Fluid and Electrolyte Metabolism/ Renal and Urologic Disorders

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Disclosures

• I have no relevant financial relationships with the manufacturers(s) of any commercial products(s) and/or provider of commercial services discussed in this CME activity.

• I do not intend to discuss an unapproved/investigative use of a commercial product/device in my presentation.
Objectives

• Design safe and effective fluid management regimens for children with maintenance, rehydration, and replacement fluid and electrolyte needs.

• Recognize which children and adolescents need regular blood pressure monitoring

• Integrate an evaluation and management strategy for children with hypertension
Maintenance Fluids

• Purpose is to provide daily fluid and electrolyte needs without requiring substantial renal compensation
• Also should provide 20% of caloric intake to prevent ketosis and limit protein catabolism
• Provides a starting point, but patient will declare whether it is adequate or not
Scenario

An otherwise healthy 4 yo boy is having his tonsils and adenoids removed for recurrent strep pharyngitis. He is told to be NPO after midnight in preparation for surgery and anesthesia. What maintenance fluids should he receive overnight:
Answer

• He does not require any maintenance fluids
• His kidneys will concentrate his urine overnight to keep him hydrated, and he’ll wake with concentrated urine
Scenario**

A 3.5 kg newborn boy requires anesthesia for a surgical procedure (nope swaddling and pacifier won’t cut this one)

He is made NPO. Assuming he is well hydrated, has normal electrolytes, is afebrile, and is at rest, an appropriate fluid regimen would be to:
Answer

• Unlike the older child, this neonate does require fluids overnight for a few reasons**
• Neonates have immature renal tubular function including Immature urinary concentrating abilities (also decreased ability to reabsorb sodium, and to excrete a potassium or acid load)**
  – He can concentrate to a limited degree, so a prolonged fast may risk free water losses and hypernatremia
• Neonates also have immature gluconeogenesis, so a prolonged fast may risk hypoglycemia
• He’ll need dextrose containing IV Fluids, such as D5 ¼NS or D5 ½NS at 10-15 mL/hr. Since his fast is for just part of the 24 hour day, it’s fine to include a small amount of potassium or to leave it out.
Scenario

Breastmilk provides all that an infant requires, and therefore must have sufficient sodium content for an infant’s maintenance requirements.**

Mature breastmilk (not colostrum) therefore contains:
Answer

A: About 5-10 mEq/L of Sodium
B: About 10-20 mEq/L of Sodium
C: About 20-30 mEq/L of Sodium
D: About 40-50 mEq/L of Sodium
E: About 60-80 mEq/L of Sodium
## Sodium Concentration of Common Hydration Solutions

<table>
<thead>
<tr>
<th>Solution</th>
<th>Sodium concentration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal Saline</td>
<td>154 mEq/L</td>
</tr>
<tr>
<td>½ Normal Saline</td>
<td>77 mEq/L</td>
</tr>
<tr>
<td>¼ Normal Saline</td>
<td>34 mEq/L</td>
</tr>
<tr>
<td>Ceralyte</td>
<td>70 mEq/L</td>
</tr>
<tr>
<td>Pedialyte</td>
<td>45 mEq/L</td>
</tr>
<tr>
<td>Gatorade</td>
<td>20 mEq/L</td>
</tr>
<tr>
<td>Term Infant Formulas</td>
<td>8-14 mEq/L</td>
</tr>
<tr>
<td>Breast Milk</td>
<td>7-10 mEq/L</td>
</tr>
</tbody>
</table>
### Standard maintenance needs

**ELECTROLYTES**

<table>
<thead>
<tr>
<th>Electrolyte</th>
<th>Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sodium</td>
<td>2-4 mEq/kg/day</td>
</tr>
<tr>
<td>Chloride</td>
<td>2-4 mEq/kg/day</td>
</tr>
<tr>
<td>Potassium</td>
<td>1-3 mEq/kg/day</td>
</tr>
</tbody>
</table>
Fluid Intake Requirements

• Based on fluid output

• Fluid output composed of
  • “Insensible” or evaporative (breathing, skin) losses
  • Measurable output (generally urine)
Evaporative Losses

- Fixed fluid loss, electrolyte free
  - Sweat is NOT included in these losses
- Based on humidity, activity, and size of individual
- Assuming resting activity, generally 300-500 mL/m²/day
- Approximates to 1/3\(^{rd}\) of the Holliday-Segar method calculated daily maintenance intake rate ("4:2:1 rule")
Factors that affect evaporative losses

