Ministry of Higher Education and Scientific Research

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Anesthesia Techniques Department

Teaching package for Anesthesia techniques

Subject: Intensive Care Unit,

4th stage.

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Intensive Care Management After Neurovascular Surgery

I. Introduction and Overview

The Critical Window

The immediate postoperative period following neurovascular surgery represents a highly vulnerable phase during which rapid clinical deterioration can occur. This 24-72 hour window demands vigilant monitoring and proactive intervention to prevent secondary brain injury and optimize outcomes.

Core Principles:

1. **Brain Protection** - Minimize secondary insults
2. **Early Detection** - Recognize complications before irreversible damage
3. **Physiologic Optimization** - Maintain cerebral homeostasis
4. **Multidisciplinary Coordination** - Seamless neurocritical care team approach

II. Immediate Postoperative Phase (First 24 Hours)

A. Airway and Ventilation Management

Extended Intubation Protocol

Indications for Continued Intubation:

- Glasgow Coma Scale (GCS) ≤ 8
- Significant posterior fossa swelling
- Inadequate airway reflexes (absent gag or cough reflex)
- Anticipated neurological deterioration
- Need for controlled hyperventilation

Ventilation Strategy:

Oxygenation: Maintain PaO_2 > 100 mmHg to ensure adequate cerebral oxygenation.

Ventilation: Maintain normocapnia ($PaCO_2$ 35-40 mmHg) unless hyperventilation is required for acute management of intracranial hypertension.

Positive End-Expiratory Pressure (PEEP): Use ≤10 cm H_2O to avoid impaired cerebral venous return.

Mode: Volume or pressure control ventilation for consistent ventilation during sedation.

Special Considerations:

- **Hyperventilation:** Reserve for acute herniation syndromes (target $PaCO_2$ 30-35 mmHg)
- **Weaning:** Only consider when neurological status has been stable for ≥12 hours

B. Hemodynamic Management

Blood Pressure Targets by Pathology:

After Aneurysm Clipping:

- Systolic blood pressure: 120-140 mmHg
- Mean arterial pressure: 70-90 mmHg
- Special consideration: Avoid hypertension to prevent rebleeding

After Arteriovenous Malformation Resection:

- Systolic blood pressure: 110-130 mmHg
- Mean arterial pressure: 65-85 mmHg
- Special consideration: Prevent normal perfusion pressure breakthrough

Acute Ischemic Stroke:

- Systolic blood pressure: 140-180 mmHg
- Mean arterial pressure: 85-105 mmHg
- Special consideration: Permissive hypertension unless thrombolysis administered

Cerebral Vasospasm:

- Systolic blood pressure: 160-200 mmHg
- Mean arterial pressure: 90-110 mmHg
- Special consideration: Induced hypertension to improve collateral flow

Pathology	SBP Target (mmHg)	MAP Target (mmHg)	Special Considerations
Aneurysm Clipping	120–140	70–90	Avoid hypertension to prevent rebleeding
AVM Resection	110–130	65–85	Prevent normal perfusion pressure breakthrough
Acute Ischemic Stroke	140–180	85–105	Permissive hypertension unless thrombolysis given
Cerebral Vasospasm	160–200	90–110	Induced hypertension to improve collateral flow

Pharmacologic Management of Blood Pressure:

First-Line Agents: β-Adrenergic Blockers

- **Labetalol:** 10-40 mg intravenous every 10-15 minutes as needed, or continuous infusion at 0.5-2 mg/minute
- **Esmolol:** Loading dose 500 μg/kg intravenous over 1 minute, followed by maintenance infusion of 50-200 μg/kg/minute
- **Metoprolol:** 2.5-5 mg intravenous every 5-15 minutes as needed

Second-Line Agents: Vasodilators

- **Nicardipine:** Continuous intravenous infusion starting at 5 mg/hour, titrated to effect (range 5-15 mg/hour)
- **Hydralazine:** 10-20 mg intravenous every 20-30 minutes as needed
- **Enalaprilat:** 0.625-1.25 mg intravenous every 6 hours

For Refractory Hypertension:

- **Sodium nitroprusside:** 0.5-10 μg/kg/minute intravenous infusion
    - Note: Use limited to 24-48 hours maximum due to cyanide toxicity risk
    - Special consideration: May increase intracranial pressure via cerebral vasodilation

Pressor Support for Hypotension or Vasospasm Therapy:

- **Phenylephrine:** Pure α_1-adrenergic agonist
    - Starting dose: 10-20 μg/minute intravenous, titrated to effect (range 10-200 μg/minute)
- **Norepinephrine:** Mixed α- and β-adrenergic agonist
    - Starting dose: 0.05 μg/kg/minute intravenous (typically 2-4 μg/minute)
    - Titration range: 0.05-1 μg/kg/minute

- **Dopamine:** Dose-dependent receptor activity
    - Renal dose: 1-3 μg/kg/minute (dopaminergic)
    - Inotropic dose: 3-10 μg/kg/minute (β_1)
    - Pressor dose: 10-20 μg/kg/minute (α_1)

Class	Agent	Typical Dosing	Notes
β-Blockers	Labetalol	10–40 mg IV q10–15 min or 0.5–2 mg/min infusion	First-line post-aneurysm clipping
	Esmolol	Load: 500 μg/kg IV, then 50–200 μg/kg/min	Useful in cardiac instability
	Metoprolol	2.5–5 mg IV q5–15 min	
Vasodilators	Nicardipine	5–15 mg/hr infusion	Avoid in ICP concerns
	Hydralazine	10–20 mg IV q20–30 min	Avoid with tachycardia
	Enalaprilat	0.625–1.25 mg IV q6h	
Refractory HTN	Nitroprusside	0.5–10 μg/kg/min	Max 24–48h, risk of cyanide toxicity
Vasopressors	Phenylephrine	10–200 μg/min infusion	Preferred in vasospasm
	Norepinephrine	0.05–1 μg/kg/min infusion	Mixed α/β agonist
	Dopamine	1–20 μg/kg/min (dose-dependent)	Renal, inotropic, or pressor based on dose

Clinical Considerations for Agent Selection:

Post-aneurysm clipping: Preferred agents include labetalol and nicardipine. Avoid nitroprusside due to potential to increase intracranial pressure.

Cerebral vasospasm: Preferred agents include phenylephrine and norepinephrine. Use β-blockers with caution if bradycardia present.

Concurrent myocardial ischemia: Preferred agents include esmolol, labetalol, and nitrates. Avoid hydralazine due to risk of reflex tachycardia.

Renal impairment: Preferred agents include nicardipine and fenoldopam. Avoid nitroprusside due to cyanide accumulation risk.

Monitoring Parameters During Therapy:

1. Continuous arterial blood pressure, heart rate, and cardiac rhythm monitoring
2. Neurological examination every 15-30 minutes initially
3. Serum electrolytes and renal function every 4-6 hours

4. For nitroprusside: Acid-base status and thiocyanate levels if prolonged use

C. Neuromonitoring

Tiered Monitoring Protocol:

Tier 1 (All Patients):
- Hourly neurological checks (Glasgow Coma Scale, pupillary response, focal deficits)
- Continuous cardiac telemetry
- Non-invasive blood pressure monitoring every 15 minutes initially

Tier 2 (High-Risk Patients):
- Invasive arterial blood pressure monitoring
- Intracranial pressure monitoring (if Glasgow Coma Scale ≤8 or computed tomography shows significant swelling)
- Central venous access for vasopressor administration or hypervolemic therapy

Tier 3 (Complex Cases):
- Multimodal monitoring including:
  - Brain tissue oxygenation (target >20 mmHg)
  - Cerebral microdialysis
  - Continuous electroencephalography for seizure detection

Tier	Patients	Monitoring Modalities
1	All	Hourly neuro checks (GCS, pupils), cardiac telemetry, non-invasive BP q15min
2	High-risk (GCS ≤8, swelling)	Invasive BP, ICP monitor, central venous access
3	Complex cases	Brain tissue O_2 (>20 mmHg), cerebral microdialysis, continuous EEG

Intracranial Pressure Management Algorithm:

For intracranial pressure > 20-25 mmHg:
- ❖ **Step 1:** Head elevation to 30°, maintain midline head position
- ❖ **Step 2:** Ensure adequate sedation and analgesia
- ❖ **Step 3:** Osmotherapy:
  - Mannitol 0.25-1 g/kg intravenous bolus OR
  - Hypertonic saline (3%) 250 mL intravenous bolus
- ❖ **Step 4:** Cerebrospinal fluid drainage (if ventricular catheter present)

- ❖ **Step 5:** Moderate hyperventilation (target $PaCO_2$ 30-35 mmHg)
- ❖ **Step 6:** Barbiturate coma (pentobarbital) for refractory cases

Step	Intervention	Details
1	Positioning	HOB 30°, midline head
2	Sedation/Analgesia	Ensure adequate comfort
3	Osmotherapy	Mannitol 0.25–1 g/kg IV or 3% HTS 250 mL IV
4	CSF Drainage	If EVD present
5	Hyperventilation	Target $PaCO_2$ 30–35 mmHg
6	Barbiturate Coma	Pentobarbital for refractory ICP

III. Management of Specific Complications

A. Cerebral Vasospasm

Proactive Surveillance Protocol:

Days 3-14 Post-Subarachnoid Hemorrhage:

- Daily transcranial Doppler ultrasonography: mean flow velocity >200 cm/s indicates severe vasospasm
- Hourly neurological examinations: new focal deficit requires immediate computed tomography or computed tomography angiography
- Low threshold for diagnostic cerebral angiography: for angioplasty if medical therapy fails

Medical Management - Triple-H Therapy:

Hypervolemia:

- Target central venous pressure: 8-12 mmHg (or pulmonary artery wedge pressure: 12-15 mmHg)
- Normal saline infusion at 1.5-2 mL/kg/hour
- Additional 5% albumin 250 mL every 6-8 hours if needed

Hypertension:

- Titrate phenylephrine or norepinephrine to systolic blood pressure target
- Monitor for cardiac strain with serial troponin measurements and echocardiography if indicated

Hemodilution:

- Target hematocrit: 30-33%

- Avoid transfusion unless hematocrit <27%

Component	Target / Action	Details
Hypervolemia	CVP 8–12 mmHg / PAWP 12–15 mmHg	NS 1.5–2 mL/kg/hr ± 5% albumin
Hypertension	Induced hypertension to improve perfusion	Phenylephrine or norepinephrine titrated to SBP target
Hemodilution	Hct 30–33%	Avoid transfusion unless Hct <27%

Endovascular Rescue Therapy:
- **Balloon angioplasty:** For proximal vessel vasospasm
- **Intra-arterial verapamil or milrinone:** For distal vasospasm
- **Early intervention consideration:** If two or more vessels with mean flow velocity >180 cm/s

B. Seizure Prophylaxis and Management

Prophylaxis Protocol:

High-Risk Groups (7-day course recommended):
- Cortical involvement (tumor, hemorrhage, stroke)
- Penetrating brain injury
- Prior seizure history

Antiepileptic Agents:
- **Levetiracetam:** 500-1000 mg intravenous every 12 hours (preferred due to fewer drug interactions)
- **Phenytoin:** Loading dose 20 mg/kg followed by maintenance 5 mg/kg/day (requires serum level monitoring)

Monitoring Indications:
- Continuous electroencephalography if:
  - Unexplained depressed consciousness
  - Paroxysmal sympathetic storms
  - Subtle facial or limb twitching

IV. Systemic Complications and Organ Support

A. Neurocardiac Syndrome

Recognition and Management:

Electrocardiogram Findings:
- QT interval prolongation
- ST segment and T wave abnormalities
- U waves (suggestive of hypokalemia)

Biomarker Monitoring:
- Troponin I every 8 hours for three measurements
- Brain natriuretic peptide if heart failure suspected

Echocardiographic Findings:
- Regional wall motion abnormalities (typically apical sparing)
- Reduced ejection fraction (usually reversible)

Management:
- β-blockers (metoprolol) for tachycardia
- Avoid excessive fluid administration if stunned myocardium present
- Inotropes (dobutamine) if cardiogenic shock develops

B. Pulmonary Complications

Prevention Bundle:

Ventilator-Associated Pneumonia Prevention:
- Head of bed elevation ≥30°
- Oral care every 4 hours with chlorhexidine
- Daily sedation holidays
- Peptic ulcer prophylaxis

Neurogenic Pulmonary Edema Management:
- High positive end-expiratory pressure (8-12 cm H_2O)
- Diuretics if hypervolemic
- Lung-protective ventilation (tidal volume 6-8 mL/kg)

Early Tracheostomy Consideration:
- Consider between days 7-10 if Glasgow Coma Scale ≤8 and poor cough or gag reflex present
- Reduces sedation requirements and facilitates ventilator weaning

Component	Target / Intervention
PEEP	≤10 cm H_2O
Oxygenation	PaO_2 >100 mmHg
Ventilation	Normocapnia ($PaCO_2$ 35–40 mmHg)
VAP Prevention	HOB ≥30°, chlorhexidine oral care q4h, daily sedation holiday
Neurogenic Pulmonary Edema	PEEP 8–12 cm H_2O, lung-protective ventilation
Tracheostomy Consideration	Days 7–10 if GCS ≤8, poor cough/gag

C. Thromboembolic Prophylaxis

Staged Approach:

Phase 1 (0-24 hours):
- Sequential compression devices
- Early mobilization (passive range of motion)

Phase 2 (24-48 hours):
- Add chemoprophylaxis if:
  - No active bleeding
  - Stable postoperative imaging
  - Platelet count >100,000/μL
- Options include:
  - Enoxaparin 40 mg subcutaneous daily OR
  - Heparin 5000 units subcutaneous every 8-12 hours

Phase 3 (>48 hours with deep venous thrombosis):
- Inferior vena cava filter if anticoagulation contraindicated
- Therapeutic anticoagulation once bleeding risk acceptable

V. Special Clinical Scenarios

A. Post-Craniotomy for Aneurysm

Critical First 24 Hours:
- Blood pressure control: systolic blood pressure 120-140 mmHg to prevent rebleeding
- Seizure prophylaxis: levetiracetam or phenytoin
- Vasospasm prevention: nimodipine 60 mg every 4 hours orally or via nasogastric tube

- Monitoring for: acute hydrocephalus (may require external ventricular drainage)

Delayed Complications (Days 3-21):

- Vasospasm: daily transcranial Doppler ultrasonography and aggressive triple-H therapy
- Hydrocephalus: approximately 20% may require shunt placement
- Hyponatremia: differentiate between syndrome of inappropriate antidiuretic hormone secretion and cerebral salt wasting

B. Post-Interventional Neuroradiology Procedures

Post-Coiling or Stenting Protocol:

- Access site monitoring: check groin site every 15 minutes for 1 hour, then every hour for 4 hours
- Antiplatelet therapy:
  - Clopidogrel 75 mg daily (if stent placed)
  - Aspirin 81-325 mg daily
- Monitor for: retroperitoneal hematoma and contrast-induced nephropathy

C. Decompressive Hemicraniectomy Patients

Special Considerations:

- Bulging bone flap: normal unless tense or progressively increasing
- Intracranial pressure monitoring: parenchymal monitor preferred
- Positioning: avoid pressure on the bone flap
- Weaning: may tolerate higher intracranial pressures (up to 25 mmHg)

VI. Nursing and Multidisciplinary Care

Comprehensive Neurological Assessment:

Components of Hourly Neuro Checks:

- **Alertness:** assessment of arousal and attention
- **Breathing pattern:** identification of Cheyne-Stokes or ataxic breathing
- **Cranial nerves:** pupillary response, eye movements, facial symmetry
- **Drift:** pronator drift, leg hold assessment
- **Extremities:** tone, spontaneous movement, posturing
- **Fluids:** intake and output, sodium trend
- **Glucose:** maintain 80-180 mg/dL
- **Head:** incision assessment, drain output, intracranial pressure

Care Bundles for Optimal Outcomes:

Brain Protection Bundle:
- Normothermia (36-37.5°C)
- Normoglycemia
- Normotension
- Normoxia

Sedation Management Bundle:
- Daily sedation vacation
- Pain assessment every 2 hours
- Delirium screening using Confusion Assessment Method for the Intensive Care Unit

Early Mobility Bundle:
- Passive range of motion every 8 hours
- Chair out of bed when hemodynamically stable
- Early physical and occupational therapy consultation

VII. Transition Planning and De-Escalation of Care

Intensive Care Unit Discharge Criteria:
- Neurologically stable for ≥24 hours
- Intracranial pressure normal without therapy for ≥24 hours
- No vasopressor requirements
- Airway protective reflexes intact
- Seizure-free (or well-controlled on medications)
- No active intracranial complication on imaging

Step-Down Unit Planning:
- **Education:** preparation of family and social work support
- **Medication reconciliation:** particularly antiepileptic medications
- **Follow-up arrangements:** outpatient neurosurgery and neurology appointments
- **Rehabilitation planning:** early involvement of physical therapy, occupational therapy, and speech-language pathology

Neurosurgery

The effects of MV on brain homeostasis are the result of a complex interaction between cerebral circulation, the characteristics of the patient, and type of surgery: cerebral perfusion pressure (CPP) is the result of the difference between mean arterial pressure and intracranial pressure (ICP); the former, according to the Monro-Kellie theory, is the sum of cerebral blood flow (CBF), brain parenchyma and cerebrospinal fluid (CSF). During MV, changes in ICP are mainly due to the variation in CBF as follows:

• PaCO2 levels inversely change CBF: if the patient becomes hypercapnic, a vasodilatory input will be delivered to cerebral vessels, while in case of hypocapnia there will be cerebral vasoconstriction, making a direct CO2 monitoring such as End-tidal CO2 a cornerstone of the ventilatory management of such patients.

• Hypoxemia and respiratory failure are also strong triggers for cerebral vasodilation, especially when the PaO2 is below 60 mmHg.

• An increased PEEP may worsen the venous return through the jugular veins, potentially causing cerebral venous congestion, especially in patients in supine position without head-tilt.

Current Evidence

It is a common clinical opinion that a low *VT* and high PEEP could be ssociated both with higher PaCO2 and higher ICP and that a RM could worsen CPP by reducing the CBF, making the OLA approach a rarely-used strategy in this subtype of patients, although in neurocritical patients a higher PEEP does not seem to affect CPP if fixed as high as 15 cmH2O. On the other hand, in neurosurgical patients, oxygenation and PaO2/FiO2 ratio were strong predictors of worse prognosis and death.

Moreover, despite a RM by continuous CPAP at 35 cmH2O significantly increases subdural pressure and decreases CPP, a study by Nemer et al. showed that a stepwise RM lowered CPP in a safe and reversible way compared to the classical CPAP RM, besides improving oxygenation in patients with subarachnoid hemorrhage, in alignment with the results of OLA in patients with traumatic brain injury and ARDS.

Finally, when compared with a conventional protective MV, it seems that a low *VT* of 6 ml/kg IBW plus RM every 30 min could reduce postoperative delirium (and lower the levels of glial fibrillary acidic protein, an emerging biomarker of brain injury in elderly patients undergoing spinal surgery).

"In neurocritical care, we don't just support organs - we protect the essence of personhood. Every intervention, every decision, every moment matters."

Airway Management Of Pediatric

Introduction

Establishing and maintaining airway patency is crucial to the care of infants and children. It is essential to recognize not only the signs of airway compromise but also the need to secure an airway in those with respiratory distress and/or pending respiratory failure. Clinicians need to be familiar with the indications, proper uses, and limitations of airway management equipment to minimize the propensity for harm during care.

Upper Airway Devices

Upper airway obstruction describes partial or complete obstruction of gas flow through the oro- or nasopharyngeal airway, past the base of the tongue. It impedes spontaneous ventilation or effective bag-mask ventilation. It is most commonly encountered among patients with obesity, those with a decreased level of consciousness due to relaxation of airway musculature, or those with certain anatomic findings, such as a small mandible or large tongue.

Upper airway devices do not provide lower airway protection. Rather, they are designed to relieve upper airway obstruction (i.e., oro- or nasopharyngeal airways) or to provide a conduit to the lower airway (supraglottic airway devices, laryngeal mask airway) and a temporary means to provide assisted ventilation.

Oropharyngeal Airways

An oropharyngeal airway is a rigid, c-shaped device that is inserted through the mouth to provide a clear passage of airflow past the obstruction of the tongue and upper airway tissue to the level of the supraglottic area. Some styles of oropharyngeal airways have a hollow center, allowing for suctioning of the airway and the passage of airflow through the lumen of the device (Figure 22-1).

An oropharyngeal airway is indicated when spontaneous ventilation is partially or fully obstructed or mask ventilation is inadequate despite optimal facemask position, mask fit, and mask seal. When correctly positioned, the oropharyngeal airway displaces the tongue forward, away from the palate and the posterior wall of the pharynx. The distal portion rests just above the larynx. Oropharyngeal airways are manufactured in several different sizes, and choosing the correct size is imperative because an airway that is either too short or too long could exacerbate airway obstruction. The correct size for an oropharyngeal airway can be determined by measuring the device against the patient's face. The appropriately sized oropharyngeal airway should extend from the level of the patient's teeth (or alveolar ridge) to the angle of the mandible (Figure 22-2).

