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Pediatrics

CRITICAL CARE

FIRST EDITION
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eyadprimed
FIRST EDITION
2025
VERSION 2.1
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"Two men looked out from prison bars, one saw the mud, the other saw stars."

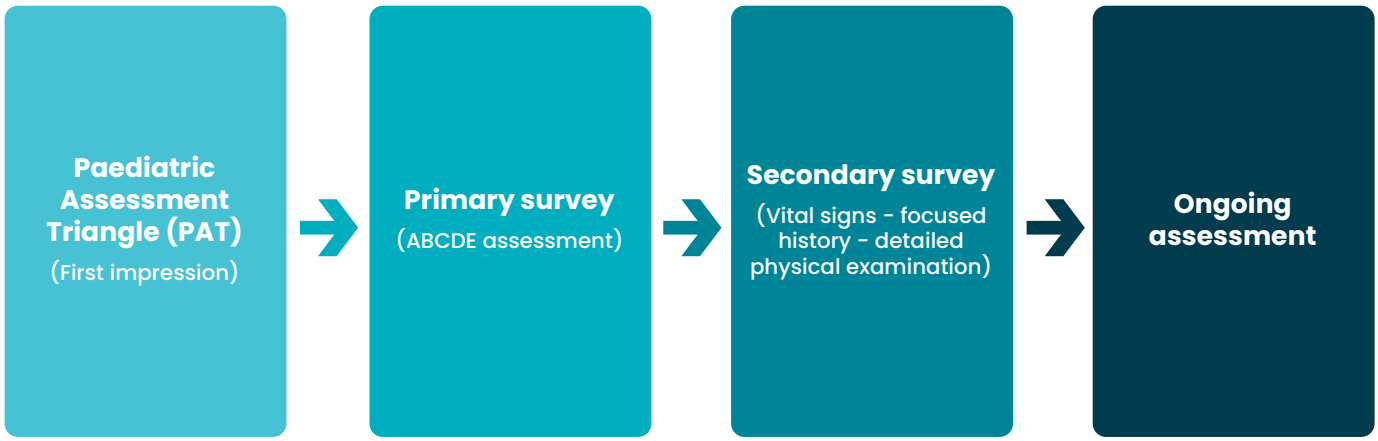
Which one will you be?

RECOGNITION OF CRITICALLY ILL CHILDREN

The care of the unwell child begins with early recognition, and aggressive resuscitation and stabilization.

Critically ill children present challenges, as there are many unique features, anatomically and physiologically, that differ significantly to adults.

The assessment of a seriously unwell child involves the following:



Paediatric Assessment Triangle

The first step in evaluating any child is to assess their general condition. This assessment should have a developmentally appropriate approach, and should be done in a short period of time.

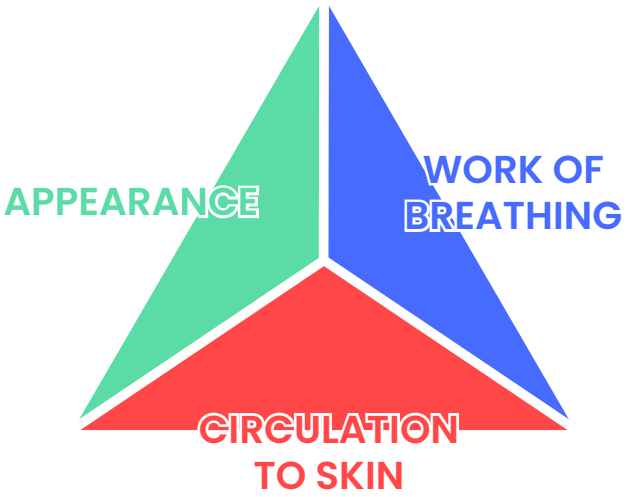
The Triangle focuses on three interdependent aspects of physical assessment that reflect:

1. Severity of illness or injury
2. Urgency of intervention

It is a rapid way to determine physiologic stability.

Components of the Triangle

The Pediatric Assessment Triangle consists of three areas of assessment:



Appearance

The "Appearance" portion of the Pediatric Assessment Triangle measures a variety of things, designed to determine whether the child is experiencing mental status changes (as these can be difficult to identify in an infant or young child).

The child's overall appearance reflects the adequacy of oxygenation, ventilation and perfusion.

Components of the "Appearance" item also help to determine whether the child's airway is clear.

The acronym "TICLS" (pronounced "tickles") is sometimes used by emergency medical providers to recall the components of the "Appearance" item:

T	Tone
I	Interactiveness
C	Consolability
L	Look and gaze
S	Speech and cry

Table 2. TICLS mnemonic for assessment of appearance in PAT

Tone	Is the child moving around and active or listless?
Interactivity/ mental status	How alert is the child? Does he/she reach for and grasp a toy, or is the child disinterested in interacting or playing with the care giver?
Consolability	Can the child be comforted by the care giver?
Look/gaze	Does the child fix the gaze on a face or is there a glassy-eyed stare?
Speech/cry	Is the child's speech or cry strong and vigorous or weak or hoarse?

	Normal	Abnormal
Tone (Muscle tone)	• Good muscle tone with good movement of the extremities. • Infants should strongly resist attempts to straighten their limbs.	• Limp, rigid, or absent muscle tone
Interactivity/ Irritability	• Strong, normal cry (this is a reliable sign of a clear airway)	• Crying is absent, or abnormal. • The child cannot be stimulated to cry. **In addition to indicating an altered mental status, this may also be a sign of an occluded airway.**
Consolability	• The child is able to be consoled by usual caregivers. • The child responds in his or her usual way to environmental stimuli.	• The child cannot be consoled or comforted by usual caregivers. • The child does not respond normally to environmental stimuli, like preferred toys.
Look (Gaze)	• Child is able to make eye contact	• Vacant stare with lack of eye contact. • The child may not seem to recognize normal caregivers.
Speech	• The child expresses himself or herself age-appropriately. • Speech (or crying) is normal (this is a reliable sign of a clear airway).	• The child is unable to express himself or herself age-appropriately. • Speech (or crying for babies) is absent or abnormal. **As with lack of crying in infants, this can be a sign of an occluded airway.**

Note

- Appearance is the single most important factor in assessment.
- There are very few false negatives (very few truly sick or injured children that have normal appearance).

Work of Breathing

"Work of Breathing" measures respiratory effort & visible signs of respiratory distress.

Normal Score	Abnormal Score
• Requires that the child's breathing be noiseless, effortless, and painless. • The child should not appear to be trying harder than usual to breathe.	• Indicates that the child is exhibiting an abnormal respiratory effort. • The respiratory effort may be increased (indicating that the child is trying harder than normal to breathe), decreased, or absent.

Signs of increased work of breathing include:

- **Noisy breathing** (including **grunting** in infants, **wheezing**, or **stridor**)
- **Retractions** (the soft tissue between the ribs gets sucked inward because the child is trying so hard to breathe in): **Suprasternal, intercostal, subcostal.**
- **Use of accessory muscles of respiration** to breathe (the child is having so much difficulty breathing that he or she needs extra muscles, like the abdominal muscles, to lift the chest and inhale)
- **Nasal flaring** in **young children**
- **Seesaw breathing** in **infants** (where the chest and abdomen "seesaw" up and down; this is a sign of severe respiratory distress in an infant)

A child exhibiting decreased work of breathing may be bradypneic (breathing too slowly) or too weak to engage the muscles required for inhalation.

Circulation to Skin

"Circulation to Skin" is measured by skin color and obvious bleeding. Circulation, as measured by skin color and capillary refill, is an excellent indicator of perfusion in children; as Inadequate perfusion of vital organs leads to compensatory vasoconstriction in non essential anatomic areas, especially the skin.

A child with normal circulation will have his or her usual skin color.

There will be no obvious bleeding.

Abnormal circulation to the skin may be indicated by:

- **Pallor** (generally an early sign of decreased circulation; pallor may also be an indication of blood loss)
- **Cyanosis**
- **Mottling**
- **Obvious blood loss**
- \+ Skin temperature
- \+ Pulse strength
- \+ CRT (capillary refill time)

Other causes of vasoconstriction (mottling, ↑ CRT):

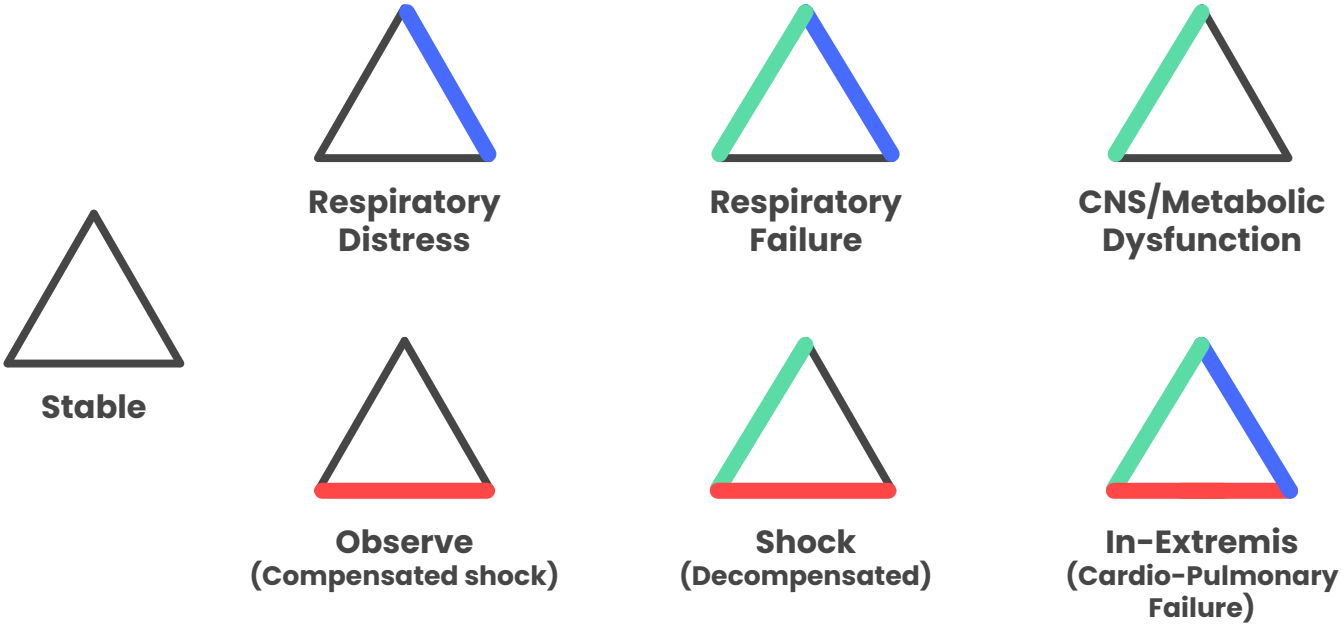
- Fever
- Hypothermia
- Medications
- Normal vasomotor lability in infants

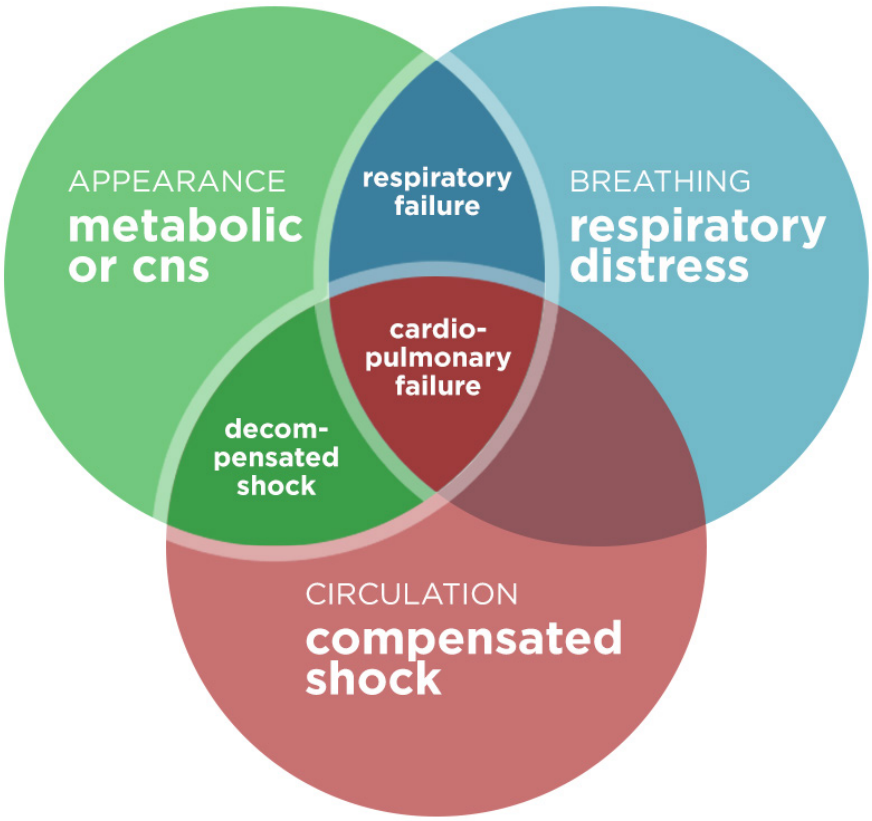
Note

The Triangle can also help identify the child with CNS or systemic problems who has normal oxygenation, ventilation and perfusion.

