

SHOCK

Shock is a life threatening emergency that may be reversible if appropriately recognized and treated. Shock is defined as the inadequate perfusion of tissue, such that the oxygen and blood volume delivery fails to meet the cellular metabolic and oxygen consumption needs.

The pathophysiology underlying shock is related to the determinant of oxygen delivery. Cardiac output, the vascular integrity and resistance, and the oxygen content (determined by hemoglobin and oxygen saturation) contribute to oxygen delivery to the tissues. Shock may originate via disturbances in the neural-hormonal regulation of heart rate and blood flow to the systemic vasculature, or with changes in preload, systemic resistive indices, or heart function.

Epidemiology / Pathophysiology

Classically, four types of shock are described based on the physiologic disturbance causing etiology.

1. **Hypovolemic Shock** - when the circulatory volume is depleted from blood or fluid losses
2. **Distributive Shock** - occurs due to inappropriate vasodilatation of the peripheral blood vessels from sepsis, anaphylaxis, drug reactions, endocrine, and neurogenic abnormalities.
3. **Obstructive Shock** - as the name implies, is associated with obstruction of the heart or the great vessels. Tension physiology, as in tension pneumo/hemothorax and cardiac tamponade, leads to high pressure in the chest; either in the hemithorax or pericardial sac, respectively. This effectively obstructs venous return and diminishes cardiac output leading to inadequate perfusion. Massive pulmonary embolism may impede outflow of the right heart and lead to ventilation and perfusion mismatch.
4. **Cardiogenic Shock** - is failure of the “pump” and may arise from Acute Coronary Syndrome (ACS), mechanical failure, and/or arrhythmias.

Patients who do not meet the above classification may be termed “undifferentiated shock”. Alternatively, patients may have a combination of the above clinical scenarios; for instance, a trauma patient with hemorrhagic shock may also have neurogenic shock, or a patient with septic shock may sustain a myocardial infarction further complicating the clinical picture.

Signs and Symptoms

In a patient presenting with hypotension and concern for shock, the clinician must evaluate for diagnostic clues to the underlying cause and type of shock. At the onset of shock, the process is compensated and often reversible. Preferential circulation is given to the vital organs, and peripheral and splanchnic vasoconstriction diverts blood flow to the essential organs. The body releases stress hormones such as catecholamines, cortisol, antidiuretic hormones, renin-

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angiotensin system among other adaptive responses to preserve fluid volume and to activate the “flight or fight” response. However, without prompt and aggressive treatment, a plasma volume loss of over 30% or a cardiac index less than 2.2 L/min may progress to end organ damage and cellular death.

I. Vital Signs: Vital signs are important indicators of the patient's physiologic status.

- *Temperature:* Fever may point the examiner to search for signs of infection. Hypothermia may accompany poor perfusion but may also be a paradoxical manifestation of infection or a symptom of endocrine dysfunction.
- *Heart rate:* Due to compensatory mechanisms, heart rate is typically elevated in hypotension. In distributive and hypovolemic shock, the heart rate will be elevated to compensate for the low stroke volume while maintaining cardiac output per the equation:

$$\text{Cardiac Output} = \text{Heart Rate} \times \text{Stroke Volume}$$

Bradycardic or normal heart rates may be observed with neurogenic and cardiogenic shock. Inappropriately low heart rates may also occur when the patient is unable to augment heart rate due to medications (beta blockers), or the presence of a pacemaker that may be set to a low heart rate.

- *Blood pressure:* Hypotension defined as MAP <65 mm Hg is often a prominent feature of shock. However, patients may present with hypertension or swings of hyper and hypotension as their physiology decompensates. Alternatively, patients who “live” at higher blood pressure ranges may present with a “normal” systolic and mean arterial pressures reading but be hypotensive compared to their baseline. Thus, as with all numeric vital sign values, the interpretation of trends and understanding the patient's physiology is essential to interpreting the clinical findings.
- *Respiratory rate:* Tachypnea is commonly observed in patients with shock. An elevated respiratory rate helps alleviate systemic acidosis by neutralizing excess hydrogen ion by tipping the buffer system to make CO₂ per the Henderson Hasselbalch equation:



This process increases ventilatory drive leading to increased respiration rate.

- Oxygen saturation is typically preserved by increasing oxygen extraction when delivery to tissue is diminished. Saturations fall only at very late stages of hypoperfusion, or when ventilation perfusion mismatch occurs, as in pulmonary emboli or pneumothorax.

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II. Examination: The physical examination of the patient presenting in shock should be expedient but thorough. Applying the ABCDEs helps to efficiently evaluate the patient while also balancing management priorities concomitantly.

