**DEFINITION**

Shock is a dramatic syndrome in which the circulatory supply of oxygen does not meet the metabolic demands of vital organs and tissues. There are five major types of shock observed: hypovolemic, septic, cardiogenic, distributive, and obstructive (see Table 1).

**PATHOPHYSIOLOGY**

An initial insult triggers shock disrupting blood flow to end organs leading to inadequate tissue perfusion. The body’s compensatory mechanisms are initiated to maintain perfusion to vital organs leading to compensated shock. If treatment is not introduced during this period of compensated shock, the patient develops decompensated shock causing tissue damage that in turn leads to multi-system organ dysfunction and death (See Figure 1). The compensatory mechanisms are neuro-hormonal and include changes in heart rate, stroke volume, vascular smooth muscle tone, and fluid retention by the kidneys, etc. Through these mechanisms, the patient shunts blood flow away from non-vital tissues such as the periphery and gut to vital organs which include the brain, the heart, and the kidneys. If through these various mechanisms adequate perfusion to the heart and other vital organs cannot be maintained, the patient develops hypotension and decompensated shock.

All forms of shock effect either preload, afterload (systemic vascular resistance – SVR), myocardial contractility or some combination of all three components leading to poor tissue perfusion. It is common for more than one of these processes to occur simultaneously.

- **Preload decrease**
  - External fluid losses: vomiting / diarrhea, bleeding, burns
  - Internal losses: excessive capillary leakage leading to significant third spacing.

- **Afterload (SVR)**
  - Abnormally decreased can lead to profound hypotension: sepsis – warm shock, anaphylaxis, spinal cord injury, toxins, etc.
  - Significantly increased as a compensatory mechanism: cardiogenic shock – which may amplify the primary problem, sepsis – cold shock

- **Depressed myocardial contractility**
  - Primary insult as seen in cardiomyopathies, arrhythmias, or immediately after cardiac surgery
  - Secondarily suppressed as noted in SIRS, pancreatitis, or septic shock.

Once shock is initiated, it is important to recognize that mediators of tissue damage are activated and may cause progression from compensated shock to
decompensated shock. These inflammatory mediators are released from multiple sources.

- The key player in this process is the vascular endothelium, which is both a target of tissue injury and a source of mediators leading to tissue injury.
- Other significant systemic factors include the complement pathway, coagulation system, multiple inflammatory mediators (see Table 3), activation of white blood cells, platelet activating factor, nitric oxide, and oxygen free radical production from reperfusion injury.
- Bacterial sources of tissue injury include endotoxin, exotoxin, and translocation of gut flora should splanchnic blood flow be compromised.
- Exotoxins and endotoxins induce production of various inflammatory molecules such as the interleukins (see Table 3) and amplify the systemic factors maintaining shock.

**CLINICAL MANIFESTATIONS**
The clinical presentations of shock depend, in part, on the cause; however, if shock is unrecognized and untreated, a very similar untoward progression of clinical signs and pathophysiologic changes occurs and leads to a common final path. The clinical features of shock also relate to the stage (early vs. late) of the process (duration vs. progression).

- Hypovolemic shock usually presents as changes in mental status, tachypnea, tachycardia, hypotension, cool extremities, and oliguria. Neonates and infants may also present with poor urine output as noted by the parents. Dry mucous membranes and poor skin turgor can also be present.

<table>
<thead>
<tr>
<th>Percent Dehydration</th>
<th>Physical Signs</th>
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<tbody>
<tr>
<td>5% (Mild)</td>
<td>Dry skin, mild tachycardia, decreased urine output</td>
</tr>
<tr>
<td>10% (Moderate)</td>
<td>Lethargy, poor perfusion</td>
</tr>
<tr>
<td>15% (Severe)</td>
<td>Obtundation, tachycardia, hypotension</td>
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- Septic shock (see sepsis chapter) in particular has two phases known as
  - “Early or warm shock”: warm extremities (from peripheral vasodilation secondary to low SVR), bounding pulses (from high stroke volume and widened pulse pressure),
  - “Late or cold shock”: cool extremities due to high SVR, prolonged cap refill, poor urine output, etc.