- **Increase**
  - Fever
  - Loss of Skin Integrity
  - Activity
  - Tachypnea
- **Decrease**
  - Hypothermia
  - Sedation
  - CNS Depression
Urinary Losses

• Volume
  • Varies based on condition and intake of patient
    • Provided intake exceeds evaporative losses and no additional losses (eg diarrhea) → remains in fluid balance through concentration vs dilution of urine
    • Oliguria does not necessarily mean dehydration
    • Polyuria may be appropriate if high intake
  • Special circumstances**
    • Diabetes insipidus, diuretics will result in increase
    • Increased ADH will result in decrease contribution
Fluid Requirements in Kidney Failure/Injury (chronic or acute)**

• Want to avoid **excessive fluid loss** as well as fluid overload
  – Patients with obstructive uropathy, tubulo-interstitial disease, cystic and/or dysplastic disease tend to have polyuria
    • Salt wasting and/or urinary concentrating impairments
  – Supporting **residual urine output** is actually important!
    • Nutrition, growth, and blood pressure control much easier
    • Reduces morbidity and enhances quality of life
    • Encourage fluid intake to balance losses– may need to measure urine output and replace output via intake
    • If sodium wasting, may need sodium supplement as well
Fluid Requirements in Kidney Failure/Injury (chronic or acute)**

- Want to avoid excessive fluid loss as well as fluid overload
  - Patients with glomerular or hypoxic-ischemic injury tend to develop oliguria or anuria
  - Fluid and sodium restriction becomes necessary
    - To support nutrition—may need concentrated formula supplement
    - Tight fluid control optimizes blood pressure control—common to need additional anti-hypertensive medication
Scenario

• A 12 month old girl presents with vomiting and diarrhea. In the emergency room she has tachycardia and delayed cap refill. She weighs 12kg. The provider estimates moderate (10%) dehydration. He/she should initiate fluid resuscitation with:
Answer

• Isotonic crystalloid (E.g. Normal Saline bolus)
Principles Behind Repleting Fluid Deficits

• Restoration of circulating volume (cardiovascular function, brain and kidney perfusion) requires repletion of sodium**
  – Thanks to Sodium-Potassium ATPase, sodium is the major cation of extracellular (including circulating) volume; potassium intracellular volume
  – Bolus (or rapid) restoration of circulating volume is always with isotonic sodium containing solution (e.g. Normal Saline, LR)
    • Standard is 20ml/kg, can repeat if necessary
    • Good response—improvement in tachycardia, urine output
Principles Behind Repleting Fluid Deficits

- Determine fluid deficit and type of dehydration (hypo-, iso-, or hypertonic)
  - Account for ongoing losses
- Potassium should be repleted once renal function and urine output established**
  - All cases of dehydration associated with potassium losses (aldosterone effect → stimulates urinary potassium excretion)
  - Serum potassium may not be reflective of total body potassium because large majority of potassium is intracellular**
- Patient’s response to therapy determines adequacy of regimen
  - Mental status, vital signs
  - Weight gain, urine output
Scenario

- The primary pediatrician of the previous case’s 12 month old girl above calls in to the ER and forwards the records from her recent 12 month health maintenance visit earlier that week.

- This is most immediately valuable because:
Determining Fluid Deficits**

- Estimate degree of dehydration and correlate with % weight loss
- Comparative Weights are ideal both in prescribing and monitoring treatment
**Determining Fluid Deficits**

- Estimate degree of dehydration and correlate with % weight loss

<table>
<thead>
<tr>
<th></th>
<th>MINIMAL (hx of losses)</th>
<th>MILD</th>
<th>MODERATE</th>
<th>SEVERE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Infants/Toddlers</td>
<td>2%-3%</td>
<td>5%</td>
<td>10%</td>
<td>15%</td>
</tr>
<tr>
<td>Older Child</td>
<td>1%</td>
<td>3%</td>
<td>6%</td>
<td>9%</td>
</tr>
<tr>
<td>Vitals</td>
<td>Normal</td>
<td>Tachycardia</td>
<td>Orthostatic hypotension</td>
<td>Shock</td>
</tr>
<tr>
<td>Urinary Output</td>
<td>Mildly decreased</td>
<td>Less but non-oliguric</td>
<td>Oliguria</td>
<td></td>
</tr>
<tr>
<td>Exam</td>
<td>Normal</td>
<td>Cranky, Tired Tachy MM, Decreased tears</td>
<td>Lethargy, Poor Skin Turgor, Dry MM, Absent Tears</td>
<td></td>
</tr>
</tbody>
</table>
Question

