Objectives

By the end of this presentation, the learner will be able to:

1. Evaluate strategies to manage septic shock in infants and children.
2. Differentiate between cardiogenic and septic shock in infants and children.

What is shock?

- BP less than 5th percentile of age normal
- Uncontrolled fluid loss/blood loss
- Tachycardia and hypotension
- Acidosis and increased lactate
- Signs of organ dysfunction with decreased UOP, altered mental status, etc.
Shock – signs and symptoms

- Evidence of end organ hypoperfusion
  - Decreased urine output
  - Altered mental status
  - Poor peripheral perfusion
- Evidence of Metabolic dysfunction
  - Lactic acidosis
  - Altered metabolic demands

Shock: Feel the feet, look at the neck

- Tachycardia? - Non-specific, but early
- Skin changes? - Prolonged capillary refill (vasoconstriction) with compensated shock. Flash refill with early distributive shock and with irreversible shock.
- Pallor? – If Hbg is fine, is your patient acidotic
- Impaired mental status? – Fussy, irritable? Sleepy?
- Oliguria? – When was the last diaper?
- Hypotension? – You have missed the ball 😓

  Widened pulse pressure (>40 mmHg)? - distributive shock, aortic insufficiency, AKMs?
Compensatory Mechanisms

- **Baroreceptors**: In aortic arch and carotid sinus, low MAP cause vasoconstriction, increases BP, CO and HR
- **Chemoreceptors**: Respond to cellular acidosis, results in vasoconstriction and respiratory stimulation
- **Renin Angiotensin Aldosterone**: Decreased renal perfusion leads to angiotensin causing vasoconstriction and aldosterone causing salt and water retentions
- **Humoral Responses-Catecholamines**
- **Autotransfusion-Redistribution of extravascular fluid**

<table>
<thead>
<tr>
<th>Stage of Shock</th>
<th>Cellular Shock</th>
<th>Compensated Shock</th>
<th>Uncompensated Shock</th>
<th>Irreversible Shock</th>
</tr>
</thead>
<tbody>
<tr>
<td>Description</td>
<td>Increased glucose; increased lactate</td>
<td>Cardiac output (HR x SV) and systemic vascular resistance (peripheral vasoconstriction)</td>
<td>Hypotension, altered mental status; increased lactic acidosis</td>
<td>Irreversible organ damage, cardiac arrest, death</td>
</tr>
<tr>
<td>Signs</td>
<td></td>
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</table>
Classifications of Shock

- **Hypovolemic Shock**
  - Decreased preload due to internal or external losses.

- **Distributive Shock**
  - Decrease in SVR, with abnormal distribution of blood flow → functional hypovolemia, decreased preload.
  - Typically, NL or ↑ CO.

- **Cardiogenic Shock**
  - "Pump failure." ↓ CO, systolic function.

- **Obstructive Shock**
  - Outflow from left or right side of heart physically obstructed.

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**Table 1. Definition of Hypotension Based on Age [5,43]**

