 code 275.41)
- Hyper/hypomagnesemia (ICD-9 code 275.2)
- Hyper/hypophosphatemia (ICD-9 code 275.3)
- Hypervolemia (ICD-9 code 276.6)
- Hypovolemia (ICD-9 code 276.5)

Sodium Concentration Abnormalities

Hypernatremia = Dehydration

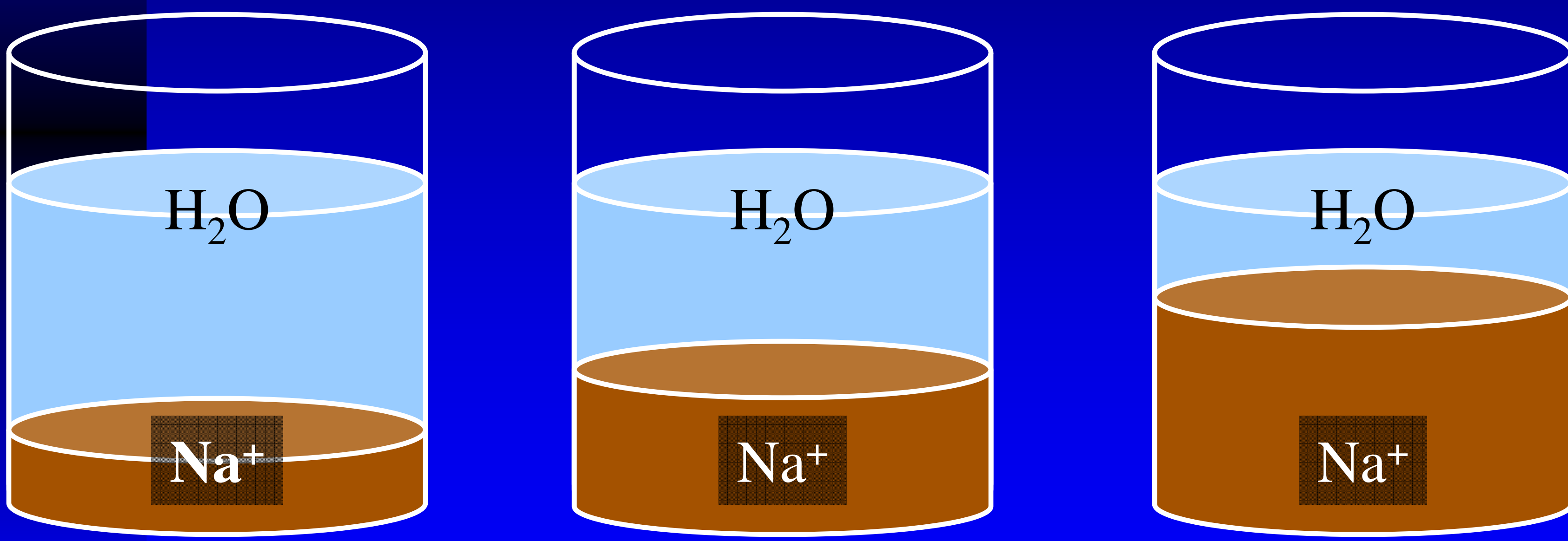