"Scoring" the Triangle

- The Pediatric Assessment Triangle assigns **no numerical scores**, its goal being to help medical providers formulate a **quick assessment** of a pediatric patient's acuity.
- However, based on the results of the assessment, some initial conclusions can be drawn.
- These **initial conclusions can help to guide medical decisions**, such as whether to call for additional medical resources, but further assessment is always done, and repeated, following the quick usage of the Pediatric Assessment Triangle.





Respiratory distress

- A child who is exhibiting **increased work of breathing,** but has normal appearance and circulation to skin, can be initially assumed to be in respiratory distress.
- While the child is having trouble breathing, he or she is getting enough oxygen to perfuse the body well (hence normal circulation) and to oxygenate the brain (preventing mental status changes).

Respiratory failure

- Respiratory failure can be presumed when a child is exhibiting **increased work of breathing,** along with either **abnormal appearance** or abnormal circulation.
- The abnormal appearance (mental status) or circulation indicate that the child is not breathing well enough to perfuse the body, or to oxygenate the brain.

Shock

- A child with **abnormal appearance** and **circulation to skin** is likely to be in shock.
- Problems in both of these areas indicate that the child's body is not perfusing the brain or other tissues. (Work of breathing is unlikely to be increased, though the child is likely to be breathing quickly.)

In extremis

- A child with **abnormal appearance, work of breathing,** and **circulation to the skin** is generally in extremis - for example, due to imminent respiratory collapse.

Primary survey

- During the primary survey, assessment and management occur simultaneously.
- The primary survey should be periodically repeated, particularly after major intervention or when a change in the patient's condition is detected.

It is done by ABCDE assessment:

A	B	C	D	E
Airway (Patency - Stridor - Wheeze - Grunting)	**Breathing** (Rate - Work - Symmetry - Cyanosis - O2 saturation)	**Circulation** and vascular access	**Disability** Mental state (AVPU Score)	**Exposure** (Fever - Rash- RBS)

Airway

> **Note**
>
> Remember that respiratory failure is the most frequent cause of cardiac arrest in children.

- **Is the airway patent with no signs of obstruction?** Determine whether or not there is airway patency.
- **Is the patient able to maintain adequate ventilation and oxy-genation with the correct positioning and suction?**
- **Are there any abnormal airway sounds** (snoring, stridor, hoarse speech, audible wheeze), or any **signs of increase work of breathing** (sniffing position, nasal flaring, grunting, retractions, paradoxical chest movements)?

In cases where the airway is not patent, or there are significant signs of respiratory distress, it is important to be aggressive in the management of airway problems.

Insertion of an airway adjunct (e.g. oropharyngeal or nasopharyngeal airway) or tracheal intubation is the first step in the management of airway problems.

Breathing

- **Look for signs of** hypoxia, dyspnoea, stridor or signs of increased work of breathing.
- **Look at the chest and abdomen for respiratory movement;** evaluate the depth (tidal volume) and symmetry of movement with each breath.
- **Determine the respiratory rate.** A respiratory rate of **more than 60 breaths per minute** is abnormal at any age

As fatigue begins and hypoxia worsens, the child may progress to respiratory failure and bradypnoea.

All children with breathing difficulties should receive high flow oxygen through a face mask oxygen as soon as the airway has been assessed and demonstrated to be adequate.

Pulse oximetry is an excellent tool to use in assessing a child's breathing.

Circulation

The goal is to assess adequate cardio-vascular function, tissue perfusion, and perfusion to vital organs (e.g. brain and kidneys).

- Signs of **neurologic dysfunction** usually indicate the brain perfusion is affected.
- **Heart rate:**
  - **Tachycardia** can be an early sign of hypoxia or low perfusion, but it can also reflect less serious conditions eg . fever, anxiety, pain).
  - **Bradycardia** (rate <60/min in children or <100/min in newborns) indicates serious illness and poor myocardial perfusion.
- **Pulse quality:**
  - Pulse quality reflects the **adequacy of peripheral perfusion.**
  - A weak central pulse may indicate decompensated shock, and a peripheral pulse that is difficult to find, weak or irregular suggests poor peripheral perfusion and may be a sign of shock.
  - Check the femoral pulse in infants and young children, or the carotid pulse in an older child or adolescent.

If no pulse is felt, and there are no, or minimal signs of life, commenced cardiopulmonary resuscitation (CPR).

- **Circulation to skin** is also an important sign to infer that cardiac output is inadequate. **Normal capillary refill time is less than two seconds** after pressing against the skin for five seconds. The CRT should be done centrally (eg. on the chest) to minimise the impact of environmental factors.
- Finally, **blood pressure determination** should be done in every child who presents to an emergency department or surgery, especially the unwell-looking child:
  - Blood pressure determination and interpretation can be difficult.
  - A low BP indicates decompensated shock.
  - An easy formula for determining the lower limit of acceptable BP is: minimal systolic blood pressure = 70 + [2 x age in years].
  - Blood pressure trends are useful in determining the child's condition and response to treatment.

Obtaining venous access in a child can be a challenge, especially for medical staff that usually don't look after very unwell children on a regular basis.

Disability

- The assessment of the neurological exam is important and can be evaluated with the **AVPU scale** (**A**lert; Responds to **V**erbal stimuli; Responds to **P**ain; **U**nresponsive). This scale is especially useful to **evaluate the level of consciousness.**
- In **trauma or acute medical patients,** the adequate scale is the **Paediatric Glasgow Coma Scale (PGCS),** which is more complicated than the AVPU as it involves memorization and numerical scoring. This test evaluates eye, verbal and motor responses:
  - Evaluate the brainstem by checking the responses in each pupil to a direct beam of light. A normal pupil will constrict after a light stimulus.
  - Evaluate the motor activity by looking for symmetrical movement of the extremities, seizures, posturing or flaccidity.

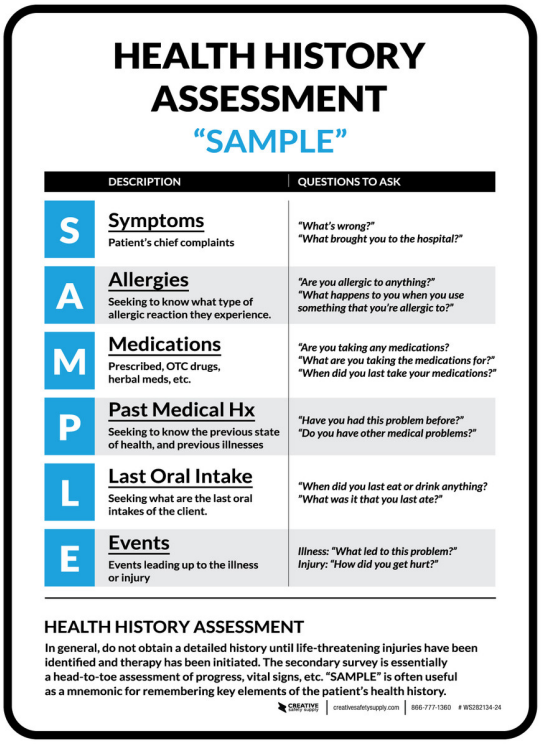
Exposure

Adequate exposure of the child is mandatory for completing the initial physical assessment.

(Note that random blood sugar is mentioned in exposure)

Secondary survey

- Focuses on performing an additional assessment with a focused history and physical examination, to **detect less immediate threats to life.**
- Done once the initial assessment is complete and resuscitation have been initiated if required.



Ongoing assessment

See rest of pediatrics

2 SHOCK IN PEDIATRICS

Shock is a physiologic state characterized by a significant, systemic reduction in tissue perfusion; resulting in decreased tissue oxygen delivery and diminished removal of harmful byproducts of metabolism (eg, lactate).

It occurs when circulation is not adequate to maintain organ perfusion.

Stages of Shock

Compensated Shock	Hypotensive Shock	Irreversible Shock
HR: ↑	**HR:** ↑↑	**HR:** ↑↑ or ↓↓
BP: Normal	**BP:** ↓↓	**BP:** ↓↓↓
Peripheral VC	**Peripheral VC**	**Organ Failure**
	Organ dysfunction (Mental state)	**Arrest**

Features indicating shock

Heart rate

- In children, **sinus tachycardia** is a consistent sign of shock (except with cardiogenic shock from bradycardia or spinal cord injury).
- For patients with compensated shock, it **may be the only abnormal vital sign.**

Age	Awake rate	Mean	Sleeping rate
Newborn to 3 months	85 - 205	140	80 - 160
3 months to 2 years	100 - 190	140	75 - 160
2 years to 10 years	60 - 140	80	60 - 90
> 10 years	60 - 100	75	50 - 90

Blood pressure

- Children with shock may have normal blood pressures.
- Measurement with a **manual cuff** may be more accurate **for children with circulatory compromise;** Blood pressures determined with automated oscillometric devices can be higher than those using manual devices, particularly for hypotensive patients.

> **Note**
>
> Hypotension must be rapidly identified, because those with low blood pressures typically deteriorate rapidly to cardiovascular collapse and cardiopulmonary arrest.

For children with normal systolic blood pressures, the classification of shock may be suggested by changes in the pulse pressure:

- **Narrow pulse pressure** occurs when diastolic blood pressure is increased as the result of a compensatory increase in systemic vascular resistance (such as with hypovolemic and cardiogenic shock).
- **Widening of pulse pressure** can be seen when diastolic blood pressure is decreased as the result of decreased systemic vascular resistance (as can occur with distributive shock).

Age	Systolic pressure, mm Hg	Diastolic pressure, mm Hg
Birth, 12 hr, <1000g	39 - 59	16 - 36
Birth, 12 hr, 3 kg	50 - 70	25 - 45
Neonate, 96 hr	60 - 90	20 - 60
Infant, 6 mo	87 - 105	53 - 66
Toddler, 2 yr	95 - 105	53 - 66
School age, 7 yr	97 - 112	57 - 71
Adolescent, 15 yr	112 - 128	66 - 88

Temperature

- **Fever** (or **hypothermia** in young infants) is often consistent with septic shock.

Method	Temperature (°C)
Rectal	36.6 - 38
Ear	35.8 - 38
Oral	35.5 - 37.5
Axillary	36.5 - 37.5

Respiratory rate

- Children with shock are usually **tachypneic.**

Age	Normal rate
Infant (< 1 yr)	30 - 53
Toddler (1 - 2 yr)	22 - 37
Preschool (3 - 5 yr)	20 - 28
School age (6 - 11 yr)	18 - 25
Adolescent (12 - 15 yr)	12 - 20

Etiology of Shock

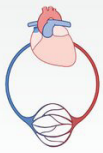
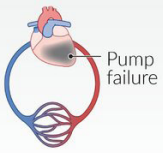
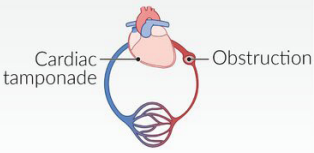
In addition to these stages of shock, four broad mechanisms of shock are recognized: Hypovolemic, distributive, cardiogenic, and obstructive.

Each type is characterized by one primary physiologic derangement.

Epidemiology

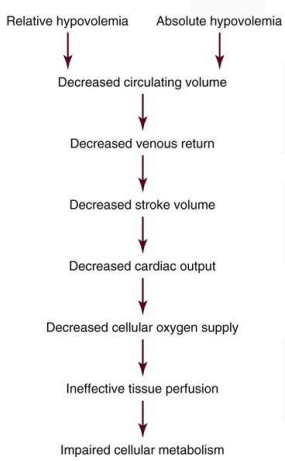
- Clinical experience suggests that frequent causes of shock among children include **hypovolemia** from diarrheal disease, sepsis, and traumatic hemorrhage.
- The most common cause of shock worldwide may be **hypovolemia** from **diarrhea.**
- Widespread use of oral rehydration therapy has substantially reduced mortality, although this intervention continues to be underutilized.
- Among children with severe sepsis, half of the cases have underlying illnesses and many are low birth weight newborns. **Experts estimate that more children die from severe sepsis than from cancer.**
- Trauma is the cause of death for over 40 percent of children between 1 and 14 years of age. It is not known, however, how many of these children died from hemorrhagic shock.