<table>
<thead>
<tr>
<th>Age</th>
<th>Systolic Blood Pressure (mmHg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-28 days</td>
<td>&lt; 60†</td>
</tr>
<tr>
<td>1 month-12 months</td>
<td>&lt;70</td>
</tr>
<tr>
<td>1-19 years</td>
<td>&lt; 70 + (2x age in years)</td>
</tr>
<tr>
<td>&gt;18 years</td>
<td>&lt;90</td>
</tr>
</tbody>
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*Parameters for normal blood pressure and hypotension in this age group are variable and influenced by post-conceptional age. For example, a nonconsecutive term newborn may have a systolic blood pressure of 40 mmHg.*
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| Hypovolemic   | Volume depletion absolute or relative, CO ↓, SVR ↑ | Tachycardia, diminished pulses, sunken eyes and fontanelles, oliguria, prolonged cap refill time | • Crystalloid bolus 20 ml/kg until hemodynamics improve  
• Reassess after each bolus  
• Blood products in hemorrhagic shock |
| Cardiogenic   | CO ↓, SVR ↑ | Tachycardia, diminished pulses, hepatomegaly, JVD | • Inotropic agents: dopamine, dobutamine, milrinone  
• Small volume boluses 5-10 ml/kg might be administered carefully while monitoring response  
• Get ECHO early  
• Consider PGE |
| Distributive | Anaphylactic Neurogenic | Angioedema, respiratory distress, stridor, wheezing, early hypotension | • Start adrenergic support while giving fluids  
• Obtain vascular access early  
• Supratherapeutic doses of inotropes might be required |
|              | CO ↑, then ↓, SVR ↓↓ | Hypotension in the absence of tachycardia | • Support SVR with vasopressors, phylaxinaphrine might be required  
• Give fluids as necessary |
| Obstructive   | Preload ↓, CO ↓, SVR normal to ↑ | Tachycardia, hypotension, JVD, tracheal deviation if pneumothorax, equalization of pressures with elevated CVP if invasive monitoring in place | • Rapidly fatal if underlying process not recognized and reversed  
• fluid boluses should be given while preparation is made for emergent drainage |
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</thead>
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<tr>
<td>Septic</td>
<td>&quot;Hyperdynamic Shock&quot; ( CO \uparrow, SVR\downarrow )</td>
<td>Tachycardia, bounding pulses, warm extremities with hypotension, hyperpnea, altered mentation</td>
<td>• Crystalloid boluses of 20 ml/kg repeated until hemodynamics stable. First choice agents: vasopressors (dopamine or norepinephrine).</td>
</tr>
<tr>
<td>Hypodynamic Shock ( \text{CO} \downarrow, \text{SVR} \uparrow ) (50% of pediatric cases)</td>
<td>Tachycardia, poor peripheral perfusion, diminished pulses, hyperpnea, altered mentation</td>
<td>• Crystalloid boluses of 20 ml/kg repeated until hemodynamics stable. Early inotropic support with dopamine or epinephrine might be required. Echocardiography might be useful to guide therapy.</td>
<td></td>
</tr>
<tr>
<td>CO \downarrow, SVR \uparrow</td>
<td>Tachycardia, diminished pulses, with hypotension, hyperpnea, altered mentation</td>
<td>• Crystalloid boluses of 20 ml/kg repeated until hemodynamics stable. Early inotropic support with dopamine or epinephrine might be required. Echocardiography might be useful to guide therapy.</td>
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What is the goal of shock treatment?
- Optimizing oxygen content of the blood
- Improving volume and distribution of cardiac output
- Reducing oxygen demand
- Correcting metabolic derangements

Treatment
- Overall goal: Normalization of tissue perfusion and homeostasis
- A - airway
  - Secure, patent
  - Oxygen administration – 100% FiO\textsubscript{2} (except in some cases of cardiogenic shock)
- B - breathing
  - Decrease WOB, intubation-mechanical ventilation may be necessary (decrease oxygen consumption)
- C - circulation
  - Improve cardiac output
  - Ensure adequate preload – FLUIDS!!!
Treatment - II

- Have I mentioned fluids?
- Give lots of fluids – fast!
- Then – give some more —up to 200 ml/kg may be required
- REASSESS! (After every step/intervention)
- Pay attention to hepatomegaly, JVD, rales, worsening respiratory distress – if your patient is not responding to the fluids, reconsider your diagnosis
- Once you reach 60 ml/kg, considerstarting vasoactive infusions —more on this later

Treatment - III

- D — “derangements”
  - Correct metabolic abnormalities — hypoglycemia, hypocalcemia, etc
- Etiology specific treatment
- DO NOT DELAY ANTIBIOTICS FOR ANY REASON IF YOU SUSPECT SEPTIC SHOCK!
- Source control
- Consider transfusion of PRBCs