- A. *Airway:* The airway should be assessed for patency. Tracheal deviation may be a sign of tension physiology from obstructive mechanisms of shock such as a tension pneumothorax or hemothorax. Mental status changes that often accompany severe forms of shock may impede the ability of the patient to protect their airway. Care must be taken to secure an endotracheal tube in patient with inability to protect the airway or a Glasgow Coma Scale of ≤ 8 .
- B. *Breathing:* The breath sounds should be equal on both sides of the chest on auscultation. Decreased breath sounds may alert the clinician to blood in the chest, pneumothorax, or tension physiology. If clinically warranted, placement of a chest tube may be required to address such findings.
- C. *Circulation:* Circulation is assessed with an evaluation of the peripheral pulses. IV access should be secured with large bore (14 or 16 gauge IV access or resuscitative lines). Crystalloid infusion of at least 30cc/ kg should be administered to support the intravascular volume while assessment of acute blood loss is determined. Active bleeding should be promptly tended to with hemostatic measures such as pressure, tourniquet, or procedural/ operative intervention. Attention should be paid to distension of the jugular veins, as this can signal obstructive physiology in the chest with tension or tamponade physiology. Finally, the perfusion of the distal extremities is a physical exam finding to help differentiate the types of shock. Acral cyanosis of the extremities with a cold, clammy feel is consistent with obstructive, hypovolemic, or cardiogenic shock. A warm dilated shock may be seen with distributive shock due to vasodilation of the peripheral vessels.
- D. *Disability:* A full neurologic exam is also important to evaluate. In trauma, disability is routinely assessed using the Glasgow Coma Scale (GCS), but an assessment of neurologic status is necessary in all forms of shock. With poor perfusion, the patient's mental status will deteriorate, risking airway compromise due to loss of the usual reflexes that allow secretion management and protect from aspiration. Low GCS (≤ 8) is an indication for intubation, and a low threshold for intubation is required for any patient who is not protecting the airway. Motor and sensation deficits, paresthesia, priapism, and decreased rectal tone suggest injury to the spinal cord and the possibility of neurogenic shock.
- E. *Exposure and secondary evaluation:* An exam of the patient's entire body is important in the critically ill patient. Evaluation of sources of infection, signs of bleeding, extremity perfusion and capillary refill, and volume status are essential to

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determining the etiology of hypoperfusion. Attention to body temperature is also important to help best maintain normothermia.

Types of Shock:

HYPOVOLEMIC SHOCK

Hypovolemic shock results from loss of the intravascular circulating volume from fluid loss or blood loss.

Class I shock (<500-750 cc): Small volumes of fluid loss are well tolerated due to the compensatory mechanisms of the body. The venous system increases resistance to increase circulating blood volume and decrease venous capacitance. This results in the first vital sign change - a narrowed pulse pressure due to an increase of the diastolic blood pressure relative to the systolic blood pressure. Heart rate, blood pressure, and urine output are maintained.

Class II shock (750-1500cc): As the body detects lower circulatory volumes, the heart rate increases to augment cardiac output. The body attempts to compensate for the lack of blood volume by diverting blood flow away from the extremities and intestinal circulation in favor of the heart and brain. Blood pressure and urine output are maintained. Patients may experience mild anxiety.

Class III shock (1500-2000 ml): Ongoing volume loss greater than 1500-2000 ml overcomes the ability of the heart to maintain blood pressure, given that this equates to a 30-40% change in circulating volume, blood pressure decreases and urine output drops to preserve remaining circulatory volume. The mental status may also decline with class III shock. Patient is nearing irreversible shock and immediate, aggressive intervention with volume and blood replacement is necessary. Physical exam findings show peripheral vasoconstriction and cold, clammy extremities, dry mucous membranes, and pallor associated with extreme anemia.

Class IV shock is reached with > 2000ml or blood or >40% of the circulating volume is loss. Patients are lethargic, with extreme tachycardia, profound hypotension, and oliguria. The patient may be moribund once stage IV shock commences.

Certain patient populations may manifest hypovolemic shock differently than the aforementioned pattern. Children and pregnant patients will often guard their physiology until the point of collapse. Tachycardia will be prominent feature of severe shock before hypotension manifests in late class III to IV hemorrhage, just before circulatory collapse. On the other extreme of age, the elderly may not be able to mount a tachycardic response to hemorrhage because of beta blockade, medications, and pacer dependence. Additionally, the elderly typically have baseline hypertension, thus, they may not manifest the traditional level of hypotension SBP <100 mm Hg or MAP <65 mmHg despite profound volume loss.

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Hypovolemic shock may arise from bleeding due to trauma or atraumatic bleeding (such as an aortic aneurysm rupture or gastrointestinal bleed). Fluid losses from the GI tract from excessive vomiting or diarrhea, malabsorption, or hormone imbalances, such as diabetes insipidus can result in excessive volume loss that may lead to shock if left untreated.

Diagnosis: History and physical may direct the diagnosis of hypovolemia. A history of trauma, recent surgery, or evidence of bleeding may help diagnose acute blood loss. Alternatively, vomiting, and diarrhea or gastrointestinal illness will point to fluid loss as the etiology of volume loss.

On exam, the patient initially appears to have a cold shock picture, and pallor may be evident in the setting of bleeding.

- CBC: Hemoglobin (Hgb) and hematocrit (Hct) are lab values that measure the iron-oxygen containing protein in blood and the volume of red blood cells compared to volume of blood, respectively. They are each a measure of concentration.
 - Hgb and Hct may be decreased in acute blood loss; however, the lab values are not a reliable indicator of the amount of blood loss in early exsanguinating hemorrhage. As patient bleeds, the concentration of remaining blood remains stable until compensatory mechanisms of the body and fluid resuscitation dilute the relative concentration of the protein or red cells. Thus, in early blood loss, the hemoglobin may remain preserved while the circulating blood volume may be significantly reduced. Trends in Hb, Hct are a better assessment of blood loss than a single value.
 - Conversely with severe fluid loss, hemoconcentration may occur elevating the concentration of the Hgb and Hct relative to circulating plasma volume.
- BMP:
 - Electrolyte assessment: GI losses may lead to hypokalemia. Massive hemorrhage with transfusion of banked blood may lead to low ionized calcium levels that need aggressive repletion for hemostasis.
 - Acid/ Base:
 - Large volume loss leads to poor oxygen delivery to the tissue and a transition to anaerobic metabolism in the tissue bed. Lactate is produced and lactic acid level elevate leading to a metabolic anion gap acidosis
 - Resuscitation with sodium chloride solutions may contribute to a hyperchloremic acidosis. Chloride rises more than sodium and results in increased production of HCL to maintain electroneutrality, hence metabolic acidosis results.
 - Loss of hydrochloric acid with excessive vomiting leads to a hypochloremic-hypokalemic metabolic alkalosis that is treated with potassium repletion and normal saline.
 - GI losses from diarrhea, ileostomy output or high output pancreatic fistula may result in the loss of bicarbonate and contribute to metabolic acidosis.