FIGURE 22-1 The Guedel airway has a hollow center that allows air to flow through and provides a path to facilitate suctioning.
Courtesy of Intersurgical Ltd/Wikimedia Commons.

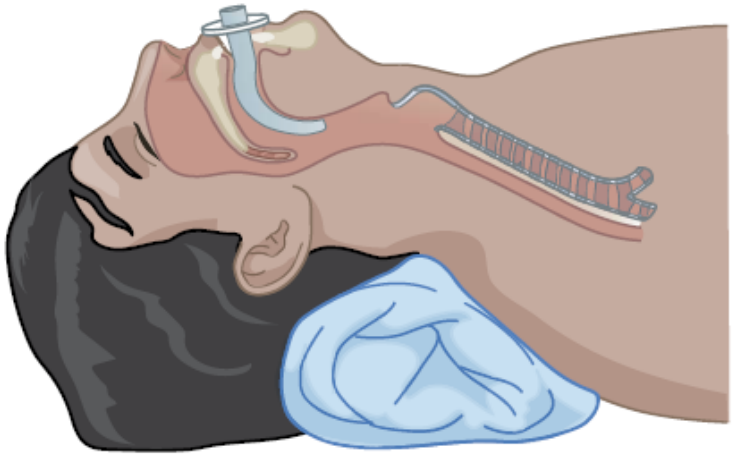


FIGURE 22-2 An illustration of a properly placed oral airway, which extends from the patient's teeth to the angle of the mandible.

An oropharyngeal airway is inserted through the mouth. The use of a tongue depressor can facilitate insertion. The clinician holds the mouth open with the nondominant hand. If a tongue depressor is used, it is held by the dominant hand to depress the tongue. The nondominant hand holds the airway with the concavity facing rostrally and inserts it into the mouth. Once the distal end of the airway passes the upper teeth, the device is rotated 180 degrees and simultaneously advanced along the surface of the tongue. The clinician should be careful not to abrade the palate or other oropharyngeal structures during insertion. Spontaneous ventilation should immediately improve with proper positioning of the oral airway. Should the patient require ventilatory assistance, mask ventilation can again be implemented or resumed and air movement evaluated. The device does not need to be secured and can remain in place until either the patient's breathing improves or a more definitive airway, such as an endotracheal tube, is inserted.

To remove the oropharyngeal airway, gently pull in a slightly caudal direction to allow the oropharyngeal airway to follow the natural course of the patient's airway.

Oropharyngeal airways are useful adjuncts to mask ventilation in the case of upper airway obstruction or in the sedated patient breathing spontaneously. However, they are not well tolerated in awake patients and can induce coughing, gagging, and choking. Their use should be reserved for deeply sedated or anesthetized patients.

Nasopharyngeal Airways

The nasopharyngeal airway is a device designed to maintain or improve upper airway patency by creating a conduit from the tip of the nose to the hypopharynx. This device often bypasses an upper airway obstruction. Unlike the oropharyngeal airway, the nasopharyngeal airway is a soft, flexible tube. The proximal end of the device, or flange, is flared to prevent it from advancing in the nasopharynx, and some nasopharyngeal airways are adjustable to ideally position the length of the airway (Figure 22-3). When properly placed, the distal aperture should rest just superior to the epiglottis (Figure 22-4). The nasopharyngeal airway is better tolerated than the oropharyngeal airway and can be used in either awake or asleep patients.

FIGURE 22-3 An adjustable nasopharyngeal airway. The circle portion just below the flange can be moved along the body of the airway to adjust its length.

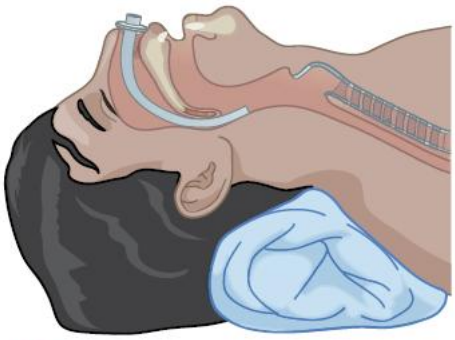


FIGURE 22-4 In a properly inserted nasopharyngeal airway, the flange rests at the nares and the distal end rests superior to the epiglottis.

The nasopharyngeal airway is indicated to treat upper airway obstruction, either in an awake patient exhibiting signs of respiratory distress or in an unconscious patient to facilitate effective mask ventilation. A spectrum of different sizes is available. The correct size should extend from the naris to the meatus of the ear. Typically the nasopharyngeal airway will be 2 to 4 cm longer than the appropriate oropharyngeal airway in a given patient.

Lubricate the nasopharyngeal airway prior to insertion to allow smooth passage through the nasopharynx. A vasoconstrictor, such as oxymetazoline, can be sprayed into the nose to reduce the risk of epistaxis. Initial insertion should be aimed directly posterior along the floor of the nasal passage. Attempting to insert the nasopharyngeal airway in a superior direction should be avoided because this could cause injury to the nasal turbinates. The device is smoothly advanced until

the flange rests against the naris. If resistance is encountered, attempt to turn the device while applying gentle pressure, and if resistance continues, the nasopharyngeal airway should be removed and insertion attempted in the opposite naris, as exerting force could produce a nose bleed. Securing the nasopharyngeal airway is rarely necessary, but in the presence of a tenuous airway, such as postsurgery or with facial trauma, the device may be secured in place with sutures or tape.

Typically, a nasopharyngeal airway is much better tolerated compared to the oropharyngeal airway. Although oropharyngeal airway use is essentially limited to the unconscious patient with absent airway reflexes, the nasopharyngeal airway is often well tolerated in awake patients.

Although nasopharyngeal airways are an excellent adjunct for effective ventilation, they are not suitable in all patients. Due to the risk of epistaxis, nasopharyngeal airways should be avoided in patients with impaired coagulation from either pharmacologic anticoagulation or a pathologic bleeding disorder. Nasopharyngeal airways are contraindicated in head trauma or facial trauma because, if the facial bones or basilar skull are compromised (broken), there is a potentially fatal risk of passing the nasopharyngeal airway through the cribiform plate into the brain.

Supraglottic Airway Devices

A supraglottic airway (SGA) provides an unobstructed airway from the mouth to the supraglottic area and a 15-mm connector to provide positive pressure ventilation. There are a number of different SGAs available for use.

Laryngeal Mask Airway

One of the first to be developed, the mostly widely used SGA is the laryngeal mask airway (LMA) developed by Dr. Archie Brain in 1981. The LMA was originally designed as an alternative to facemask ventilation for delivering anesthesia when endotracheal intubation was impossible. Currently, there are many different types of SGAs, and their clinical application has broadened to include a role in anesthesia, resuscitation, and intensive care.

The original LMA developed is a reusable silicone device that can be autoclaved and reused up to 40 times, and it is still commercially available. Several manufacturers produce disposable versions that are typically made of polyvinyl chloride. The LMA is a small, elliptically shaped mask designed to fit in the hypopharynx and to provide a conduit that bypasses the upper airway and allows positive pressure ventilation. The rim of the mask is an inflatable cuff, which is connected to a pilot tube and balloon through which the cuff is inflated and

intracuff pressure can be monitored (Figure 22-5). There is an anterior aperture that, when correctly positioned, will overlie the laryngeal inlet. On the posterior surface of the mask, a ventilating tube extends from the central aperture to the mouth, with a standard 15-mm adapter allowing connection to a breathing circuit. Properly positioned, the distal aperture opens to the laryngeal inlet, and the tip of the cuff rests in the proximal esophagus posterior to the cricoid cartilage (Figure 22-6). Upon inflation of the cuff, a seal is created within the hypopharynx, allowing for positive pressure ventilation.

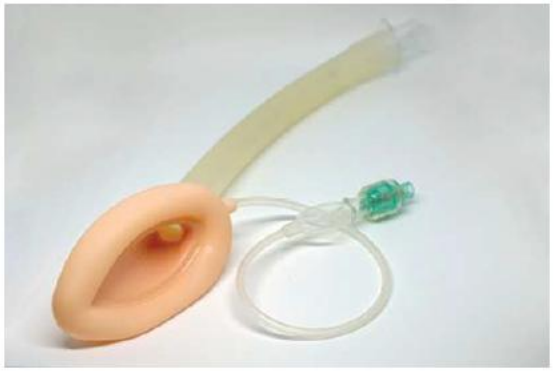


FIGURE 22-5 A laryngeal mask airway is available in a variety of sizes to facilitate insertion in very small or larger children.

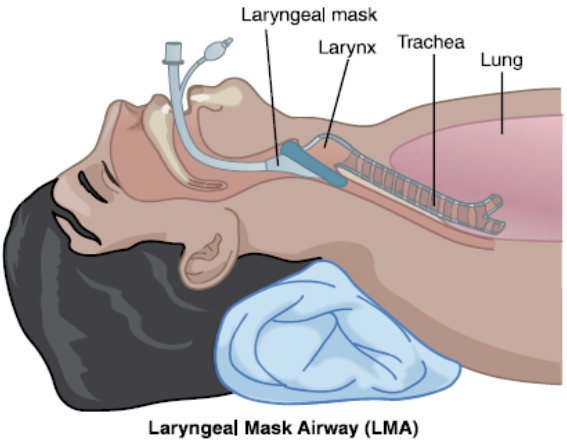


FIGURE 22-6 An illustration of a laryngeal mask airway properly positioned in the airway.

The LMA is available in sizes ranging from infant to adult, and correct size is usually determined by the patient's weight. The manufacturer recommends choosing the largest size that fits in the oral cavity, then inflating the cuff to the minimum pressure that will allow ventilation using up to 20 cmH2O of pressure to the airway without significant air leak.

Prior to insertion of the LMA, the patient is placed in the sniffing position. The cuff of the LMA is fully deflated, ensuring that the posterior surface of the mask is smooth and wrinkle-free (although some recommend having a slight amount of air in the cuff). The tip of the LMA should be deflected backward, away from the aperture, encouraging the LMA to slide posterior to the epiglottis without pushing it over the glottis opening. The posterior (pharyngeal) surface should be lubricated to facilitate smooth insertion. Using the nondominant hand at the patient's occiput to extend the head, the LMA is held in the dominant hand like a pencil, with the index finger at the junction of the mask and barrel. The LMA is inserted into the mouth and advanced against the hard palate toward the larynx until resistance is felt. The hand is then removed and the cuff inflated to an intracuff pressure of less than 60 cmH2O The LMA can be secured with tape.

Laryngeal masks and other SGAs are poorly tolerated in awake or lightly anesthetized patients. Insertion in a patient who has an intact gag reflex can result in coughing, laryngospasm, gagging, and emesis. Contraction of the pharyngeal and laryngeal musculature prevents optimal positioning of the LMA. The LMA

partially protects the airway from pharyngeal secretions but does not protect the patient from aspiration of gastric contents. The cuff need not be deflated prior to removal, as the inflated cuff may aid in extraction of oropharyngeal secretions.

After becoming commercially available in the United Kingdom in 1988 and the United States in 1991, the LMA gained wide acceptance for its role in anesthesia practice and airway management. Over the first 3 years of clinical availability, the LMA replaced the endotracheal tube (ETT) as the airway management technique in >40% of routine general anesthesia. With widespread use, numerous other SGAs were introduced, with design modifications aimed to provide more dependable positive pressure ventilation. Design modifications included disposability to minimize the potential for cross-contamination, an integrated bite block, and features to reduce the risk of pulmonary aspiration of gastric contents. Several SGAs were invented that had the ability to accommodate decompression of the stomach by passing a suction or nasogastric tube. Modifications were made to facilitate intubation through the lumen of some SGAs.

There are several advantages to using an LMA compared to endotracheal intubation. Insertion of an LMA is simple and easy to learn and has a high success rate, even among inexperienced operators. Insertion is typically faster and does not require a laryngoscope. Insertion is also accomplished with a lighter level of anesthesia, and no muscle relaxation is necessary. There are fewer changes in hemodynamics or intracranial and intraocular pressure compared to tracheal intubation and extubation. There is decreased laryngeal trauma associated with LMA use versus tracheal intubation. When used for administration of general anesthesia, there is a lower incidence of postoperative sore throat when using the LMA. Compared to facemask ventilation, the LMA is easier to learn and use and provides a better seal in bearded patients or those with abnormal facial anatomy. The LMA protects the airway from secretions and may reduce the risk of facial nerve injury and eye trauma.

Esophageal-Tracheal Combitube

The Esophageal-Tracheal Combitube (Covidien-Nellcor, Boulder, CO) is another laryngeal airway that has proven especially useful in the prehospital setting or other emergency situations because it is inserted blindly and ventilation can be established whether the device enters the trachea or the esophagus. Unfortunately, the Combitube can only be used in the adult population, as no pediatric sizes are available.

King Laryngeal Tube

The Laryngeal Tube (LT; King Systems, Noblesville, IN) is an SGA that is easy to insert and designed to minimize airway trauma. There are several variations of the design in the LT family, and all are composed of a slightly curved tube with a larger proximal pharyngeal cuff and a smaller distal esophageal cuff (Figure 22-7). Both are low-pressure, high-volume cuffs served by a common inflation line, designed to equalize pressures between the two cuffs. A ventilating lumen exists between the two cuffs to allow air movement through the larynx. It is available in both disposable and reusable models, and modifications exist to allow suction through the distal tip and a ventilating lumen that will accept a flexible bronchoscope or tube exchanger for tracheal intubation. It is available in pediatric sizes for children as small as 12 kg and 35 inches tall.

FIGURE 22-7 An example of a laryngeal tube (King LTS).
Courtesy of King Systems.

Both cuffs are deflated and lubricated prior to insertion. With the head in neutral or sniffing position, the LT is inserted in the midline of the mouth. It is advanced along the hard palate in a caudal direction until resistance is felt. The cuffs are inflated to a pressure no greater than 60 cmH2O . Position is confirmed by auscultating breath sounds and detecting CO2 on capnometry.

Clinical Application/Indications of Laryngeal Airways

Although the LMA was originally designed for administration of anesthesia, the use of laryngeal airways has expanded to play an important role in many avenues of airway management. The most critical new role for SGAs is to rescue the airway when traditional attempts to oxygenate or ventilate the patient fail. In the American Society of Anesthesiologists' Difficult Airway Algorithm, the LMA is recommended for patients in whom initial intubation attempts fail and facemask ventilation is inadequate. In an observational study, the LMA provided rescue ventilation in 94% of patients in whom tracheal intubation and mask ventilation were impossible. In the pediatric population, the LMA has been shown to prevent significant desaturation in patients with difficult airways.

SGAs also serve as an aide to tracheal intubation. This technique is particularly useful in patients with a known difficult airway or those who have had a rescue

laryngeal airway placed for emergency ventilation and oxygenation. A key advantage is the ability to continue ventilation through the device during the intubation. Several different modifications were made to early SGAs to provide a conduit for either blind or fiberoptic intubation. In the perfectly positioned LMA, where the ventilating aperture lies against the glottis line, blind tracheal intubation is possible. However, in children it is common to have the epiglottis fold inside the mask of the LMA yet not produce airway obstruction. Therefore, in children we recommend inserting a fiberoptic bronchoscope through the LMA where a complete view of the glottis is possible in the majority of patients, making fiberoptic-guided techniques for intubation a safer option than blind intubation techniques.

Airway management of children is a significant challenge in the emergency prehospital setting. Often, personnel lack advanced airway management expertise, some standard supplies are not available, and physical conditions are suboptimal. Optimal patient preparation is impossible. Although tracheal intubation is the gold standard for securing the airway, it is often difficult and occasionally impossible in the prehospital setting. Because of their ease of insertion and ability to provide reliable ventilation better than bag-mask ventilation, SGAs have come to play a prominent role in prehospital airway management. They can also be inserted without mobilization of the cervical spine, which is advantageous in trauma patients. Tracheal intubation is also a challenge during a cardiopulmonary resuscitation and often requires cessation of chest compressions. There is a high incidence of failed intubations, unrecognized esophageal intubation, and unrecognized dislodgement of the tracheal tube. For these reasons, the use of an SGA device has been recognized as an acceptable method of airway management during cardiopulmonary resuscitation.

Complications

Although they have proven to be a safe and effective adjunct to airway management, a significant failure rate exists with the use of SGAs. The majority of devices report a failure rate of 0% to 5% . Ventilatory failure most likely results from a malpositioned device, which can partially or completely obstruct the airway. This may be exacerbated by an improperly sized device. Torque from the ventilator circuit can induce mechanical kinking or twisting of the ventilation shaft and compromised ventilation, especially in smaller devices for pediatric patients.

Pulmonary aspiration of gastric contents remains a rare but potential risk associated with SGA use. The incidence of pulmonary aspiration with LMA use is between 0.85 and 2/10,000 patients. There is no increased risk of aspiration with positive pressure ventilation through an LMA compared to an ETT. Most correctly positioned laryngeal airway devices have a high esophageal seal

pressure (>50 - 60 cmH2O) , inhibiting esophageal insufflation, but the LMA is associated with a reduced lower esophageal sphincter tone compared to facemask ventilation. Newer designs of SGAs have aimed to reduce the risk of pulmonary aspiration, incorporating gastric vents to decompress the stomach. Factors that likely increase the risk of aspiration include improper positioning of the device and excessive peak airway pressures. Cadaver studies have demonstrated esophageal insufflation with airway pressures >20 cmH2O through various SGA devices, including those with modifications to reduce the risk of aspiration.23 For this reason, airway pressures should be maintained at < 20 cmH2O whenever possible. Despite these findings, the use of an SGA should still be considered in an emergency situation, even for patients at increased risk for aspiration.

Airway injury can occur with SGA use, most likely related to improper positioning of the device or excessive cuff pressure. Postoperative sore throat is common after SGA use, and tongue congestion or edema can occur if the SGA is improperly positioned or holds high intracuff pressure. Avulsion of the frenulum of the tongue can occur if the tongue is caught by the mask during insertion. If intracuff pressure exceeds the pressure of the pharyngeal mucosa, local tissue necrosis and resulting edema can occur. Compression injuries to pharyngeal nerves have been reported, including the lingual, hypoglossal, and recurrent laryngeal nerves. In order to minimize the risk of airway injury, cuffs should be inflated to a pressure no greater than 60 cmH2O . Package inserts of some devices recommend a maximum volume of air to be inflated as well. Use of a manometer attached to the pilot balloon can confirm an appropriate cuff pressure.

Contraindications

The routine use of SGAs should be avoided in patients who have an increased risk of pulmonary aspiration, such as those with active gastroesophageal reflux, intestinal obstruction, hiatal hernia, pregnancy, recent trauma, or intoxication. Because peak airway pressures are limited when ventilating through an SGA, they are best avoided in patients with low pulmonary compliance. SGAs should not be used in the presence of pharyngeal pathology, such as pharyngeal abscess or obstruction. In an emergency situation, however, providing oxygenation and ventilation is of utmost importance and the use of an SGA should be considered, even in the presence of these risk factors.

Limitations

Although they play a prominent role in airway management, SGAs are not considered a definitive airway and should be exchanged for a tracheal tube in patients who have continued need for ventilatory support. They may not provide adequate ventilation in patients with lung pathology requiring high inspiratory

pressures. There also exists a low but identified risk for pulmonary aspiration of gastric contents.

Pediatric Airway Management in Trauma & Emergency Settings

Introduction to Trauma-Specific Considerations
The principles of pediatric airway management are critically applied in trauma and emergency scenarios, where anatomical vulnerabilities are exacerbated by injury, and rapid, correct action is essential to prevent hypoxia and secondary brain injury. This section outlines the specific adaptations and priorities for managing the compromised airway in an injured child.

1. Anatomical Vulnerabilities: Why Children are High-Risk in Trauma

- **Narrower Airways:** Even minimal edema, blood, or external compression can cause critical obstruction. Resistance increases exponentially with small decreases in radius.
- **Larger Tongue & Adenoids:** Increase propensity for obstruction and complicate laryngoscopy.
- **Softer Tissues:** More susceptible to iatrogenic injury from aggressive or repeated intubation attempts.
- **Higher (More Anterior) Larynx:** Alters the axis for visualization, often requiring a straight laryngoscope blade.
- **Shorter Trachea:** High risk of endobronchial (typically right mainstem) intubation. **A post-intubation chest X-ray is mandatory to verify tube position.**
- **Higher Metabolic Rate & Reduced Functional Residual Capacity (FRC):** Leads to **rapid oxygen desaturation** during periods of apnea (e.g., during intubation attempts).