• Dehydration in children

A. Provides a stimulus for the Renin-Angiotensin-Aldosterone system so providers should avoid isotonic solutions to prevent development of hypertension
B. Provides a stimulus for ADH, so providers should avoid using solutions more hypotonic than ½ NS to prevent the development of hyponatremia
C. Provides a stimulus for the Renin-Angiotensin-Aldosterone system so providers should avoid adding potassium to the fluids
Answer

• Dehydration in children

Provides a stimulus for ADH, so providers should avoid using solutions more hypotonic than ½ NS to prevent the development of hyponatremia.
The choice of fluid (i.e. composition of the fluid) to rehydrate a patient with must factor in:

A. The degree of dehydration
B. The serum osmolarity (or serum sodium)
C. The type and severity of the acid-base disorder
D. All of the above
Answer

The choice of fluid (i.e. composition of the fluid) to rehydrate a patient with must factor in:

The serum osmolarity (or serum sodium)
Acid-Base

• Metabolic Acid-Base derangements are usually not helpful in determining severity or percentage of dehydration

• They are helpful in telling us *how* the patient got dehydrated
  • Non-gap acidosis—diarrhea predominant
  • Alkalosis—vomiting or chloride wasting predominant

• During rehydration (w/saline solutions) may see worsening prior to improvement
  • Renal sodium chloride retention
  • Reperfusion of vasoconstricted areas (muscle, soft-tissue)
**Classification of Acid Base Disorders**

<table>
<thead>
<tr>
<th>DISORDER</th>
<th>PROXIMATE CAUSE(S)</th>
<th>Direct effect on blood gas</th>
<th>Compensation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Respiratory acidosis</td>
<td>Retention of CO₂</td>
<td>pH ↓, PCO₂ ↑↑</td>
<td>[HCO₃⁻] ↑</td>
</tr>
<tr>
<td>Respiratory alkalosis</td>
<td>Exhalation of CO₂</td>
<td>pH ↑, PCO₂ ↓↓</td>
<td>[HCO₃⁻] ↓</td>
</tr>
<tr>
<td>Metabolic acidosis</td>
<td>Addition of fixed acid OR</td>
<td>pH ↓, [HCO₃⁻] ↓↓</td>
<td>PCO₂ ↓</td>
</tr>
<tr>
<td></td>
<td>Loss of alkali</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Metabolic alkalosis</td>
<td>Addition of alkali OR</td>
<td>pH ↑, [HCO₃⁻] ↑↑</td>
<td>PCO₂ ↑</td>
</tr>
<tr>
<td></td>
<td>Loss of fixed acid</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
(NOT PRESENTING) Differential Diagnosis of Acid-Base Disorders**

<table>
<thead>
<tr>
<th>Respiratory Acidosis--Hypoventilation</th>
<th>Metabolic Acidosis</th>
<th>Metabolic Alkalosis—Chloride Loss</th>
<th>Respiratory Alkalosis--Hyperventilation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Airway obstruction</td>
<td>Increased anion gap (MUDPILES)</td>
<td>Renal chloride loss (eg diuretics)</td>
<td>Anxiety</td>
</tr>
<tr>
<td>Acute or chronic lung disease</td>
<td>Normal anion gap (Hyperchloremic)</td>
<td>Extra-renal chloride loss (eg vomiting, sweat in CF pts)</td>
<td>Hypoxemia</td>
</tr>
<tr>
<td>Resp. depression</td>
<td></td>
<td></td>
<td>Salicylates</td>
</tr>
<tr>
<td>Weakening of resp. muscles</td>
<td></td>
<td></td>
<td>Pulmonary embolism</td>
</tr>
</tbody>
</table>
(NOT PRESENTING) Normal Anion Gap**

AG = [Na⁺] - [Cl⁻] - [HCO₃⁻] = 12

140 Na⁺

24 HCO₃⁻

104 Cl⁻

12 unmeasured⁻
(NOT PRESENTING) A Case of Anion Gap Acidosis**
AG = [Na⁺] - [Cl⁻] - [HCO₃⁻] = 24
(NOT PRESENTING) High Anion Gap Acidosis**

- Methanol
- Uremia
- DKA
- Paraldehyde
- INH, Iron
- Lactic Acidosis
- Ethylene Glycol
- Salicylates
(NOT PRESENTING) High Anion Gap Acidosis**

- Methanol
- Uremia
- Lactic Acidosis
- Ethylene Glycol
- Paraldehyde
- Aspirin
- Ketoacidosis

- MULEPAK
(NOT PRESENTING) Hyperchloremic Metabolic Acidosis (normal anion gap)**