Classification of Shock

Volume				Output			
Shift Distributive shock		**Loss** Hypovolemic shock		**Cardiac** Cardiogenic shock		**Extracardiac** Obstructive shock	
Septic	Capillary leakage	Hemorrhagic (traumatic or nontraumatic)	Blood (whole)	Myocardial causes	Myocardium	Impaired diastolic filling	E.g., cardiac tamponade
Anaphylactic Anaphylactoid Neurogenic	Vascular tone dysregulation	Nonhemorrhagic (nontraumatic)	Body fluids (e.g., GI loss)	Arrhythmias	Conduction system	↑ Ventricular afterload	E.g., massive PE
		Nonhemorrhagic (traumatic)	Plasma (e.g., from burns)	Valvular heart disease		Obstruction of venous return	E.g., tension pneumothorax
 Vasodilation		 Hypovolemia					

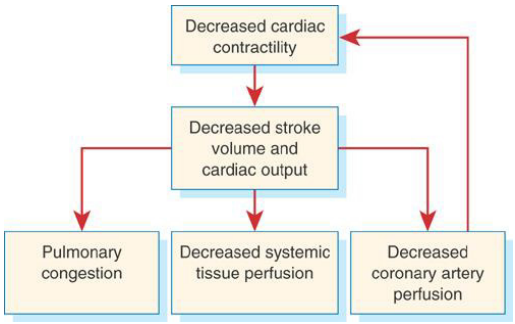
1. Hyovolemic Shock

Decreased preload caused by volume loss including hemorrhage, gastrointestinal losses, insensible losses (eg, burns), or third spacing.



2. Cardiogenic Shock

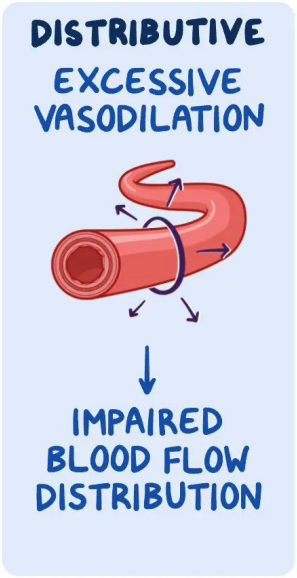
Cardiogenic shock is caused by inadequate contractility of the heart.



- One of the key differences between hypovolemic and cardiogenic shock is the **work of breathing.** In both cases, there will be tachypnea, but in hypovolemic shock the effort of breathing is only ***mildly increased.***
- In cardiogenic shock, the **work of breathing** is often significantly increased as evidenced by grunts, nasal flaring, and the use of accessory thorax muscles.
- Also, since the heart is pumping ineffectively, blood remains in the pulmonary vasculature. This causes **pulmonary congestion** and edema, which can clinically be heard as crackles in the lungs and visualized as jugular vein distension.
- **Pulses** are often weak, capillary refill is slow, extremities are cool and cyanotic, and there may be a decrease in the level of consciousness.

3. Distributive Shock

Distributive shock is a condition in which the majority of blood is inappropriately distributed in the vasculature.



- Decreased vascular resistance due to vasodilation caused by conditions such as sepsis, anaphylaxis, or acute injury to the spinal cord or brain.
- A common way to conceptualize distributive shock is as a condition in which **the vasculature has relaxed and dilated to the point of inadequacy.** The arterial blood supply needs to maintain a certain tension in order to maintain blood pressure. Likewise, the venous system must maintain tension as well, so as not to retain too much of the total blood supply.

In distributive shock, the blood is not being maintained in the required and needed useful blood vessels.

Distributive shock is most commonly caused by:

- Sepsis, anaphylaxis, or a neurological problem.
- All of which cause vascular dilation or loss of blood vessel tone.

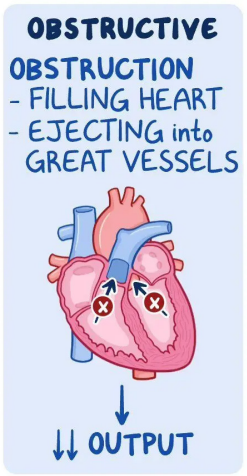
Note

In distributive shock, the preload, contractility, & afterload vary depending on etiology.

Anaphylactic shock

- A severe allergic reaction that results in the release of chemicals that dilate blood vessels and increase capillary permeability, causing fluid to leak out of capillaries into the tissues.
- Pooling of blood in peripheral tissues and the shift of fluid out of the capillaries cause venous return and cardiac output to fall.
- Allergic reaction also causes constriction of the bronchi and airway obstruction.

4. Obstructive Shock



Increased vascular resistance leading to impaired heart function

- Obstructive shock is similar to cardiogenic shock in that the **impaired heart function is the primary abnormality.** In cardiogenic shock, the contractility is impaired; but in obstructive shock, the **heart is prevented from contracting appropriately.**

Common causes of obstructive shock:

- **Congenital heart disease with ductal dependent lesions:** e.g. hypoplastic left heart.
- **Acquired obstructive conditions:** Pneumothorax, cardiac tamponade, or Massive pulmonary embolism.

Obstructive and cardiogenic shock is most easily distinguished by the contractility of the heart. In obstructive shock, heart contractility is normal, although pumping function is not.

Cardiac tamponade

- Associated with **muffled heart sounds** since blood is present in the pericardial space.
- **Pulsus paradoxus** (e.g. a drop in blood pressure on inspiration) may also be present.

Tension pneumothorax

- Is a **clinical diagnosis.**
- The trachea may be deviated away from the side of the lesion, and there are absent breath sounds over the affected side of the chest.

Pulmonary embolism

- Consider a pulmonary embolism when: the person is cyanotic and/or hypotensive, experiences chest pain, and has respiratory distress without lung pathology or airway obstruction.
- **Risk factors include:** obesity, hormone use, family history of abnormal clotting, and coagulation factor abnormalities.

5. Septic Shock

Sepsis is defined as life threatening organ dysfunction caused by a dysregulated host response to infection.

- **Organ dysfunction can be identified as:** an acute change in total SOFA score > 2 points consequent to the infection.
- The baseline SOFA score can be assumed to be zero in patients not known to have pre existing organ dysfunction.

Patients With septic shock can be identified with a clinical construct of:

- ***Sepsis,***
- With persisting ***hypotension*** requiring vasopressors to maintain MAP ≥ 65 mmHg,
- And having a ***serum lactate*** level > 2 mmol/L (18 mg/dL)

Despite adequate volume resuscitation.

With these criteria hospital mortaliy is in excess of 40%.

Septic shock is further categorized into warm and cold shock:

Warm shock: If the person is experiencing warm shock, they commonly will have warm, erythematous peripheral skin and a wide pulse pressure in the setting of hypotension.

Cold shock: If the person is experiencing cold shock, they commonly will have pale, vasoconstricted skin and narrow pulse pressure hypotension.

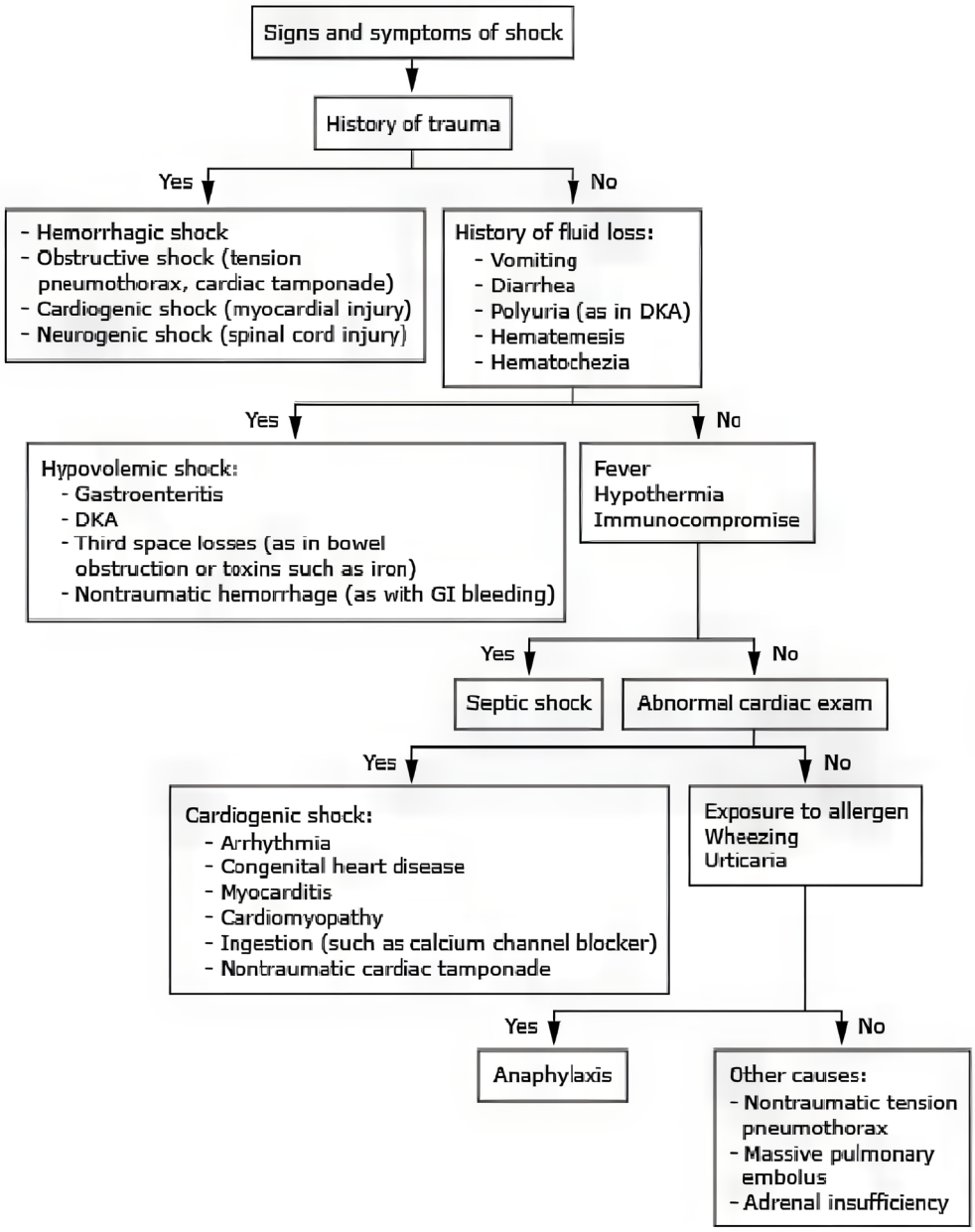
Sepsis Related Organ Failure Assessment (SOFA) score

The sepsis 3 guidelines recommended the use of the Sepsis Related Organ Failure Assessment (SOFA) score for early identification of sepsis in adults:

- An alteration in **mental status**
- A decrease in **systolic blood pressure** of less than 100 mm Hg
- A **respiration rate** greater than 22 breaths/min

The Liverpool qSOFA score (LqSOFA)

Table 1. Scoring thresholds for each component of LqSOFA		
Criterion	Points allocated	
	1 point	0 points
Capillary refill time	≥3 seconds	<3 seconds
AVPU	VPU	A
Heart rate	>99th centile Bonafide et al. age-specific thresholds	≤99th centile Bonafide et al. age-specific thresholds
Respiratory rate	>99th centile Bonafide et al. age-specific thresholds	≤99th centile Bonafide et al. age-specific thresholds
Abbreviations: AVPU, Alert/Voice/Pain/Unresponsive scale. LqSOFA, Liverpool quick Sequential Organ Failure Assessment.		



> **Note**
>
> A patient may have more than one type of shock (such as an infant with cardiogenic shock from supraventricular tachycardia who is also hypovolemic because he has been unable to drink or a child with underlying cardiomyopathy who is septic).

Management of Shock

Shock treatment varies according to etiology.

The goal of shock management is to get oxygen to the tissues and to the organs.

This requires:

- Having enough oxygen in the blood,
- Getting the blood to the tissues, and
- Keeping the blood within the vasculature.

Thus, shock management is dedicated to achieving these three critical goals.

In objective terms, this means:

- Returning the person to the correct blood pressure and
- Heart rate for their age, and
- Restoring normal pulses, capillary refill, and mental status along with a urine output of at least 1 mL/kg an hour.