2. Primary Assessment & Immediate Maneuvers

A. Initial Action – The Jaw Thrust

- **In any trauma patient with a potential spinal injury, use a JAW THRUST exclusively. Do NOT use head tilt-chin lift.**
- **Technique:** Place fingers behind the angles of the mandible and displace the jaw anteriorly (towards the tip of the nose).

B. Sequence for Persistent Obstruction
If obstruction persists after jaw thrust:

1. Re-optimize head position and reapply jaw thrust.
2. **Perform a rapid oropharyngeal examination** using a laryngoscope.
3. **Remove any visible foreign body** using Magill forceps or Yankauer suction.
4. If the airway is only patent during laryngoscopy, insert an **oropharyngeal airway (OPA)** as a temporizing measure.

3. Assessment of the Trauma Airway

A. Signs of Obstruction (As detailed in general assessment, with emphasis on):

- **Stridor** (suggesting extrathoracic, laryngeal obstruction).
- **Hoarseness** (indicative of laryngeal injury).
- **Gurgling** (signifying fluid/foreign material in the oropharynx).
- **Subcutaneous Emphysema** in the neck (indicating aerodigestive tract injury).

B. The "TW" Examination of the Anterior Neck (A Trauma Mnemonic):

- **T** – **Tracheal Deviation:** A late sign of tension pneumothorax or massive hemothorax.
- **W** – **Wounds:** Assess for penetrating or blunt injury to the neck that may directly damage the airway or cause expanding hematoma.
- **E** – **Emphysema (Subcutaneous):** Palpable crepitus indicating air tracking from a pneumothorax or airway injury.
- **V** – **Venous Distension:** Jugular venous distension (JVD) may signal obstructive shock (tension pneumothorax, cardiac tamponade).

4. Adjuncts & Intubation in Trauma

A. Oropharyngeal Airway (OPA) – Critical Technique Alert

- **Sizing:** The flange should rest at the lips, and the tip should reach the angle of the mandible.
- **Insertion in Children < 8 Years:**
    - **DO NOT use the 180-degree rotation technique** common in adults, as this can lacerate the soft palate.
    - Insert directly using a tongue depressor to flatten the tongue.

- **Use: Only in unconscious patients without a gag reflex.**

B. Preparation for Rapid Sequence Intubation (RSI)
A structured approach is vital for success and safety.

- **Pre-Oxygenation:**
  - Use a T-piece resuscitator with high-flow oxygen (>15 L/min).
  - Provide positive pressure breaths with Positive End-Expiratory Pressure (PEEP) if possible.
  - Decompress the stomach with a small-bore orogastric/nasogastric tube.
- **Equipment Check ("Two are one, one is none"):**
  - **Laryngoscopes:** Have two functional handles and appropriately sized blades (straight/Miller for infants) ready.
  - Suction: A Yankauer suction must be turned on, functional, and within immediate reach.
- **Pharmacological Preparation (Drugs drawn up & labeled):**
  - **Induction/Sedative: Ketamine** (1-2 mg/kg IV). *Use the lower end of the dose range (1 mg/kg) in patients with hemodynamic instability or hypovolemic shock.*
  - **Neuromuscular Blocker: Rocuronium** (1.2-1.6 mg/kg IV) for optimal intubating conditions.
  - **Access:** Secure IV/IO access and have flush syringes prepared.

C. Endotracheal Tube Selection & Intubation

- **ETT Size Estimation:**
  - **Quick Check:** Internal diameter roughly equal to the size of the child's little finger (5th digit).
  - **Age-based Formula (for children >2 years):** ETT size (mm ID) = 4.5 + (Age in years / 4)
  - Have tubes 0.5 mm smaller and larger immediately available.
- **Absolute Contraindication in Trauma:**
  - NEVER perform nasotracheal intubation in a child with suspected head or facial trauma. The risk of passing the tube through a fractured cribriform plate into the cranial vault or causing severe epistaxis is unacceptably high.
- **Laryngoscopy Technique:**
  - Use a gentle technique. **The laryngoscope is a lifting tool, not a lever.** Do not use the teeth or gums as a fulcrum.
  - Protect the lips to avoid pinching them between the blade and teeth.

- For infants and young children, a straight (Miller) blade is often preferred to lift the floppy, omega-shaped epiglottis.

D. Operator Expertise

- Pediatric intubation in an emergency is a high-risk procedure. It should be performed by the **most experienced clinician available**. An attempted but failed intubation can rapidly convert a difficult airway into a catastrophic one. Unskilled attempts should be reserved for true "cannot ventilate, cannot oxygenate" last-resort scenarios.

NEUROMUSCULAR WEAKNESS SYNDROMES

Normal Physiology at the Neuromuscular Junction

The following physiological events occur during neuromuscular transmission:

1. A nerve action potential propagates down the axon and depolarizes the presynaptic nerve terminal.
2. Voltage-gated calcium channels open in response to depolarization, allowing an influx of calcium ions into the nerve terminal.
3. Synaptic vesicles fuse with the presynaptic membrane and release **acetylcholine (ACh)** into the synaptic cleft.
4. ACh molecules bind to **acetylcholine receptors (AChR)** on the postsynaptic membrane, inducing a conformational change that opens the associated ion channel.
5. Membrane conductance to Na^+ increases (Na^+ influx, K^+ efflux), depolarizing the endplate region and generating an **endplate potential (EPP)**.
6. If the EPP is sufficient to depolarize the adjacent muscle membrane to threshold, an action potential is generated in the muscle fiber. If insufficient, no muscle action potential occurs.

Resting State Activity

In the resting state, ACh is intermittently released across the synaptic cleft. Binding to AChR briefly opens a cation channel (~1 ms), resulting in Na^+ influx and K^+ efflux. This produces miniature endplate potentials (MEPPs).

Regulation of ACh Release

ACh release occurs via exocytosis. Increased intracellular calcium concentration in the presynaptic terminal enhances the quantal release of ACh into the synaptic cleft, leading to a larger depolarization and a suprathreshold EPP that triggers a muscle action potential.

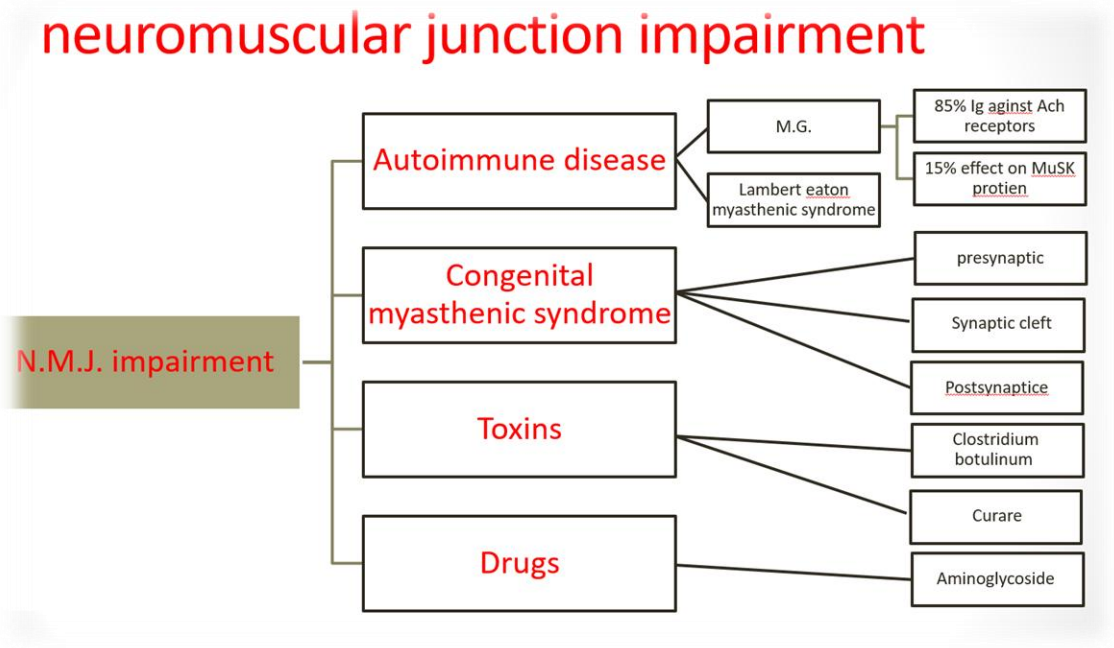
Termination of Signal

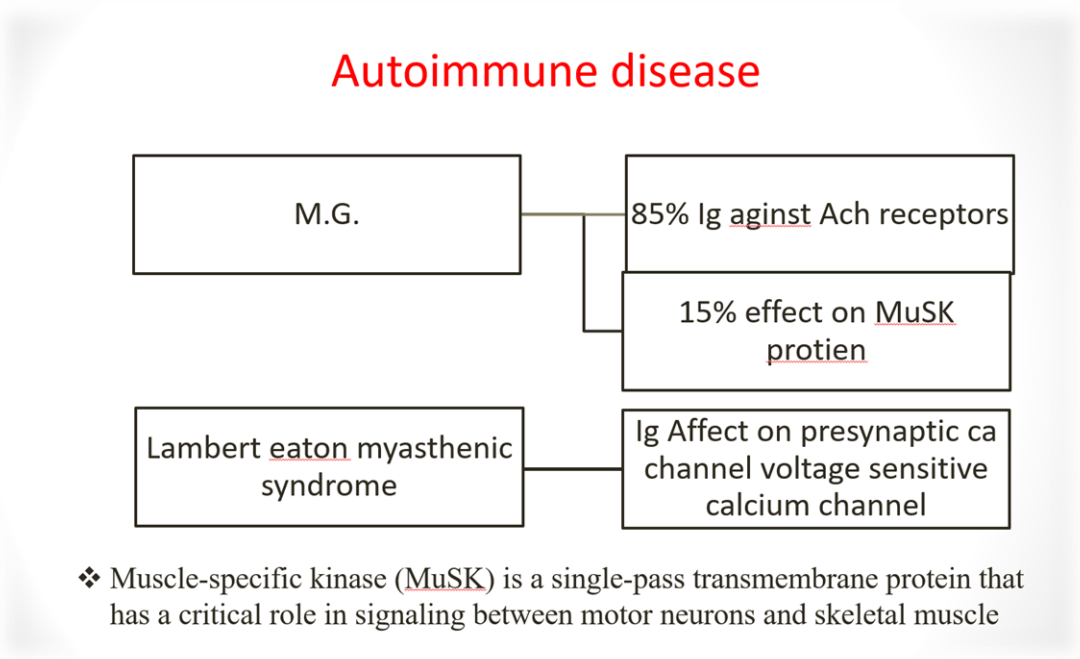
ACh action is rapidly terminated within milliseconds by hydrolysis via **acetylcholinesterase** into acetic acid and choline. Choline is recycled into the presynaptic terminal for resynthesis of ACh.

Impairment at the Neuromuscular Junction

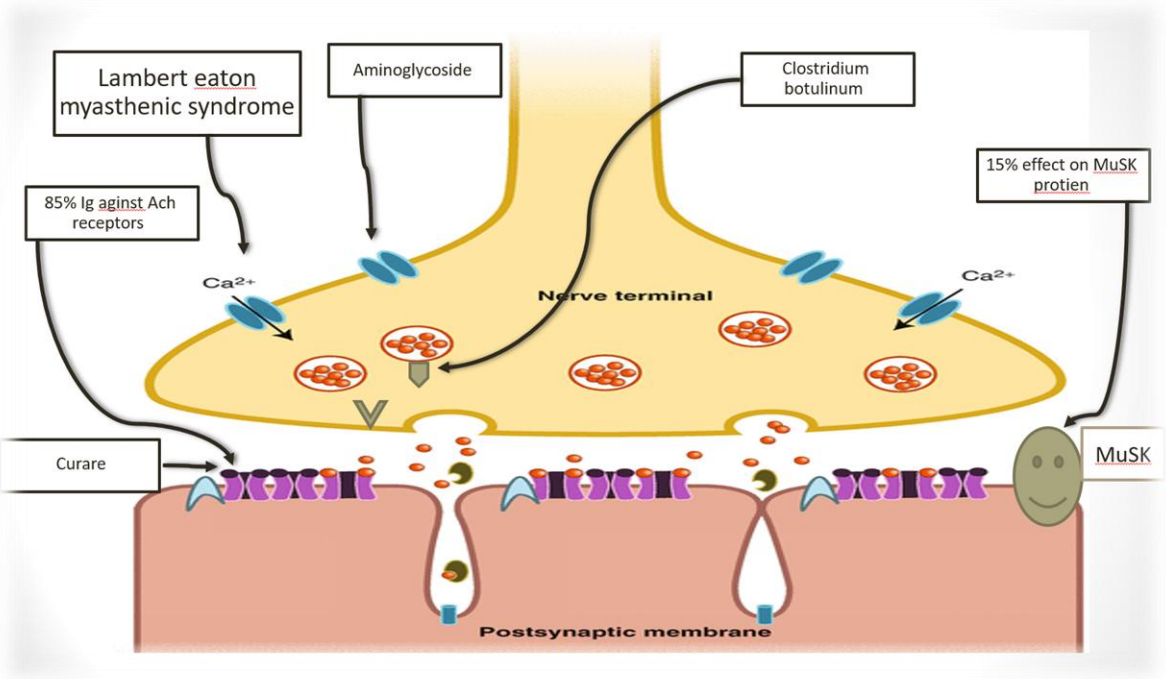
Muscle-specific kinase (**MuSK**) is a transmembrane protein essential for signaling between motor neurons and skeletal muscle. Autoimmune disorders targeting **MuSK** or **cholinesterase** can disrupt neuromuscular transmission.

The neuromuscular weakness syndromes that deserve attention include myasthenia gravis, Guillain-Barré syndrome, and critical illness neuromyopathy.





❖ Muscle-specific kinase (MuSK) is a single-pass transmembrane protein that has a critical role in signaling between motor neurons and skeletal muscle



A. Myasthenia Gravis

Myasthenia gravis (MG) is an autoimmune disease caused by antibody-mediated destruction of acetylcholine receptors at neuromuscular junctions.

1. Predisposing Conditions

MG can be triggered by major surgery or illness. Thymic tumors are present in up to 20% of cases. Certain drugs can worsen MG, including some antibiotics (e.g., aminoglycosides, ciprofloxacin) and cardiac drugs (e.g., beta-blockers, lidocaine, procainamide, quinidine).

2. Clinical Features

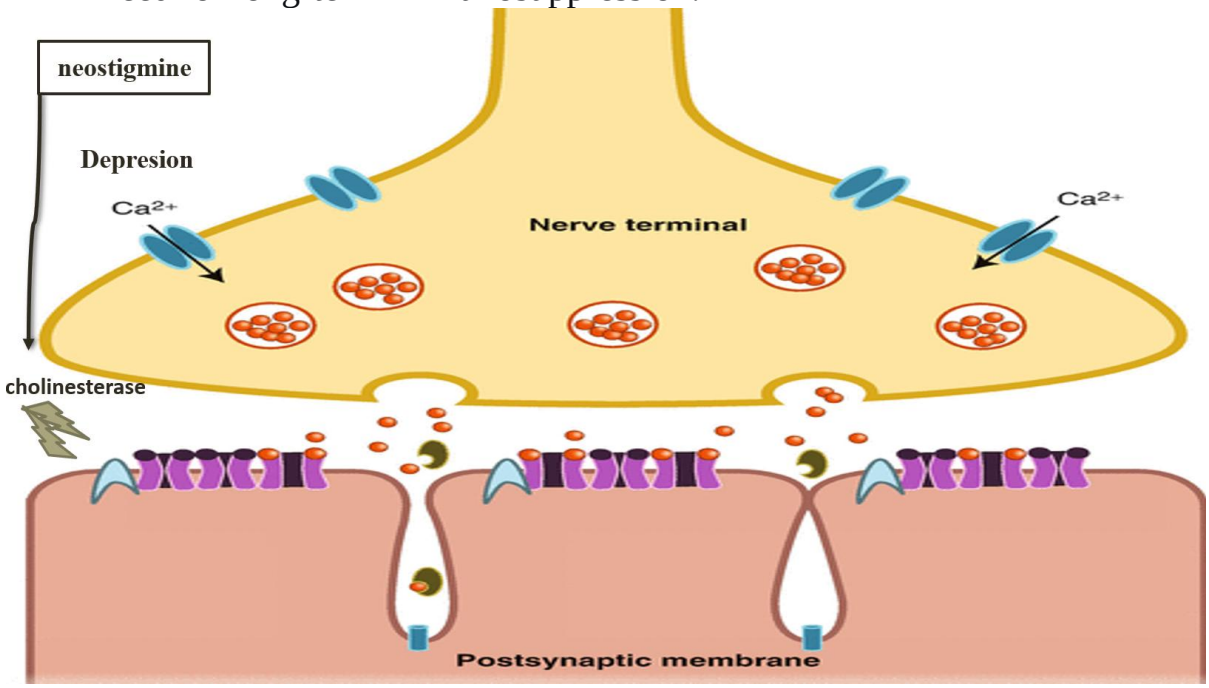
- Weakness increases with activity and improves with rest.
- Weakness typically begins in the eyelids and eye muscles, followed by limb weakness in 85% of cases.
- Progression can involve the chest wall and diaphragm. A rapid decline to respiratory failure (myasthenic crisis) occurs in 15–20% of patients.
- Weakness is purely motor; deep tendon reflexes remain normal.

3. Diagnosis

- Suggested by weakness that worsens with repeated use of muscles (especially in the eyes).
- Confirmed by:
    - Improvement in strength after administration of edrophonium (a test drug).
    - Detection of acetylcholine receptor antibodies in the blood (present in 85% of patients).

4. Treatment

- **First-line:** Acetylcholinesterase inhibitors (e.g., pyridostigmine), started orally and adjusted as needed. Intravenous forms are used for crisis.
- **Immunotherapy:** Added if needed, using drugs like prednisone, azathioprine, or cyclosporine.
- **Thymectomy:** Often recommended for patients under 60 to reduce the need for long-term immunosuppression.



5. Advanced Cases (requiring mechanical ventilation)

- **Plasmapheresis:** Removes harmful antibodies from the blood; acts quickly.

- **Intravenous Immunoglobulin (IVIG):** Neutralizes harmful antibodies; often preferred due to easier administration.

B. Guillain-Barré Syndrome (GBS)

GBS is a subacute inflammatory demyelinating polyneuropathy, often occurring 1–3 weeks after an acute infection. An immune cause is suspected.

1. Clinical Features

- Presents with tingling in the hands/feet and symmetric limb weakness that develops over days to weeks.
- Progresses to respiratory failure in 25% of cases.
- Autonomic nervous system instability can occur in advanced cases.
- Most patients (80%) recover spontaneously, but residual weakness is common.

2. Diagnosis

Based on the clinical picture, nerve conduction studies (showing slowed signals), and cerebrospinal fluid analysis (showing elevated protein).

3. Treatment

Primarily supportive. For advanced cases with respiratory failure, plasmapheresis or IV immunoglobulin are equally effective for short-term improvement. IVIG is often preferred for ease of use.

C. Critical Illness Neuromyopathy

Two disorders can occur in critically ill patients with severe systemic inflammation: critical illness polyneuropathy (CIP) and critical illness myopathy (CIM). They often co-exist and are suspected when a patient cannot be weaned off a ventilator.

1. Critical Illness Polyneuropathy (CIP)

A diffuse nerve damage affecting sensation and movement, occurring in at least 50% of patients with severe sepsis or septic shock. Onset varies from 2 days to weeks after the septic episode.

2. Critical Illness Myopathy (CIM)
A diffuse muscle inflammation affecting limbs and trunk. Associated with severe sepsis, prolonged use of paralytic drugs (especially with high-dose steroids), and status asthmaticus treated with high-dose steroids.

3. Clinical Features
Both conditions manifest as unexplained difficulty weaning from the ventilator. Examination reveals flaccid weakness in all four limbs with reduced or absent reflexes.

4. Diagnosis

- **CIP:** Confirmed by nerve conduction studies showing slowed conduction.
- **CIM:** Confirmed by electromyography (showing muscle damage) and muscle biopsy.

5. Outcome
No specific treatment exists. About half of patients recover completely, but recovery can take months.

III. NEUROMUSCULAR BLOCKADE

Drug-induced neuromuscular blockade is used to facilitate intubation, prevent shivering during therapeutic hypothermia, and manage severely agitated patients on ventilators.

These drugs work by binding to acetylcholine receptors. There are two types:

- **Depolarizing agents** (e.g., succinylcholine): Cause sustained activation of the receptor.
- **Non-depolarizing agents** (e.g., rocuronium, cisatracurium): Block the receptor and prevent activation.