Assessing efficacy of treatment

- Blood pressure: Normal *
- Quality of central and peripheral pulses: Strong, distal pulses equal to central pulses.
- Skin perfusion: Warm, with capillary refill 1-2 seconds.
- Mental status: Normal.
- Urine output: >1 mL/kg per hour, once effective circulating volume is restored.
Sepsis

- High mortality despite improvements
  - KID database: 4.2% in all-comers, 2.3% in previously healthy, 7.8% in chronically ill
- Guidelines are not effective unless protocol driven
- Early intervention is critical — no delay is acceptable.
- Every hour spent without reversing shock increases OR of mortality

Septic Shock Pathophysiology

SIRS/Sepsis/Septic shock

Mediator release: exogenous & endogenous

Maldistribution of blood flow
Cardiac dysfunction
Imbalance of oxygen supply vs demand
Alterations in metabolism

<table>
<thead>
<tr>
<th>SIRS</th>
<th>SEPSIS</th>
<th>SEVERE SEPSIS</th>
<th>SEPTIC SHOCK</th>
</tr>
</thead>
<tbody>
<tr>
<td>T &gt; 38.5 or &lt; 36</td>
<td>SIRS + Infection (suspected or proven)</td>
<td>SEPSIS + CV dysfunction or ARDS or ≥ 2 organ failures</td>
<td>SEPSIS + CV dysfunction despite &gt;40 ml/kg in 1 hr</td>
</tr>
<tr>
<td>Tachycardia</td>
<td>Tachypnea</td>
<td>WBC</td>
<td>2 of the above 4</td>
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2 of the above 4
SIRS
Temp. >38°C or <36°C, HR >90, RR >20 or PaCO₂ <32,
WBCs >12,000 or <4,000 or >10% bands

SEVERE SEPSIS
Sepsis + End Organ Damage

EARLY GOAL-DIRECTED THERAPY IN THE TREATMENT OF SEVERE SEPSIS AND SEPTIC SHOCK

Early Goal-directed Therapy
Early Goal-directed Therapy

1. Recognize decreased mental status and perfusion.
   Begin high-flow O2, establish IV access.

2. Fluid resuscitation:
   - Initial resuscitation: Push boluses of 20–40 mL/kg isotonic saline or colloid up to 1 & over 30 mL/kg until perfusion improves or baseline values are restored.
   - Consider high-dose inotropic agents.
   - Consider plasma expander (HYDROXENE).