Management of Septic Shock

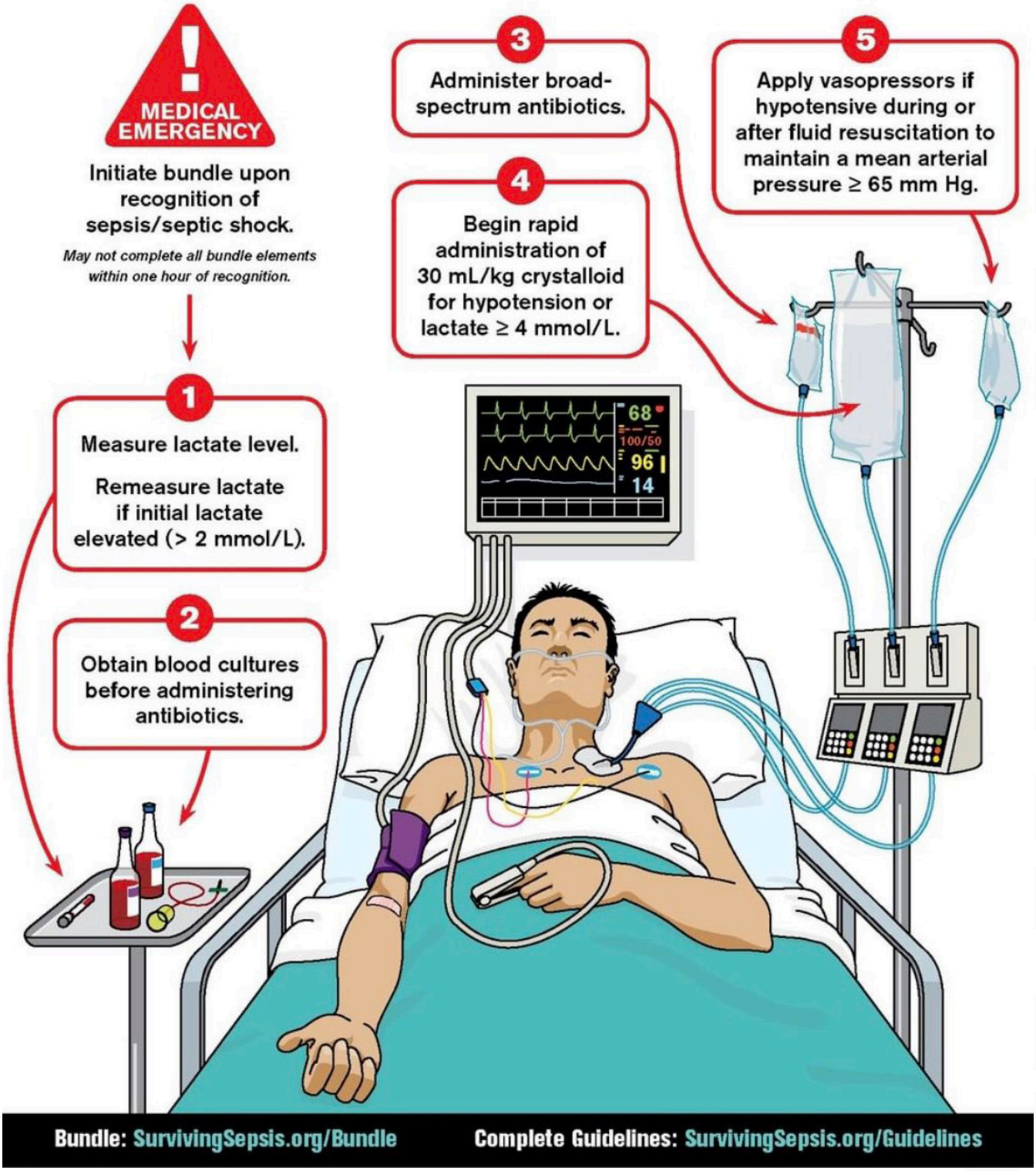
1-hour Bundle (Initial resuscitation):

- Measure serum lactate. Re-measure if initial > 2 mmol/L.
- Obtain blood cultures prior to antibiotics.
- Administer broad spectrum antibiotics.
- Begin rapid crystalloid 30 ml/kg
- Apply vasopressors if hypotension remains after fluid resuscitation to MAP > 65 mm Hg.

Hour-1 Bundle

Initial Resuscitation for Sepsis and Septic Shock

Surviving Sepsis Campaign



Antimicrobial therapy

- Empiric broad spectrum therapy with **one or more antimicrobials to cover all likely pathogens is recommended.**
- Once the pathogen(s) and sensitivities are available, narrowing empiric antimicrobial therapy coverage si recommended.
- If no pathogen is identified, narrowing or stopping empiric antimicrobial therapy according to clinical presentation, site of infection, host risk factors, and adequacy of clinical improvement in discussion with infectious disease and/or microbiological expert advice is recommended.

Choice of Empiric Antibiotic depends on:

- Site of Infection
- Previous antibiotic course
- Host Risk Factors
- CAI Or HAI

Fluid therapy

Hypotension:

- **In ICU:** 40:60 ml/kg
- **Not in ICU:** 40 ml/kg

No hypotension: Maintenance IVF

Type of IV fluid

- Crystalloid, **not colloids** (albumin): Although there is no difference in outcomes, this recommendation takes into consideration cost.
- Balanced/buffered crystalloids, rather than 0.9% saline, for the initial resuscitation of children with septic shock or other sepsis-associated organ dysfunction
- No gelatin
- No starch

Hemodynamic monitoring

- Usage of bedside clinical signs in isolation to categorize septic shock in children as "warm" or "cold" is ***not*** suggested.
- Usage of trends in **blood lactate** levels, in addition to clinical assessment, to guide resuscitation is suggested.
- Usage of **advanced hemodynamic variables,** when available, in addition to bedside clinical variables to guide the resuscitation of children with septic shock or other sepsis associated organ dysfunction is suggested:
  - Cardiac output/cardiac index,
  - Systemic vascular resistance,
  - Or central venous oxygen saturation ($S_{cv}O_2$)

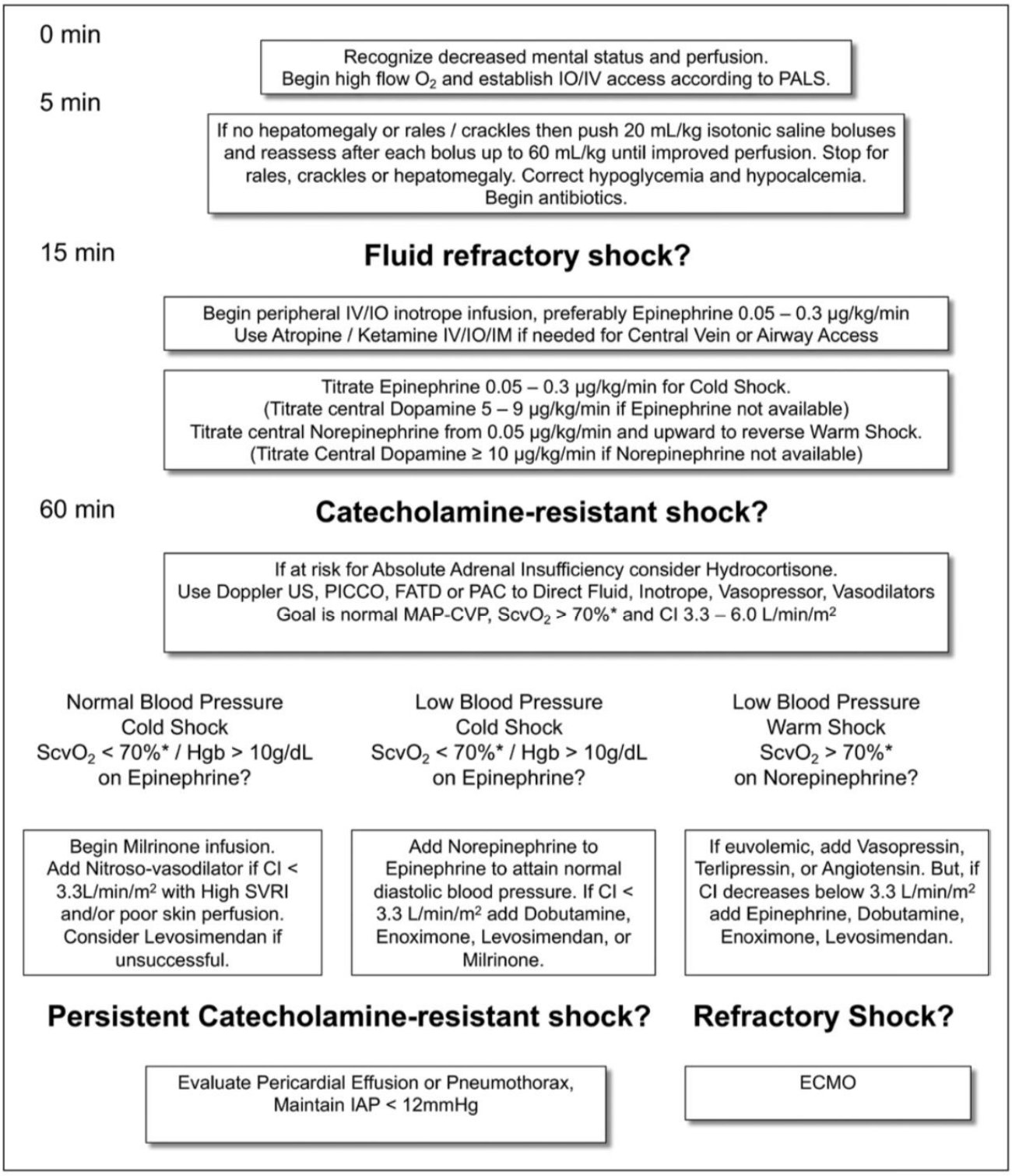


Figure 2. American College of Critical Care Medicine algorithm for time-sensitive, goal-directed stepwise management of hemodynamic support in infants and children. Proceed to next step if shock persists. 1) First-hour goals—restore and maintain heart rate thresholds, capillary refill ≤ 2 s, and normal blood pressure in the first hour/emergency department. 2) Subsequent ICU goals—if shock not reversed proceed to restore and maintain normal perfusion pressure (MAP – CVP) for age, $Scvo_2$ > 70% (* except congenital heart patients with mixing lesions), and cardiac index > 3.3 < 6.0 L/min/m² in PICU.

Vasopressors & Inotropes

Done after efficient fluid resuscitation

Vasoactive medications:

TABLE 3				
Agent	**Common Name**	**Mechanism**	**Effects**	**Uses for Shock**
Dobutamine		β1, β2 agonist	Increased CO	Cardiogenic, Septic
Dopamine		Low Doses: DA agonist High Doses: α1, α2, β1 agonist	Increased CO and mild increase in SVR	Cardiogenic, Septic, Neurogenic
Epinephrine		α1, α2, β1, β2 agonist	Increased HR, SVR, and CO	Cardiogenic, Septic, Anaphylactic
Norepinephrine	Levophed	α1, β1, β2 agonist	Vasoconstriction	Cardiogenic, Septic
Phenylephrine		α1 agonist	Increased SVR	Septic
Vasopressin		V1, V2 agonist	Vasoconstriction and water reabsorption	Septic

Terlipressin dose in septic shock:
Loading dose 20 mic/kg/ dose followed by continuous infusion 4- 20 mic/ kg/ hour

Dopamine	V.C.	**Epinephrine**	V.C.+ Br dilator+ Inotropic
Dobutamine	Inotropic effect	**Norepinephrine**	V.C.
Milrinone	Improves cardiac contractility		

Other lines of management

Corticosteroids: Septic shock, fluid and catecholamine refractory with suspected/proven adrenal insufficiency.