• Gain of HCl
  – Input of extra $H^+$ or $Cl^-$ (e.g. saline infusion, hyperalimentation)
  – Decreased renal elimination of acid (e.g. distal renal tubular acidosis, K-sparing diuretics, mineralocorticoid deficiency/resistance)

• Loss of Alkali
  – Diarrhea or other alkaline GI losses (e.g. pancreas)
  – Impaired renal reabsorption of $HCO_3^-$ (e.g. proximal renal tubular acidosis, acetazolamide)
Types of Dehydration**

• Isonatremic (Iso-osmolar)
  – Assuming BUN and Glucose are not elevated, osmolality can be approximated from serum sodium**
  – This is most common form of volume depletion, serum sodium is essentially within normal range
Types of Dehydration**

• Hyponatremic
  – Volume depletion with attempted rehydration with easily available hypotonic solution (e.g. child is drinking juice)
  – Rehydrate with saline, since patient is in free water excess relative to solute
Types of Dehydration**

- Hypernatremic
  - Hyperconcentrated formula or supplement
  - Volume depletion and insufficient free water rehydration, in particular seen in immobilized patients not receiving sufficient free water when free water losses increase (e.g. with hypotonic diarrheal losses)
  - Consider rehydrating with fluids containing some free water, as patient is relatively free water depleted
(NOT PRESENTING) Choice of Fluid for Iso-natrelemic Volume Depletion

- **ADH**—stimulated in volume depletion
  - In volume depletion if give excess free water may result in reduction of serum osmolality
  - Shifting of fluid into intracellular volume, including CNS cells and associated complications**

- **Renin/Angiotensin/Aldosterone**
  - Work together to support circulating volume by telling the kidney to retain/reabsorb sodium (and water)
  - If you give the volume depleted kidney sodium, it will retain it (Fractional Excretion of Na <1%)**
(NOT PRESENTING) Choice of Fluid for Iso-natreemic Volume Depletion

• Rehydration with hypotonic fluids may result in hyponatremia and intracellular brain swelling
  – Most often mild without clinical sequelae, but rarely a cause serious morbidity, seizures
  – Complications clearly associated with solutions more hypotonic than ½ NS
  – Data with respect to ½ NS of unclear clinical significance
(NOT PRESENTING) Choice of Fluid for Iso-natrelemic Volume Depletion

• Is rehydration with isotonic solutions the answer?
  – Maybe
• Physiologically, kidney should be reabsorbing as much sodium as it can
  – So it may not be, technically, a “physiologic” solution
• A Practical solution?
  – Practically (and clinically), it ensures sufficient sodium repletion
  – In an otherwise healthy child, the kidney will dump (not reabsorb) any excess sodium given
  – The child is likely taking some enteral hypotonic fluids too
(NOT PRESENTING) Caution

- In conditions in which excess sodium administration may cause complications
- Conditions sensitive to extracellular volume (sodium) overload**
  - Hypoalbuminemia (hypoproteinemia → low circulating oncotic pressure)**
    - Nephrotic syndrome, cirrhosis, malnutrition, etc...
    - Excess sodium may result in clinically relevant edema
    - Delivery of the sodium and volume to the interstitial volume rather than circulating volume
  - Congestive Heart Failure
  - Hypertension
(NOT PRESENTING) On the other hand...

- Be mindful of conditions in which there are excess sodium losses
  - Uncontrolled Diabetes—glucose acts like an osmotic diuretic
  - Polyuria recovery phase of Acute Kidney Injury or Obstructive Uropathy**
  - Primary or secondary renal salt wasting disorders—diuretic use, Fanconi Syndrome, Renal Tubular disorders**

- ...these patients will need more sodium so benefit for isotonic rehydration
A 4 month old boy presents with RSV bronchiolitis and is admitted for hypoxia. In addition to resp symptoms, he has not been eating/drinking his formula. He has post-tussive emesis. At his recent well visit he weighed 6kg, and now he weighs 5.6 kg.

Propose a rehydration plan
Plan

- With good resp supports to control tachypnea, this baby may do very well with oral rehydration therapy**
- Many “commercial” solutions available
- Principle to enhance GI absorption of sodium is to couple sodium with organic solute carriers (e.g. glucose)**
  - Solution should have total osmolality between 200-310 mosml/L (higher osmolality will promote diarrhea and decrease absorption)
  - Glucose and Sodium concentration should be “equimolar” to enhance transport
Scenario

An 1 mo girl presents with weeks of watery diarrhea. Her parents are mixing the formula powder and when doublechecked, it’s three times as concentrated as it’s supposed to be. She weighs only 3.5 kg (5%ile). Birth-weight was 3kg (50%ile). Her serum sodium is 165 mEq/L, K 3.5, Cr 0.3

Propose a rehydration plan
Plan

• This baby is free water depleted. The excessively concentrated formula aggravates this further through diarrhea and poor GI fluid absorption.