A. Selected Neuromuscular Blockers

Feature	Succinylcholine	Rocuronium	Cisatracurium
IV Bolus Dose	1 mg/kg	0.6 mg/kg	0.15 mg/kg
Onset Time	1–1.5 min	1.5–3 min	5–7 min
Recovery Time	10–12 min	30–40 min	40–50 min
Cardiovascular Effects	Bradycardia	None	None
Contraindications	Multiple*	None	None
***Succinylcholine is contraindicated in conditions like hyperkalemia, malignant hyperthermia, burns, major muscle trauma, and certain neurological diseases.**			

1. Succinylcholine

A depolarizing agent with very fast onset and recovery. Ideal for rapid intubation but has several side effects, notably a dangerous rise in potassium in susceptible patients and bradycardia.

2. Rocuronium

A non-depolarizing agent with relatively fast onset and intermediate recovery. A common alternative to succinylcholine for intubation. Well-tolerated with no cardiovascular effects.

3. Cisatracurium

A non-depolarizing agent with slower onset and intermediate recovery. An isomer of atracurium but without the risk of histamine release. Well-tolerated with no cardiovascular effects.

B. Monitoring

Paralysis is monitored by applying electrical stimulation to the ulnar nerve at the wrist and observing thumb movement. The goal is typically 1 or 2 visible twitches out of 4 stimuli. The drug infusion is adjusted to maintain this level.

C. Complications

- Patients cannot communicate, making it impossible to assess sedation. Being awake while paralyzed is terrifying and painful.
- Prolonged paralysis increases the risk of:
    - Critical illness myopathy.
    - Pneumonia from pooled secretions.
    - Blood clots (venous thromboembolism).
    - Pressure ulcers.

ACUTE STROKE

I. Definitions and Classification

A. Stroke
An acute brain disorder of vascular origin accompanied by neurological dysfunction that persists for **longer than 24 hours**.

B. Transient Ischemic Attack (TIA)
An acute episode of focal neurological dysfunction lasting **less than 24 hours**, with no apparent cause other than vascular origin. Critically, up to one-third of TIAs are associated with cerebral infarction on imaging, highlighting the urgency of evaluation.

C. Stroke Classification

Type	Prevalence	Subtypes & Notes
Ischemic	87%	- **Thrombotic (80%)**: Arising from local thrombosis. - **Embolic (20%)**: Often from cardiac sources (e.g., AF, MI) or paradoxical embolism via a Patent Foramen Ovale (PFO).
Hemorrhagic	13%	- **Intracerebral Hemorrhage (97%)** - **Subarachnoid Hemorrhage (3%)** *Note: Epidural/Subdural hematomas are not classified as strokes.*

II. Initial Evaluation: "Time is Brain"

Each minute of cerebral infarction destroys **1.9 million neurons**. The evaluation must be swift and systematic.

A. Bedside Neurological Evaluation
The clinical presentation localizes the area of brain injury.

Brain Region	Associated Neurological Deficits
Cerebral Hemisphere	Aphasia (left hemisphere), **Contralateral** hemiparesis/sensory loss, spatial neglect, homonymous hemianopsia, impaired conjugate gaze.
Subcortex	Hemiparesis, dysarthria, ataxic hemiparesis. Cognition, language, and vision are typically spared.
Cerebellum	**Ipsilateral** limb ataxia, gait ataxia.
Brainstem	Motor/sensory loss in all limbs, "crossed" signs (e.g., facial weakness on one side, body weakness on the other), dysconjugate gaze, nystagmus, ataxia, dysarthria, dysphagia.

- **Mental Status:** Most unilateral infarctions do **not** cause coma. Coma with focal deficits suggests intracerebral hemorrhage, brainstem infarction, or seizures.
- **Aphasia:** Indicates injury to the dominant (usually left) hemisphere.
- **Stroke Mimics:** Up to **30%** of suspected strokes are mimics. Common ones include nonconvulsive seizures, sepsis, and metabolic encephalopathy.

B. NIH Stroke Scale (NIHSS)

A standardized 11-item scale (score 0-41) to quantify stroke severity. A score ≥22 generally indicates a poor prognosis.

C. Neuroimaging

Modality	Role & Characteristics
Non-Contrast CT (NCCT)	**First-line test.** ~100% sensitive for hemorrhage. **Insensitive** for early ischemia—up to 50% of ischemic strokes are not apparent initially.
MRI with Diffusion-Weighting (DWI)	**Gold standard** for detecting ischemic stroke. Can show changes within **5-10 minutes**. DWI shows ischemia as a **bright/hyperintense** signal. Can also identify the "penumbra" (threatened tissue).

D. Echocardiography

Indicated to identify an embolic source (e.g., AF, mural thrombus, endocarditis) or a Patent Foramen Ovale (PFO) in the context of a cryptogenic stroke.

III. Reperfusion Therapy: Thrombolysis and Thrombectomy

A. Thrombolytic Therapy with tPA

The goal is to administer tPA within **4.5 hours** of symptom onset. Time of onset must be accurately identified.

tPA Dosing Regimen:

- **Drug:** Recombinant tissue Plasminogen Activator (tPA).
- **Dose:** 0.9 mg/kg (max 90 mg).
- **Administration:** 10% of dose as IV bolus over 1-2 min, then the remainder infused over 60 min.
- **Post-tPA:** Avoid anticoagulants/antiplatelets for 24 hours. Monitor for hemorrhage (neuro checks, BP monitoring).

B. Mechanical Thrombectomy

- Superior to tPA alone for large vessel occlusions (e.g., proximal MCA, internal carotid).
- Can be performed up to **8 hours** (sometimes longer) from symptom onset.
- **Does not preclude** concurrent tPA therapy; they are often used together.

IV. Supportive Care and Protective Measures

A. Blood Pressure Management (Based on Table 42.2)

Clinical Scenario	Recommended Agents
BP too high for tPA (SBP >185 or DBP >110)	**Labetalol:** 10-20 mg IV, repeat once. **Nicardipine:** 5 mg/hr infusion, titrate up to 15 mg/hr.
Marked Hypertension (SBP >220 or DBP >120)	**Labetalol:** 10 mg IV, then infusion 2-8 mg/min. **Nicardipine:** 5 mg/hr infusion, titrate up. **Nitroprusside:** For DBP >140 mm Hg.
Post-tPA	Maintain BP < **180/105 mm Hg** for at least 24 hours.

- **General Principle:** Do not aggressively lower BP in the first 24 hours unless for tPA eligibility or if SBP >220 / DBP >120, as this may extend the ischemic penumbra.

B. Oxygen Therapy

- **Do not** administer supplemental oxygen if O_2 saturation is ≥94%.
- Unnecessary oxygen can cause cerebral vasoconstriction and increase oxidative stress.

C. Antipyretic Therapy

- Fever occurs in 30% of stroke patients and worsens outcomes.
- Aggressively treat fever with antipyretics and search for an underlying infection.

D. Glycemic Control

- Hyperglycemia aggravates ischemic injury.
- Maintain plasma glucose between **140–180 mg/dL**. Avoid hypoglycemia, which is also detrimental.

V. Mechanical Ventilation in Acute Stroke (Anesthesia Focus)

Mechanical ventilation in stroke patients aims to protect the brain, maintain adequate cerebral perfusion, and avoid secondary injury. Ventilation strategy differs slightly between ischemic stroke, hemorrhagic stroke, and post-thrombectomy anesthesia care.

A. Indications for Intubation in Stroke

Intubate if **any** of the following are present:

- **Decreased consciousness** (GCS ≤8 or inability to protect airway)
- **Loss of gag or cough reflex**
- **Severe agitation** interfering with imaging or treatment
- **Respiratory failure** (hypoxia or hypercapnia)
- **Impending herniation signs**
- **Need for general anesthesia** during mechanical thrombectomy

B. Ventilation Goals

1. Oxygenation

- Maintain **SpO_2 94–98%**
- Avoid unnecessary high FiO_2 (hyperoxia → cerebral vasoconstriction)

2. CO_2 Management (VERY IMPORTANT)

CO_2 strongly influences cerebral blood flow (CBF):

CO_2 LEVEL	EFFECT ON BRAIN	CLINICAL USE
HYPOCAPNIA ($PACO_2 < 35$)	Cerebral vasoconstriction → ↓CBF	**Avoid** in ischemic stroke (worsens infarct)
NORMOCAPNIA ($PACO_2$ 35–40)	Stable CBF	**Primary target** in most strokes
MILD HYPERVENTILATION ($PACO_2$ 30–35)	Temporary ↓ICP	Use **only in acute herniation**, avoid prolonged use

Target: $PaCO_2$ 35–40 mmHg

C. Ventilation Strategy by Stroke Type

1. Ischemic Stroke

Goal: **maximize cerebral perfusion and prevent secondary ischemia**

- Mode: Volume-controlled or Pressure-controlled, whichever provides stable ventilation
- **Normocapnia mandatory** ($PaCO_2$ 35–40)
- Avoid high PEEP (>10 cmH_2O) → may reduce venous return & cerebral perfusion
- FiO_2: Lowest FiO_2 to keep SpO_2 ≥94%
- Avoid hypotension at induction—use etomidate or ketamine cautiously

2. Hemorrhagic Stroke (ICH or SAH)

Goals: **control ICP and prevent rebleeding**

- Slightly higher PEEP acceptable (8–10 cmH_2O) if needed for oxygenation
- Maintain **$PaCO_2$ 35–38 mmHg**
- Avoid hypercapnia → ↑ICP
- Avoid high airway pressures (plateau pressure ≤30 cmH_2O)
- Maintain strict BP control to prevent rebleeding

3. Post-Thrombectomy / Perioperative Care

Patients often return from thrombectomy under sedation or intubated.

- Maintain **strict normocapnia**
- Avoid big swings in BP, HR, or CO_2
- Extubate early if:
    - No airway compromise
    - No large infarct
    - Hemodynamically stable
    - Acceptable neurological status

Patients with large MCA infarcts, poor consciousness, or risk of cerebral edema often need continued ventilation.

D. Recommended Ventilator Settings (Starting Points)

Parameter	Ischemic Stroke	Hemorrhagic Stroke
Mode	VC or PC	VC or PC
Tidal Volume	6–8 mL/kg IBW	6–8 mL/kg IBW
PEEP	5–8 cmH_2O	5–10 cmH_2O
FiO_2	As needed (SpO_2 ≥94%)	As needed (SpO_2 ≥94%)
$PaCO_2$	**35–40 mmHg**	**35–38 mmHg**
Plateau Pressure	<30 cmH_2O	<30 cmH_2O

E. Sedation Strategy (ICU/OR)

Preferred Agents

- **Propofol**: fast, titratable, decreases ICP
- **Dexmedetomidine**: good for neurological exams
- **Remifentanil**: short-acting, useful in procedures

Avoid

- Benzodiazepines (prolong sedation, mask neuro exams)
- Ketamine is controversial; modern data suggests it's safe and does **not** increase ICP, but use cautiously in ICH.

F. Extubation Criteria in Stroke Patients

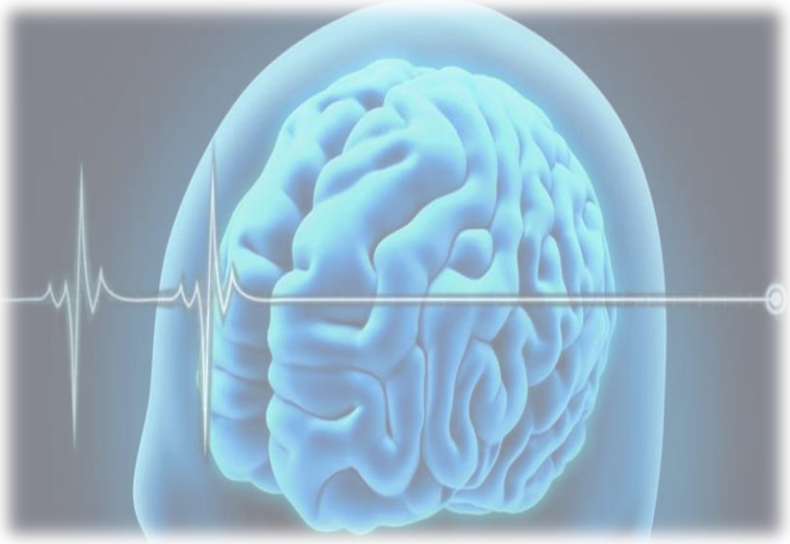
- Conscious, able to follow commands
- Strong cough and gag reflex
- No significant bulbar dysfunction
- Adequate gas exchange
- No large cerebral edema or mass effect
- Hemodynamically stable

High-risk features for failed extubation:

- Brainstem stroke
- Large MCA infarct
- Oropharyngeal weakness
- Poor mental status

BRAIN DEATH

The Uniform Determination of Death Act defines death as the irreversible cessation of either circulatory and respiratory functions or all functions of the entire brain, including the brainstem. This section details the determination of death by neurologic criteria.

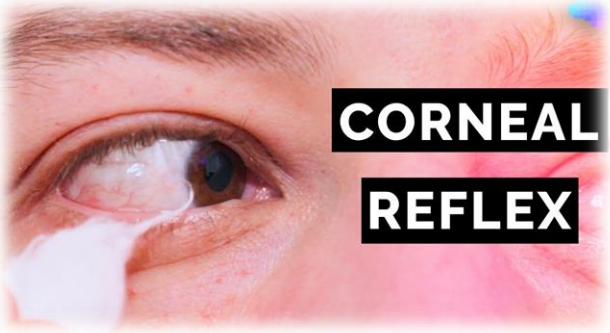


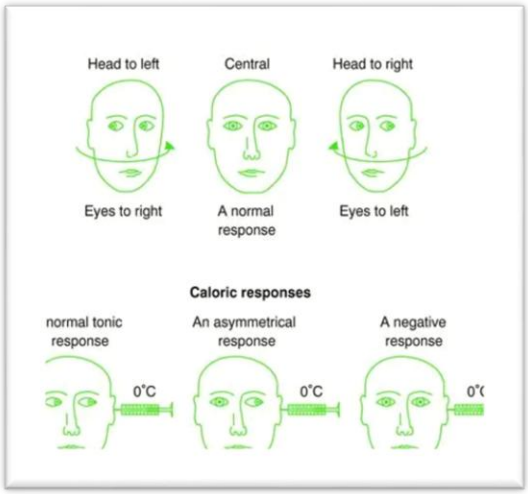
A. Diagnostic Criteria and Prerequisites

The diagnosis of brain death is clinical, based on the demonstration of irreversible coma, the absence of brainstem reflexes, and apnea.

Coma: The patient must exhibit irreversible, unresponsive coma with a known cause sufficient to explain the loss of brain function.

1. **Absence of Brainstem Reflexes:** This includes no pupillary, corneal, oculocephalic (doll's eyes), oculovestibular (caloric), gag, or cough reflexes.
    - No pupillary light reaction
    - No corneal reflex
    - No oculocephalic reflex (doll’s eyes)
    - No oculovestibular reflex (caloric testing)
    - No gag reflex
    - No cough reflex on tracheal suction





2. **Apnea:** The absence of spontaneous respiratory effort during a formal CO_2 challenge (apnea test).

The clinical examination must be performed under the following prerequisite conditions to exclude confounding factors:

- **Hemodynamic Stability:** Systolic blood pressure ≥100 mm Hg.
- **Normothermia:** Core body temperature >36°C.
- **Absence of CNS Depressants:** No evidence of sedation or the presence of neuromuscular blocking agents.
- **Metabolic Stability:** Euglycemia and normal thyroid function.

Note: A single neurologic examination is sufficient for diagnosis in most U.S. states, though some require two separate examinations.

B. The Apnea Test

The apnea test confirms the absence of the brainstem's respiratory drive. It involves disconnecting the patient from the ventilator and observing for spontaneous breaths as the arterial PCO_2 ($PaCO_2$) rises.

Procedure:

1. **Pre-oxygenation and Baseline:** The patient is pre-oxygenated with 100% FiO_2 for at least 10 minutes. Ventilator settings are adjusted (e.g., reduced rate) to establish a baseline $PaCO_2$ via an arterial blood gas (ABG), provided oxygen saturation (SpO_2) remains >95%.
2. **Disconnection:** The patient is disconnected from the ventilator. Apneic oxygenation is maintained by insufflating 100% O_2 via a catheter through the endotracheal tube.
3. **Observation and Target:** The patient is observed for any respiratory effort. The goal is for the $PaCO_2$ to rise by ≥20 mm Hg above the baseline. The $PaCO_2$ typically rises at a rate of 3 mm Hg per minute, making a test duration of 6–7 minutes usually sufficient.
4. **Confirmation:** A final ABG is obtained. The absence of respiratory effort with a $PaCO_2 \geq$ the target threshold (typically ≥60 mm Hg) confirms apnea.
5. **Abortion Criteria:** The test must be aborted if systolic blood pressure falls below 90 mm Hg or if SpO_2 falls below 85% for more than 30 seconds.

C. Ancillary Testing

Ancillary tests, such as cerebral angiography (CTA or MRA), nuclear scintigraphy, or electroencephalography (EEG), can support the diagnosis but are not a substitute for a clinical examination.

Indications:

- When components of the clinical examination or apnea test cannot be reliably performed.
- When there is uncertainty or equivocal findings.

Limitation: Current guidelines caution that evidence for the reliability of some ancillary tests is insufficient, and they should be interpreted in the full clinical context.

D. Lazarus' Sign

Brain-dead patients may occasionally exhibit spontaneous, brief movements of the limbs or torso, known as Lazarus' sign. These are spinal reflexes, not evidence of brainstem activity, and are often triggered by hypoxemia or spinal cord ischemia after ventilator disconnection.

E. The Potential Organ Donor

The diagnosis of brain death often precedes the opportunity for organ donation. While a detailed discussion of organ procurement is beyond the scope of this text, management of the potential organ donor is a critical process in the ICU, and relevant guidelines are available (28).

Checklist for Brain Death Determination

Step	Component	Key Criteria & Conditions
1	**Prerequisites**	• **Systolic BP** ≥100 mm Hg • **Core Temperature** >36°C (>96.8°F) • **Metabolic Status:** Normal thyroid/adrenal function & Euglycemia (normal blood sugar) • **No Confounding Drugs:** Absence of CNS depressants & neuromuscular blocking agents
2	**Establish Cause of Coma**	The identified cause of coma is known and is sufficient to account for the irreversible loss of brain function.
3	**Absence of Cortical & Brainstem Function**	• **Coma:** The patient is **unconscious**. • **No Motor Response:** Absence of facial grimacing to noxious stimulus. • **Absent Brainstem Reflexes:** - Pupillary response to light - Corneal reflex - Gag and cough reflexes - Oculocephalic reflex (doll's eyes) - Oculovestibular reflex (caloric test)
4	**Apnea Test**	No spontaneous breathing efforts are observed when the arterial PCO_2 ($PaCO_2$) rises to **≥20 mm Hg above the patient's baseline level** (or ≥60 mm Hg absolute).
5	**Confirmation & Legal Requirements**	• The examination must be performed by qualified physicians as per institutional and state law. • Some jurisdictions require two separate examinations.

VENTILATOR-ASSOCIATED PNEUMONIA

The clinical approach to pneumonia can be characterized by one word: *problematic*. Fundamental problems include a limited ability to detect parenchymal lung infections, and the lack of a standardized method for identifying responsible pathogen(s).

I. General information

The following statements summarize some of the relevant observations about ventilator-associated pneumonia (VAP).

1. Pneumonia is the most common nosocomial infection in ICU patients, and more than 90% of these pneumonias occur during mechanical ventilation. However, the prevalence of VAP is overstated, because post-mortem studies have shown that over half of the cases of VAP are false-positive diagnoses.
2. Unlike community-acquired pneumonias, where the predominant pathogens are pneumococci, atypical organisms, and viruses, three-quarters of the responsible pathogens in VAP are gram-negative aerobic bacilli and *Staphylococcus aureus* (see Table 16.1).
3. The mortality rate associated with VAP varies widely, from 0% to 65%, and there are claims that VAP is not a life-threatening illness. However, VAP-associated mortality rates must be viewed with caution because of the tendency for overdiagnosis of VAP.

Table 16.1	Pathogenic Isolates in Ventilator-Associated Pneumonia
Organisms	**Frequency**
Gram-negative Bacilli	56.5%
Pseudomonas aeruginosa	18.9%
Escherichia coli	9.2%
Hemophilus spp	7.1%
Enterobacter spp	3.8%
Proteus	3.8%
Klebsiella pneumoniae	3.2%
Others	10.5%
Gram-positive Cocci	42.1%
Staphylococcus aureus	18.9%
Streptococcus pneumoniae	13.2%
Hemophilus spp	1.4%
Others	8.6%
Fungal Isolates	1.3%

II. Preventive measures

Aspiration of pathogenic organisms from the oropharynx is believed to be the inciting event in most cases of VAP. The pathogens that most often colonize the oropharynx in ICU patients are gram-negative aerobic bacilli, and this explains the predominance of these pathogens in VAP.

A. Oral Decontamination

1. The realization that VAP begins with pathogenic colonization of the oropharynx resulted in the introduction of measures to decontaminate the oropharynx as a preventive measure for VAP.
2. The methods of oral decontamination (i.e., with chlorhexidine or topical antibiotics) are can be used.