Mechanical Ventilation | **Plasma exchange, RRT, ECMO** | **IVIG transfusion**

Drugs for different types of shock

- **Drugs of cardiogenic shock:** Dobutamine & Milrinone
- **Drugs of anaphylactic shock:** Epinephrine
- **Drugs of septic shock:** Dopamine - Norepinephrine - Vassopresin

Treatment of Etiology

INTRAVENOUS FLUID THERAPY

Key terms

Basic principles

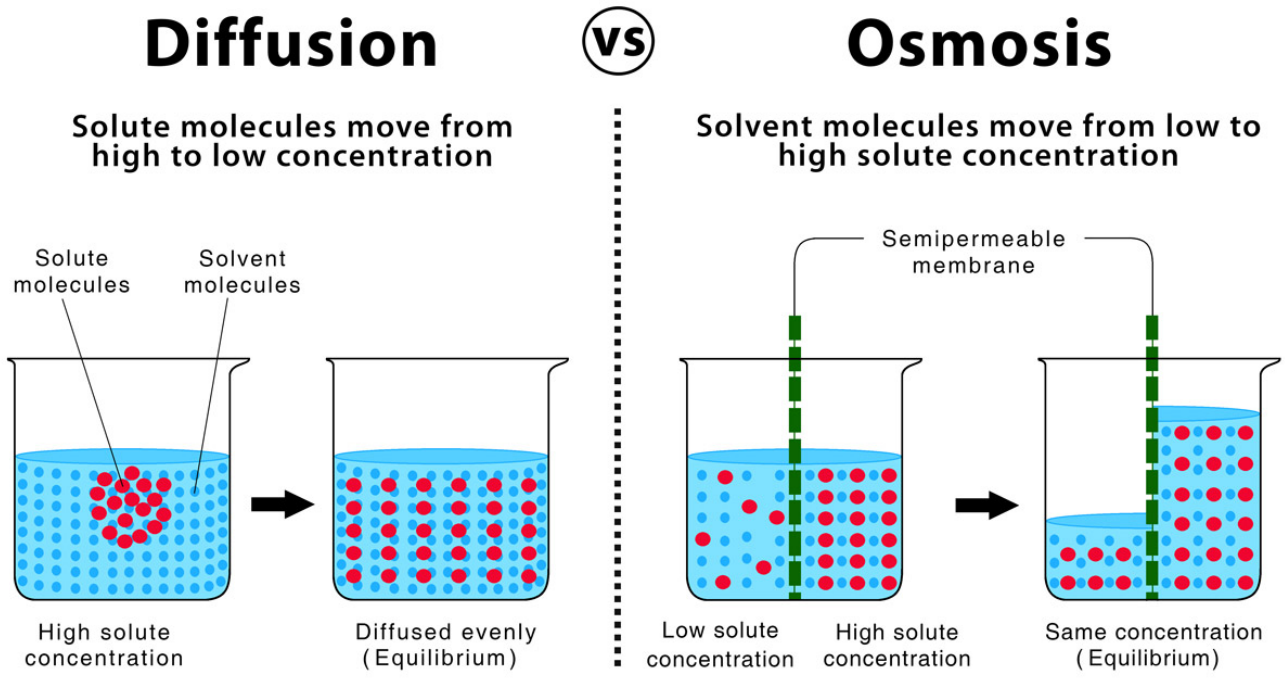
Diffusion: The passive movement of particles from a region of high concentration to a region of low concentration until equilibrium is reached. (Molecules still move after equilibrium is reached)

Osmosis:

- The movement of water across a semipermeable membrane from an area of lower solute concentration to an area of higher solute concentration.
- This movement of water allows the equalization of the solute-to-solution ratio across the membrane.

Solute: Particles that are dissolved in the sterile water (solvent) of an IV fluid.

Solvent: The liquid portion of an IV solution that the solute(s) dissolves into. The most common solvent is sterile water.



Body fluid compartments

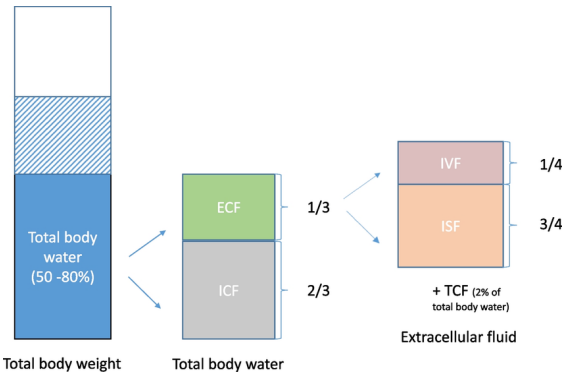
Total body water: Water contained within the cells, around the cells, and in the bloodstream. Water comprises about **60%** of the body's weight.

Extracellular space: Space outside cells consisting of **intravascular & interstitial spaces.**

Intracellular space: Space within the **cells.**

Intravascular volume: Volume of blood contained within the **blood vessels.**

Plasma: Fluid surrounding the cells of the body.



Intravenous fluids

- Are chemically prepared solutions that are administered to the patient.
- They are tailored to the body's needs and used to replace lost fluid and/or aid in the delivery of IV medications.
- For patients that do not require immediate fluid or drug therapy, the continuous delivery of a small amount of IV fluid can be used to keep a vein patent (open) for future use.

IV fluids come in different forms and have different impacts on the body, making it important to understand the different types of IV fluids, along with their indications.

Colloid solutions: IV fluids containing **large proteins and molecules** that tend to stay within the vascular space (blood vessels).

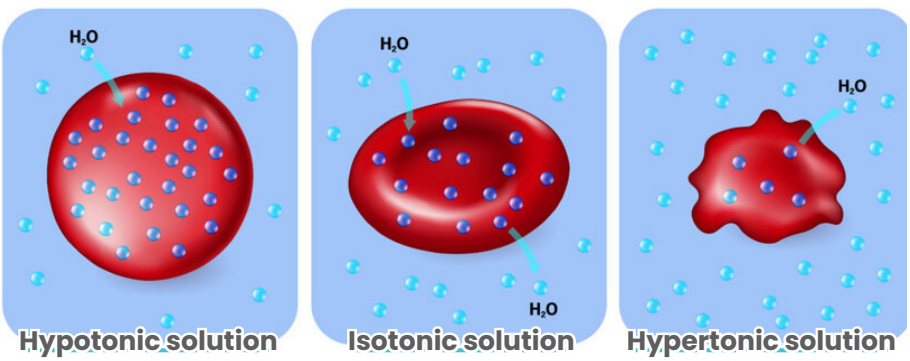
Crystalloid solutions: IV fluids containing varying concentrations of **electrolytes.**

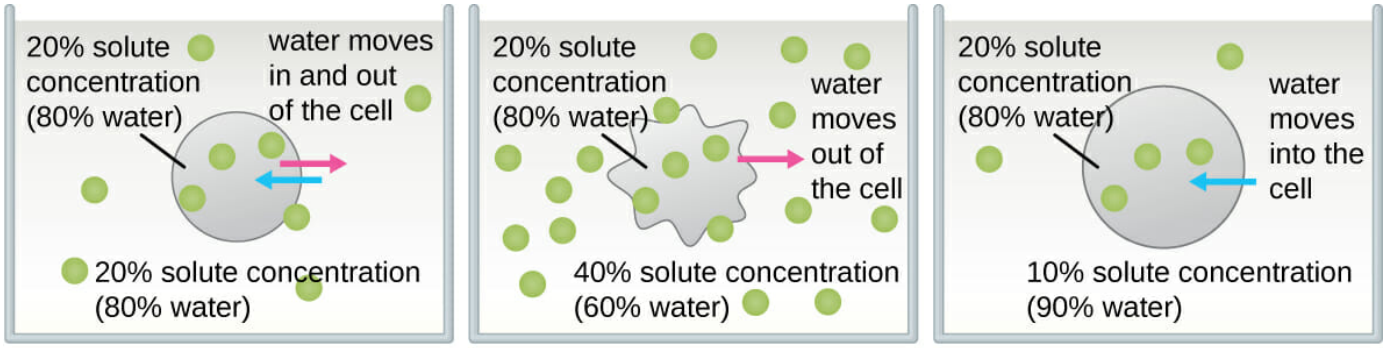
Hypertonic crystalloid: A crystalloid solution that has a **higher concentration of electrolytes than the body plasma.**

Hypotonic crystalloid: A crystalloid solution that has a **lower concentration of electrolytes than the body plasma.**

Isotonic crystalloid: A crystalloid solution that has the **same total concentration of electrolytes as the body plasma.**

Oxygen-carrying solutions: Chemically prepared solutions that can carry O2 to the cells.





a **Isotonic solution**
A solution that has the *same* solute concentration as another solution. There is no net movement of water particles, and the overall concentration on both sides of the cell membrane remains constant.

b **Hypertonic solution**
A solution that has a *higher* solute concentration than another solution. Water particles will move out of the cell, causing crenation.

c **Hypotonic solution**
A solution that has a *lower* solute concentration than another solution. Water particles will move into the cell, causing the cell to expand and eventually lyse.

Specific types of fluids

5% Dextrose in water (D5W):

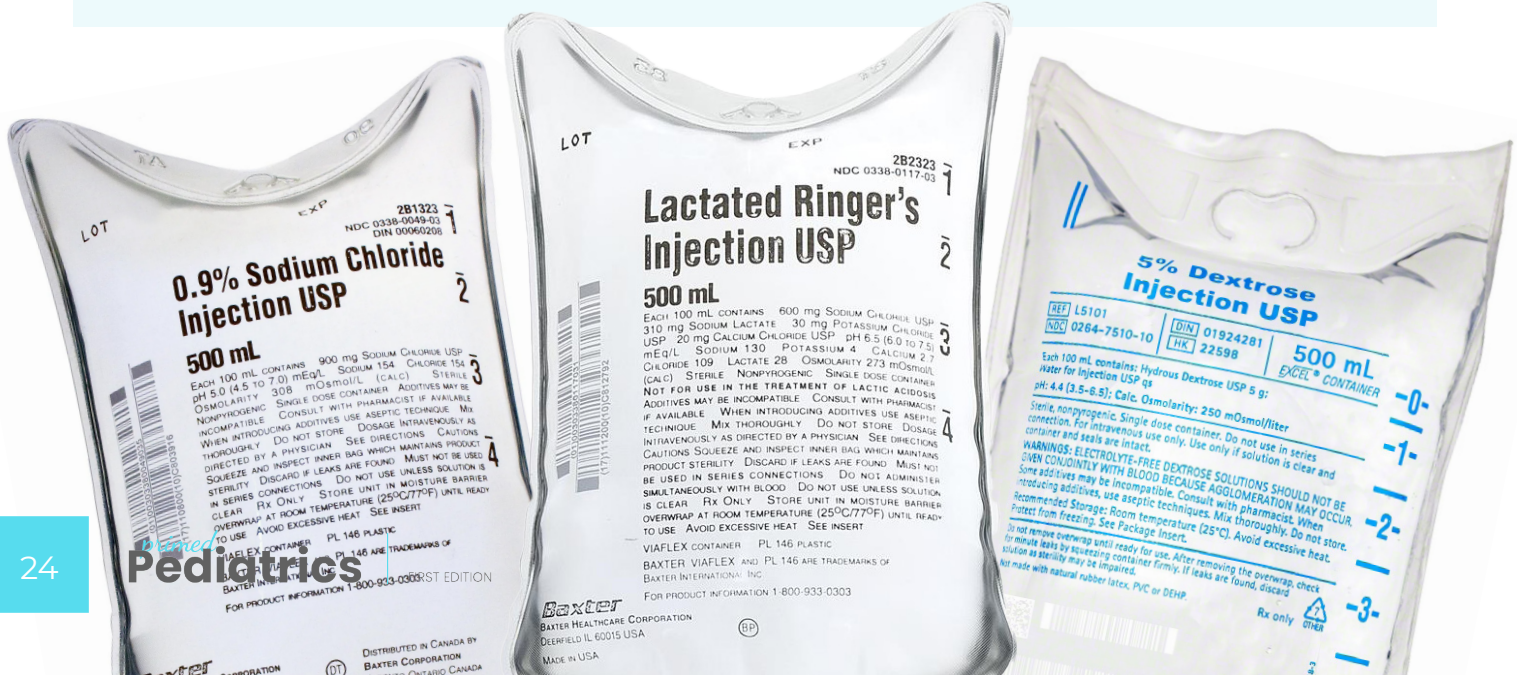
- A carbohydrate solution that uses glucose (sugar) as the solute dissolved in sterile water.
- Five percent dextrose in water is **packed as an isotonic solution but becomes hypotonic once in the body** because the glucose (solute) dissolved in sterile water is metabolized rapidly by the body's cells.

Lactated Ringer's (LR): An isotonic crystalloid solution containing the solutes sodium chloride, potassium chloride, calcium chloride, and sodium lactate, dissolved in sterile water (solvent).

Normal saline solution (NS, NSS):

- An isotonic crystalloid solution that contains sodium chloride (salt) as the solute, dissolved in sterile water (solvent).
- The specific concentration for normal saline solution is 0.9%.

NS: Normal saline. NSS: Normal saline solution.



Preparation of intravenous fluids

There are several types of IV fluids that have different effects on the body.

- Some IV fluids are designed to **stay in the intravascular space** (intra, within; vascular, blood vessels) to increase the intravascular volume, or volume of circulating blood.
- Other IV fluids are specifically designed so the fluid **leaves the intravascular space** and enters the interstitial and intracellular spaces.
- Still others are created to **distribute evenly** between the intravascular, interstitial, and cellular spaces.