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- Renal function: BUN, Creatinine
 - In severe hypovolemic shock the BUN: creatinine ratio is often ≥ 20 . As shock progresses, renal failure may ensue from acute tubular necrosis and cause further elevation of these parameters.
- Coagulation studies (PT/ INR; PTT, fibrinogen, fibrin related markers): In severe hemorrhagic shock coagulopathy, secondary to an overactivation of clot breakdown (termed fibrinolysis) may occur.
- SVO₂: Mixed venous oxygen saturation due to poor delivery of O₂ to the periphery, the body will maximally extract oxygen leading to a decreased SVO₂.
- Imaging:
 - Chest X-Ray (CXR) and Pelvic X-Ray (PXR) are mainstays of the trauma workup. Identification of hemothorax, or unstable pelvic fractures can be immediately addressed with chest tube placement or the application of a pelvic binder, respectively.
 - Focused Assessment with Sonography for Trauma (FAST exam), a bedside four view ultrasound that evaluates the hepatorenal and splenorenal recesses, the pelvis, and the pericardial free fluid may help triage the abdomen for intraperitoneal bleeding.
 - CT Scan: In the hemodynamically stable patients CT may help identify injury and source of blood loss.
 - Angiography may localize sources of bleeding and be a therapeutic measure to stop ongoing blood loss.
 - Direct peritoneal aspiration/lavage (DPA/ DPL): Largely replaced by increased utilization of the non-invasive FAST exam, DPA and DPL rapidly diagnose intraperitoneal bleeding at the bedside in blunt and penetrating trauma. A catheter is placed in the umbilical or supraumbilical position and the abdominal cavity is aspirated and then lavaged with 1 liter of normal saline. Aspiration of free blood or a red blood cell count $>100,000/\text{mm}^3$, white blood cell count $>500/\text{mm}^3$, elevated fluid amylase, or the presence of succus is deemed an indication for emergent laparotomy.

Treatment: Aggressive replacement of volume while attending to the underlying etiology is the mainstay of treatment of hypovolemic shock. In traumatic bleeding, patients should be triaged per the ABCDE's of Advanced Trauma Life Support (ATLS). Temporary measures to control bleeding such as pressure, tourniquets, and pelvic binders may be applied to help with immediate hemorrhage control until definitive management can stop the bleeding.

In atraumatic bleeding, the identification of the source must be expeditiously sought. All forms of hemorrhage necessitate large bore IV access (14 or 16 gauge IV or short, large diameter

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resuscitation lines) (ATLS trauma et al). Crystalloid resuscitation should be limited to 1-2 liters of IV fluid, with a transition to early blood and plasma resuscitation in the exsanguinating patient. This recent paradigm shift in management has been guided by recent evidence suggesting that a 1:2 resuscitation (1 unit of plasma for every 2 units of packed blood cells) leads to less overall product transfused, improved coagulopathy, and a mortality benefit in trauma and non-trauma patients (Holcomb, 2015; Holcomb, Cotton, Johansen). With massive transfusion, the citrate in stored blood will lead to low free plasma calcium; thus repletion of calcium, an essential element for coagulation, vasoconstriction, and cardiac function, is critical. Avoidance of hypothermia and correction of acidosis are also key factors that improve the patient's physiology and homeostatic response to therapy.

Hypovolemic shock from fluid loss must also aggressively be repleted with like fluid. The source of volume loss must also be addressed. Oral rehydration may be attempted in early forms of hypovolemia. Solutions with sucrose, and minerals, such as potassium and magnesium, are required for severe dehydration with volume of oral rehydration of 70-100 ml/kg over 12 hours to restore hydration. In patients with significant shock or those unable to take or absorb PO intake, isotonic fluid can be administered IV with Normal Saline (NS) or Lactated Ringers (LR). Administered as a bolus of 20-30 cc/kg, and repeated every 5-10 minutes, may quickly restore circulating volume. Care must be taken to avoid fluid overload in certain patient populations. Patients with heart failure, severe malnutrition, diabetic ketoacidosis (DKA), and Syndrome of Inappropriate Antidiuretic Hormone (SIADH), and extremes of age must be judiciously rehydrated with care not to overcorrect their volume status. Colloid resuscitation, while safe in most patient populations, has failed to show benefit over crystalloid except in patients with liver disease, in whom it may be indicated (Finfer et al; Bernardi M.)

DISTRIBUTIVE SHOCK

Distributive shock results from the inappropriate vasodilation of the peripheral vasculature. Septic shock, anaphylactic shock, and neurogenic shock are all examples of this pathophysiology.

Septic shock: Severe sepsis and septic shock are highly lethal conditions that occur in response to infection.