Hyponatremia = Overhydration

Dehydration ≠ Hypovolemia

Overhydration ≠ Hypervolemia

Concentration Changes

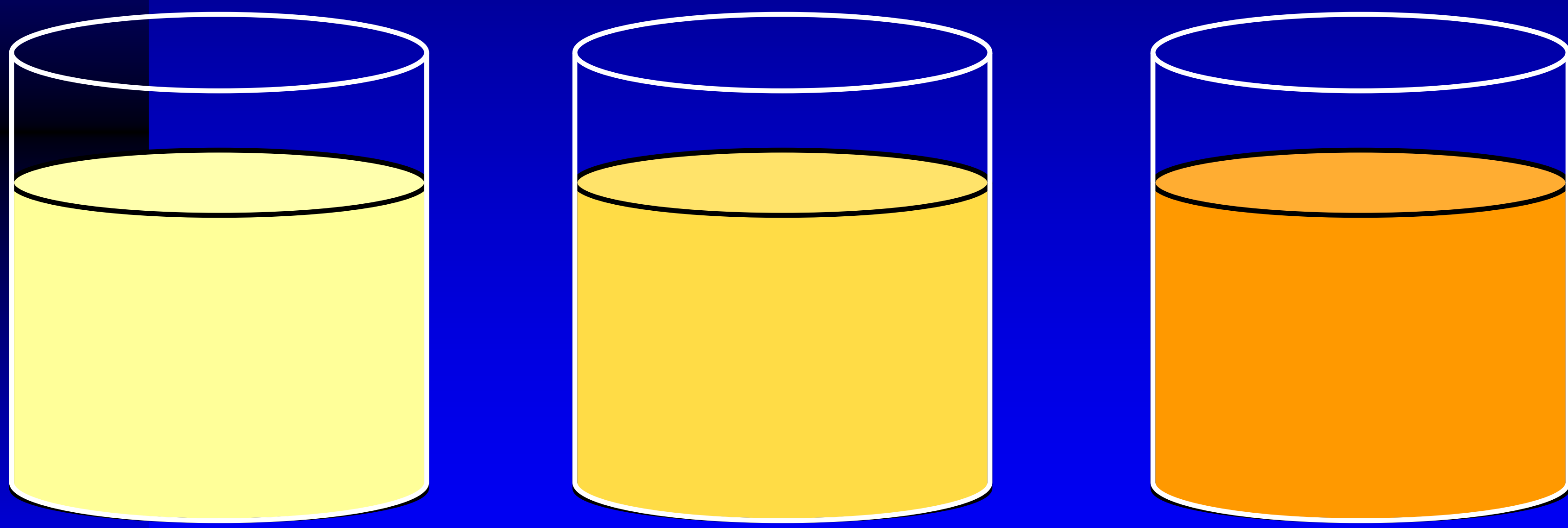
Overhydration | Normal hydration | Dehydration



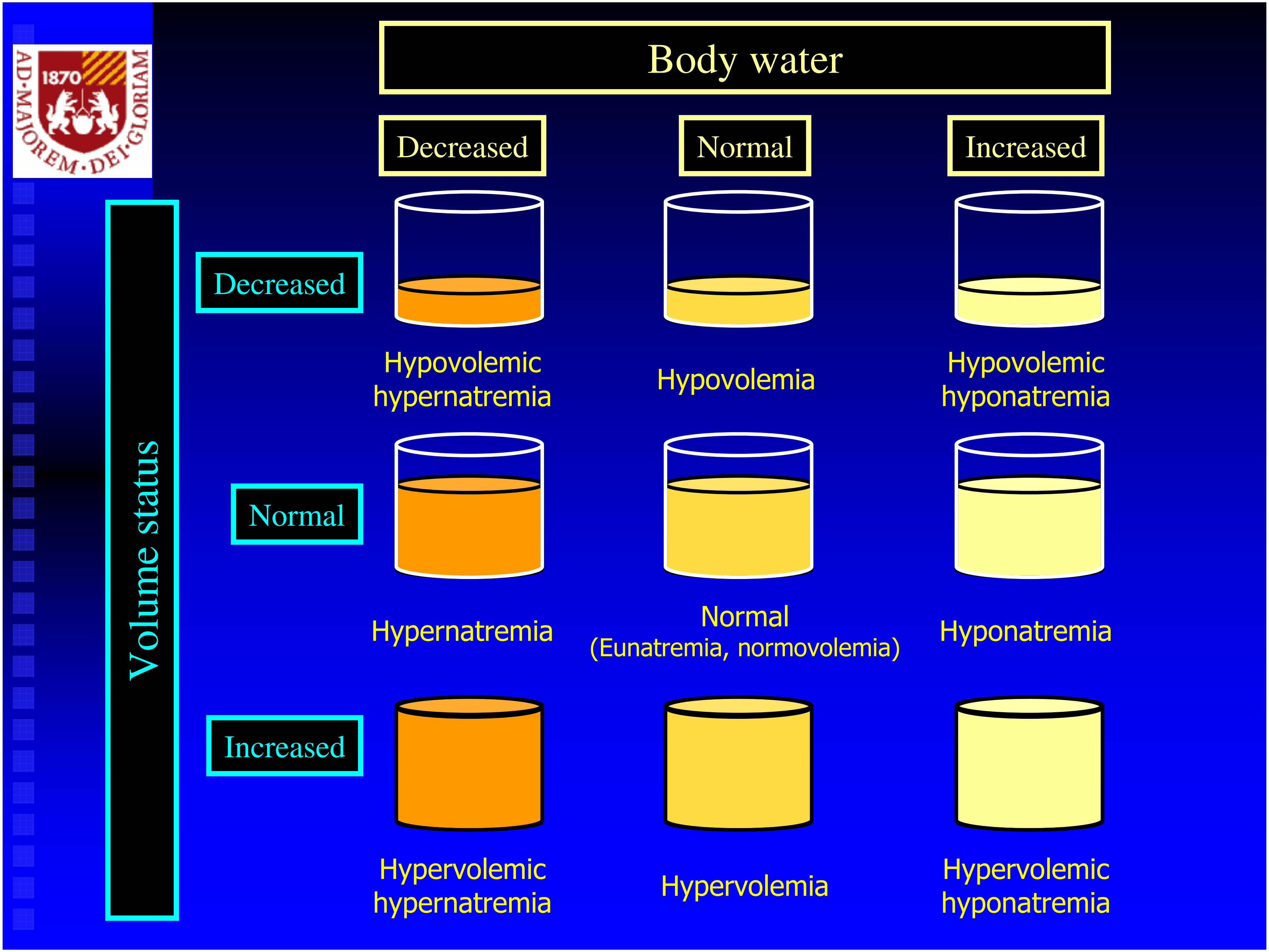
Hyponatremia | Eunatremia | Hypernatremia