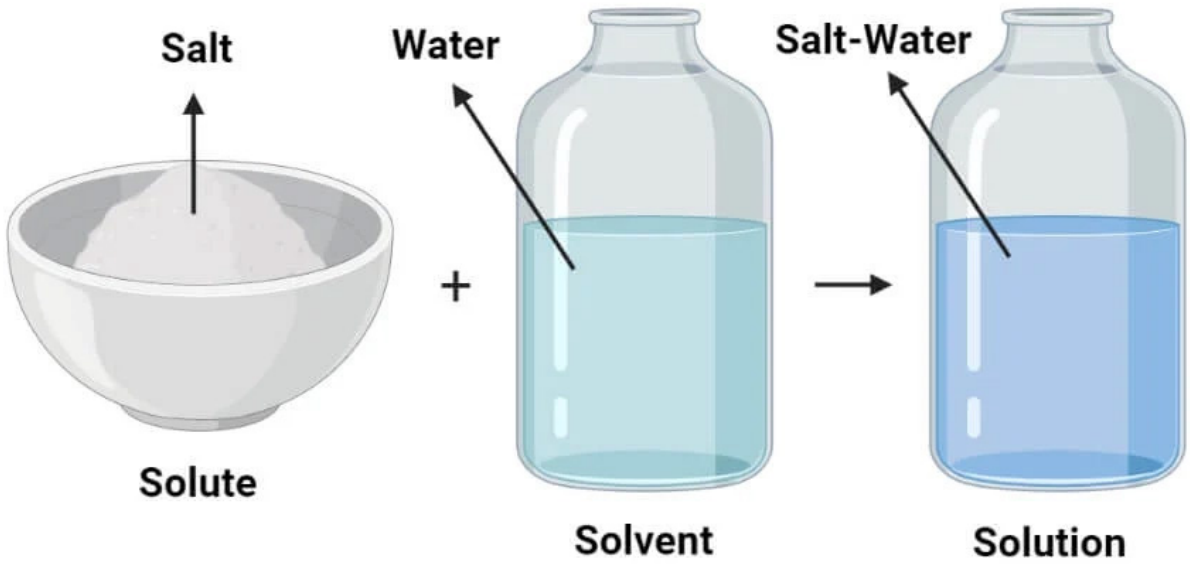
The properties that an IV solution has within the body depends on how it is created and the specific materials it contains.

It also determines the best type of IV solution to use in relation to the patient's needs.

The majority of an IV solution is sterile water:

- Chemically, water is referred to as a "solvent."
- A solvent is a substance that dissolves other materials called "solutes."
- Within IV solutions, the solutes can be molecules called **electrolytes** (charged particles such as sodium, potassium, and chloride) and/or other larger compounds such as **proteins or molecules.**
- Together, the solvent (water) and solutes (electrolytes, proteins, or other molecules dissolved in the water) create the IV solution.

Consider a cup of coffee to which sugar is added for sweetness; The coffee is the solvent, which dissolves the solute sugar.



Forms of IV fluids

Crystalloid

Relatively low tendency to stay intravascular

Examples:

- Normal saline
- 1/2 Normal saline
- D5 1/2NS + 20 mEq/L KCL
- Lactated Ringer's

Colloid

Relatively high tendency to stay intravascular

Examples:

- Albumin
- Fresh frozen plasma
- Dextran
- Hydroxyethyl starch

Electrolyte-free water

Examples: D5W - D10W

Blood and blood products

Examples: Packed RBCs

Understanding these IV fluids is important because each has a different impact on the body and particular indications for use.

Colloid Solutions

Colloid solutions are IV fluids that contain solutes in the form of large proteins or other similarly sized molecules.

- The proteins and molecules are so large that they cannot pass through the walls of the capillaries and onto the cells.
- Accordingly, colloids remain in the blood vessels for **long periods of time** and can significantly increase the intravascular volume (volume of blood).
- The proteins also can attract water from the cells into the blood vessels.
- However, although the movement of water from the cells into the bloodstream may be beneficial in the short term, continual movement in this direction can cause the cells to lose too much water and become dehydrated.
- Colloids are useful in maintaining blood volume, but their use in the field is limited. Colloids are expensive, have specific storage requirements, and have a short shelf life.
- This makes their use more suitable in the hospital setting.

Commonly used colloid solutions include: plasma protein fraction, salt poor albumin, dextran, and hetastarch.

Crystalloid Solutions

Crystalloids contain electrolytes (e.g., Sodium, potassium, calcium, chloride) but lack the large proteins and molecules found in colloids.

- Crystalloid solutions are the primary fluid used for **prehospital IV therapy.** They come in many preparations.

Crystalloids are classified according to their "tonicity":

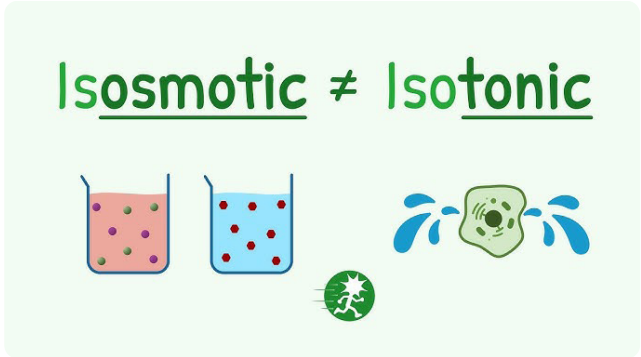
A crystalloid's tonicity describes the concentration of electrolytes (solutes) dissolved in the water, as compared with that of body plasma (fluid surrounding the cells).

- When the crystalloid contains the **same amount of electrolytes** as the plasma, it has the same concentration and is referred to as **"isotonic"** (iso: same, tonic: concentration).
- If a crystalloid contains **more electrolytes than the body plasma,** it is more concentrated and referred to as **"hypertonic"** (hyper: high, tonic: concentration).
- If a crystalloid contains **less electrolytes than the body plasma,** it is less concentrated and referred to as **"hypotonic"** (hypo: low, tonic: concentration).

Tonicity and osmolarity

- The terms osmolarity and tonicity are inter-related as both these terms compare the solute concentrations in a solution.
- But, at the same time, the terms are distinct chemical concepts according to the types of solutes that they are taking into account in their measurements.
- Hence, the key difference between tonicity & osmolarity is that:
  - **Tonicity** measures only the concentration of **non-penetrating solutes** through a semipermeable membrane.
  - **Osmolarity** measures the total concentration of **penetrating and non-penetrating solutes.**

	Tonicity	Osmolarity
DEFINITION	Tonicity is the measure of the osmotic pressure gradient by means of water potential of two solutions separated by a semipermeable membrane.	Osmolarity or osmotic concentration is the measure of solute concentration given by the unit osmoles of solutes per litre of solution.
TYPE OF SOLUTE	Measures only the concentration of non-penetrating solutes through a semipermeable membrane.	Measures the total concentration of penetrating and non-penetrating solutes.
CLASSIFICATION OF SOLUTIONS	Hypertonic solutions, hypotonic solutions and isotonic solutions.	Isosmotic, hyperosmotic and hypoosmotic.



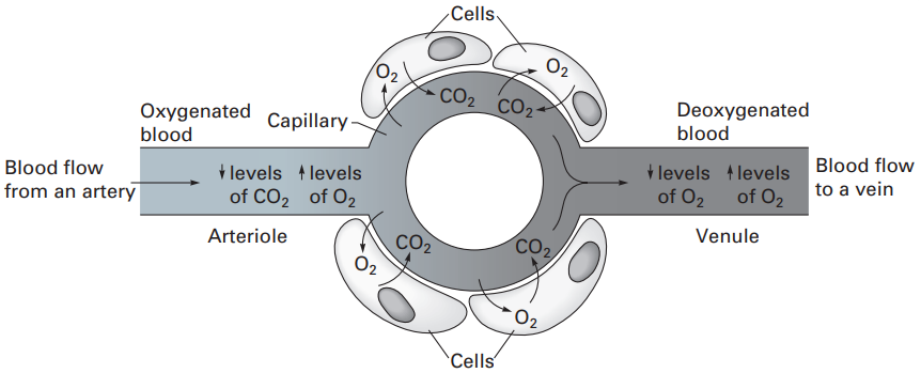
Total Body Water (TBW)

Describes the entire amount of water contained within the body and accounts for approximately 60% of body weight.

It is distributed among the intracellular and extracellular compartments:

- **The intracellular space** is the space within all the body cells (intra, within; cellular, cell).
- **The extracellular space** is the space outside the cells (extra, outside; cellular, cells). It can be further divided into:
  - **The intravascular space** (space within the blood vessels)
  - **The interstitial space** (space between the cells but not within the blood vessels)

Locations of intracellular, interstitial, and intravascular spaces in a capillary bed.



- The different compartments are separated by membranes through which the body water can easily pass. As a rule, body water is pulled toward the solution with a higher concentration of dissolved molecules.
- The movement of water across a semipermeable membrane that selectively allows certain structures to pass while inhibiting others (i.e., a capillary wall or cellular wall) is known as **Osmosis.**
- The osmotic movement of water occurs as the body attempts to create a balance between the different solute concentrations that exist on either side of a semipermeable membrane. What this means is that the water will easily cross the semipermeable membrane **from the side that has a lower concentration of particles to the side that has a higher concentration of particles.**

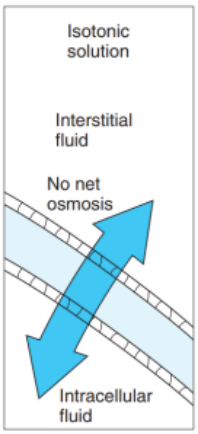


Figure 3-2. Isotonic solutions do not result in any significant fluid shifts across cellular or vascular membranes.

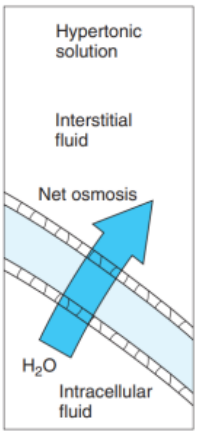


Figure 3-3. A hypertonic solution given IV will draw fluids from the cells and interstitial spaces into the vasculature.

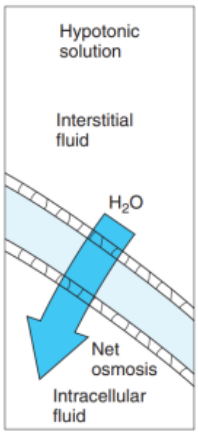


Figure 3-4. A hypotonic solution given IV will cause fluids to leave the vasculature for the interstitial and intracellular spaces.

The net movement of water stops when each side of the membrane becomes equal in its concentration of water and particles. Isotonic, hypertonic, and hypotonic IV fluids cause the following shifts of body water:

Hypotonic

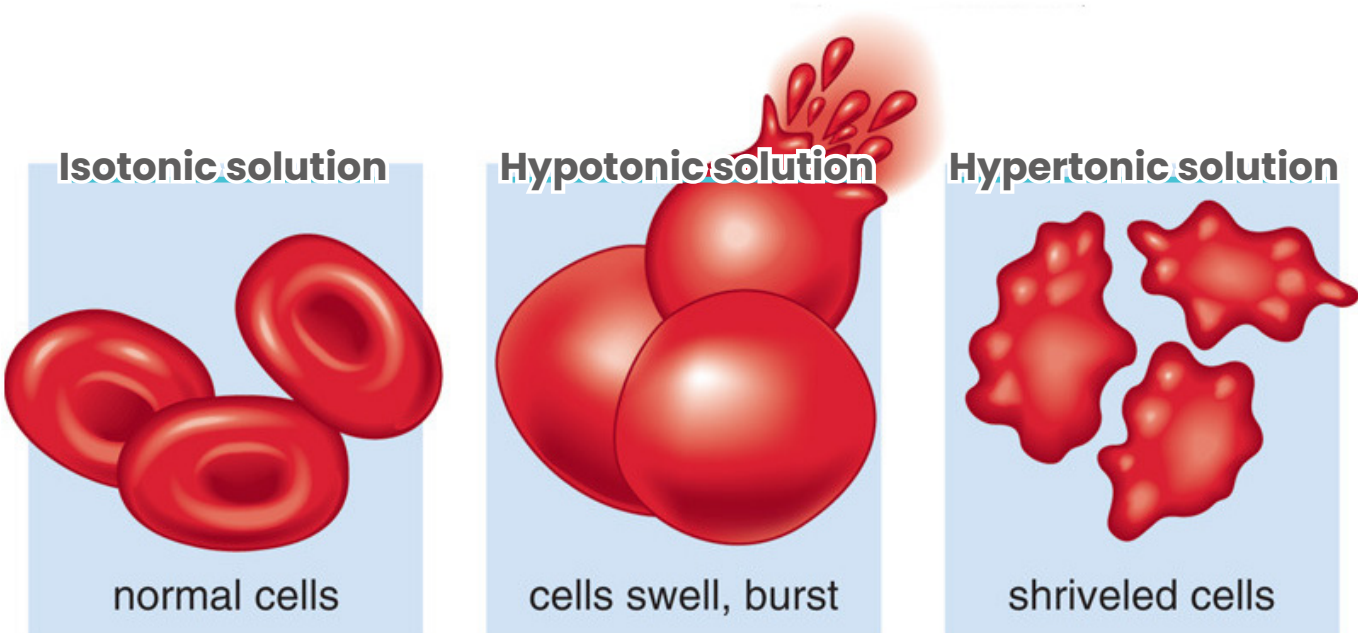
- Hypotonic crystalloids have a **tonicity lower than the body plasma.**
- The administration of a hypotonic crystalloid causes water to shift from the intravascular space to the extravascular space, and eventually **into the tissue cells.**
- Because the IV solution being administered is hypotonic, it creates an environment where the extravascular spaces have higher concentrations of electrolytes.
- The **osmotic change** results in the body moving water from the intravascular space to the cells to dilute the electrolytes.

isotonic

- Isotonic crystalloids have a **tonicity equal to the body plasma.**
- When administered to a normally hydrated patient, isotonic crystalloids do not cause a significant shift of water between the blood vessels and the cells.
- Thus, there is no (or minimal) osmosis occurring.