- Severe sepsis is defined as a systemic host response to infection that leads to organ dysfunction.
- Septic shock is termed when the response to the infection leads to hypotension requiring vasopressors to maintain a mean arterial pressure (MAP) of >65mm Hg with concomitant lactic acidosis (>2 mmol/L) (Singer).

In the United States, leading infective sources remain gram positive cocci from respiratory sources (200,000 cases per year) followed closely by gram negative bacterial pathogens

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(150,000 cases per year) (Martin). The incidence of fungal infection has been rising likely due to increased number of immunosuppressed hosts and increasing rates of nosocomial infections. The clinical sequela of sepsis is mediated by the host response to the pathogen. Infection leads to the release of pro and anti-inflammatory cytokines. Tumor necrosis factor α , interleukins (IL) such as IL-2, IL-6, IL-8, and IL-10 lead to the recruitment of macrophages, neutrophils, and monocytes which compounds the responses by secreting more cytokines such as leukotrienes and prostaglandins that lead to systemic alterations in perfusion, microcirculation, cell death, and organ dysfunction. Each system of the body is affected by the host response to infection. The nervous system may manifest with mental status changes and encephalopathy.

Early sepsis leads to a hyperdynamic state of the cardiac function with tachycardia, and proinflammatory arrhythmias, such as atrial fibrillation. Later in sepsis, myocardial depression may become manifest. Microcirculatory dysfunction leads to poor oxygen utilization and resultant high mixed venous oxygen saturations. Hypotension and a dilated shock process ensue. Respiratory dysfunction with acute lung injury and potentially adult respiratory distress syndrome often requires ventilator support. Acute renal failure is common in severe sepsis and septic shock, secondary to inflammatory mediators and kidney hypoperfusion. The gastrointestinal system often manifests with paralytic ileus, and hypoperfusion can lead to intestinal ischemia, acalculous cholecystitis, pancreatitis, gastritis, and ulcer formation. Finally, dysregulation of the coagulation system, immunologic response, and endocrine systems is common to septic physiology.

Diagnosis: Physical exam findings classically show a febrile or hypothermic patient with tachycardia, elevated respiratory rate, and hypotension when shock has set in. On exam, the patient initially appears to have warm and dilated extremity perfusion. Skin mottling can proceed once tissue hypoperfusion and microcirculatory dysfunction have set in. Identification of the patient at risk of sepsis or septic shock is achieved by bedside evaluation with the qSOFA (quick Sequential Organ Failure Assessment)

1. Alteration in mental status
2. Systolic blood pressure ≤ 100 mm Hg
3. Respiratory rate ≥ 22 / min

Positive screening on the qSOFA is associated with a mortality of 10% in severe sepsis. With the diagnosis of septic shock, mortality sky rockets to 18-46% (Dellinger; Howell), and is responsible for over half of all in-hospital deaths (Liu, V. 2014). Labs test to aid in the diagnosis of septic shock include:

- CBC:
 - Leukocytosis ($>12,000$ cells/ mm^3)
 - Leukopenia ($<4,000$ cells/ mm^3)
 - $>10\%$ Bandemia
 - Thrombocytopenia (low platelet count is common in sepsis)

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- BMP:
 - Electrolyte assessment
 - Acid/ Base: Cl⁻, HCO₃⁻, anion gap/base excess
 - Renal function: BUN, Cr, K clearance
- Liver function tests (LFTS) may help guide evaluation of the liver and biliary tract for source diagnosis and may be revealing of end organ dysfunction of the liver.
 - Coagulation studies (PT/ INR; PTT, fibrinogen, fibrin related markers): Identifies DIC and other coagulation disturbances
 - Lactate: Elevated due to hypoperfusion and an endpoint of resuscitation. Lactate clearance may be limited in cases of liver and renal failure
 - SVO₂: Mixed venous oxygen saturation. Often elevated in sepsis due to impaired oxygen utilization in the tissue
 - ABG: Evaluates acidosis, and ventilation parameter endpoints
 - Blood cultures/ Urine cultures: to identify infective sources
 - Procalcitonin: Value > 2 SD above normal serve as a biomarker that has greater specificity than other cytokines for bacterial infections (Ming et al)
 - Imaging: The identification of the source is essential to management of sepsis; appropriate imaging should be obtained to guide diagnosis and source control.

Treatment: Management priorities are largely based on the recommendations of the Surviving Sepsis campaign first presented in 2002 (Rivers), and updated and revised in 2012 (Dellinger 2012). The foundation of treatment rests on early recognition with prompt therapeutic response to the:

1. Infection source
2. Resuscitation and life support in critically ill patients

Infection identification and control are essential to treatment.

- Broad spectrum antibiotics are strongly recommended within 1 hour of sepsis recognition. The risk of dying from septic shock increases by 10% per hour of delay to antibiotics; making speed of administration a therapeutic priority (Kumar et al).
- Identification of the infectious source with cultures, preferably drawn before antibiotic administration, is recommended to assist in diagnosis and to inform antibiotic stewardship.
- Source control of infection is essential and may necessitate prompt surgical and procedural intervention (Howell, 2017).

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The remainder of therapy is tailored to the treating the dysregulated host response and supporting homeostasis.