- Cardiogenic shock presents as cool extremities, prolonged capillary filling time (> 2–3 seconds), hypotension, tachypnea, increasing obtundation, and decreased urine output (all caused by peripheral vasoconstriction and decreased cardiac output).
Distributive shock is usually caused by an acute insult, e.g. spinal trauma or anaphylaxis, and presents with profound hypotension and tachycardia.

Obstructive shock is due to increased afterload of the right ventricle (saddle embolus) or left ventricle (critical coarctation). Patients often present with signs / symptoms similar to Cardiogenic shock – tachycardia, tachypnea, hypotension, decreased mental status, and poor urine output.

Uncompensated shock (high vascular resistance, decreased cardiac output, obtundation, oliguria) occurs late in the progression of shock, regardless of its etiology. The transition from compensated to decompensated shock is not always easy to identify.

Cellular level: increased lactic acid production occurs as the tissue transitions from aerobic to anaerobic metabolism

Systemic level:
- Hypotension is a very good sign, but a late sign, of uncompensated shock in pediatric patients.
- Low mixed venous oxygen saturation (defined below) is a hallmark of uncompensated shock.

Mixed venous oxygen saturation [MvO$_2$] is a measure of the oxygen extraction by peripheral tissue. A low MvO$_2$ indicates inadequate oxygen delivery, increased oxygen consumption or both. The MvO$_2$ can be drawn from
- Pulmonary artery (the gold standard)
- Right ventricle
- Right atrium
- Superior vena cava – the usual location
- Inferior vena cava – can be used as a trend, but is not the preferred location

The MvO$_2$ should be 20–25% less than the arterial oxygen saturation (75–80% in a patient without a mixing cyanotic heart lesion).

A low MvO$_2$ can occur due to:
- Inadequate oxygen delivery: due to depressed cardiac output from decreased preload, abnormal afterload, arrhythmias, cardiomyopathy, sepsis, etc.
- Increased end organ oxygen extraction: due to higher metabolic demand, e.g. sepsis – cold shock, fever, increased work of breathing, agitation, etc.

An elevated MvO$_2$ can occur due to:
- Primarily due to decreased extraction: e.g. sepsis – warm shock, brain death

**TREATMENT**
- ABCDs
- Aggressive fluid resuscitation (except in cardiogenic shock)
• On-going reassessment
• Treat underlying etiology

❖ **ABCD (see chapter 6-Codes):** As with all acutely ill patients, airway, breathing and circulation must be evaluated and stabilized as required for patients presenting in shock.
  • **AB:** Some patients may need intubation on presentation to stabilize the airway – due to depressed mental status - and/or increased work of breathing.
  • **C:** Vascular access via a peripheral IV or central venous catheter needs to be established emergently; an intraosseous needle should be considered in an acutely decompensating patient.
  • **D:** The ‘D’ stands for dextrose and is important in the pediatric population. Neonates and infants in particular may develop profound hypoglycemia associated with shock due to poor glycogen stores.

❖ **Fluid resuscitation:**
  • A fluid bolus of 20 mL/kg of normal saline or lactated Ringer solution should be given rapidly, i.e. within 5-10 minutes. For patients with concerns of cardiogenic shock, the fluid bolus should either be a smaller volume given over a longer time period since the clinician cannot be sure where on the startling curve the patient falls. The patient should be continually reassessed to determine if more fluids are required. If the patient is decompensating during the fluid bolus, inotropes should be initiated concomitantly. Children in severe hypovolemic shock may require and tolerate fluid boluses totaling 60–200 mL/kg within the first 1–2 hr of presentation.
  • After the initial stabilization, ongoing losses (continued diarrhea, vomiting, burns) should be addressed. Once a central line is placed, the patient should be fluid resuscitated to a CVP of 8-12 mm Hg in a spontaneously breathing patient and 12-15 mm Hg in mechanically ventilated patients. The replacement fluids should equate the fluids lost; e.g., trauma patients can be transfused with whole blood while a burns patient should receive 5% albumin. Potential replacement fluids include:
    o Crystalloid: normal saline (NS), lactated Ringer solution (LR)
    o Colloid: 5% Albumin, hetastarch
    o Blood products: fresh frozen plasma, whole blood, or packed red blood cells
  • There is continuing debate about the relative risks and benefits of choosing crystalloid solutions versus colloid for fluid resuscitation. The theoretical concern with colloid solutions for patients with vascular endothelial injury and leaky capillaries is that albumin may leak into interstitial spaces and may be difficult to reabsorb. The organs of particular concern are the lungs and the gut; leaked albumin may
decrease pulmonary compliance increasing difficulty in oxygenation and ventilation. However, at present no definitive data exists to support one form of fluid in resuscitation over another. Therefore, most clinicians initially prefer crystalloids unless the patient’s disease process demands a specific form of fluid.