Concentration Changes

Overhydration	Normal hydration	Dehydration



Hyponatremia	Eunatremia	Hypernatremia


Body water
Decreased
Normal
Increased
Volume status
Decreased
Hypovolemic hypernatremia
Hypovolemia
Hypovolemic hyponatremia
Normal
Hypernatremia
Normal
(Eunatremia, normovolemia)
Hyponatremia
Increased
Hypervolemic hypernatremia
Hypervolemia
Hypervolemic hyponatremia

Hypernatremia & hyponatremia

- Abnormalities of sodium concentration most commonly result primarily from alterations in water balance
- Hypernatremia typically results from loss of water, not from excess sodium content of the body
- Hyponatremia most commonly results from overhydration (i.e., excess water), not from inadequate salt content

Hyponatremia

- Symptoms:
  - Mental obtundation
  - Seizures
- Differential diagnosis:
  - Total body water excess
  - Factitious (i.e., hyperglycemia)
    - [Na+] is reduced by 1.6 mEq/L for every 100 mg/dl (5.5 mmol/L) rise in glucose above normal
  - SIADH
  - Sepsis
  - Renal Failure
    - Associated with increased total body sodium content
    - Pitting edema

Management of Hyponatremia

- Assessment of volume status
  - Hypervolemia
    - Seen with excess free water intake or SIADH
    - Treated with fluid/free water restriction
  - Euvolemia
    - May be factitious
    - Free water restriction usually helpful
  - Hypovolemia
    - Hypotension & oliguria must be treated promptly to avert acute renal failure
  - Severe hyponatremia: < 120 mEq/L
    - Calculate sodium deficit & replace accordingly

Treatment of Severe Hyponatremia

Normal Na^+ (mEq/L) – actual Na^+ (mEq/L) = Na^+ deficit (mEq/L)

Example: 140 – 110 = 30

0.6 x body wt. (kg) = Total body water (L)

Example: 0.6 x 60 = 36

TBW (L) x Na^+ deficit (mEq/L) = estimated Na^+ deficit (mEq)