1. Fluid management - a 30cc /kg crystalloid infusion in the first 3 hours of the identification of sepsis is strongly recommended to support blood pressure. Frequent assessments of the patient's response to volume and end points of resuscitations have been suggested to guide management. To date, a simple bedside test, the passive leg raise, remains one of the most clinically relevant, evidence based bedside evaluations to aid in this determination (Monnet). Additionally, urine output greater than 0.5cc/kg in the non-oliguric patients is also a helpful determination of adequate volume status. Early Goal Directed Therapy (EGDT) monitors the impact of clinical interventions and is assessed by endpoint goals in central venous pressure, mean arterial pressure, SVO₂, and lactate clearance. Pressors are often needed to support blood pressure in septic shock patients.
 - a. Norepinephrine is the first line agent with both vasoconstrictive properties and inotropic support.
 - b. Epinephrine is second line therapy, also acting as a sympathomimetic increasing heart rate and tone.
 - c. Vasopressin may be added as a third line agent, a potent vasoconstrictor, it raises systemic vascular resistance and enhances water reabsorption from the kidney.
2. Typically, after 3 pressors, refractory shock consideration of corticosteroids is often empirically started to treat Critical Illness-Related Corticosteroid Insufficiency (CIRCI) (Annane).
3. Mechanical ventilation is often needed to support patient with sepsis and sepsis related acute respiratory distress. Management of the ventilator is per ARDS net guidelines:
 - a. Target a tidal volume of 6 mL/kg of predicted body weight (QOE)
 - b. Plateau pressures of ≤30 cm H₂O (Brower et al).
4. Renal replacement therapy may be required in cases of severe acute kidney injury with hyperkalemia, severe acidosis, uremia or volume overload.

Neurogenic shock: Injury to the spinal cord at the level of the cervical spine or above the level of the 6th thoracic vertebra may lead to a form of vasogenic shock. This is estimated to occur in up to 20% of cervical spine injuries. The damage to the spinal cord, in effect, leads to a sympathectomy. Bradyarrhythmias, inappropriate vasodilation, and resultant hypotension and temperature dysregulation result. This form of vasoplegic shock is to be differentiated from spinal shock - a temporary loss or reduction of motor and sensory function after injury to the spinal cord.

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Most often, neurogenic shock is the consequence of traumatic injury; however, any spinal cord pathology that results in loss of the sympathetic signal at the cervical and upper thoracic level may cause the pathology.

Diagnosis: In traumatic injury, the physical exam may suggest a high level spinal cord injury. Patients will present with a warm dilated shock due to inappropriate vasodilatation. Bradycardia may or may not be present. Other signs of spinal cord injury such as diminished motor and sensory exam, priapism, loss of rectal tone and reflexes help confirm the diagnosis. Other sources of shock should be ruled out, particularly in the polytrauma patient where concomitant bleeding, traumatic brain injury, and obstructive causes of shock may be present.

Imaging with X-ray, CT, or MRI may confirm the diagnosis. A form of Spinal Cord Injury Without Radiographic Abnormality, termed SCIWORA, may occur in 3% of adult patients as per subset within the NEXUS study (Hendey, 2002).

Treatment: After ruling out other concomitant forms of shock, fluids and pressor use may be required to support the patient.

1. The first step in treatment is addressing fluid status and increasing the circulating volume.
 - a. An infusion of 1 -2 liters of isotonic crystalloid will help with hypotension from the vasodilation, and improve preload.
2. Mean arterial blood pressure should be sustained to 85-90 mmHg to aid in spinal perfusion (Licina, Stein).
3. Pressor administration to assist in maintaining a MAP of 85-90 mm Hg:
 - a. Norepinephrine is a sympathomimetic that increases heart rate and cardiac output by working both as an alpha and a Beta-1 agonist, and is the first line agent for neurogenic shock.
 - b. Dopamine also vasoconstricts the peripheral circulation and increases heart rate and is considered a second line agent.
 - c. Phenylephrine, an alpha adrenergic receptor agonist will help vasoconstrict the peripheral vasculature in cases without bradycardia (Stein 2012).

Anaphylactic shock: Severe allergic reactions liberate vasodilatory substances such as histamine through immunoglobulin E (Ig-E) reaction to an allergen. Non-immunologic phenomena may also trigger mast cell degranulation and basophil release of histamine leading to “anaphylactoid reactions”. Massive systemic vasodilation occurs leading to cardiovascular collapse, facial and tongue swelling leading to airway compromise, and bronchospasm of the airways.

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Diagnosis: Identification of anaphylactic and anaphylactoid reactions is largely clinical; however, plasma tryptase can be obtained within the first 3 hrs, and may be supportive of the diagnosis. Plasma histamine levels can also be obtained in the acute exposure within 15 to 20 minutes of presenting symptoms. Urine histamine metabolites may be detected if checked within an hour of the event.

Treatment: Halting the exposure to the trigger while assessing the patient's airway and hemodynamic stability is tantamount to therapy.

1. Airway: Lip and tongue swelling, called angioedema, as well as pharyngeal and glottic swelling may compromise the airway.
 - a. For signs of impending airway compromise, securing an endotracheal tube early is a priority.
 - b. Supplemental O₂ and continuous monitoring are necessary.
2. Epinephrine injected intramuscularly 0.3-0.5 mg intramuscularly with repeat dosing every 5-15 minutes as needed.
 - a. If an IV is present, IV forms should be emergently administered and a drip prepared for refractory response.
3. IV access should be emergently obtained and normal saline administered to support the patient to normotension.
4. Albuterol is a vasodilator for bronchospasm and can be given as a nebulizer.
5. Both H₁ and H₂ antihistamines should be administered to effectively block histamine receptors.
6. Consider steroid for airway edema and severe reactions. 125mg of IV methylprednisolone is administered.
7. Epinephrine is the primary vasopressor of choice; however, others may be added to maintain MAP >65 mm Hg.