3. Routine oral care with chlorhexidine (as a mouth rinse or gel, used 2–3 times daily) has become a standard practice in ventilator-dependent patients.

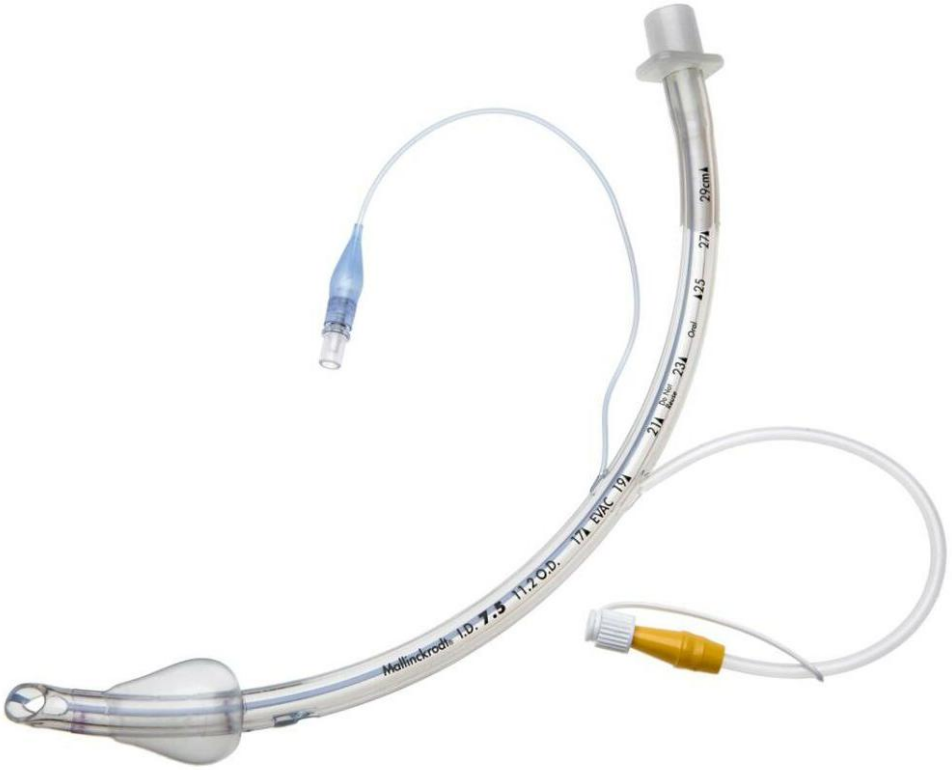
B. Routine Airway Care

The inner surface of artificial airways (endotracheal and tracheostomy tubes) becomes colonized with pathogenic organisms, and passing a suction catheter through the tubes can dislodge these organisms and introduce pathogens into the lower airways. Because of this risk, *endotracheal suctioning is not recommended as a routine procedure, and should be used only when necessary to clear secretions from the airways*.

C. Clearing Subglottic Secretions

1. Contrary to popular belief, inflation of the cuff on tracheal tubes to *create a seal does not prevent aspiration of mouth secretions into the lower airways*. Aspiration of saliva and liquid tube feedings has been documented in over 50% of patients with tracheostomies, and the aspiration is clinically silent in most cases.
2. Concern about aspiration around inflated cuffs prompted the introduction of specialized endotracheal tubes equipped with a suction port just above the cuff (Mallinckrodt TaperGuard Evac Tube). The suction port is connected to a source of continuous suction (usually not exceeding -20 cm H_2O) to clear the secretions that accumulate in the subglottic region, as illustrated in Figure 16.1.

3. Clinical studies have shown a significant reduction in the incidence of VAP when subglottic secretions are cleared using these specialized endotracheal tubes.



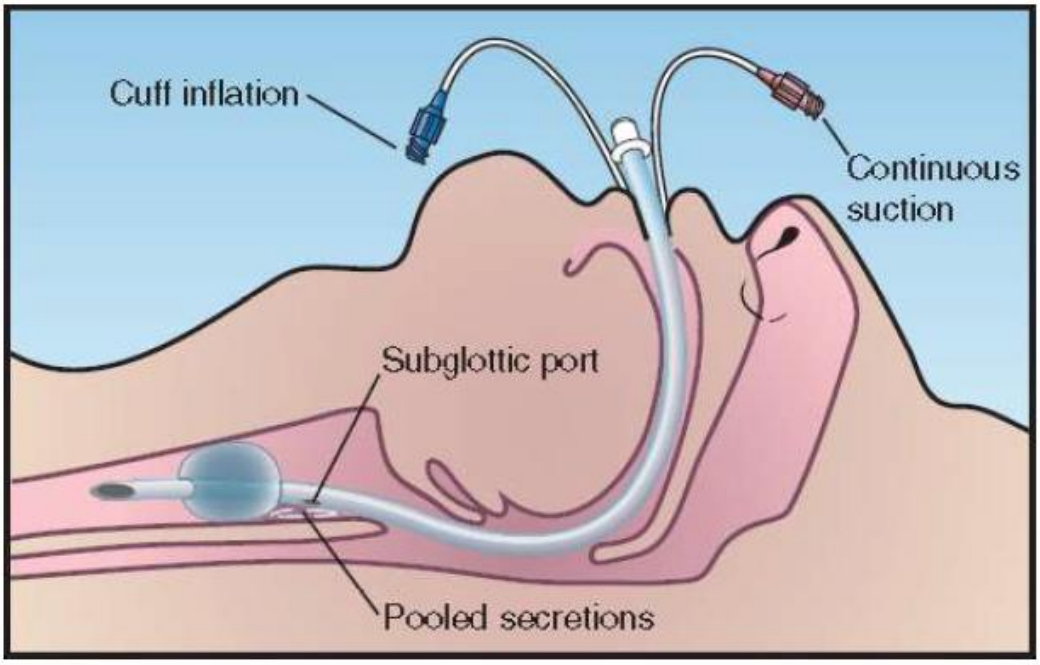


FIGURE 16.1 Endotracheal tube with a suction port placed just above the cuff to clear secretions that accumulate in the subglottic region.

III. Clinical features

A. Diagnostic Accuracy

The traditional clinical criteria for the diagnosis of VAP include:

(a) fever or hypothermia,

(b) leukocytosis or leukopenia,

(c) an increase in volume of respiratory secretions or a change in character of the secretions, and

(d) a new or progressive infiltrate on the chest x-ray.

1. In cases of VAP diagnosed using traditional clinical criteria, the incidence of pneumonia on postmortem exam is only 30% to 40%.
2. The accuracy of clinical criteria for the diagnosis of VAP is demonstrated in Table 16.2. This table shows the results of two studies that used autopsy evidence of pneumonia to evaluate the premortem diagnosis of VAP based on clinical findings. In both studies, the clinical findings were just as likely to occur in the presence or absence of pneumonia. These studies demonstrate that *the diagnosis of VAP is not possible using clinical criteria alone.*

Table 16.2 Predictive Value of Clinical Criteria for Identifying Ventilator-Associated Pneumonia

Study	Clinical Criteria	Likelihood Ratio for Pneumonia on Autopsy†
Fagon et al. (14)	Radiographic infiltrate + purulent sputum + fever or leukocytosis	1.03
Timset et al. (15)	Radiographic infiltrate + 2 of the following: fever, leukocytosis, or purulent sputum	0.96

†The likelihood ratio is the likelihood that patients with pneumonia will have the clinical findings compared to the likelihood that patients without pneumonia will have the same clinical findings. A likelihood ratio of 1 indicates that a pneumonia is just as likely to be present or absent based on the clinical findings.

B. Chest Radiography

Portable chest x-rays perform poorly in the diagnosis of ventilator-associated pneumonia, with an overall accuracy of only about 49%. This is largely because they have a low sensitivity of approximately 38%, meaning they often fail to detect actual pulmonary infiltrates even when pneumonia is present.

The limitations of portable chest radiography can be vividly illustrated by comparing it with computed tomography (CT) in the same patient. In many cases, a portable chest x-ray may show no apparent infiltrates, while a subsequent CT scan of the lungs reveals clear evidence of consolidation, particularly in dependent regions like the posterior lung fields. This discrepancy confirms that a negative or inconclusive portable chest x-ray cannot reliably exclude VAP.

C. Lung Ultrasound

Ultrasound examination of the lungs is a more reliable method for detecting pulmonary consolidation than portable chest x-rays

D. Proposed Algorithm

The National Healthcare Safety Network has recently published an algorithm for the diagnosis of VAP that does not include findings on a chest x-ray. This algorithm is shown in Figure 16.3. Note that the diagnosis of “probable VAP” is not based on clinical criteria, but requires some evidence of a pulmonary infection.

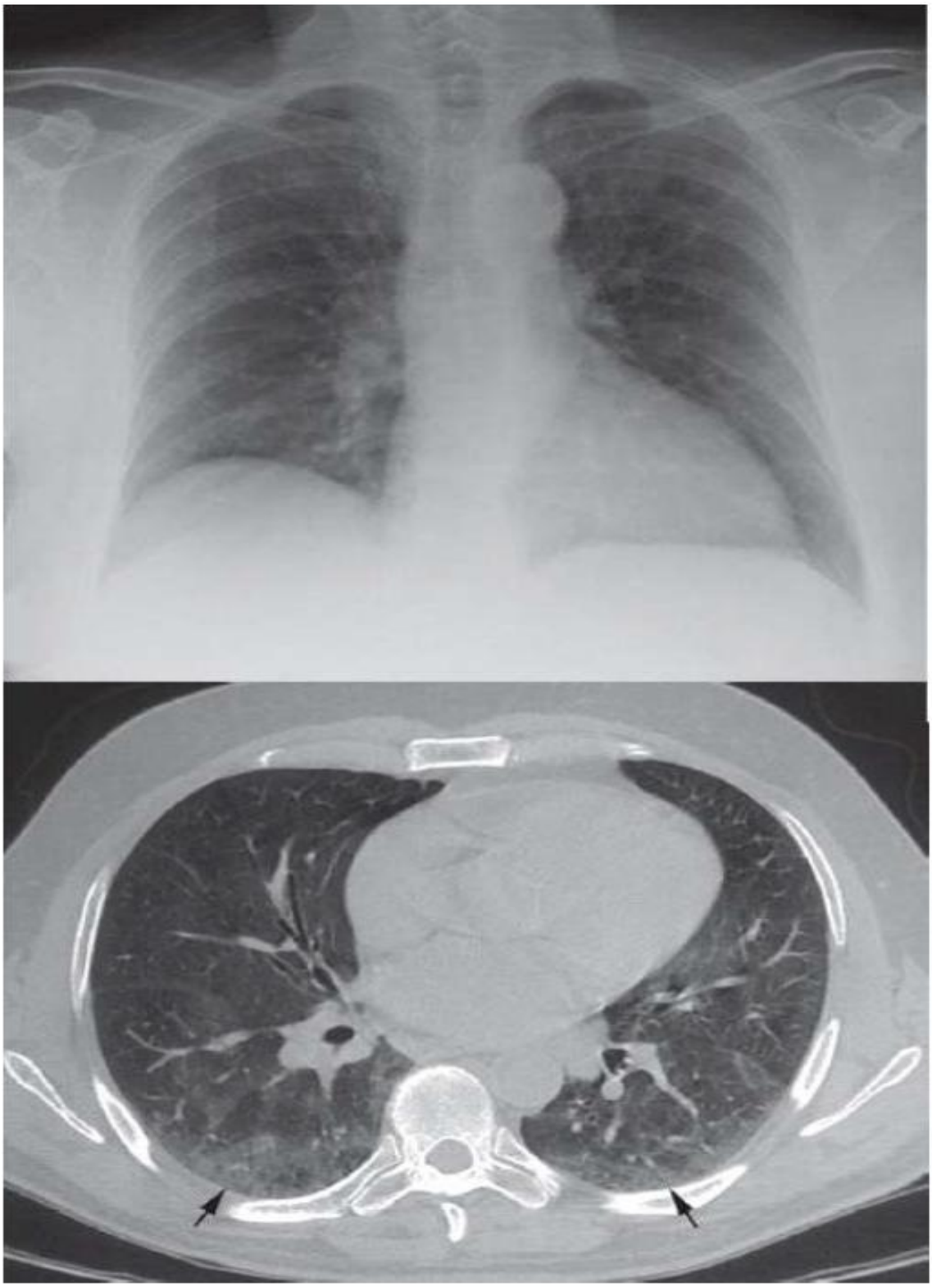


FIGURE 16.2 Demonstration of the limited sensitivity of portable chest radiography in the detection of pulmonary infiltrates. A portable chest x-ray of a patient with fever shows no apparent pulmonary infiltrates, while the CT image from the same patient reveals infiltrates in the posterior region of both lungs (indicated by the arrows).

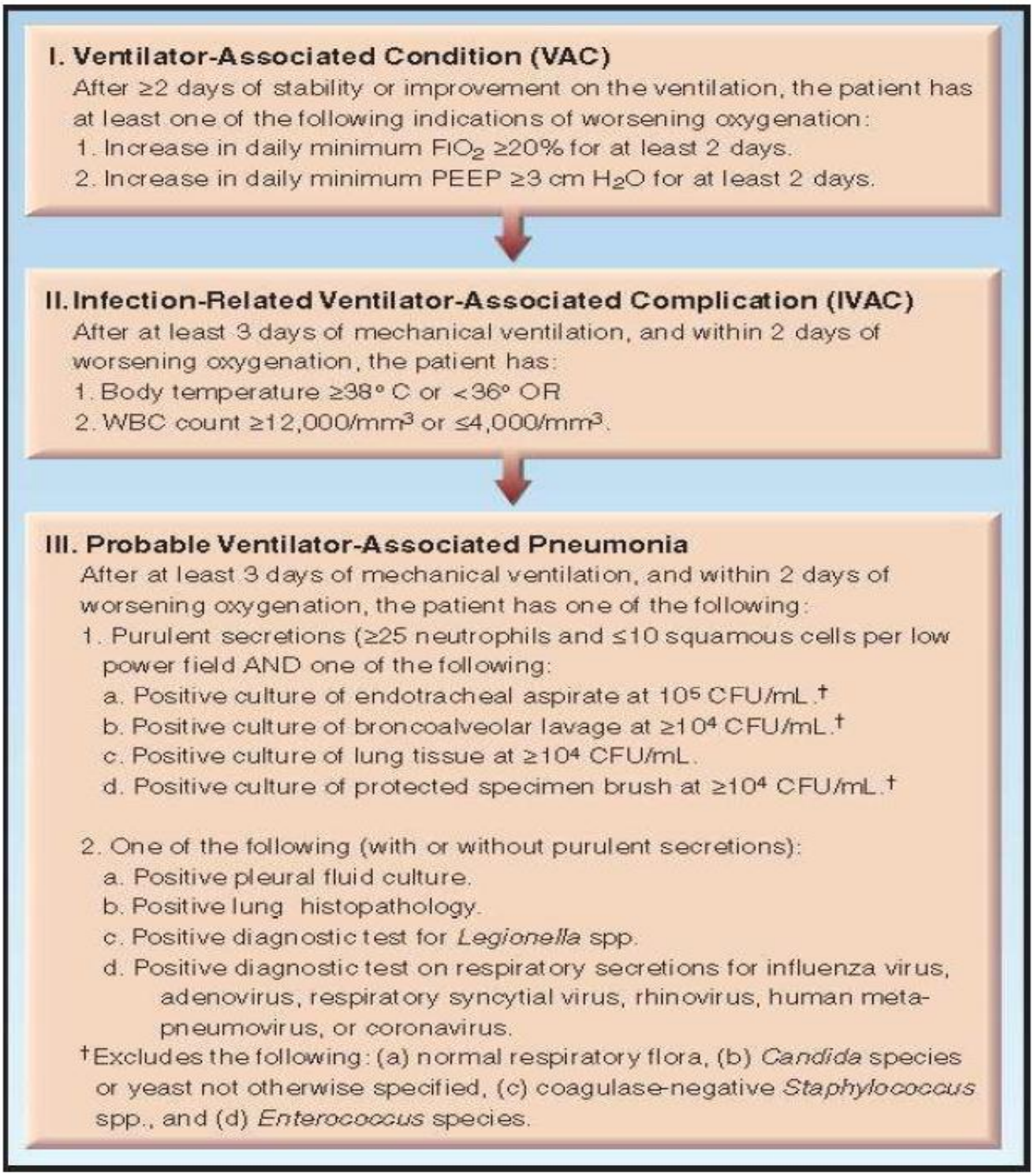


FIGURE 16.3 National Health Safety Network algorithm for the diagnosis of ventilator-associated pneumonia. From Reference 1.

IV. Parapneumonic effusions

Pleural effusions are present in up to 50% of bacterial pneumonias. These parapneumonic effusions are more likely to be detected by ultrasound than by portable chest x-rays.

A. Thoracentesis

1. Thoracentesis is generally advised for all parapneumonic effusions except small, free-flowing effusions in patients who are not severely ill or are responding to antimicrobial therapy.
2. Ultrasound guidance is advised for aspiration of pleural fluid, especially in ventilator-dependent patients.
3. The following pleural fluid studies are needed to guide decisions regarding drainage of the effusion.
   a. Gram stain and culture
   b. pH (measured with a blood gas analyzer)
   c. Glucose concentration (if pH measurement is unavailable)
4. Other pleural fluid studies (e.g., cell count, protein, LDH) are not necessary.

B. Indications for Drainage

The presence of any of the following is an indication for drainage of a parapneumonic effusion:

1. Effusions that are large (≥ half the hemithorax) or localized.
2. Purulent pleural aspirate.
3. Presence of organisms on gram stain, or positive culture.
4. Pleural fluid pH <7.2.
5. Pleural fluid glucose <60 mg/dL (if the pH measurement is not available).

C. Drainage

Tube thoracostomy is used for pleural fluid drainage (at least initially). Small-bore chest tubes (10–14 French) are advised, because they are less painful, and they are as effective as large-bore tubes in most cases.

V. Antimicrobial therapy

Antimicrobial therapy for pneumonia accounts for half of all antibiotic use in the ICU, and 60% of this antibiotic use is for suspected pneumonia that are not confirmed by bacteriologic studies. There is evidence that the mortality rate in VAP is increased by delays in initiating appropriate antibiotic therapy, so prompt initiation of empiric antimicrobial therapy is considered essential.

A. Empiric Antibiotic Therapy

1. Empiric antimicrobial therapy for VAP should include coverage for gram-negative aerobic bacilli and *Staphylococcus aureus* (especially methicillin-resistant strains), which are the principal pathogens listed in Table 16.1.

2. Popular regimens include *piperacillin/tazobactam*, *cefepime*, or a carbapenem (e.g., *meropenem*), plus *vancomycin* (for methicillin-resistant *Staph aureus*).

B. When a Pathogen is Identified

1. When a responsible pathogen is identified, antibiotic therapy will be dictated by the antibiotic susceptibilities of the pathogens at your hospital.
2. One week of antimicrobial therapy is adequate for most cases of VAP, except those caused by non-fermenting gram-negative bacilli (*Pseudomonas aeruginosa* and *Acinetobacter baumannii* account for most of these organisms), in which case 10–15 days of antibiotic therapy is advised.

VI. Mechanical ventilation management in VAP

Mechanical ventilation management plays a crucial role in both the pathophysiology and the supportive care of patients with ventilator-associated pneumonia (VAP). The primary goals are to support adequate gas exchange while minimizing further lung injury, preventing ventilator-induced complications, and optimizing conditions for recovery from infection.

A. Lung-Protective Ventilation Strategy

A lung-protective ventilation strategy is the cornerstone of management for any patient with acute lung injury, including VAP. The principles aim to minimize ventilator-induced lung injury (VILI).

1. Low Tidal Volume Ventilation

- **Recommendation:** Use tidal volumes of 6–8 mL/kg of **predicted body weight (PBW),** not actual body weight.
- **Rationale:** Higher tidal volumes cause alveolar overdistension (volutrauma), promote inflammation (biotrauma), and can worsen existing lung injury. The landmark ARDS Network trial demonstrated a significant mortality benefit with a low tidal volume strategy.
- **Calculation of PBW:**
    - Male: PBW (kg) = 50 + 0.91 * (height in cm – 152.4)
    - Female: PBW (kg) = 45.5 + 0.91 * (height in cm – 152.4)

2. Plateau Pressure Limitation

- **Recommendation:** Maintain an end-inspiratory plateau pressure (Pplat) ≤30 cm H_2O (2, 35).
- **Action:** If Pplat exceeds 30 cm H_2O on 6 mL/kg PBW, further reduce tidal volume in 1 mL/kg increments (to a minimum of 4 mL/kg) if possible.