• Most important aspect of plan is to correct hypernatremia slowly.**
  – Overly fast correction results in movement of fluid intracellulary, in particular brain swelling and resulting CNS symptoms and complications**
Plan

• Most important aspect of plan is to correct hypernatremia slowly.**
  – This can safely be done with iso-osmolar or ½ iso-osmolar solution at a conservative fixed rate
  – Monitor serum sodium closely to achieve rate of correction of ~10 mEq/L per day. If correcting too fast, slow down rate.

• As volume depletion corrects, kidney should assist by excreting a concentrated urine and retain necessary free water
  – which is why repletion can be accomplished with an iso-isomolar solution
Scenario

A 4 year old boy with nephrogenic DI develops vomiting and diarrhea. He is admitted to monitor and maintain his hydration; he weighs 20 kg

Prior weight 2 weeks ago at a nephrology f/u visit was 21 kg, giving him a 1 Liter deficit and 5% or “moderate-ish” dehydration. Despite this deficit he continues to illustrate polyuria

The following can be given to rehydrate this patient:
Answer Options

A. Saline Bolus, then D5 ½ NS + 20 KCL at 100mL/hr over the next 10 hours

B. Saline Bolus, then D5 ½ NS + 20 KCl at 100mL/hr plus urine output replacements over the next 10 hours

C. D5W Bolus, then D5 ¼ NS + 20 KCl at 100 mL/hr plus urine output replacements over the next 10 hours

D. No Bolus, but give D5 ¼ NS + 20 KCl at 100mL/hr over the next 10 hours
Answer

• Saline Bolus, then D5 ½ NS + 20 KCl at 100mL/hr plus urine output replacements over the next 10 hours.
• He is volume depleted because of his gastroenteritis (salt and volume losses), so he requires rehydration just like anyone else.**
• Unlike the infant in the previous case, the kidneys will not assist and continue to output a high rate of dilute urine**
  – Therefore, this urine volume requires replacement
  – Once volume repleted, switch from saline based solutions to those with less solute/more free water (ideally self regulated by his thirst mechanism rather than intravenous)
Scenario

An 7 mo girl presents with 2 days of vomiting and watery diarrhea. She is tired and somewhat lethargic. Her mother isn’t sure how much she is voiding (mixed with high volumes of watery stool). She is 8kg, HR 120-140s, BP normal, cap refill 3 seconds.

She gets a 20mL/kg NS bolus and IVF D5NS + 20 KCl at 35mL/hr. She does not seem to be getting better—still tired, not drinking, HR still 120-140s

Troubleshoot the problem. Propose a solution
Plan

This girl has high output stool losses. The rate of IV fluids were likely not sufficient to replace stool losses.

Continue rehydration but quantitate and replace stool losses as part of the plan until they slow down.
Scenario

A 16 year old girl with Cystic Fibrosis presents for admission related to respiratory infection/exacerbation. In addition to respiratory symptoms, she has fever, poor PO fluid intake, and weight loss. Which set of serum electrolytes seem most consistent:

A. 132/3.4/90/32
B. 142/4.8/88/24
C. 134/4.8/108/16
Answer

- Patients with cystic fibrosis have high sodium chloride loss in their sweat**
- When they become volume depleted, this results in high extra-renal chloride losses predisposing to metabolic alkalosis, enhancing the physiologic tendency of volume “contraction” to result in alkalosis**
- Treatment is correction of volume depletion, generally successful with isotonic sodium chloride
Take Home Points for Practice

• Daily fluid and electrolyte intake needs to be in balance with their losses. Special circumstances exist where losses become unregulated and providers should be mindful of intake requirements.

• Most cases of volume depletion result in extracellular (sodium) volume losses; priority is to replete and support circulating volume with repletion of sodium.