Adrenal insufficiency (AI): The adrenal glands are essential for circulatory support and water conservation through its glucocorticoid (cortisol) and mineralocorticoid (aldosterone) production. Cortisol and aldosterone function to retain water and enhance receptiveness of renin-angiotensin system and norepinephrine. Insufficient adrenal production (primary adrenal insufficiency from Addison's disease or adrenal infarct or surgical removal) or insufficient pituitary stimulation (secondary adrenal insufficiency) or insufficient exogenous pharmacologic support (tertiary adrenal crisis) may lead to hypotension and shock until recognized. Fatigue, lethargy, abdominal complaints, fever, and psychiatric manifestations often accompany low blood pressure in all forms of adrenal crisis. In primary adrenal insufficiency, increased

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stimulation of the pituitary leads to production of ACTH and melanocyte stimulating hormone leading to hyperpigmentation. Additionally, dehydration, hyponatremia, and hyperkalemia are more prominent features due to the lack of aldosterone mineralocorticoid activity. This contrasts with secondary and tertiary adrenal insufficiency due to the presence of aldosterone.

Diagnosis: Adrenal crisis often is precipitated by another pathology such as an infection. A history of steroid use may suggest tertiary adrenal insufficiency.

1. A thorough evaluation for the triggering pathology is necessary to fully treat the patient.
2. Clinical hypotension that is refractory to volume replacement and pressor therapy is suggestive.
3. However, a low threshold for *clinical* diagnosis and therapy in critically ill patients should be maintained.
4. A short corticotropin test (250µg) is the "gold standard" diagnostic tool.

Treatment: Treatment of adrenal crisis is aimed at volume repletion and hormonal replacement

1. Infusion of 0.9% NS +/- Dextrose 5% will address hypovolemia, hyponatremia, and low serum glucose.
2. Dexamethasone 4 mg/kg is recommended for patients who require diagnostic workup for confirmation of adrenal insufficiency as this will not interfere with serum cortisol levels.
3. Hydrocortisone 50 mg every 6 hours may be used in those with known primary adrenal insufficiency.
4. Treatment of infection or another trigger (Bornstein SR).

OBSTRUCTIVE SHOCK

Impediment to the flow of blood in the cardiopulmonary circuit results in obstructive shock. Classic examples of obstructive shock are from tension and tamponade physiology, pulmonary emboli, pericarditis, and restrictive cardiomyopathies.

Tension and tamponade: A history of trauma, central venous line or cardiothoracic procedures may raise the concern for tension or tamponade physiology. On exam, the patient initially appears to have a cold shock picture, with peripheral vasoconstriction. In tension physiology, the trachea may be deviated away from the pressurized hemithorax. Breath sounds are diminished on the affected side. The patient will be hypoxemic, and if intubated, the ventilator will register elevated peak inspiratory pressures as tension builds. Distension of the neck veins in the absence of volume overload results from the transmitted pressure within the chest cavity.

Cardiac tamponade presents with similar findings. Anxiety is prominent, and often the patient will fight to remain upright and leaning forward. In addition to distended neck veins, muffled heart sounds may be present, although this is often an unreliable finding in the trauma bay. A narrowed pulse pressure is often one of the first abnormal vital signs. Pulsus paradoxus, an

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exaggerated drop in the systolic blood pressure with inspiration, is a classic finding in tamponade and is a harbinger of impending cardiovascular collapse (Swami, 2003). Pulsus alternans is a beat to beat variation in the amplitude of the systolic pressure that accompanies left ventricular dysfunction associated with tamponade or left ventricular failure.

Pulmonary Embolism (PE): Pulmonary emboli are blood clots that obstruct the pulmonary venous circulation. When of sufficient volume or size to obstruct the outflow from the right heart, or create clinically significant shunt, hemodynamic and respiratory compromise may ensue. Virchow's triad of hypercoagulability (often detected in the patient past medical history as previous venous thrombosis or pulmonary emboli, limb swelling), stasis from immobility, or the risk factor of endothelial injury commonly seen in trauma, surgery and other procedures should elevate the clinical suspicion for PE.

Cardiomyopathy and constrictive pericarditis are other etiologies that contribute to obstructive physiology.

Diagnosis: based primarily on clinical suspicion and physiology.

1. Life threatening tension and tamponade should be addressed immediately based on clinical findings. Waiting for imaging may risk cardiopulmonary collapse and patient demise. Similarly, massive pulmonary emboli, when presenting with life threatening shock should also be clinically diagnosed and empirically treated along this same reasoning.
2. Imaging chest X-ray, CT or CTA is an important adjunct to the diagnosis of obstructive etiologies.
3. Ultrasound is a highly effective bedside modality to assist in diagnosis of obstructive shock. Pneumothorax and pericardial effusion can easily be detected by the trained ultrasonographer. Furthermore, cardiac function and evidence of right heart strain, constrictive pericarditis and cardiomyopathy can be detected on Doppler cardiac echography.
4. Perfusion scans may show evidence of ventilation perfusion mismatch consistent with pulmonary emboli.
5. Arterial blood gas may also reveal hypoxemia and hypocarbia (from tachypnea) or hypercarbia with severe shunt. Lactate and base deficit are reported on blood gas analysis.
6. Svo₂ will show evidence of increase tissue oxygen extraction, and thus a lower SVo₂.