3. Positive End-Expiratory Pressure (PEEP)

- **Recommendation:** Apply adequate PEEP to prevent alveolar collapse at end-expiration (atelectrauma). There is no single "best PEEP" for VAP; it must be individualized.
- **Strategy:** Use PEEP/FiO_2 tables from ARDS protocols as a starting point. Titrate PEEP to achieve adequate oxygenation (SpO_2 88-95% or PaO_2 55-80 mmHg) with the lowest possible FiO_2 (≤0.6). Higher PEEP may be needed in patients with significant consolidation or atelectasis from pneumonia.

B. Management of Airway Secretions and Hygiene

Effective clearance of infected respiratory secretions is critical for source control in VAP.

1. Endotracheal Suctioning

- **Recommendation:** Perform suctioning **only as needed**, based on audible or visible secretions, increased peak airway pressures, or desaturation, rather than on a fixed schedule.
- **Technique:** Use a closed/in-line suction system to maintain PEEP and minimize environmental & caregiver contamination. Limit suction pressure (< -120 mmHg) and duration of each pass (< 15 seconds).

2. Bronchial Hygiene Adjuncts

- **Considerations:**
    - **Chest Physiotherapy (CPT):** May be beneficial in select patients with lobar consolidation and difficulty mobilizing secretions, though evidence in VAP is limited (37).
    - **Mechanical Insufflation-Exsufflation (MI-E):** Can be considered in patients with neuromuscular weakness and retained secretions, but routine use in general VAP is not supported.

C. Ventilator Weaning and Spontaneous Breathing Trials (SBTs)

Early liberation from mechanical ventilation reduces the risk of VAP and other complications.

1. Daily Assessment for Readiness to Wean

- **Criteria for SBT Consideration:**
    1. Evidence of infection improvement (e.g., decreasing fever, leukocytosis, and purulent sputum).
    2. Adequate gas exchange (e.g., PaO_2/FiO_2 >150-200, PEEP ≤8 cm H_2O, FiO_2 ≤0.5).
    3. Hemodynamic stability without significant vasopressors.

4. Ability to initiate spontaneous breaths.

2. Conducting the SBT

- **Method:** A 30–120-minute trial on a low level of pressure support (e.g., 5–8 cm H_2O) with PEEP (5 cm H_2O) or on a T-piece.
- **Failure Criteria:** Development of tachypnea (RR >35), hypoxia (SpO_2 <90%), tachycardia/bradycardia, hypertension/hypotension, agitation, diaphoresis, or signs of increased work of breathing.
- **Recommendation:** Perform a daily SBT on all eligible patients. Patients who pass should be evaluated for prompt extubation.

D. Sedation and Mobility

- **Sedation Strategy:** Use a protocol of **light sedation** (e.g., RASS score 0 to -2) with daily interruption or a "no sedation" strategy where feasible. Deep sedation increases aspiration risk, promotes atelectasis, and delays weaning.
- **Early Mobility:** Implement early, progressive mobilization (passive range of motion, sitting at edge of bed, standing, ambulating) as soon as the patient is hemodynamically and respiratory stable. This improves secretion clearance, reduces atelectasis, and decreases ventilator days.

Diabetic Ketoacidosis (DKA)

Diabetic ketoacidosis (DKA) is a metabolic emergency caused by absolute or relative deficiency of insulin. It is characterized by hyperglycemia (>300>300 mg/dL), metabolic acidosis (pH <7.30<7.30), low bicarbonate level (<15<15 mEq/L), with ketonemia and ketonuria.

In the absence of insulin, peripheral tissues (muscle, fat, and liver) do not take up glucose. Counterregulatory hormones (e.g., glucagon, growth hormone, and catecholamines) lead to breakdown of triglycerides into free fatty acids and accelerate gluconeogenesis, resulting in elevated serum glucose levels. Hyperglycemia itself reduces any residual insulin secretion and further impairs peripheral glucose uptake. Beta-oxidation of free fatty acids produces ketone bodies (acetone, acetoacetate, and ββ-hydroxybutyrate), which deplete extracellular and cellular acid buffers, producing acidosis. Excess fatty acids and lactic acidosis, due to poor tissue perfusion, are other important contributors.

Hyperglycemia (exceeding the renal threshold for glucose) and ketonemia produce osmotic diuresis, which depletes sodium, potassium, phosphates, and water. Hyperventilation and vomiting also contribute to dehydration. Dehydration and hypokalemia are significant concerns in DKA patients. When respiratory compensation is insufficient, metabolic acidosis and dehydration can lead to renal failure, circulatory collapse, coma, and death.

Clinical Assessment

History

The patient may present with classic symptoms of hyperglycemia:

- Thirst
- Polyuria
- Polydipsia
- nocturia

Or other nonspecific symptoms:

- Confusion
- Generalized weakness
- Malaise/lethargy
- Nausea/vomiting
- Fatigue
- Dramatic weight loss (especially in children)
- Muscle pains and cramps

- Abdominal pain (may mimic a surgical emergency)
- Symptoms of precipitating illness (e.g., infection)

In young children, early signs are often missed. DKA may mask an underlying illness, so a high index of suspicion is essential for diagnosis.

Examination

The patient appears ill and may be drowsy. Signs of dehydration include:

- Dry skin
- Decreased skin turgor
- Hypotension & tachycardia
- Dry mucous membranes
- Capillary refill may initially be normal due to acidosis-induced vasodilation until severe dehydration impairs tissue perfusion.

Features of acidosis/ketosis:

- Labored respirations (Kussmaul breathing)
- Ketotic breath (fruity, acetone smell)
- Abdominal tenderness

Other findings:

- Altered level of consciousness (assess GCS)
- Decreased reflexes
- Hypothermia or fever (if infection is present)

Causes

The most common scenarios are:

- Infection (~40%)
- Noncompliance with insulin (~25%)
- Previously unknown diabetes presenting for the first time (~15%)

Other associated causes:

- Myocardial infarction (silent in diabetes)
- Cerebrovascular accident
- Complicated pregnancy
- Stress, trauma, surgery
- Alcohol
- Emotional disturbances
- Illicit drugs (e.g., cocaine)

- Heavy use of concentrated carbohydrate beverages (e.g., sodas)
- Acromegaly
- Idiopathic (20–30%)

Investigations & Implications

- **Blood glucose**: Random capillary glucose is acceptable for monitoring, but measure at least one whole blood glucose at presentation. Note: High triglyceride levels may cause falsely low glucose readings.
- **Serum electrolytes**:
    - **Sodium**: For every 100 mg/dL glucose over 100 mg/dL, serum sodium is reduced by ~1.6 mEq/L. Corrected sodium = measured sodium + [1.6 × (glucose – 100) / 100]. Failure of sodium to rise with treatment may indicate increased risk of cerebral edema.
    - **Potassium**: Levels drop quickly with insulin. Initial levels are usually normal or high due to intracellular potassium leakage from acidosis, despite total body potassium deficits.
- **Blood urea and creatinine**: Ketones can falsely elevate creatinine; blood urea is a better measure of dehydration and renal function.
- **Full blood count**: High WBC (>11×109/L>11×109/*L*) or left shift may suggest infection.
- **Infection workup**: Blood cultures, urine cultures, chest X-ray as indicated.
- **Urinalysis**: May indicate urinary infection.
- **Arterial blood gas (ABG)**: pH often <7.3. Venous pH is ~0.03 lower than arterial in DKA and can be used for monitoring.
- **Ketones**: Measure blood/urine acetone and acetoacetic acid. Beta-hydroxybutyrate testing is available; Rothera's test (ketonuria) and Benedict's test (glycosuria) can be used in resource-limited settings.
- **Repeat labs**: Check potassium every 1–2 hours initially; glucose and electrolytes every 2 hours; phosphate every 4 hours if initially low.
- **Head CT**: Consider if altered consciousness (especially in children) to rule out cerebral edema.
- **Amylase**: Often elevated in DKA; can be misleading with abdominal pain. Acute pancreatitis occurs in ~10% of DKA patients.
- **ECG**: Assess for cardiac events or electrolyte abnormalities (hypo-/hyperkalemia).

Management of DKA

Treatment of DKA is as dangerous as DKA itself. It may cause life threatening,
predictable hence avoidable acute complications such as:

- Hypokalemia

- Hypoglycemia
- Hyponatremia
- Fluid overload

Airway management is the primary concern in any patient with a significantly
lowered level of consciousness. Breathing and circulatory stability should also
be established before proceeding to specific management.

General measures

- Gain IV access by a large bore cannula
- If patient's level off consciousness is altered, insert a NG tube to prevent vomiting & aspiration
- If the patient is in a state of respiratory decompensation, consider intubation and ventilation
- If oliguria is present, catheterize and monitor urine out put
- patient should be kept nil by mouth at least 6 hours as gastroparesis is common in DKA.

There are three main problems which should be reversed in DKA.
1. Hyperglycaemia
2. Dehydration
3. Acidosis

Hence insulin treatment & fluid replacement are the mainstay of treatment. As the half life of soluble human insulin is short, continuous replacement is essential.

Fluid Replacement

Time (duration)	0.9% NaCl	KCl*
30 minutes	1 L	20 mmol
1 hour	1 L	20 mmol
2 hours	1 L	20 mmol
4 hours	1 L	20 mmol
6 hours	1 L	20 mmol

If the serum K+ exceeds 5.5 mmol/L, K+ should not be to the replacement fluid. However the levels should be monitored closely as it may drop suddenly due to insulin treatment. If the K+ level is below 3.5 m mol/L at the beginning, consider giving 40 meq of KCl per each litre of fluid replaced.

If BP <90 mmHg, consider colloid. Monitor:

- Blood pressure
- Pulse rate & volume
- Hydration status
- Signs of pulmonary edema
- Urine output

❖ The Insulin infusion should be continued until the acidosis resolves, i.e., until the pH and anion gap are normal, even if the blood glucose levels are normal.

Insulin replacement

Blood glucose concentration [mmol/L]	Rate of Insulin [units/Kg/hour]	Rate of Insulin for a 60 Kg person [units/hour]	Route of insulin	Comments
>20	0.1	6	Use IV infusion	Up to 11 mmol/L use NaCl as the replacement fluid
20-15	0.07	4		
15-11	0.05	3		This is the ideal blood sugar level to maintain until ketonaemia is corrected
11-07	0.03	2		Use 5% dextrose to replace volume.
07-05	0.02	1	Switch to subcutaneous insulin	
<05		**Stop infusion**	**Stop insulin**	

Complications

- Hypokalemia
- Hypophosphatemia
- Metabolic acidosis
- Hypoglycemia
- Cerebral edema (especially in children)
- Thromboembolism (due to dehydration and sluggish perfusion)

Central Nervous System Infections

Introduction

Central nervous system (CNS) infections represent critical diagnoses in the intensive care unit (ICU), with the most significant entities being meningitis, encephalitis, brain abscess, and other parameningeal foci of infection. Although these disease processes have distinct pathophysiological features, their clinical presentations often exist on a spectrum with considerable overlap. Classic meningitis manifests with headache, neck stiffness, and fever, whereas encephalitis is characterized by disturbances in cerebral function, and brain abscesses typically present as space-occupying lesions. However, all three can lead to alterations in mental status, seizures, or coma. A high index of suspicion and rapid recognition are paramount to initiating life-saving therapy without delay.

General Clinical Approach

The initial evaluation of a patient with a suspected CNS infection should focus on characterizing the nature of the symptoms distinguishing meningitic from encephalitic features and determining the pattern of neurological involvement, whether focal or diffuse. When bacterial meningitis is suspected, rapid analysis of cerebrospinal fluid (CSF) is essential. This urgency must be balanced with the imperative to administer antibiotics promptly, as even a delay as short as three hours has been associated with worse outcomes. If a lumbar puncture (LP) must be postponed, antibiotics (and adjunctive dexamethasone) should be administered immediately after blood cultures are drawn, while efforts to obtain CSF continue concurrently.

The LP procedure itself carries risks. In patients with bleeding disorders, it should be deferred until coagulation abnormalities are corrected. The presence of an intracranial mass lesion also poses a hazard. A widespread but often unfounded practice is the routine performance of a head computed tomography (CT) scan prior to LP, driven by concerns for cerebral herniation. Evidence indicates that CT scans rarely reveal contraindications to LP except in patients with specific risk factors: a prior history of CNS disease, immunosuppressive disorders, seizures, moderate-to-severe impairment of consciousness, papilledema, or focal neurological findings.

Acute Bacterial Meningitis

Acute bacterial meningitis is arguably the most definitive emergency in infectious diseases. Delayed or inadequate treatment substantially increases the risk of death or permanent neurological impairment.

Etiology of Bacterial Meningitis

In the United States, bacterial meningitis is predominantly caused by five pathogens. *Streptococcus pneumoniae* is the most common cause in adults, accounting for over half of community-acquired cases, and is associated with high mortality (20-30%) and a significant risk of sequelae. Risk factors include CSF leaks, alcoholism, asplenia, and cochlear implants. *Neisseria meningitidis*, though its incidence has declined due to vaccination, still causes over 10% of cases, with peak incidence in children under five, adolescents and young adults (16-21 years), and adults over 65. It is notable for epidemic potential. *Listeria monocytogenes* is a common cause in neonates and immunocompromised adults and may present with atypical CSF findings, such as a lower white blood cell count and a relatively higher glucose level. *Haemophilus influenzae* type B, once the leading cause of childhood meningitis, is now rare due to vaccination; in adults, it usually occurs in the setting of humoral immune defects. Group B Streptococcus (*Streptococcus agalactiae*) remains the leading cause of neonatal meningitis and is increasingly recognized in adults, particularly those with diabetes.

Other important pathogens include gram-negative bacilli, which are common after neurosurgery, trauma, or in neonates; *Staphylococcus aureus*, associated with neurosurgical procedures, trauma, or systemic infections like endocarditis; and various skin flora and coagulase-negative staphylococci, which are frequent culprits in infections related to CSF shunts or other implanted devices.

Diagnosis of Acute Bacterial Meningitis

The diagnostic pathway begins with recognition. Classic symptoms include fever, headache, nuchal rigidity, and altered mental status. In the ICU, red flags include unexplained altered consciousness, new-onset seizures, or fever in a neurosurgical or immunocompromised patient. High-risk groups include the elderly, alcoholics, asplenic individuals, those with complement deficiency, and patients with CSF shunts or cochlear implants.

Immediate actions in the ICU follow a structured approach. First, securing the airway, breathing, and circulation is paramount, as patients can deteriorate rapidly; anesthesiologists must be prepared for rapid sequence intubation if the Glasgow Coma Scale score drops. Second, two sets of blood cultures should be drawn prior to antibiotic administration to aid pathogen identification. Third, empiric antibiotic therapy—along with dexamethasone for suspected pneumococcal meningitis—must be initiated without delay, ideally within three hours of presentation. Common empiric regimens include ceftriaxone plus vancomycin, with the addition of ampicillin for patients over 50 or those who are immunocompromised to cover *Listeria*. The decision to perform an LP

immediately or obtain a CT scan first is crucial; routine pre-LP CT is not indicated unless specific contraindications exist, such as focal neurological deficits, papilledema, seizures, immunocompromised state, or depressed consciousness.

Performing the LP is a key procedural skill. The patient should be positioned in the lateral decubitus or sitting position with continuous monitoring of ECG, oxygen saturation, and blood pressure. Strict aseptic technique is mandatory, and the opening pressure should be measured, as it is frequently elevated in meningitis.

Interpretation of CSF results is diagnostic. The classic profile of bacterial meningitis includes an elevated opening pressure, a white blood cell count greater than 1000 cells/µL with neutrophil predominance, low glucose (typically below 40 mg/dL), and elevated protein. A Gram stain may reveal bacteria, guiding targeted therapy.

ICU practitioners must anticipate and manage several complications: increased intracranial pressure, manifesting with signs like Cushing's triad and managed with head elevation, osmotherapy, and possibly CSF drainage; seizures, requiring readily available anticonvulsants; hyponatremia from SIADH or cerebral salt wasting, necessitating careful sodium monitoring; septic shock, which may require vasopressor support; and airway compromise, mandating intubation for patients with a GCS below 8.

Therapy for Acute Bacterial Meningitis

Management requires the prompt and aggressive initiation of antimicrobial and anti-inflammatory therapies, alongside vigorous control of complications and measures to prevent disease spread. The overall mortality rate of 20-30% is influenced by both the pathogen—*S. pneumoniae* being among the deadliest—and host factors, with elderly patients being particularly vulnerable. Most patients therefore require ICU-level care.

The cornerstone of antimicrobial therapy is the selection of agents that achieve bactericidal concentrations in the CSF. Empiric therapy is based on age and clinical context, as detailed above, and is refined once CSF Gram stain and culture results are available. Third-generation cephalosporins like ceftriaxone or cefotaxime form the mainstay for most patients. Treatment duration varies: meningococcal meningitis is treated for 7 days, pneumococcal disease for 10-14 days (longer if drug-resistant), gram-negative bacillary meningitis for 3 weeks, and staphylococcal meningitis with bacteremia for 4-6 weeks.

Adjuvant therapy with dexamethasone is critical, especially for suspected or confirmed pneumococcal meningitis. Administered at a dose of 0.15 mg/kg every

six hours for four days, starting before or with the first antibiotic dose, it reduces mortality and neurological sequelae. This benefit is most established in industrialized nations; its routine use is not recommended in developing countries due to inconsistent observed benefits.

Supportive care focuses on managing seizures and increased intracranial pressure. For patients with meningitis related to CSF shunts, optimal management involves initiating antibiotics, removing the entire shunt apparatus, instituting temporary external drainage, and replacing the shunt once follow-up CSF cultures are sterile.

Infection control is a vital component of management. Patients with *N. meningitidis* or *H. influenzae* type B meningitis require droplet precautions until 24 hours after effective antibiotic therapy begins. Chemoprophylaxis is recommended for close contacts: for meningococcal disease, household and daycare contacts, as well as healthcare workers involved in unprotected resuscitation, should receive ceftriaxone, ciprofloxacin, or rifampin; for *H. influenzae* type B, rifampin prophylaxis is indicated for household contacts if there is an unvaccinated child under four or an immunocompromised child present, or if two or more cases occur in the same daycare setting within 60 days.

ENCEPHALITIS

Encephalitis is an inflammatory process of the brain parenchyma that causes neurological dysfunction. Its presentation overlaps significantly with meningitis, leading to the term meningoencephalitis when both are present. Etiologies are diverse, including infectious and noninfectious causes. Viruses are responsible for most infectious cases, but the cause remains unidentified in over 50% of patients. Early recognition of treatable causes—especially herpes simplex encephalitis (HSE), other pathogens, and autoimmune conditions—is critical for prognosis. Even without a specific agent, distinguishing infectious from noninfectious causes provides important prognostic and epidemiological insight.

The etiology is often elusive. Where a cause is found, viruses are most common, with HSV being the leading identifiable agent. Other viruses include VZV, enteroviruses, EBV, HHV-6, and arboviruses. Nonviral infectious causes include *Mycobacterium tuberculosis*, rickettsiae, *Mycoplasma pneumoniae*, *Bartonella* species, *Treponema pallidum*, *Borrelia burgdorferi*, amoebae, *Listeria monocytogenes*, and *Toxoplasma gondii*. Noninfectious causes, particularly autoimmune encephalitis such as anti-NMDAR encephalitis, are increasingly recognized and often present similarly to infectious forms, especially in young women.

Diagnosis and management of encephalitis

I. Diagnostic Approach

The goal is early identification of treatable causes, focusing on (1) HSE, (2) nonviral pathogens, and (3) autoimmune etiologies. Over 50% of cases remain undiagnosed despite investigation.

II. Clinical Evaluation

History should include travel, season, exposures, immune status, and recent infections. Psychiatric and behavioral changes are common. Classic presentations include HSE (fever, personality change, seizures), rabies (hydrophobia, delirium), West Nile virus (flaccid paralysis), and autoimmune encephalitis (psychosis, movement disorders).
Physical exam focuses on neurological assessment, fever, skin rash (though VZV may occur without rash), and respiratory signs.

III. Diagnostic Workup – ICU Protocol

CSF analysis is essential. Collect at least 20 mL, reserving 5–10 mL for future studies. Measure opening pressure. Typical CSF shows <1000 cells/µL (lymphocytic), mildly elevated protein, and normal glucose. RBCs suggest hemorrhagic encephalitis (e.g., HSE); eosinophils suggest parasites/fungi.
Tailor testing: immunocompromised patients require EBV, CMV, HHV-6 PCR; arbovirus season warrants serum/CSF IgM; tick exposure prompts Lyme, Rickettsia, Ehrlichia testing.
Special challenges:

- **Rabies**: nuchal skin biopsy with PCR/fluorescence (premortem).
- **Amebic encephalitis**: CSF wet mount, CDC consultation.
- **Autoimmune encephalitis**: oligoclonal bands, abnormal IgG index, antineuronal antibodies (e.g., anti-NMDAR).

IV. Imaging & Neurophysiology

MRI is recommended for all patients; it may show temporal lobe involvement (suggestive of HSE) and rule out abscess, tumor, or vasculitis. Repeat in 3–7 days if suspicion remains high.