• Choices of fluid and approach to rehydration must factor in changes in osmolality and ongoing losses.
Case Presentation

• 13 yo male with BPs ~130-140/80-90 at health maintenance
  – Re-tested x 3 over next few months
  – No headache, chest pain, urinary symptoms, ROS completely negative
• PMHx notable for mild persistent asthma, otherwise negative
  – On Pulmicort QD, Albuterol PRN; no other meds including OTC, supps, etc...
• Social Hx: Starting 8th grade, active in tennis and basketball, no tobacco/EtOH/drugs
• Family Hx: Mom with high blood pressure (onset in 30’s)
Case Presentation cont’d

• PE 69.3kg; 172.7cm (>95%); BMI 90%
  – Regular Adult Cuff (R arm): 138/82
  – Large Adult Cuff (R arm): 126/78
  – Thigh Cuff (L leg): 136/84

• Exam otherwise without significant findings
  – No cardiac or pulmonary abnormalities noted
  – No bruit in abdomen; good pulses b/l, no edema
What is Hypertension (HTN) in Children?**

- Average Systolic BP and/or Diastolic BP that is >95%ile for gender, age, and height on 3+ occasions

- Prehypertension is defined as:
  - Between 90-95%ile for gender, age, and height
  - or >120/80, irrespective of gender/age/height
Defining HTN cont’d

- Stage 1 Hypertension (95-99% + 5mm Hg for gender, age, and height)**
- Stage 2 (severe) Hypertension (>99% + 5mm Hg for gender, age, and height)**
- Our patient—13 yo male, 95%ile for height
  - 95%ile BP is 130/83
  - Recall his measurements:
    - Regular Adult Cuff (R arm): 138/82
    - Large Adult Cuff (R arm): 126/78
    - Thigh Cuff (L leg): 136/84
How Should BP Be Measured?**

• Manual auscultation
• If oscillometric (automated)
  – BP>90%, then repeat via manual auscultation
  – These cuffs don’t directly measure systolic and diastolic BP
  – They measure mean BP and calculate systolic and diastolic BP off an algorithm
• Cuff Size and Positioning
Cuff Size**

- The length of the inflatable bladder should be at least 80% of the arm’s circumference; at least 40% of length of arm olecranon to acromion
  - If too small, blood pressure will be overestimated
  - If too large, blood pressure will **not** be underestimated
  - So err on the big cuff side
Differential Diagnosis of BP Elevation**

- Essential (Primary) Hypertension
- White Coat Hypertension, Inaccurate Measurement Technique
- Medications (e.g. steroids, stimulants, decongestants)
- Kidney Disease**
  - Structural (e.g. cystic kidney disease, renal scarring, renal dysplasia, congenital GU anomalies, renal mass)
  - Functional (e.g. renal insufficiency, renal tubular “monogenic” hypertension)
  - Parenchymal (e.g. nephritis, glomerulosclerosis)
Differential Diagnosis of BP Elevation**

• Renovascular, Coarctation of Aorta, Mid-Aortic Syndrome
  – Neurofibromatosis Type 1 (NF1) and Williams Syndrome associated with renovascular and mid-aortic syndrome**
  – Turner Syndrome associated with aortic coarctation**

• Excess Glucocorticoid, Mineralocorticoid, Catecholamine, Thyroid
  – NF1, Von Hippel Lindau, and Multiple Endocrine Neoplasia Type 2 are associated with Pheochromocytoma**

• Pain, Anxiety, Stress, Increased Intracranial Pressure
Question**

• Which of the following patients do the most recent guidelines for high blood pressure in children suggest having a BP checked at yearly health maintenance?

A) A 16 yo girl on oral contraceptives
B) A 4 yo boy generally healthy
C) A 2 yo boy with a history of VSD
D) A 12 mo girl with history of 26 week prematurity
E) An 18 mo boy whose mother has vesicoureteral reflux nephropathy
Answer

• All of the above
Who Should Get BP Measured?

- All kids >3yo, at least once a year.
- Children <3yo should have BPs taken at health maintenance if:
  - Premature, VLBW or other neonatal complication requiring intensive care
  - Congenital Heart Disease
  - Recurrent UTI, hematuria, proteinuria
  - Known Renal or Urologic disease
  - FamHx of congenital renal disease
  - s/p Transplant, Malignancy
  - Med or Illness known to increase BP
    - E.g. Steroids, Elevated Intracranial Pressure
Primary Hypertension aka Essential Hypertension**

- Becoming more common in children and adolescents
- Most often mild/stage 1 HTN.
- Associated with family history of hypertension or cardiovascular disease
- Overweight, insulin resistance, hyperlipidemia, metabolic syndrome
  - risks for cardiovascular disease and Type 2 Diabetes
Secondary Hypertension**

- Remains more common in children than adults and should be considered in every child with new diagnosis of hypertension
- Especially more likely in:
  - Young children
  - Stage 2 (severe) hypertension
  - Symptomatic hypertension**
    - Hypertensive Emergency (heart failure, severe headache, encephalopathy, stroke, seizure)
    - Hypertensive Urgency (mild headache, some nausea or vomiting, decreased appetite, decreased energy level)
  - Signs of systemic illness
Another Case