Example: 36 x 30 = 1,080

3.0% hypertonic saline solution contains 0.5 mEq/ml

Therefore, replacement is calculated:

(Estimated Na^+ deficit [mEq])/0.5 = volume of 3% saline (ml)

Example: 1,080/0.5 = 2,160

Treatment of Severe Hyponatremia

- To avoid neurologic complications, $[Na^+]$ should not be raised by more than 12 mEq/L during the first 24 hours
- Once $[Na^+] \geq 120$ mEq/L or symptoms have resolved, further aggressive correction generally is not required

Hypernatremia

- Causes
  - Inadequate free water intake
    - Elderly, debilitated
  - Excessive free water losses
    - Gastrointestinal (diarrhea, vomiting), sweating (without water replenishment)
  - Inadequate postoperative fluid replacement
  - Diabetes insipidus
    - Central
    - Nephrogenic
  - Sodium overload
    - Intake of hypertonic sodium solutions

Causes of Diabetes Insipidus

- Central
  - Idiopathic
  - Traumatic
  - Neurosurgical
  - CNS neoplasms
  - Alcohol
  - Diphenylhydantoin
  - Eosinophilic granuloma
  - Sarcoidosis
- Nephrogenic
  - Congenital (usually sex-linked dominant)
  - Lithium
  - Demeclocycline
  - Amphotericin
  - Methoxyflurane
  - Propoxyphene overdose

Treatment of Hypernatremia

- Overly rapid correction can produce cerebral edema, seizures, permanent neurologic damage, or death
- No sequelae observed when [Na^+] lowered at rate of 0.5 mEq/L/hr or less
  - Thus, 14 mEq/L concentration excess should be lowered over 28 hours or more
  - 4.8L/28 hours = 170 ml/hour D_5W
  - ***Don't forget to keep up with ongoing losses in addition to replacing this deficit***

Diabetes Insipidus Management

- Ideally, hypernatremia can be corrected by supplementing with free water
- In cases where water alone is inadequate, dDAVP (a 2-AA substitute of ADH) can be used
  - usual dose 5 to 20 mg QD-BID
  - nasal spray
  - no vasopressor activity
  - Disadvantages
    - Long duration of action→water retention & hyponatremia
    - Can be a problem in acute head injury with cycling between SIADH & DI
    - Expensive

Case #3

- A 28-year-old 72 kg male sustained a severe intracerebral hemorrhage following a motorcycle crash 4 hours ago. He underwent arteriography to embolize a bleeding splenic vessel. He has received 3,500 ml of crystalloid resuscitation. He is now producing 600-1,200 ml of urine per hour.
- What are the possible causes of his high urine output?

A. SIADH
B. Contrast load ✓
C. Diabetes insipidus ✓
D. Diuretic administration

Case #3

- Which of the following tests would most quickly distinguish between IV contrast load and diabetes insipidus?
  - A. Serum chloride and urine osmolality
  - ✓ B. Serum sodium and urine specific gravity
  - C. Serum and urine osmolality
  - D. BUN and urine osmolality

Distinction between Specific Gravity and Osmolality

- Specific gravity
  - Density of a solution relative to the density of water
    - Water's density is set arbitrarily at 1
  - Density is defined as mass/volume
  - Therefore, SpG is related to the ***weight*** a substance provides
- Osmolality
  - Relates to the number of particles exerting an osmolar effect that are in solution
  - Therefore, Osm depends upon a molecular ***concentration***

Case #3

- The patient's serum sodium is 154 mEq/L and his urine specific gravity is 1.006.
- His urine concentration & volume are:

A. Physiologically appropriate

✓ B. Physiologically inappropriate

Case #3

- The patient's serum sodium is 154 mEq/L and his urine specific gravity is 1.006.
- His urine concentration & volume is:
  - A. Physiologically appropriate
  - ✓ B. Physiologically inappropriate
- He has:
  - ✓ A. Diabetes insipidus
  - B. Contrast load

What is the patient's free water deficit?