- **On-going reassessment:** Once adequate fluid resuscitation to a normal CVP has occurred, if the patient continues to demonstrate signs of shock with poor end organ perfusion and decreased MvO$_2$, then further interventions are required. The two methods of treating the shock at this point are to increase oxygen delivery, decrease oxygen demand, or both.
  - **Increase supply:**
    - Vasoactive agents (see Chapter 15): inotropes &/or vasopressors
    - Improve oxygen-carrying capacity – consider a PRBC transfusion to a hematocrit >30% if the patient is anemic
    - Improve oxygen saturation (95–99%) – nasal cannula to face mask to intubation should be considered to optimize oxygenation
  - **Decrease demand:**
    - Consider intubation – the work of breathing is a significant metabolic demand and can account for up to 40% of the cardiac output in neonate and infants. Acidosis can also cause tachypnea and increase the work of breathing. Intubation may significantly decrease the metabolic demand.
    - Seizures should be controlled – anticonvulsants
    - Fevers should be controlled – antipyretic agents, cooling measures,
    - Agitation can also increase demand – consider sedation

- **Begin treatment of the primary insult:**
  - Hypovolemic shock: If the cause of hypovolemia can be treated, then do so; i.e. a trauma patient with abdominal bleeding may require surgical intervention. For patients with AGE, often replacement and maintenance hydration must be continued until the viral process resolves.
  - Septic shock: Begin appropriate antibiotics quickly.
  - Anaphylactic shock: Administer epinephrine. The route of delivery is a point of debate, but if a patient has an IV most sources will suggest IV administration of the epinephrine slowly titrated to symptoms rather than IM delivery. Assure removal of the antigen.
  - Cardiogenic shock: If the patient has a structurally normal heart, i.e. cardiomyopathy, then initiate the appropriate inotropes quickly. If the shock is secondary to an anatomic lesion as often occurs in neonates, then consider either a palliative procedure in the catheterization lab, e.g. a Rashkind, or emergent surgical repair.
  - Obstructive shock: The primary insult needs to be addressed. The pulmonary embolus needs to be removed or the critical coarctation of the
aorta needs to be repaired for the patient to improve. All other parameters can be optimized, but the patient will not improve until the obstructive lesion is corrected.

**CARDIOVASCULAR MANAGEMENT** (See Table 2)
Decompensated shock often will require inotropes, vasopressors, or both. These agents should be a continuous intravenous infusion through a central venous catheter usually in an intensive care setting. They are titrated by careful monitoring of BP with an indwelling intra-arterial catheter. The type of shock the patient presents with guides the specific vasoactive agents used. Patients may be started on several agents concomitantly or sequentially as the individual clinical course dictates. It is important to recognize most inotropes increase myocardial oxygen consumption and the risk of arrhythmias.

- **Hypovolemic shock:** These patients may require inotropic support due to initial hypotension despite rapid fluid resuscitation or profound acidosis effecting myocardial function. In such situations a transient dopamine / epinephrine infusion may be required until the myocardial function improves and the metabolic abnormalities are corrected.