- Elevated Blood Pressure in an 11 yo obese boy, otherwise previously healthy
- Presents with office blood pressure 130’s/90’s; previously normal; rechecks with school nurse and still in same range
- Feeling well, wouldn’t have known anything was wrong, ROS otherwise negative, not taking meds or supplements
- Lives with mom, 3 bros, stepfather. In 4th grade doing well. Plays soccer and basketball
  - Stepfather obese and many arguments over diet/lifestyle
  - Mom cooks healthy, but stepfather orders in pizza and other take out which the kids will share
- FHx – MGF with HTN, otherwise neg
Exam

- Weight 48kg (96%ile); Height 133cm (17%ile) BMI 27 (99%ile)
- Vitals: HR 92, BP 132-138/92-98 in upper extr (large adult cuff) and lower extr (thigh cuff), manual
  - Alert interactive NAD
  - NCAT mmm, no edema, no LAD, fundi WNL
  - CTA B/I, RRR no m, 2+ pulses upper and lower
  - Soft nt obese nabs, no bruits no cvat
  - FROMx4 wwp no edema, neuro intact/nonfocal
  - Skin is clear—no rashes or birthmarks or other findings
Does he have hypertension?

- Yes, stage 2 hypertension. His 95%ile cutoff is 118/78; 99%ile is 125/86 so his stage 2 cutoff is 130/91

- Which of the following next step(s) should be pursued**:
  A) Dietary and healthy lifestyle counseling
  B) Diagnostic evaluation for secondary causes of hypertension
  C) Pharmacologic treatment
  D) Diagnostic evaluation for co-morbidities or complications related to hypertension
Management of Elevated Blood Pressure**

• For patients with Pre-hypertension
  – Lifestyle management (weight counseling, exercise, diet management)
    • Can hold off on medication or further workup
    • unless co-morbidity eg chronic kidney disease, diabetes, heart failure, left ventricular hypertrophy
  – Recheck in 6 months
Lifestyle Changes

• Weight Reduction—very effective, but very difficult
  – Decreases other comorbidities
  – Exercise (restrict tv/video games, family activities)
  – Dietary Modification--consultation with nutritionist often helpful
  – Increased vegetables, fruits, fiber, nonsugary drinks, nonfat dairy
  – Decreased portion sizes and energy-dense snacks

• Sodium restriction

• Avoidance of caffeine, “energy” drinks, some OTC meds (eg decongestants)
Managing HTN cont’d**

• Stage 1 Hypertension (95-99%ile + 5mm Hg)
  – Same as Pre-hypertension but recheck over next few weeks; if BP remains elevated x 2, this confirms Stage 1 HTN and should begin diagnostic evaluation
  – Initiate pharmacotherapy if:
    • symptomatic
    • secondary htn
    • target organ damage
    • comorbidities (eg diabetes)
    • persistent htn despite weight control and exercise/diet modifications
Managing HTN cont’d**

• Stage 2 Hypertension (>99%ile + 5mm Hg)
  – Begin diagnostic evaluation for secondary causes/co‐morbidites/complications promptly
    • Immediately if patient is symptomatic
  – Begin pharmacotherapy concurrent to diagnostic evaluation and instituting healthy lifestyle
    • Immediately and generally as inpatient for patients with hypertensive emergency and urgency
Diagnostic Evaluation of High Blood Pressure**

- History--will focus subsequent evaluation
  - Focus on symptoms of systemic disease or consequences of increased blood pressure
    - hematuria, edema
    - fatigue, chest pain, dyspnea
  - Sleep history, family history (eg htn, diabetes, renal disease, endocrinopathies)
  - Medications (over-the-counter & prescription), nutritional supplements
  - Diet, exercise, smoking, drugs of abuse
Diagnostic Evaluation of High Blood Pressure**

• Physical Exam--look for clues of severity, cause, and comorbidity
  – Obesity/BMI
  – Poor Growth (sign of chronic disease)
  – Upper and Lower Extremity BP (coarctation)
  – Signs of underlying disorder (endocrinopathy, systemic disease, genetic syndrome)
Diagnostic Evaluation of High Blood Pressure**

- Serum Electrolytes, BUN, Cr, Urinalysis
  - Consider Urine Culture
  - Investigate for primary renal and adrenal disease
- Renal Ultrasound (often w/Doppler)
  - Identify renal size and scarring, congenital anomaly, with Doppler for renovascular screening
- Consider CBC
  - Anemia can be suggestive of chronic renal disease
Diagnostic Evaluation for Co-Morbidities and Target Organ Damage**