Hypertonic

- Hypertonic crystalloids have a **tonicity higher than the body plasma.**
- The administration of a hypertonic crystalloid **causes water to shift** from the extravascular spaces into the bloodstream, **increasing the intravascular volume.**
- Thus **osmotic shift occurs** as the body attempts to dilute the higher concentration of electrolytes contained within the IV fluid by moving water into the intravascular space.



Crystalloid Fluids

Fluid	Na^+ mEq/L	Cl^- mEq/L	K^+ mEq/L	Ca^{2+} mEq/L	Glucose g/L	Buffer	Osmolarity mOsm/L	Tonicity	Typical Indication
Normal plasma	~ 140	~ 100	~ 4	~ 2.4	~ 0.85	HCO_3^- ~ 24 mEq/L	~ 290	N/A	N/A
0.9% saline (a.k.a. "normal saline" or NS)	154	154	0	0	0	0	308	"Isotonic"	Resuscitation
0.45% saline (a.k.a. ½ NS)	77	77	0	0	0	0	154	Hypotonic	Maintenance
3% saline	513	513	0	0	0	0	1026	Hypertonic	Severe Hyponatremia
D5 ½NS + 20 meq KCL	77	97	20	0	50	0	446	Hypertonic → Hypotonic	Maintenance
D5W	0	0	0	0	50	0	252	Hypotonic	Hypernatremia Hypoglycemia
Lactated Ringer's (LR) / Hartmann's solution*	130	109	4	3	0	Lactate 28 mEq/L	273	Isotonic	Resuscitation

* Most, but not all, sources imply the terms lactated Ringer's and Hartmann's solutions are interchangeable. Also, there is small variability in the reported electrolyte concentrations between sources.

Indications of intravenous fluid therapy

The indications for fluid administration encompass ***resuscitation***, ***rehydration***, and ***maintenance.***

Resuscitation

Patients needing resuscitation lack hemodynamic stability, and fluids are used to address acute volume loss or an existing intravascular depletion resulting in a deficit.

- If children and young people need IV fluid resuscitation, use glucose-free crystalloids that contain sodium in the range 131-154 mmol/litre, with a bolus of 20 ml/kg over less than 10 minutes.
- Take into account pre-existing conditions (for example, cardiac disease or kidney disease), as smaller fluid volumes may be needed.

Seek expert advice (for example, from the paediatric intensive care team) if 40-60 ml/kg of IV fluid or more is needed as part of the initial fluid resuscitation.

Note

Recent guidelines consider amount of bolus therapy to be 10 to 20 mL/kg and 5 mL/kg if cardiac or renal chronic diseases are present as premorbid condition.

What is Fluid Resuscitation and Who Needs It?

Old paradigm: "Is this patient hypovolemic, euvolemic, or hypervolemic?"

New paradigm: "Is this patient fluid responsive?"

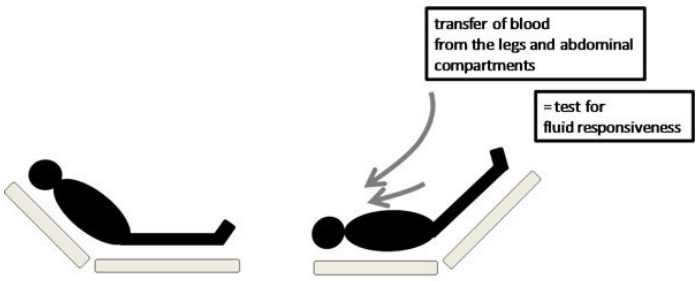
General concept: Fluid responsiveness means that a patient will improve O2 delivery to peripheral tissues after being given fluids

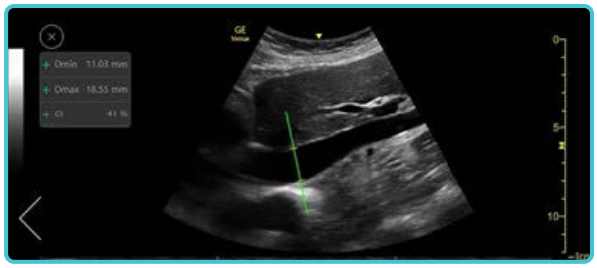
Specific definition: Fluid responsiveness is present when stroke volume (or CO) increases by ≥ 15% after receiving a 500mL bolus of IV fluid.

Dynamic tests of fluid responsiveness

In a spontaneously breathing patient:

- ↑ pulse pressure in response to passive leg raise.
- Collapsibility of IVC with inspiration.





In a fully sedated & mechanically ventilated patient:

- Pulse pressure variation.
- Stroke volume variation.
- Aortic flow velocity.

Evidence that a Patient is Adequately Resuscitated

- MAP ≥ 65 mmHg
- CVP = 8- 12 mmHg
- Urine output ≥ 0.5 mL/kg/hr
- $S_{cv}O_2$ ≥ 70%
- Normalized lactate
- Normalized mental status

Rehydration

Rehydration corrects an ongoing or preexisting deficit that the patient cannot rectify with oral fluids alone.

Assessment of dehydration:

	Dehydration		
Variable/Sign	Mild (4%-5%)	Moderate (6%-9%)	Severe (≥10%)
General appearance	Thirsty, restless, alert	Thirsty, drowsy, postural hypotension	Drowsy, limp, cold, sweaty, cyanotic extremities
Radial pulse	Normal rate and strength	Rapid and weak	Rapid, thready, sometimes impalpable
Respirations	Normal	Deep, may be rapid	Deep and rapid
Anterior fontanelle	Normal	Sunken	Very sunken
Systolic blood pressure	Normal	Normal or low	Low
Skin elasticity	Pinch retracts immediately	Pinch retracts slowly	Pinch retracts very slowly
Eyes	Normal	Sunken	Grossly sunken
Tears	Present	Absent	Absent
Mucous membranes	Moist	Dry	Very dry

*Adapted with permission from Vega and Avner.[4]

Calculation of deficit for rehydration:

% Of dehydration X **Weight (Kg)** = **mL/Kg**

For example: a 10 kg infant with mild dehydration has a deficit of:

5 x 10 = 50 mL/kg = 500 mL total

Maintenance fluids calculation

Patients receiving maintenance fluids are hemodynamically stable and cannot orally meet their daily fluid and electrolyte requirements. Refer to lecture.

The Holliday – Segar 4-2-1 Rule

to estimate Maintenance Hourly Fluid (WATER) Requirements

Weight (kg)	Hourly	Daily
<10 kg	4 mL/kg/hr.	100 mL/kg/day
10 –20 kg	40 mL + 2 mL/kg for every kg >10 kg	1000 mL + 50 mL/kg/day for every kg >10
>20 kg	60 mL + 1 mL/kg for every kg >20 kg	1500 mL + 20 mL/kg/day for every kg > 20

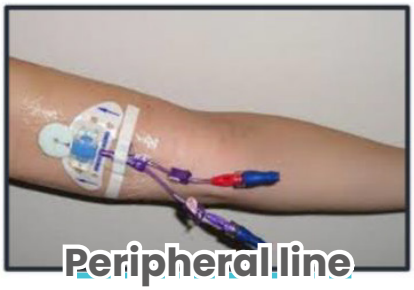
4-2-1 rule EXAMPLES

For a 5 kg infant, Maintenance Hourly Fluid (water) Requirements would be:

4 x 5 = 20ml/hr.

Daily rate: 20 x (24hr) = 480 ml/day

Methods of introduction of IV fluids


Peripheral line


Central line


Intraosseous line

Follow up

- Revise fluid and electrolyte prescription (in ml per hour).
- Revise types and volumes of fluid input and output (urine, gastric ……)
- Measure fluid balance at least every 24 hours, but preferably every 6 hrs.
- Assess vital data including HR, CVP and systolic, diastolic blood pressure.

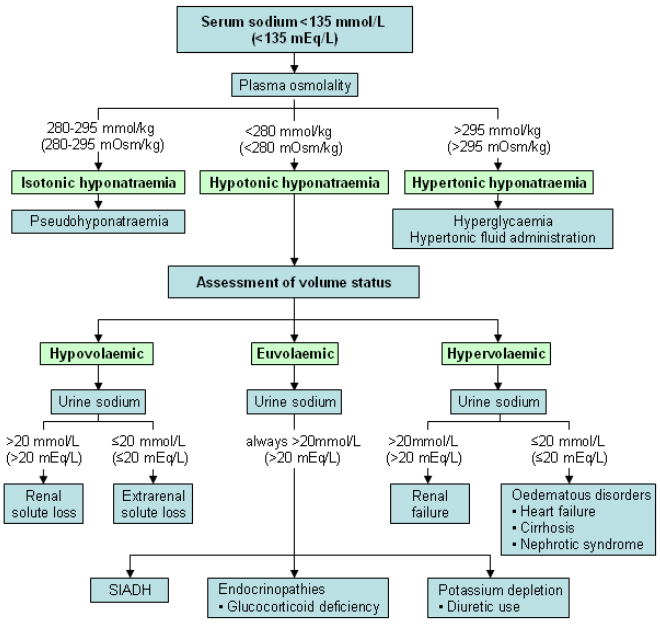
4 ELECTROLYTE DISTURBANCES

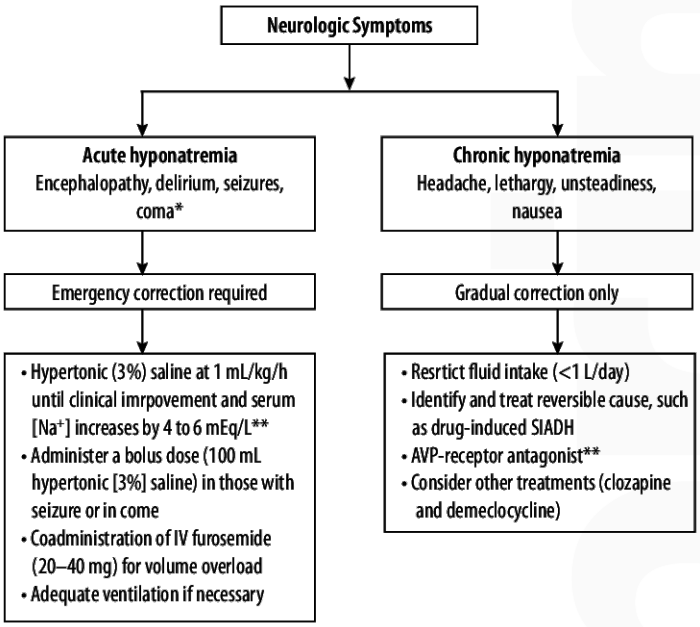
Hyponatremia

Hyponatremia requires regular monitoring of serum sodium levels, with a heightened risk associated with using hypotonic solutions.

- Notably, it is essential to recognize that many hospitalized patients have underlying risks, including elevated antidiuretic hormone (ADH) release, which can result in volume retention and the exacerbation of hyponatremia.
- In patients with inappropriate ADH secretion (SIADH), isotonic fluids are the preferred choice for maintenance fluids.
- The risks associated with hyponatremia encompass the possibility of ***cerebral edema,*** carrying the potential for severe neurological complications, including seizures.

In the event of significant hyponatremia, it is crucial to avoid correcting the serum sodium levels too rapidly, as this could lead to severe neurological complications known as osmotic demyelination syndrome.





Hypernatremia

Hypernatremia can occur due to:

- Administering hypertonic saline or incorrectly formulated hyperalimentation solutions
- Dehydration.

Correction of hyponatremia or hypernatremia should be gradually in a rate of 0.5 meq/ hour increase or decrease.