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7. EKG may show tachycardia with most forms of obstructive physiology.
 - a. In acute pulmonary embolism with right ventricular dysfunction, EKG findings may show T wave inversion in the right precordial leads (V1-V4) and inferior leads (II, III, aVF). Deep S wave in lead I, a Q wave and inverted T wave in lead III are the classic $S_1Q_{III}T_{III}$, is found in a minority of patients.
 - b. Nonspecific ST and T wave changes and low voltage are findings associated with pericarditis.
 - c. Increased precordial voltages, with nonspecific ST and T wave changes, or deep sharp Q waves in the lateral (V5-6, I, aVI) and inferior leads (II, III, aVF) may be a prominent feature of obstructive left ventricular hypertrophy.

Treatment: The mainstay of treatment is directed at the underlying etiology of the obstruction to cardiopulmonary flow. In tension pneumothorax, placement of an angiocatheter in the midclavicular line in the second intercostal space will change a tension pneumothorax to a pneumothorax. Pressurized hemothorax and moderate to large pneumothoraces should also be treated with a placement of a chest tube in the 4th intercostal space in the anterior axillary line. Pericardiocentesis or surgical treatment of tamponade or effusive pericarditis will alleviate the pressure around the heart. If related to trauma, definitive treatment of the source (i.e., repair of a cardiac injury, pericardiotomy) may be required.

Pulmonary emboli are treated with anticoagulation. In cases of right heart strain, thrombolysis and other interventional therapies or surgical embolectomy may be required to alleviate the obstructive shock. Intubation and supportive critical care are often necessary. Cardiomyopathies are treated with multimodal therapy aimed at optimizing the Starling curve and preventing ventricular outflow collapse, and underlying etiologic management.

CARDIOGENIC SHOCK

Cardiogenic shock results from failure of the cardiac “pump.” Failure of forward delivery of blood and, therefore, oxygen to the tissues, leads to shock. Cardiac Index is determined by dividing cardiac output by the patient’s body surface area. Normal values are between 2.5-4 L/min/m²; in cardiogenic shock, this value is greatly reduced to ≤ 2.2 L/min/m². Pressure in one or both ventricles may elevate due to inefficiencies in the right or left side of the heart. When pressures elevate on the left side, pulmonary edema may occur, when there is right heart dysfunction, systemic congestion may result. In response to the reduction in the cardiac output, the systemic resistance increases in response to catecholamine stimulation and angiotensin II. Increased oxygen extraction in the tissue bed leads to reduced SvO₂.

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Classical cardiogenic shock is most often thought of as myocardial infarct (MI); however, valvular insufficiency, and arrhythmias may also lead to diminished cardiac output and cardiogenic shock.

Diagnosis: In MI, patients classically present with crushing substernal chest pain, upper extremity, back, epigastric or jaw pain. Women and patients with neuropathic changes in the heart innervation (i.e., diabetics, recipients of heart transplants) may present with atypical pain or nausea. Thus, recognition of at risk patient populations is essential to diagnosis. With valvular disruption, a new or changing murmur may be appreciated on physical exam. Signs of elevated filling pressures may be jugular venous distension in right heart dysfunction, and pulmonary edema with left heart dysfunction. Cool and mottled extremities reflect the body's response attempt to vasoconstrict in response to diminished cardiac output. Vital signs may reveal tachycardia, normal heart rate, or bradycardia. Blood pressure may be normal or hypotensive. Respiratory rates may be elevated and, with pulmonary congestion, the oxygen saturation may decrease.

1. Prompt evaluation with EKG, potentially even in the prehospital setting (Diercks2008), may expedite reperfusion. New ST changes, new Q waves or a new left bundle branch block suggests ischemia of the myocytes.
 - a. ST elevation MI (STEMI). ST elevations in the vascular territory of the infarct will be evident in the respective leads. The Universal Definition of Myocardial Infarction as new ST elevation at the J point in at least 2 contiguous leads of ≥ 2 mm (0.2 mV) in men or ≥ 1.5 mm (0.15 mV) in women in leads V2–V3 and/or of ≥ 1 mm (0.1 mV) in other contiguous chest leads or the limb leads
 - b. Non-ST elevation MI (NSTEMI) and Unstable Angina (UA):
2. Troponin
3. Diagnosis of myocardial infarction per the WHO guidelines requires
 - a. Detection of increase and/or decrease of cardiac biomarkers (preferably troponin) with at least 1 value above the 99th percentile of the upper reference limit
 - b. Evidence of myocardial ischemia with at least 1 of the following: symptoms, ECG changes, or supportive imaging (Mendis S, 2011)
4. Transthoracic or transesophageal Echography may show evidence of depressed ejection fraction, wall motion abnormalities, valvular dysfunction and other mechanical defects.

Treatment: Addressing the ABCs of resuscitation is essential to the management of cardiogenic shock. Intubation and ventilatory support (where appropriate) and obtaining excellent IV access and invasive blood pressure monitoring is crucial to effectively supporting the critical patient.