3. Blood gas:
   - Monitor PaO2, SVO2, and pH.
   - Adjust ventilation to maintain SaO2 > 92%.

4. Oxygenation:
   - Adjust FiO2 to maintain SpO2 > 96%.

5. Tachypnea:
   - Consider noninvasive ventilation.

6. Hypotension:
   - Consider isotonic saline or balanced crystalloid.
   - Consider vasopressor therapy.

7. Hypothermia:
   - Consider warming blankets.

8. Hypertension:
   - Consider diuretics.

9. Cardiac arrest:
   - Immediate resuscitation.

10. Neurological deterioration:
    - Consider intravenous immunoglobulin.

11. Platelet dysfunction:
    - Consider platelet transfusion.

12. Hemorrhage:
    - Consider blood transfusion.

13. Infection:
    - Consider antibiotics.

14. Renal failure:
    - Consider renal replacement therapy.

15. Liver dysfunction:
    - Consider liver support.

16. Pulmonary edema:
    - Consider diuretics.

17. Gastrointestinal bleeding:
    - Consider endoscopy.

18. Blood pressure monitoring:
    - Monitor blood pressure every 5 minutes.

19. Ventilator settings:
    - Adjust ventilator settings to maintain adequate oxygenation.

20. Oxygen saturations:
    - Maintain SaO2 > 96%.

21. Blood glucose:
    - Maintain blood glucose < 150 mg/dL.

22. Hemoglobin:
    - Maintain hemoglobin > 9 g/dL.

23. Serum creatinine:
    - Maintain serum creatinine < 2.0 mg/dL.

24. Serum potassium:
    - Maintain serum potassium < 5.0 mEq/L.

25. Serum sodium:
    - Maintain serum sodium > 130 mEq/L.

26. Serum bicarbonate:
    - Maintain serum bicarbonate > 22 mEq/L.

27. Urine output:
    - Maintain urine output > 0.5 mL/kg/h.

28. Urinary catheter:
    - Maintain urinary catheter in place.

29. Central venous catheter:
    - Maintain central venous catheter in place.

30. Intravenous lines:
    - Maintain intravenous lines in place.

31. Nasogastric tube:
    - Consider nasogastric tube for decompression.

32. Hemodynamic monitoring:
    - Use continuous hemodynamic monitoring.

33. Hemodynamic support:
    - Consider inotropic support.

34. Invasive pressure monitoring:
    - Consider invasive pressure monitoring.

35. Pulmonary artery catheter:
    - Consider pulmonary artery catheter.

36. Surgical consultation:
    - Consider surgical consultation.

37. Hemorrhage control:
    - Consider surgical hemorrhage control.

38. Anticoagulation:
    - Consider anticoagulation therapy.

39. Thromboembolism prophylaxis:
    - Consider thromboembolism prophylaxis.

40. Oxygen therapy:
    - Consider high-fidelity oxygen therapy.

41. Sedation:
    - Consider sedation therapy.

42. Nutrition:
    - Consider enteral or parenteral nutrition.

43. Antibiotics:
    - Consider broad-spectrum antibiotics.

44. Blood products:
    - Consider blood products.

45. Postoperative care:
    - Consider postoperative care.

46. Pain management:
    - Consider pain management.

47. Recovery:
    - Consider recovery care.

48. Discharge:
    - Consider discharge planning.

49. Follow-up:
    - Consider follow-up care.

50. Postoperative care:
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100. Follow-up:
    - Consider follow-up care.
Shock II – Cardiogenic Shock

Flow
Fluid
Pipes
Site of exchange

Fluid status
Dry
Wet

Dry and Warm
Wet and Warm
Dry and Cold
Wet and Cold

Perfusion
Warm
Cold
**Shock II – Cardiogenic Shock**

- Tachycardia
- Tachypnea
- Hx of sweating/tiring with feeds
- Vomiting, feeding intolerance
- Fussiness
- Gallop
- Hepatomegaly
- Rales
- Decreased UOP
- Cardiomegaly
- Altered mentation
- "Septic" newborn!
- Cyanosis

**VENTRICULAR FUNCTION CURVES NORMAL AND FAILING LV**

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Cardiogenic shock

- Electrical failure
- Mechanical failure
  - Myocarditis
  - Cardiomyopathy
  - Anatomic
    - Obstructive
    - Congestive
  - Ischemic
  - Trauma

- Anatomic
  - Left sided obstructive = ductal dependent systemic flow
    - IAA, critical AS, HLHS, etc
    - HCM
  - Congestive
    - large L → R shunts
    - Acute valvular regurgitation
    - Ductal dependent pulmonary blood flow
    - Parallel circulation – TGA-IVS
    - Obstructed pulmonary flow – TAPVR, obstructed
Ischemic Heart Disease in Children

- ALCAPA
  - Anomalous Left Coronary Artery arising from the Pulmonary Artery

- Kawasaki Disease
  - Aneurysms

Treatment

- Support the failing pump
- Decrease oxygen consumption/metabolic demand
  - Intubation*, mechanical ventilation
  - Sedation, NMB
  - Prevention of fever, stress
- Consider bolus 5-10 ml/kg
- Consider PGE
- ECHO early