- **Septic Shock:** (see chapter 17 - Sepsis) the inotropes of choice tend to depend on if the patient presents in warm or cold shock.
  - Warm shock: Dopamine / norepinephrine are the inotropes of choice
  - Cold shock: Dopamine / epinephrine are the medications of choice.
  - Consider Vasopressin to treat shock unresponsive to catecholamines; there is some demonstration of vasopressin depletion in vasodilatory septic shock.
  - Consider stress dose steroids in all patients unresponsive to inotropes / vasopressors, but particularly in patients that have recently been on steroids. If a full ACTH stimulation test cannot be done, check a spot cortisol level prior to initiation of stress dose steroids.
  - Assure adequate source control – e.g. drain any abscesses, etc.

- **Cardiogenic Shock:** The pathophysiology is one of poor cardiac output with elevated SVR. The ideal inotropic agents optimize output while decreasing SVR. Also, both systolic and diastolic myocardial support is required.
  - For normotensive patients – compensated shock:
    - Milrinone is the first line agent because it increases systolic function, improves diastolic relaxation, increases ventricular preload, without a significant increase in heart rate. Note this medication has a long half life and therefore, its effects are usually not observed for 4-6 hours after initiation. Also, from a practical standpoint, patient’s are often not administered a loading dose of the medication unless done on cardio-pulmonary bypass in the
operating room. The loading dose may also be administered over a longer period or divided into several doses to avoid hypotension.
  o Dobutamine is another agent that improves systolic function and decreases SVR.

- For hypotensive patients – decompensated shock: Introducing an agent that decreases SVR in a hypotensive patient, places them at risk of arresting. Therefore, the inotropes administered to this patient population must increase blood pressure and coronary perfusion pressure.
  o Dopamine can be considered as a first line agent
  o Epinephrine is also used to improve blood pressures despite the significant increase in myocardial oxygen consumption.
- Vasodilators such as nipaide, nitroglycerin, and nicardipine should also be considered in patients that persist with poor perfusion and acidosis despite adequate cardiac output.

- **Distributive shock**: These patients often have adequate cardiac output, but have lost vascular tone. Initiating an agent that will provide vasoconstriction only, pure alpha support, is the ideal drug. Phenytoin is the first line treatment for a patient with spinal cord injury for example. Although anaphylaxis is considered distributive, epinephrine is often the treatment for these patients since the release of various inflammatory mediators will also cause myocardial depression.

**OTHER MODES OF SUPPORT**

- **Coagulation disorders**, secondary to DIC, are frequently found in severe shock and should be corrected particularly if the patient is experiencing active bleeding.

- **Correction of metabolic derangements**: Correction of acidosis is important since the myocardial contractility and the efficacy of inotropic agents are decreased in an acidotic environment. Calcium can act as a direct myocardial stimulant particularly in the neonate; hypocalcemia should therefore be aggressively corrected.

- **Mechanical Support**: Rarely, other invasive techniques may be needed to support children in shock who are not responding to fluid, pharmacologic support, or other modes of treatment when the cause of shock is considered treatable and reversible.
  - Extracorporeal membrane oxygenation (ECMO) may be effective in treating young children with septic shock. In severe cardiogenic shock, ECMO can be a bridge to transplant or until the patient has a ventricular assist device (VAD) placed. In patients who have undergone cardiac surgery, and in those who have difficulty separating from bypass, ECMO can be instituted until the patient recovers. ECMO, unlike a VAD, provides
both cardiac and pulmonary support for the patient. Systemic anticoagulation is required while on ECMO. Given the precarious position of the large ECMO cannulas, standard of care is to maintain patients in a state of deep sedation with minimal movement. Complications of greatest concern, therefore, are an overwhelming intra-cranial hemorrhage due to the high level of anticoagulation, and infection secondary to large invasive intravascular cannulas.

- Left ventricular (LVAD) or biventricular (BiVAD) assist devices have also been used in older adolescent patients to manage severe cardiogenic shock as a bridge to transplantation. The Berlin heart, another ventricular assist device, is now being evaluated for younger, smaller patients. The ventricular assist devices have the advantage of requiring a lower level of anticoagulation and the patients can be more mobile with these devices. Unlike ECMO however, these devices do not provide ventilatory support; they only provide cardiac support. A patient with poor pulmonary function is therefore not a candidate for an assist device.

- Dialysis and hemofiltration have been used to manage fluid overload or pulmonary edema and may remove inflammatory mediators.