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1. Optimization of intravascular volume will assist with cardiac optimization.
2. Medication administration
 - a. Aspirin 325 mg and heparin IV should be administered expediently.
 - b. Glycoprotein IIb/IIIa inhibitor with NSTEMI may be beneficial.
3. Pressor support to a MAP of 65 mmHg
 - a. Norepinephrine and dopamine are first line agents.
4. Percutaneous Coronary Intervention (PCI) is the mainstay of therapy and should be administered to all STEMI within 12 hours of symptoms and, all patients with cardiogenic shock regardless of time of onset (Andersen HR).
5. Alternatively, if PCI cannot be administered within 120 minutes of arrival, then fibrinolytic therapy should be administered in absence of contraindication. Return of symptoms or failure to improve is an indication for emergent transfer to a PCI center.
6. Coronary Artery Bypass Grafting (CABG) is indicated in patients with STEMI and coronary anatomy not amenable to PCI who have ongoing or recurrent ischemia, cardiogenic shock, severe HF, or other high-risk features or mechanical defects.
7. Mechanical support
 - a. Intra-Aortic Balloon Pump (IABP) is a type of mechanical circulatory support for the failing left ventricle. The balloon pump is placed in the proximal descending aorta. During systole, it deflates and assists with afterload reduction and improved filling of the aorta with offloading of volume from the left ventricle. During diastole, the balloon inflates to improve filling of the coronary arteries. It may serve as an assist device in cardiogenic shock, to improve cardiac output before and after interventions, to improve left main coronary filling, and as a bridge to further therapy for arrhythmia, heart failure, and refractory ischemia.
 - b. Ventricular assist devices (VADs). The ventricular assist device is introduced into the left ventricle from the aorta via a femoral artery access and assists the ventricle with its ejection of blood. It may be utilized in cardiogenic shock and for similar indications as the IABP.

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Questions

1. A 68-year-old male is admitted to the Emergency Department after crushing chest pain. EKG shows a NSTEMI. Which of the following parameters is most suggestive of cardiogenic shock?
 - a. Cardiac index > 2.5
 - b. SVO2 55%
 - c. Peripheral vasodilatation
 - d. Hypertension with tachycardia

2. What is the first vital sign to change when a patient begins to hemorrhage?
 - a. Hypotension
 - b. Tachycardia
 - c. A narrowed pulse pressure
 - d. An increased in SVO2

3. A 78-year-old female presents to the emergency room with altered mental status, blood pressure of 70/30, atrial fibrillation with rapid ventricular response to the 120s. WBC is 8 with a 20% bandemia. SVO2 is 88%. What is the most likely type of shock?
 - a. Cardiogenic shock
 - b. Septic shock
 - c. Neurogenic shock
 - d. Adrenal insufficiency

4. The deflation of an intra-aortic balloon pump is timed with the following portion of the EKG:
 - a. P wave
 - b. Q wave
 - c. T wave
 - d. R wave

Answers

1. A 68-year-old male is admitted to the Emergency Department after crushing chest pain. EKG shows a NSTEMI. Which of the following parameters is most suggestive of cardiogenic shock?
 - a. Cardiac index > 2.5
 - b. SVO2 55%**
 - c. Peripheral vasodilatation
 - d. Hypertension with tachycardia

Cardiogenic shock leads to decreased blood delivery to the tissue due to failure of the heart “pump.” The result is that the tissues increase their extraction of oxygen from circulating hemoglobin. The percentage of oxygen bound to hemoglobin returning to the right side of the heart is, therefore, lower. The SvO₂ can be thought of as the amount of oxygen “left over” after the tissues have taken what they need. There are four causes of low SvO₂: insufficient cardiac output to meet tissue demand, low hemoglobin, low SaO₂, increased oxygen consumption with a stable O₂ delivery. Normal SvO₂ is 65-75%. Cardiac index of under 2.2 would be more consistent with cardiogenic shock. Peripheral vasodilation would be more consistent with neurogenic or septic shock. Hypertension and tachycardia would not be consistent with pump failure, as this would increase the workload and oxygen demand of the heart.

2. What is the first vital sign to change when a patient begins to hemorrhage?
 - a. Hypotension
 - b. Tachycardia
 - c. A narrowed pulse pressure**
 - d. An increased in SVO₂

A narrowed pulse pressure is one of the first vital sign changes seen in hemorrhagic shock. As a patient bleeds, the body will increase peripheral vascular resistance through systemic vasoconstriction. The diastolic blood pressure is an indirect measure of vascular resistance and decreased venous capacitance, thus, as the body attempts to maintain perfusion, the diastolic pressure increases relative to systolic pressure, thus, “narrowing the pulse pressure.” Tachycardia is seen with class II to III hemorrhage, and hypotension is classically seen in class III hemorrhage. SvO₂ would decrease in the setting of hemorrhage and low hgb.

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3. A 78-year-old female presents to the emergency room with altered mental status, blood pressure of 70/30, atrial fibrillation with rapid ventricular response to the 120s. WBC is 8 with a 20% bandemia. SVO₂ is 88%. What is the most likely type of shock?
 - a. Cardiogenic shock
 - b. Septic shock**
 - c. Neurogenic shock
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The patient is displaying the signs and symptoms of septic shock. As blood pressure decreases, altered mental status is commonly seen in older adult patients. Although older individuals may not mount a leukocytosis, bandemia or leukopenia are harbingers of severe infection in older patient populations and in the immunosuppressed and critically ill. SVO₂ is often elevated in sepsis and makes cardiogenic or neurogenic shock less likely.

4. The deflation of an intra-aortic balloon pump is timed with the following portion of the EKG:
 - a. P wave
 - b. Q wave
 - c. T wave
 - d. R wave**

The deflation timing of the IABP is timed with the onset of LV systole. LV systole corresponds to the R wave on EKG. The design of the IABP is to deflate during systole to increase forward flow into the aorta. The IABP Inflates during the diastole to increase the pressure in the coronaries.

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