Treatment - II

- Optimize contractility
- Correct metabolic derangements
- Inotropic support
- Afterload reduction
- Address the underlying cause – surgery?
- Mechanical support
  - ECMO
  - Implantable devices, VAD, etc.
Table 4. Indications for Mechanical Support in Children
Adapted from Dewick et al. [34]

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  • Dopamine, dobutamine, epinephrine, milrinone  
  • Small volume boluses 5-10 ml/kg might be administered carefully while monitoring response  
  • Get ECHO early  
  • Consider PGE |
Question

• 13 month old patient with DCM, HR 180 (sinus), CVP 25 mm Hg, BP 55/24, lactate >8, SvO₂ 50%, capillary refill of 5 seconds, best choice of action is:
  a. Epinephrine drip
  b. Milrinone drip
  c. Phenylephrine drip
  d. NS bolus 20 ml/kg
  e. Esmolol (B-blocker) for HR control

Question

• 12 year old female presents with fever, tachycardia, right flank pain, WBC count is elevated. Vital signs are HR 110, RR 25, BP 124/83, T 102. She is AAO x 3. Working diagnosis is sepsis secondary to pyelonephritis. What is the next most appropriate intervention?
  A. Renal US
  B. Normal saline bolus
  C. Antibiotics
  D. Vasopressor infusion
  E. Urinalysis

Question

• 12 year old female presents with fever, tachycardia, right flank pain, WBC count is elevated. Vital signs are HR 155, RR 35, BP 124/73, T 102°F. She is somnolent. Working diagnosis is sepsis secondary to pyelonephritis. What is the next most appropriate intervention?
  A. Renal US
  B. Normal saline bolus
  C. Antibiotics
  D. Vasopressor infusion
  E. Urinalysis
Case 1

- 15-year-old male is just transferred to PICU to stepdown unit, POD #3 from partial small bowel resection after multiple gunshot wounds to the abdomen. The nurse calls the RRT because his HR has increased in the last hour from 90 to 130, despite pain score of 1/10 on morphine drip. On exam, he is afebrile, HR is 140, BP 80/50. Capillary refill is >3 seconds in his cool extremities and pulses are 1+.

What is your assessment?

- What is the stage of shock?
- What is the classification of shock?
- What is your initial management?

Case 2

- 6-year-old previously healthy girl is transferred from ER with fever, bloody diarrhea x 1 day. She’s had no urine x 24 hrs and is becoming harder to awaken. On exam, her HR is 152, BP 72/32, temp 103. She’s sleepy but arousable. She’s flushed with capillary refill <1 second.

What is your assessment?

- What is the stage of shock?
- What is the classification of shock?
- What is your differential for the etiology?
- What is your initial management? If a higher level of care is needed, how would you obtain it?

Case 3

- 4-month-old boy former premie, presents to ED with decreased po x 2 days with 2 times daily emesis, following what sounds like viral URI. Urine output has been 3 wet diapers daily. He is afebrile with HR 180; BP has not been obtained. He has a weak cry, is mottled with 3-second capillary refill, pulses 1+ in all extremities. Liver is palpable 4 cm below RCM. S$_4$ is present without murmur.

What is your assessment?

- What is the stage of shock?
- What is the classification of shock?
- What is your differential for the etiology?
- What is your initial management?
What is the end goal for resuscitation?

- Traditional clinical variables – UOP, perfusion, pulses, CVP
- Mixed venous saturation
- Lactate clearance
- Combination of all three with common sense

Recognition and Classification

Initial Management of Shock
Final Thoughts

- Recognize compensated shock quickly - have a high index of suspicion, remember tachycardia is an early sign. Hypotension is late and ominous.
- Gain access quickly - if necessary use an intraosseous line.

Final Thoughts

- Fluid, Fluid, Fluid - Administer adequate amounts of fluid rapidly. Remember ongoing losses.
- Correct electrolytes and glucose problems quickly.
- If the patient is not responding the way you think he should, broaden your differential, think about different types of shock.