EEG can provide early clues; 80% of HSE cases show temporal foci. Normal EEG correlates with better prognosis.
Brain biopsy is a last resort for progressive deterioration with unknown etiology; samples should undergo comprehensive analysis.

V. Therapy
Empiric: Start acyclovir (10 mg/kg IV q8h) immediately in all suspected cases while awaiting HSV PCR.
Specific:

- **HSE**: Acyclovir IV for 14–21 days; repeat CSF PCR before stopping if symptoms persist.
- **VZV**: Acyclovir.
- **CMV/HHV-6**: Ganciclovir ± foscarnet (in immunocompromised).
- **Rickettsial/Ehrlichial**: Empiric doxycycline in summer months.
- **Autoimmune**: Treat underlying cancer if paraneoplastic; use immunotherapy (plasma exchange, IVIG, immunosuppressants) for antibody-mediated forms.

Supportive Care in ICU

- **Airway**: Intubate if GCS <8 or respiratory failure; minimize prolonged intubation.
- **Seizures**: Have anticonvulsants available; monitor for status epilepticus.
- **Cerebral edema**: Elevate head of bed; use osmotherapy if herniation suspected; maintain euvolemia.
- **High-risk groups**: Patients >65 have worse outcomes; immunocompromised hosts require aggressive workup and management.

Comparative Table: Bacterial Meningitis vs. Encephalitis

Feature	Bacterial Meningitis	Encephalitis
Definition	Inflammation of the meninges (membranes) around the brain and spinal cord.	Inflammation of the brain parenchyma (brain tissue itself).
Overlap with other CNS infections	Can overlap with encephalitis, resulting in meningoencephalitis.	Often overlaps with meningitis, resulting in meningoencephalitis.
Key symptoms	Fever, headache, nuchal rigidity, altered mental status.	Neurological dysfunction (e.g., mental status changes, personality changes, seizures, focal deficits).
Etiology (most common)	*Streptococcus pneumoniae*, *Neisseria meningitidis*, *Listeria monocytogenes*, *Haemophilus influenzae* type B, Group B *Streptococcus*, Gram-negative bacilli, *Staphylococcus aureus*, skin flora (in shunt infections).	Infectious: HSV (most common identifiable), VZV, enteroviruses, EBV, HHV-6, arboviruses, *Mycobacterium tuberculosis*, rickettsiae, *Mycoplasma pneumoniae*, *Bartonella* sp., *Treponema pallidum*, *Borrelia burgdorferi*, amoebae, *Listeria monocytogenes*, *Toxoplasma gondii*. Noninfectious: Autoimmune (e.g., anti-NMDAR encephalitis).
CSF findings	- Elevated opening pressure - WBC >1000 cells/µL (neutrophil predominance) - Low glucose (<40 mg/dL) - Elevated protein - Gram stain may show bacteria	- WBC usually <1000 cells/µL (lymphocytic predominance) - Mildly elevated protein - Normal glucose - RBCs suggest hemorrhagic encephalitis (e.g., HSE) - Eosinophils suggest parasites/fungi - Oligoclonal bands/abnormal IgG in autoimmune cases
Diagnostic priority	Rapid LP for CSF analysis; do not delay antibiotics >3 hours.	Identify treatable causes: HSE, nonviral pathogens, autoimmune etiologies.
Empiric treatment	Antibiotics + dexamethasone (if pneumococcal suspected): - Ceftriaxone + Vancomycin ± Ampicillin (age >50 or	Acyclovir 10 mg/kg IV q8h for all suspected cases until HSV ruled out.

	immunocompromised) - Vancomycin + Cefepime (post-neurosurgery)	
Specific treatment	- Meningococcal: Ceftriaxone × 7 days - Pneumococcal: Ceftriaxone × 10–14 days - Gram-negative: 3 weeks - Staphylococcal: 4–6 weeks	- HSE: Acyclovir IV × 14–21 days - VZV: Acyclovir - CMV/HHV-6: Ganciclovir ± foscarnet - Rickettsial: Doxycycline - Autoimmune: Immunotherapy (IVIG, plasma exchange, immunosuppressants)
Imaging role	Head CT before LP only if: focal deficit, papilledema, seizure, immunocompromised, ↓ consciousness.	MRI recommended for all to assess temporal lobe involvement (HSE), rule out abscess/tumor/vasculitis. Repeat in 3–7 days if high suspicion.
Neurophysiology	Not specified in file.	EEG: 80% of HSE show temporal foci; normal EEG = better prognosis.
ICU supportive care	- Manage increased ICP (elevate HOB, osmotherapy, CSF drainage) - Seizure control - Monitor/treat hyponatremia (SIADH) - Airway protection (intubate if GCS <8) - Manage septic shock	- Airway: Intubate if GCS <8 or respiratory failure - Seizures: Anticonvulsants ready; monitor for status epilepticus - Cerebral edema: Elevate HOB, osmotherapy if herniation, maintain euvolemia - Minimize prolonged intubation to reduce pneumonia risk
Infection control	- Droplet precautions for *N. meningitidis* & *H. influenzae* type B × 24h of antibiotics - Chemoprophylaxis for contacts (Ceftriaxone, Ciprofloxacin, or Rifampin)	Depends on etiology; standard precautions during workup unless specific pathogen identified.
Prognosis	Mortality 20–30%; high risk of neurological sequelae.	>50% cases unknown etiology; HSE has high mortality if untreated; autoimmune forms are treatable.
High-risk groups	Elderly, alcoholics, asplenic, complement deficiency, CSF shunt, cochlear implant.	Age >65 (poorer outcomes), immunocompromised (need aggressive workup).

Toxicological Emergencies in Critical Care

Universal Approach to the Poisoned Patient (Applies to ALL Toxic Exposures)

I. Primary Survey – Immediate Life-Saving Priorities (ABCDE)+F

Airway

▪Assess airway patency, protective reflexes, and risk of aspiration

▪Indications for early intubation include (GCS ≤ 8, Copious secretions (e.g., organophosphate poisoning), Loss of airway reflexes, and Severe respiratory acidosis (hypercapnia)

Breathing

▪High-flow oxygen for *all* suspected poisonings

▪Assess: Respiratory rate and pattern, Oxygen saturation, ABG (early and serial)

▪Mechanical ventilation if: Hypoventilation ± neurologic compromise (DLOC, fit)

Circulation

▪Establish two large-bore IV lines

▪Continuous ECG + basic standards of monitoring (BP, SPO2, Capnography & Temperature)

▪Treat hypotension : Maintain MAP ≥ 65 mmHg, use Isotonic crystalloids first and Vasopressors if refractory hypotension encountered (norepinephrine preferred)

Disability (Neurologic Assessment)

▪GCS scoring, Pupillary size and reactivity

▪Bedside glucose (treat hypoglycemia immediately), Maintain blood glucose if 140-180 mg/dl

Exposure

▪Undress patient completely, Prevent hypothermia

▪Look for transdermal toxins, injection marks, odors

Full documentation & Further management

▪Record findings, treatments, timelines, toxicology results

▪Plan definitive management including ICU transfer.

II. Focused History and Risk Assessment

*(Often obtained from relatives, EMS, or pill bottles) - **6W** for Toxicology History*

▪***Who**? – Patient factors: age,weight, & comorbidities (*liver, renal, cardiac diseases & medications in use*)*

▪***What**? – Substance and amount taken*

▪***When****? – Time of ingestion or exposure*
▪**Where**? **-** Route of exposure (ingestion, inhalation, injection).
▪***Why****? – Intent (accidental / suicidal)*
▪***With*** *what? – Co-ingestions, medications, alcohol*

III. Signs and Symptoms in One-Line Diagnostic Tips for Major Toxicological Emergencies (Clinical Pattern Recognition)

▪Pinpoint pupils + respiratory depression + dry lungs → Opioids overdose
▪Pinpoint pupils + wet lungs + muscle fasciculations → Organophosphate poisoning
▪Tinnitus + hyperventilation → Salicylate toxicity
▪Unexplained bradycardia with hypotension ± hypoglycemia → β-blocker overdose
▪Normal pulse oximetry + headache/confusion ± multiple exposed patients → CO poisoning
▪Mild symptoms followed by marked transaminase elevation (24–72 h) → Paracetamol overdose

IV. Baseline Investigations for Poisoned Patients

▪**Arterial Blood Gas (ABG):**
¤ (pH: 7.35–7.45), ($PaCO_2$: 35–45 mmHg), (PaO_2: 80–100 mmHg at room air), (Serum Bicarbonate HCO_3^- : 22–28 mmol/L), (Blood Glucose: 70–110 mg/dL) (Lactate: <2.0 mmol/L important to rule out the possibility of anaerobic metabolism in shock state or toxin related cellular hypoxia eg. CO or Cyanide toxicity)
¤ Serum Electrolytes (Sodium Na^+ : 135–145 mmol/L), (Potassium K^+ : 3.5–5.0 mmol/L), (Chloride Cl^- : 98–106 mmol/L)
▪**Renal Function Tests (RFT):** Blood Urea Nitrogen (BUN): 7–20 mg/dL and Serum Creatinine: 0.6–1.2 mg/dL
▪**Creatine Phosphokinase (CPK)** 20–200 U/L to check for rhabdomyolysis (muscle fibers destruction → myoglobin casts deposit in renal tubules → AKI (which can occur in CO or organophosphate poisoning)
▪**Liver Function Tests (LFTs):** (AST : <40 U/L), (ALT : <40 U/L), (Bilirubin: 0.3–1.0 mg/dL), (Albumin: 3.5–5.0 g/dL) and (INR: ~1.0)
▪**Electrocardiogram (ECG):** Mandatory for all poisoning patients in addition to **basic standards of monitoring** (BP, SPO2, Capnography & Temperature)
▪**Toxicology Screen:** Qualitative urine/blood screen.
▪**Additional Tests** as Indicated: CXR, urinalysis, coagulation profile, serum pregnancy test, specific drug levels (e.g., acetaminophen, salicylate).

V. Specific Poisonings

1. Paracetamol (Acetaminophen) Toxicity
2. Aspirin (Salicylate) Toxicity
3. Opioid Toxicity
4. Beta-Blocker Toxicity
5. Organophosphorus Poisoning
6. Carbon Monoxide (CO) Poisoning

1. Paracetamol (Acetaminophen) Toxicity

Toxic doses
▪Paracetamol **acute** overdose >150 mg/kg → Potentially toxic acute dose.
▪**Gradual** intake >150 mg/kg/24h → High risk of toxicity

Pathophysiology
▪**Saturation of glucuronidation pathway** → NAPQI accumulation
Normally, paracetamol is safely metabolized by the liver via glucuronidation and sulfation. In overdose, these pathways become saturated. More paracetamol is then metabolized by the Cytochrome P450 system, producing a toxic metabolite called NAPQI.
▪**Hepatic glutathione depletion** → liver necrosis
NAPQI is normally neutralized by binding to glutathione, a protective antioxidant. In overdose, glutathione stores are depleted. Unbound NAPQI then accumulates and causes direct oxidative damage to liver cells (hepatocytes), leading to centrilobular hepatic necrosis (cell death).

Clinical Approach to Paracetamol Toxicity

During the primary survey, focused history, clinical pattern recognition, and baseline investigations, the following should be specifically considered
Clinical Features
▪Early signs: nausea and vomiting
▪Late signs (24-72 hrs after ingestion): right upper quadrant pain due to progressive liver injury
▪Malaise and fatigue

Key Investigations
▪Serum **paracetamol level** at ≥4 hours post ingestion
▪**LFTs, INR, arterial blood gas**
▪Use **Rumack–Matthew nomogram:** A graph to determine when to give NAC in acetaminophen overdose but treatment should not be delayed if paracetamol level test is unavailable

Management

▪**Activated Charcoal**: Activated charcoal reduces paracetamol absorption from the gastrointestinal tract when given early (within 1–2 hours of ingestion), thereby reducing the amount of hepatotoxic metabolite formed and decreasing liver injury risk.

▪**N-Acetylcysteine (NAC) as Antidote:** NAC works by replenishing glutathione stores and acting as an alternative substrate to bind NAPQI, preventing liver injury. It is **immediately indicated if:**

1. Rumack-Matthew nomogram evidence of paracetamol toxicity
2. There is a staggered overdose (gradual) or unknown time of ingestion.
3. There is any evidence of liver injury (elevated ALT/INR) regardless of the paracetamol level.

▪**NAC Dosing Regimens:**

¤ ***IV Protocol*** (21-hour, preferred in ICU): Load: 150 mg/kg over 1 hour, then: 50 mg/kg over 4 hours then: 100 mg/kg over 16 hours

¤ ***Oral Protocol*** (72-hour, for awake patient with preserved airway reflexes): Load: 140 mg/kg, then maintenance: 70 mg/kg every 4 hours × 17 doses (total 18 doses)

¤ *Tip for memory*: (IV: "150 → 50 → 100" over 21 h), (Oral: "140 load → 70 q4h × 17)

¤ Note: Both regimens are **equally effective if started within 8-10 hours** of ingestion. IV is preferred in pregnancy, vomiting, or evolving liver failure.

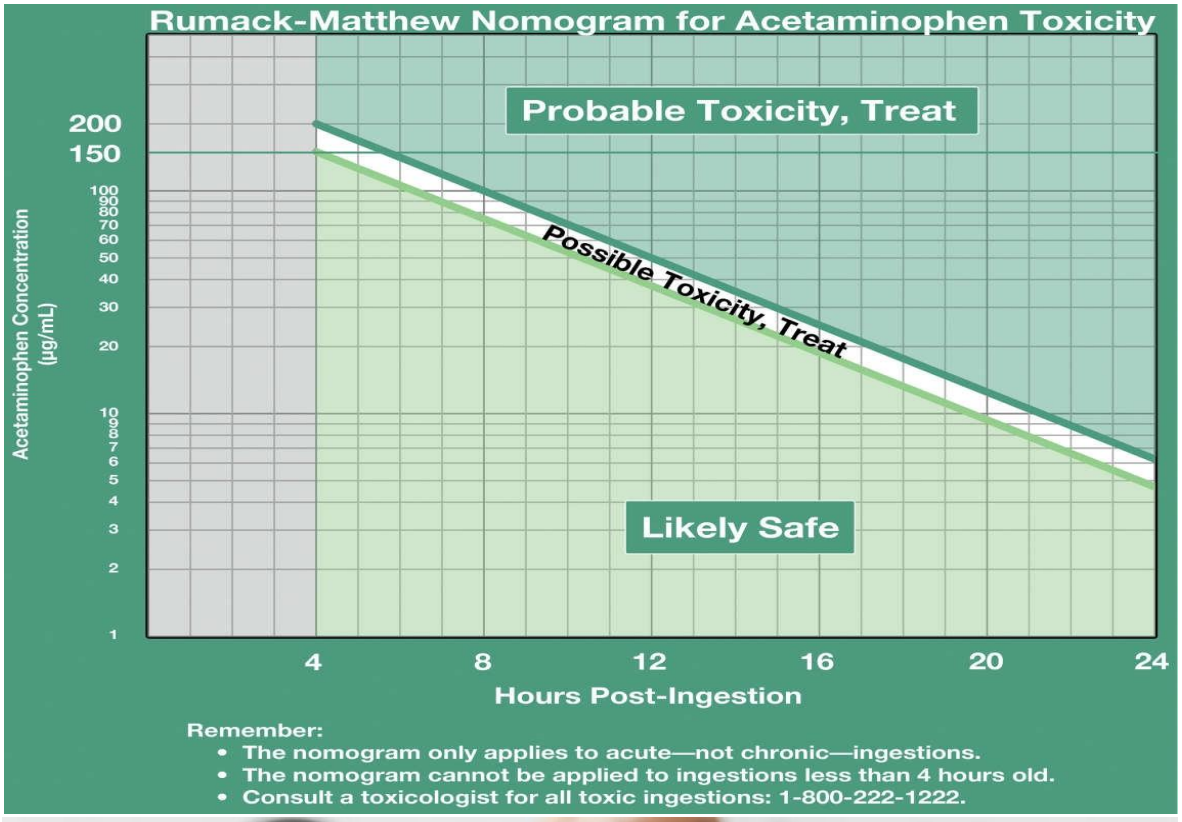
▪**ICU Indications**: Transfer to ICU is required for signs of acute liver failure which include:

¤ *Hepatic Encephalopathy* (altered mental status)

¤ *Coagulopathy* with INR > 2.0

¤ *Metabolic Acidosis* (pH < 7.3 after resuscitation), especially if refractory

¤ *Hypoglycemia, renal failure, or hemodynamic instability.*



vetic

What is Activated Charcoal?

- Made from burned organic material.
- Comes as tablets, powders, or liquid suspensions.
- Highly porous, traps toxins in the stomach.

Activated Charcoal
(Mechanism of Action)

2. Aspirin (Salicylate) Toxicity

Mechanism and effects of salicylate toxicity

▪**Salicylates uncouple oxidative phosphorylation in mitochondria** → mitochondrial dysfunction → failed aerobic metabolism → shifting to anaerobic metabolism → lactic acid and ketoacid accumulation, leading to metabolic acidosis → Compensatory Hyperventilation (CO_2 washout) → respiratory alkalosis

▪**Mixed acid-base disorder**

▪**Cells burn glucose inefficiently** → produce heat (fever, sweating) and acidic waste

▪**Failed energy (ATP) production** → fatigue and organ dysfunction.

Clinical Approach to Salicylate Toxicity

During the primary survey, focused history, clinical pattern recognition, and baseline investigations, the following should be specifically considered

Clinical Features

▪Tinnitus, vomiting, hyperventilation

▪Hyperthermia

▪Altered mental status

Key Investigations

▪Serum **salicylate leve**l (repeat every 2–4 h): to assess severity

▪**ABG / VBG: mixed** respiratory alkalosis + metabolic acidosis

▪**Serum potassium**: often low → worsens acidosis and alkalinization efforts

▪**Serum glucose**: blood glucose levels can be misleading. They may appear normal or slightly high in the blood while the brain is actually experiencing a glucose deficit ("neuroglycopenia") due to its high metabolic demand, so consider giving glucose if there are neurologic symptom
▪**Urine pH**: Measured to guide urine alkalinization; if acidic, administer bicarbonate to raise pH and promote salicylate excretion

Management
▪**Activated charcoal** (early)
▪**IV sodium bicarbonate:** to alkalinize serum untill target serum pH of (7.45–7.55) and target urine pH of ≥ 7.5. Alkalanization **traps salicylate in urine and accelerates its removal**
▪**Potassium** replacement
▪**Hemodialysis** indicated for Severe acidosis, Renal failure, Altered mental status, and Salicylate level >100 mg/dL as acute toxicity. It is advantageous for rapid salicylate removal and correction of acid-base disturbances

3. Opioid Toxicity

Opioids are drugs bind to opioid receptors in the central and peripheral nervous system to produce analgesia, sedation, and euphoria, and can also cause respiratory depression, miosis, & dependence.

Types of opioids:
▪**Natural** (Opiates): Morphine, Codeine
▪**Semi-synthetic:** Heroin, Oxycodone, Hydrocodone
▪**Synthetic**: Fentanyl, Methadone, Tramadol

Natural Opioids Origin and Forms
▪**Plant: Opium Poppy** - Cultivation is strictly regulated and permitted only for medical and scientific purposes under international law (e.g., for morphine and codeine production).
▪**Opium**: The raw, dried latex extracted directly from the poppy pod.
▪**Taryak**: A prepared substance for consumption, typically a mixture of processed opium and other materials (e.g., tobacco). It is a preparation of opium.
▪Active Compound: **Both contain morphine and other alkaloids**. They are highly addictive narcotics with severe health and legal consequences.