Case #3

$$\text{Free } H_2O \text{ deficit (L)} = \frac{[Na^+] - 140}{140} \times \frac{2}{3} \times \text{Wt. (kg)}$$

$$= \frac{154 - 140}{140} \times \frac{2}{3} \times 72 \text{ kg}$$

$$= \frac{14}{140} \times \frac{2}{3} \times 72 \text{ kg}$$

$$= 0.1 \times \frac{2}{3} \times 72 \text{ kg}$$

$$= 4.8 \text{ L}$$

Acid-Base Metabolism

- Intracellular
  - Renal excretion of inorganic acids anions with NH_4
  - Metabolism of organic acid anions
- Extracellular
  - $HCl + NaHCO_3 \rightarrow NaCl + H_2CO_3$

Buffer Systems

- Intracellular
  - Proteins
  - Phosphates
- Extracellular
  - Bicarbonate/Carbonic Acid system
  - (proteins)
  - (hemoglobin)

Differentiation of Acid-Base Status

	Metabolic	**Respiratory**
Acidosis	↓Base excess (↓ HCO_3^-)	↑Pco_2
Alkalosis	↑Base excess (↑ HCO_3^-)	↓Pco_2

Respiratory Acidosis

- Defined as hypoventilation
- More common in medical patients
  - COPD (chronic compensation)
  - “50-50” club
- Seen with oversedation, poor pulmonary toilet
  - Can cause agitation
  - Needs to be evaluated before sedating patient

Respiratory Alkalosis

- More common than previously thought
- Secondary to hyperventilation
  - pain
  - apprehension
  - hypoxia
  - CHI
- Tachypnea ≠ hyperventilation
- Associated with hypokalemia → arrhythmias

Metabolic Acidosis

- Anaerobic metabolism from
  - Inadequate circulation
    - Volume depletion
    - Poor cardiac function
    - Sepsis
- Excessive alkali loss
  - Diarrhea, fistulae
- Diabetic Ketoacidosis
- Renal failure

Metabolic Alkalosis

- Excessive alkali intake
- Loss of acid
  - High gastric output
    - NG tubes, vomiting, pyloric obstruction
    - “Paradoxical aciduria”

Paradoxical Aciduria in Metabolic Alkalosis from High Gastric Losses

Volume loss

↓

↑ Aldosterone secretion

↓

↑ K^+/H^+ exchange for Na^+ absorption

↓

Aciduria

Hypokalemia

- Symptoms:
  - Weakness
  - Flattened T-waves on EKG
- Differential diagnosis:
  - Metabolic alkalosis causing shift of K+ in exchange for H+
  - Renal losses from diuretic use
  - GI losses
    - NG
    - Diarrhea
  - Inadequate supplementation

Hypokalemia

Treatment

- No accurate calculation of potassium deficit
  - Decrease of 2 mEq/L = 200 mEq deficit
  - Decrease of 3 mEq/L = 400-500 mEq deficit
- Preferable to replace by enteral route (40-60 mEq p.o./day)
- IV route no more that 20 mEq/hr

Hyperkalemia

- Symptoms:
  - Nausea, vomiting, abdominal pain
  - Cardiac arrhythmias
  - Peaked T-waves, wide QRS, ST depression
- Differential diagnosis:
  - Renal failure
  - Iatrogenic potassium administration

Hyperkalemia Treatment

- Counteract cardiac toxicity
  - Administer Ca^{++} gluconate or CaCl
- Drive K^{+} into the cells
  - Administer Na^{+} Bicarbonate - raises pH
  - Administer Insulin 25U IV and D50
  - Administer Albuterol
    - for resistant hyperkalemia
    - increases plasma insulin concentration
    - lowers K+ level by 0.5-1.5 mEq/L
    - Beneficial in patients when fluid overload is concern (i.e., renal failure)
- Bind K^{+}
  - K^{+} binding resins - Kayexalate (25 - 50g)
- Dialysis
  - True last resort

Summary

- The surgical patient can manifest a variety of fluid and electrolyte disorders in a variety of settings
- A thorough understanding of basic physiology coupled with clinical acumen is the physician's toolkit for managing these disorders