• Co-Morbidities
  – In overweight patients or concerning family history, obtain fasting lipid panel, insulin, glucose
  – If history suggestive obtain drug/tox Screen or polysomnography

• Target Organ Damage
  – Echocardiogram to identify left ventricular hypertrophy or other cardiac complication
  – Retinal Exam to assess for retinal vascular changes
Additional Evaluation if Indicated**

• Consider in “young” children or any child with stage 2 HTN
  – Plasma Renin Activity/Aldosterone, additional renovascular imaging
  – Plasma and/or Urine Steroids, Catecholamines (Plasma Metanephrines—
    more sensitive and specific than 24 hour urine catecholamines for
    pheochromocytoma)

• Ambulatory BP Monitoring—If “white-coat” hypertension is suspected
  – Recent guidelines from American Heart Association illustrate this is a
    cost-effective approach in children
  – fewer unnecessary diagnostic evaluations, fewer medications started
    when not needed, fewer provider visits for data to decrease
    uncertainty/monitor control
Back to Case 2

- Urinalysis: Normal
- Electrolytes, BUN, Cr: Normal
- Renal Ultrasound:
  - Normal Right Kidney—slightly on the large side
  - Left kidney severely hypoplastic/dysplastic
    - Very small, and “bright” and poorly “differentiated”
- Echocardiogram, Ophtho exam all normal
Question

• For this 11 yo boy with dysplastic left kidney, which would be the preferred treatment option(s)

A) Dietary and Lifestyle changes alone
B) ACE Inhibitor
C) Beta Blocker
D) Diuretic
E) Calcium Channel Blocker
Pharmacotherapy

• Indications:**
  – Stage 2 Hypertension
  – Secondary Hypertension
  – Insufficient Response to Lifestyle Changes
  – Symptomatic Hypertension
    • if severe may need IV control to begin with
  – Target Organ Damage
  – Co-Morbidities (eg Diabetes, Heart Disease, Chronic Kidney Disease)
Treatment Approach

• Goal is BP reduction to <95%ile; if comorbidities then target BP <90%ile**
• Begin with a single drug, start at lowest dose, and increase dose until achieve desired affect
• ACE Inhibitors/Angiotensin Receptor Blockers
  – Targeted therapy for primary kidney diseases or certain comorbidities (eg diabetes)
  – Contraindicated in pregnancy
  – Monitor for hyperkalemia, elevated BUN and creatinine after starting
  – Cough and angioedema are much less common with newer agents
  – Tolerated extremely well, so used commonly even for essential hypertension in children
Treatment Approach

Diuretics**—long history of use, effectiveness, and safety

- **Furosemide/loop diuretics**
  - Very potent and typically used for acute hypertension from fluid overload
  - Not as well tolerated for long-term BP control because of polyuria, hypokalemia, metabolic alkalosis, and complications of hypercalciuria

- **Thiazide diuretics**
  - Well tolerated and most commonly used for long-term anti-hypertensive control either as primary agent or second agent
  - Monitor for hypokalemia, metabolic alkalosis
  - Enhances calcium reabsorption so lowers urine calcium but can have hypercalcemia as side effect

- **K-Sparing diuretics**
  - Weak diuretic effects, generally used for hypokalemia and K-sparing effects
Treatment Approach

- **Calcium Channel Blockers**—
  - well tolerated in children (less well tolerated in adults)
  - may cause tachycardia, edema, flushing, headache
  - don’t use in patients with heart-block

- **Beta Blockers**—
  - not as well tolerated in children
  - heart rate can be dose-limiting and make it harder to exercise
  - relative contra-indications in asthma and diabetes
Case 2 Follow-up

• Started on a low dose ACE Inhibitor with excellent effect. BP normal, and even average for age
• As this was due to a focal lesion, rather than stay on medication indefinitely, mother opted to see a pediatric urologist and have unilateral nephrectomy
  – He responded well to this surgery, his BPs remain normal off medication
Take Home Points for Practice

• Regular monitoring, appropriate techniques, and mindful interpretation of blood pressures in children are essential to manage high blood pressure in a timely and effective manner to prevent cardiovascular co-morbidity

• All children with Stage 1 and 2 hypertension should be evaluated for
  – secondary causes of high blood pressure
  – co-morbidities
  – target organ damage

• Management of high blood pressure should begin with and continually emphasize lifestyle changes that promote exercise, healthy weight and diet, and in particular awareness of sodium in the diet
Suggested Reading