Table 2. Differential Diagnosis and Treatment of Hypernatremia

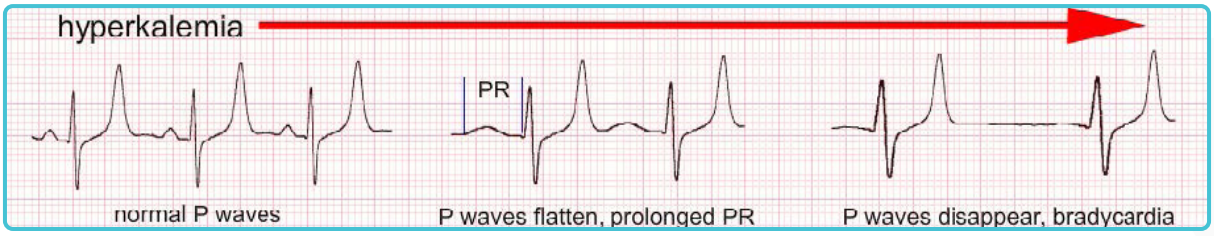
Condition	*Diagnosis*	*Treatment*
Hypovolemic hypernatremia		
Body fluid loss (e.g., burns, sweating)	Clinical	Free water replacement
Diuretic use	Clinical	Stop diuretic
Gastrointestinal loss (e.g., vomiting, diarrhea, fistulas)	Clinical	Free water replacement
Heat injury	Elevated temperature, myoglobinuria, elevated creatinine level	Intravenous fluids, supportive care
Osmotic diuresis (e.g., hyperosmolar nonketotic coma, mannitol use, enteral feeding)	Elevated glucose level; sodium level often elevated after correction	Correct glucose level, stop causative agent
Post-obstruction	Clinical	Supportive care
Hypervolemic hypernatremia		
Cushing syndrome	24-hour urinary cortisol and adrenocorticotropic hormone levels, dexamethasone suppression test	Treat underlying disease
Hemodialysis	Clinical history	Treat underlying disease
Hyperaldosteronism	History of hypertension and hypokalemia, plasma aldosterone-to-renin ratio,[3] history of hypertension and hypokalemia	Treatment usually not needed for hypernatremia
Iatrogenic (e.g., salt tablet or salt water ingestion, saline infusions, saline enemas, intravenous bicarbonate, enteral feedings)	Recent administration of hypertonic saline, enteral feedings, sodium bicarbonate infusion, or hypertonic dialysis	Stop causative medication, rapid free water replacement

Information from references 3, 12, 33, and 34.

Hyperkalemia

- Can be a significant concern for patients with renal failure who receive potassium-containing solutions.
- In such cases, the impaired ability to effectively clear the potassium load may lead to life-threatening cardiac arrhythmias.

Key changes in ECG should be checked in every patient with hyperkalemia.



Treatment of Hyperkalemia

Mild	Moderate
Non-potassium-sparing diuretics: Furosemide 40-80 mg IV Resins: Kayexalate 15-30 grams to 100 mL of 20% Sorbitol either orally or by retention enema	Glucose+Insulin: *50mL D50 + 10 U regular Insulin Over 15-30 minutes Sodium Bicarbonate: 50 mEq IV over 5 minutes Albuterol: 10-20 mg nebulized over 15 minutes

Severe

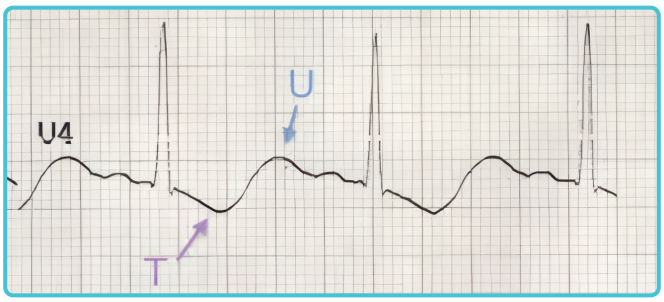
All of the above therapies should be utilized.

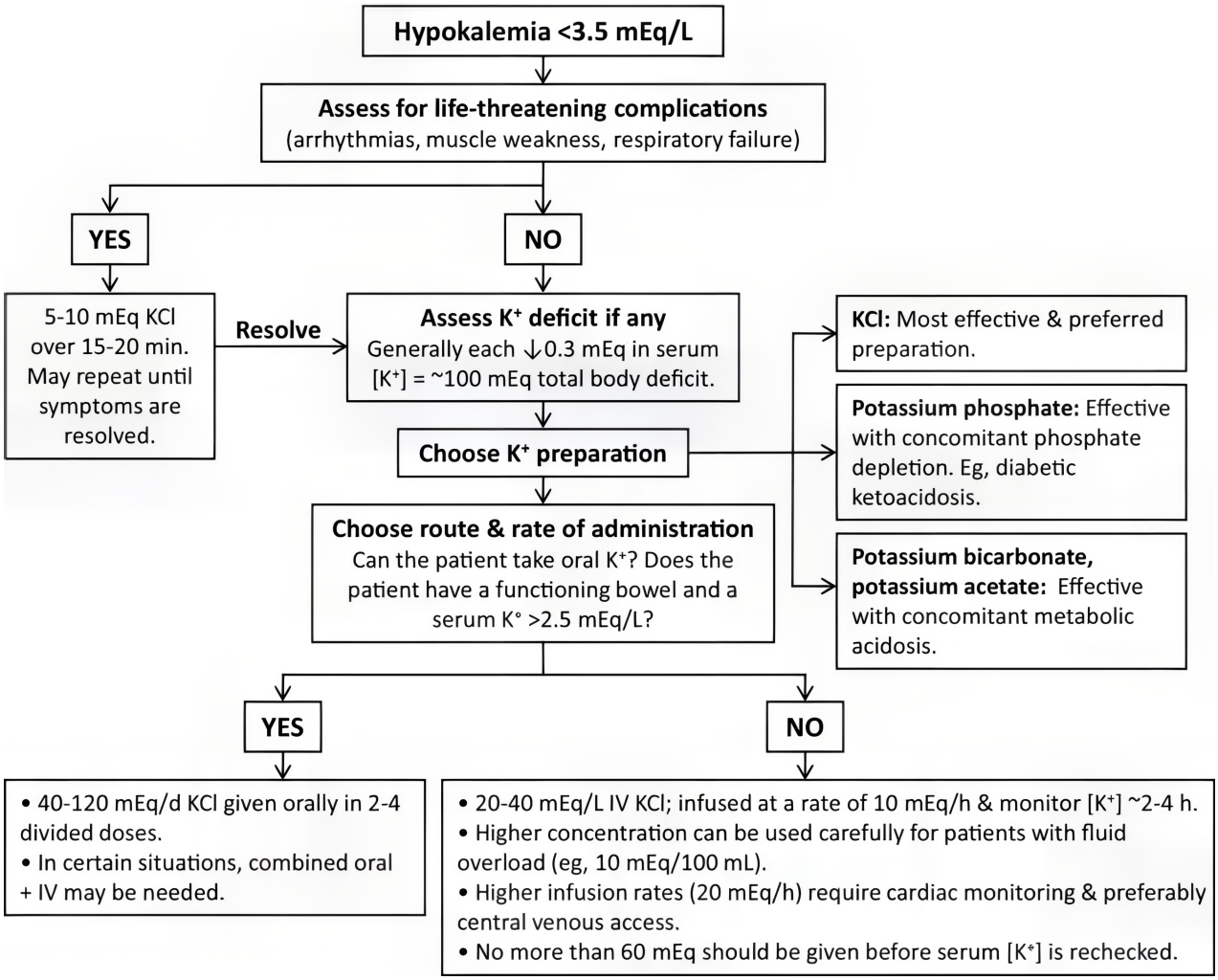
Also: Calcium chloride (10%): 500 to 1000 mg IV over 2-5 minutes to reduce the effects of potassium
This Lowers the risk of ventricular fibrillation

Hypokalemia

- It is a common finding that could complicate diuretic use, gastroenteritis
- Can manifest by feeling of skipped heart beats or palpitations, fatigue, muscle damage, muscle weakness or spasms and tingling or numbness.

ECG changes when hypokalemia occurs.





END.

Questions

1. Failure of the heart to pump effectively causes the following type of shock:

A. Anaphylactic.
B. Cardiogenic.
C. Hypovolemic.
D. Septic.

2. Overwhelming infection and resulting vasodilatation can lead to:

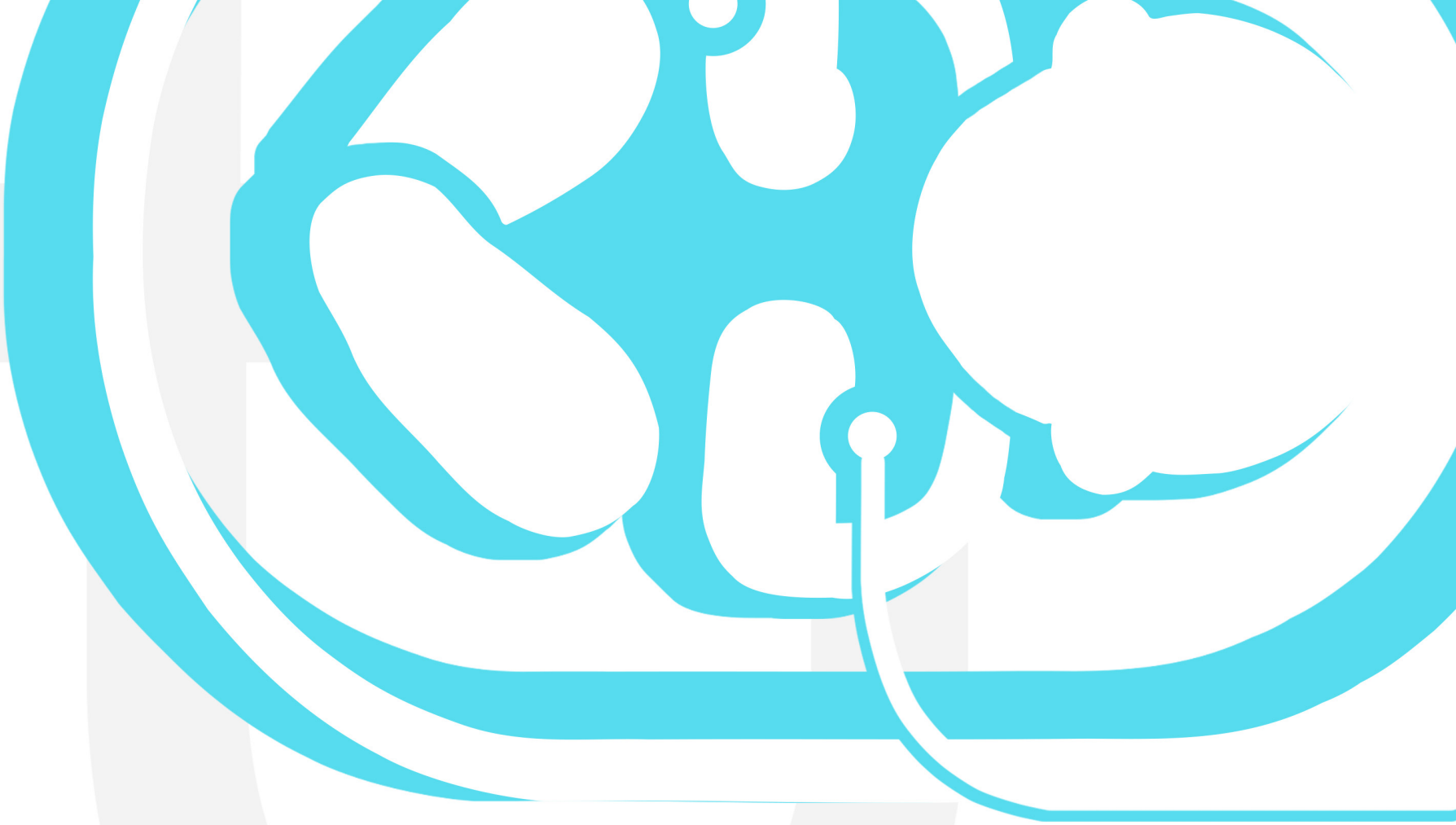
A. Hypovolemic shock.
B. Anaphylactic shock.
C. Septic shock.
D. Cardiogenic shock.

3. What is the preferred treatment for an anaphylactic shock?

A. Epinephrine.
B. Placing the patient in sitting position and administer oxygen.
C. Preventing the reaction from occurring through patient teaching.
D. Placing a bag of ice on the area, administer antihistaminic and corticosteroids.

4. The acid-base disturbance which commonly accompanies shock is:

A. Metabolic acidosis.
B. Metabolic alkalosis.
C. Respiratory acidosis.
D. Respiratory alkalosis.



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