Types of Opioid Receptors
▪ **μ (Mu) receptor:** simulation results in analgesia and respiratory depression
▪ **κ (Kappa) receptor:** simulation results in analgesia ± hallucinations

▪ **δ (Delta) receptor:** simulation results in modulation of analgesia and mood

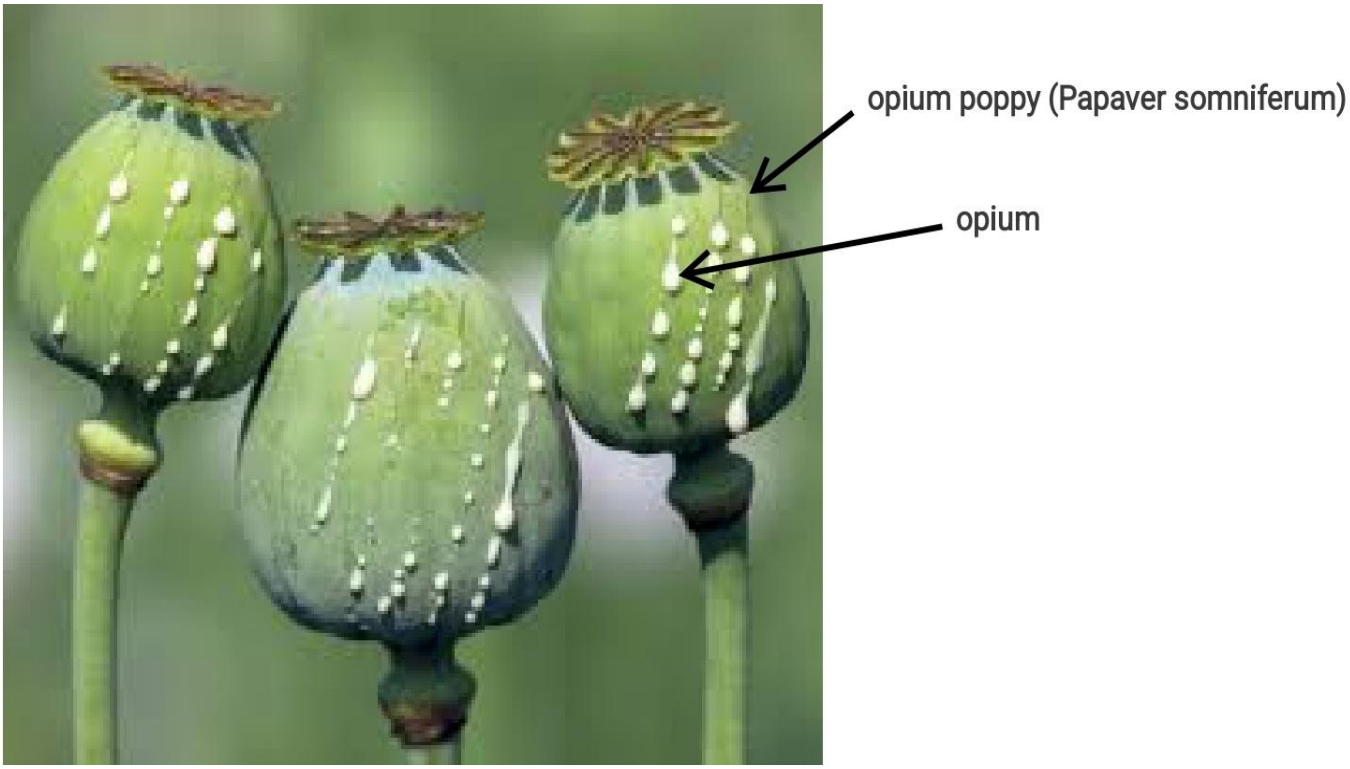
Mechanism of opioids toxicity
▪Excessive μ-opioid receptor activation → CNS depression and respiratory depression

Clinical Approach to Opioids Toxicity

During the primary survey, focused history, clinical pattern recognition, and baseline investigations, the following should be specifically considered

Clinical Features
▪**Classic Triad of (**Pinpoint pupils, Respiratory depression and Decreased consciousness level)

Key Investigations
▪ABG: **respiratory acidosis** (hypoventilation, hypercapnia)
▪Pulse oximetry **(hypoxia)** & capnography **(↑ EtCO2):** for early detection of hypoventilation
▪Serum **acetaminophen level**: mandatory (common co-ingestion)
▪**Toxicology** screen: for blood and urine
▪**Chest X-ray**: if aspiration or non-cardiogenic pulmonary edema suspected



Management of opioids toxicity
▪**Airway** protection is priority
▪**Naloxone:** Continuous infusion for long-acting opioids toxicity **(titrate to ventilation, not arousal)**
Dose: 0.4-2 mg IV bolus, followed by infusion of 0.4-2 mg/hour, **titrated to respiratory rate**
▪**Observe** for re-sedation

4. Beta-Blocker Toxicity

Common Beta-Blockers in use are;
▪**Non-Selective** (Block β_1 & β_2 receptors): Propranolol: Widely available, used for hypertension, anxiety, migraine prophylaxis, and thyrotoxicosis symptoms.
▪**Cardioselective** (Primarily block β_1 receptors): Atenolol & Metoprolol Very common for hypertension and angina
▪**With Additional Alpha-Blocking Activity:** Carvedilol: for heart failure and hypertension.

Clinical Approach to Beta-Blocker Toxicity

During the primary survey, focused history, clinical pattern recognition, and baseline investigations, the following should be specifically considered

Clinical Features of beta-blockers toxicity

▪Bradycardia with hypotension refractory to fluids
▪Hypoglycemia (especially children, propranolol toxicity)
▪Dizziness, syncope and Seizures (especially propranolol)
▪Cardiogenic shock

Hypoglycemia in Beta-Blocker Toxicity

▪**Normally**: Hypoglycemia triggers glucagon and catecholamine release, promoting glycogenolysis and gluconeogenesis to restore blood glucose.
▪**In β-blocker toxicity:** the mechanisms leading to hypoglycemia are:
¤ ***Metabolic***: $\beta_2$blockade prevents catecholamine-mediated glucose production → hypoglycemia
¤ ***Clinical***: β_1/β_2 blockade masks typical hypoglycemia warning signs (tachycardia, tremor, sweating), delaying recognition and leading to neuroglycopenia (confusion, seizures, coma).
▪Key Point: Hypoglycemia may be **severe and silent** in β-blocker overdose.

Key Investigations

▪**Serial ECG:** bradycardia, AV block, QRS/QT changes
▪Serum glucose: **hypoglycemia** (especially children, propranolol)
▪**Serum lactate:** marker of shock / poor perfusion which results in anaerobic metabolism
▪**Echocardiography** (bedside): assess myocardial depression

Management of Beta-Blocker Toxicity

▪**Glucagon (first-line antidote):**
¤ ***Cardiac effect:*** Increases intracellular cAMP → improves heart rate and myocardial contractility independent of β-receptors → restores cardiac output.
¤ ***Metabolic effect:*** Stimulates hepatic glycogenolysis and gluconeogenesis → helps correct β-blocker induced hypoglycemia.
▪**High-dose insulin euglycemia therapy (HIE) "insulin-dextrose combination"**/ High-dose insulin is administered with dextrose to enhance myocardial glucose uptake and utilization, thereby improving cardiac contractility. Dextrose is co-infused to maintain euglycemia (normal glucose level) and prevent hypoglycemia. The **therapeutic goal is (hemodynamic support)**, not (glucose reduction).
▪**Vasopressors** / They do NOT reverse beta-blockade but they support perfusion while definitive therapies (glucagon, high-dose insulin) take effect. Target MAP ≥ 65 mmHg is essential to preserve end-organ perfusion
▪**Vasopressors choices in β-Blocker Overdose:**
¤ **First-line: *Norepinephrine***: Strong α_1 vasoconstriction → raises SVR and blood pressure; little dependence on β_1 receptors, which are often blocked
¤ **Second-line / Adjunct (if first-line fails):**

- ***Epinephrine***: α_1 + β_1 effects; may improve contractility, but β_1 effect can be reduced.

-***Vasopressin***: V_1-mediated vasoconstriction via a non-adrenergic pathway.

-***Dobutamine*** **/ Isoproterenol:** Limited benefit; mainly β-agonists—consider only in partial blockade

▪**Lipid emulsion therapy (refractory cases)**/ Especially for lipid-soluble beta-blockers (e.g.,propranolol). Creates a "lipid sink" in the blood to pull the drug out of tissues & reduce its toxic effect

▪**Temporary pacing** if needed/An electrical pacemaker takes over to maintain a safe heart rate. Used for severe bradycardia or heart block unresponsive to drugs.

5. Organophosphorus Poisoning

Introduction: What is Acetylcholinesterase (AChE)

Acetylcholinesterase is a critical enzyme found primarily in the nervous system (at cholinergic synapses and neuromuscular junctions). Its main function is to rapidly break down the neurotransmitter acetylcholine into acetate and choline, terminating nerve signal transmission. This process is essential for normal muscle contraction, cognition, memory, and autonomic nervous system regulation

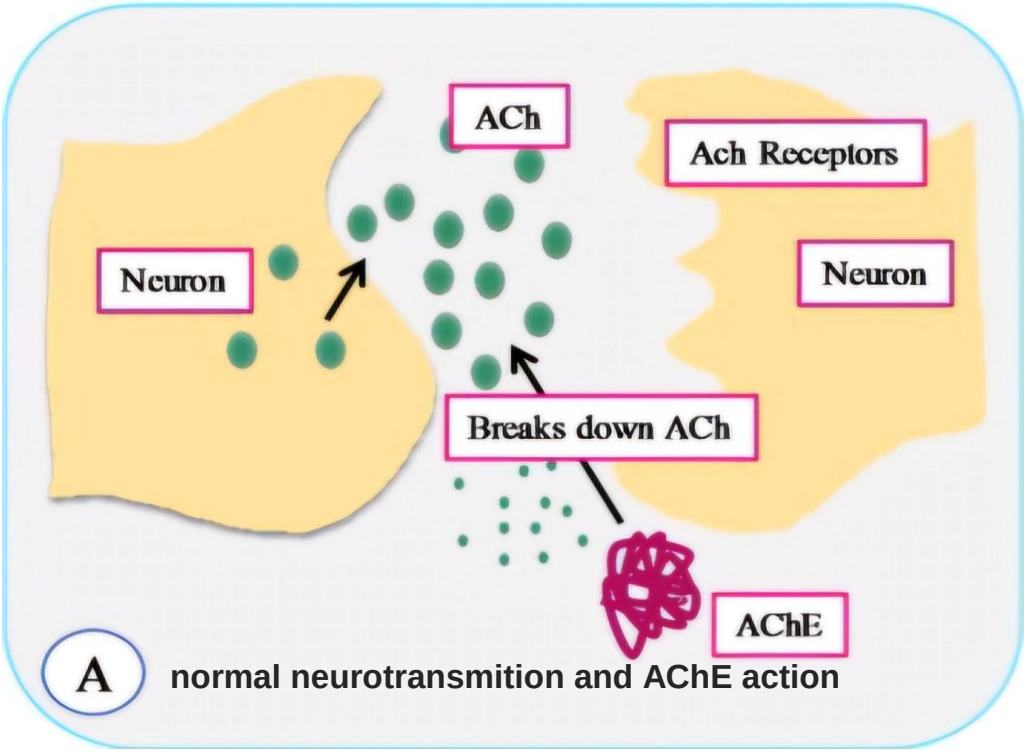
Organophosphate Toxicity Mechanism

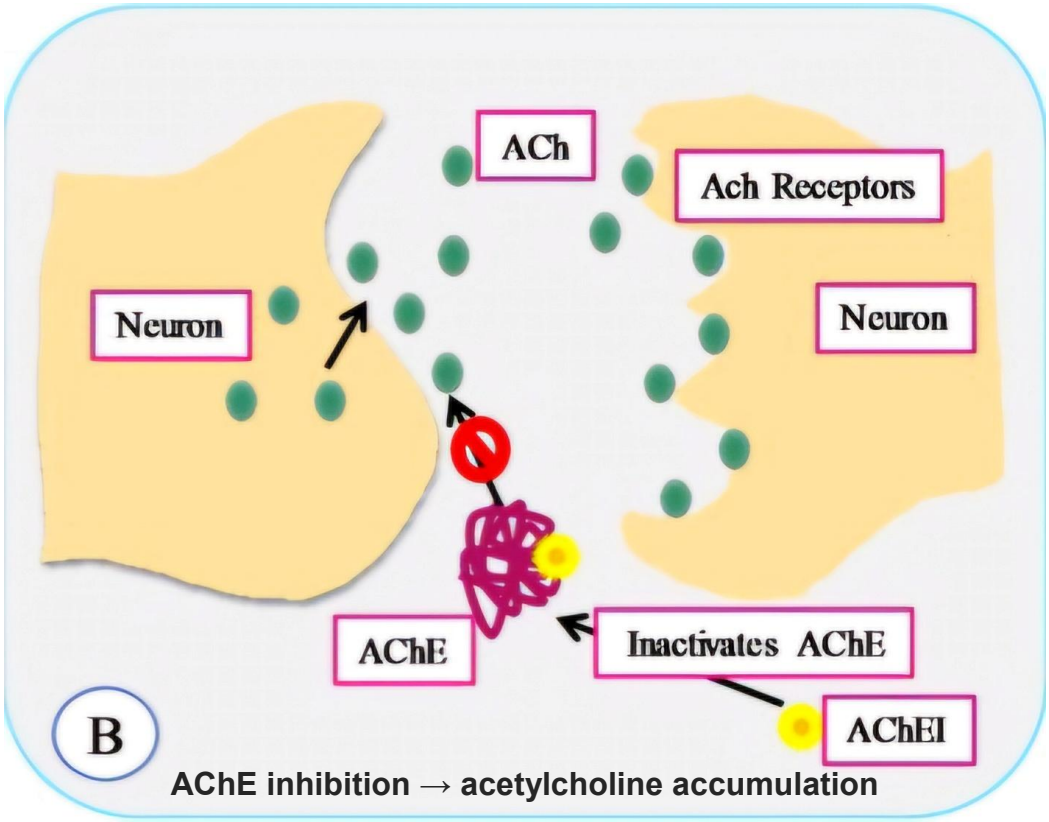
Organophosphates (OPs) are a class of chemicals used in many pesticides (e.g., malathion, parathion) and some nerve agents (e.g., sarin, VX).

They disrupt nervous system function by irreversibly inhibiting acetylcholinesterase, and so called acetylcholinesterase inhibitors AChEI


MAXIDE
Diazinon
ORTHO
Hornet & Wasp Killer
ORTHO
Ortho-Klor
GRANT'S KILLS ANTS
ANT & SPIDER KILLER
Ready-To-Use Granules
KILLS ANTS AND SPIDERS
KILLS OTHER LISTED INSECTS


KNOCK OUT
INSECTICIDE
ALL PURPOSE INSECT
SPRAY
KILLS ALL INSECTS
Net:400ml
KNOCK OUT
INSECTICIDE
Multi Insect Killer
Net : 300ml


ACh
Ach Receptors
Neuron
Neuron
Breaks down ACh
AChE
A
normal neurotransmition and AChE action


ACh
Ach Receptors
Neuron
Neuron
AChE
Inactivates AChE
AChEI
B
AChE inhibition → acetylcholine accumulation

What happens (pathophysiological consequences of organophosphate poisoning)

1. **Inhibition of AChE:** OPs bind Irreversibly to AChE enzyme preventing it from deactivating acetylcholine
2. **Resulting physiological effects**
   ¤ Acetylcholine accumulates in synapses and neuromuscular junctions.
   ¤ This causes continuous overstimulation of cholinergic receptors → Parasympathetic Overdrive or so called "**cholinergic crisis**."
3. Target Organ Effects – Cholinergic overstimulation affects specific organs, causing the characteristic **muscarinic, nicotinic, and CNS manifestations** summarized below

Effector Organ / Site	Receptor Class	Response to ACh Stimulation
Heart (SA/AV nodes)	Muscarinic	Bradycardia, slowed AV conduction
Bronchial smooth muscle	Muscarinic	Bronchoconstriction
Bronchial glands	Muscarinic	Increased mucus secretion
Gastrointestinal smooth muscle	Muscarinic	Increased peristalsis, abdominal cramps
Gastrointestinal glands	Muscarinic	Increased secretions
Bladder sphincter	Muscarinic	Relaxation → urination
Pupillary sphincter	Muscarinic	Miosis
Salivary glands	Muscarinic	Salivation
Sweat glands	Muscarinic	Diaphoresis
Skeletal muscle (neuromuscular junction)	Nicotinic	Fasciculations → weakness → paralysis
Central nervous system	Both	Confusion, seizures, coma

Clinical Approach to Organophosphate Toxicity

During the primary survey, focused history, clinical pattern recognition, and baseline investigations, the following should be specifically considered

Clinical symptoms

Signs and symptoms of cholinergic crisis can be remembered by the “ABCD” Mnemonic for Organophosphate Poisoning - Grouped by System as follows:

A – Autonomic Dysfunction (muscarinic): Parasympathetic Overdrive with signs and symptoms of Diarrhea, Urination, Miosis, Bradycardia, Bronchospasm, Emesis, Lacrimation and Salivation

B – Biphasic neuromuscular effects (nicotinic)
• Early phase: <24 hours → muscle fasciculations from continuous nicotinic receptor stimulation
• Late phase: >24 hours → nicotinic receptor desensitization → progressive weakness and paralysis (including respiratory muscles) → Respiratory failure
C – Central Nervous System Effects: (nicotinic & muscarinic) → S&S of Confusion, Seizures, Coma, and Central respiratory depression
D – Diaphoresis and Excess Secretions like Profuse sweating, Salivation and Lacrimation

Key Investigations
▪**Plasma pseudocholinesterase** level: ↓ (diagnostic and follow-up marker)
▪**RBC acetylcholinesterase** (if available): best correlate of severity
▪**ABG**: hypoxia, respiratory acidosis
▪**Chest X-ray:** bronchorrhea, aspiration, pulmonary edema
▪**CPK**: detect rhabdomyolysis in severe cases

Management of Organophosphate Poisoning
▪**Personal protective equipment** for staff
▪**Decontamination** (remove clothing, wash skin)
▪**Atropinization**/ Atropine – blocks muscarinic acetylcholine receptors, reduces secretions and some autonomic symptoms
▪Recommended **Atropine dosing & targets**
¤ ***Initial and subsequent doses***: "Start with 2 mg IV, double every 4 minutes until full atropinization"
¤ ***Target end-points:***
- *Dry lungs* (resolution of bronchorrhea/bronchospasm)
- *Adequate oxygenation*
- *Heart rate > 80 bpm*
- *Systolic BP ≥ 90 mmHg*

▪Key points regarding atropinization
¤ ***Mydriasis may occur late*** or not at all and should NEVER be used as a treatment endpoint
¤ ***Large cumulative atropine doses*** (tens to hundreds of mg) may be required
▪**Antidote**: **Pralidoxime or called 2-PAM** (1g IV over 30 minutes, then infusion of 0.5g /hour) – reactivate AChE if given within the first 6–12 hours of exposure **before aging** (aging is the Irreversible OPs-ACHE Bond formation after which pralidoxime is ineffective)

Mechanism of action of Pralidoxime: Binds to the organophosphate and removes it from the AChE enzyme, reversing neuromuscular paralysis (muscle weakness, respiratory failure). It works alongside with atropine, which treats excessive secretions.
▪**Benzodiazepines** – like Diazepam or Lorazepam for seizures
▪**Supportive care** – especially respiratory support. Mechanical ventilation often required

6. Carbon Monoxide (CO) Poisoning

Carbon Monoxide (CO) – Brief Introduction
Carbon monoxide is a **colorless, odorless, tasteless, non-irritant gas** produced by **incomplete combustion of carbon-containing fuels**. Because it is **undetectable by human senses**, exposure often occurs unknowingly. CO is highly toxic due to its ability to **bind hemoglobin with high affinity**, impairing oxygen delivery and causing **systemic cellular hypoxia**, particularly affecting the brain and heart.

Common Causes of CO Toxicity in Iraq
▪**Incomplete combustio**n from fuel-burning sources: Poorly ventilated or malfunctioning heaters, stoves, generators, and vehicle engines operating in enclosed or inadequately ventilated spaces
▪Traditional and **domestic heating practices**: Indoor combustion of wood, coal, kerosene, or biomass fuels in poorly ventilated environments
▪**Fires and smoke inhalation**: Exposure during house fires or combustion of synthetic materials, particularly in confined spaces
▪**Urban environmental exposure:** Elevated ambient CO levels related to heavy traffic and air pollution in densely populated areas

Mechanism of CO Toxicity
▪CO binds hemoglobin with ~200× the affinity of oxygen → formation of carboxyhemoglobin (COHb) → **impaired oxygen delivery**
▪Inhibition of mitochondrial oxidative phosphorylation → cellular hypoxia → shift to anaerobic metabolism → **lactic acidosis**
▪Causes direct **myocardial** depression and arrhythmias

Clinical Approach to Carbon Monoxide Toxicity
During the primary survey, focused history, clinical pattern recognition, and baseline investigations, the following should be specifically considered

Key Signs & Symptoms
▪Pulse oximetry **may appear normal or falsely reassuring**, as conventional devices cannot differentiate carboxyhemoglobin from oxyhemoglobin

▪Headache, dizziness, confusion, or coma **disproportionate** to SpO_2
▪**Cardiac** ischemia or focal **neurologic** deficits without primary lung pathology
▪**Cherry-red skin**: pathognomonic, but uncommon and should NEVER be relied upon for diagnosis

Key Investigations
▪**CO-oximetry (gold standard):** Multi-wavelength spectrophotometric analysis that directly measures carboxyhemoglobin (COHb) and differentiates it from oxy- and deoxyhemoglobin
▪**Carboxyhemoglobin (COHb) Level (confirmatory)**: Quantifies exposure severity; elevated levels confirm diagnosis and guide treatment decisions (e.g., hyperbaric oxygen)
▪**ABG**: metabolic acidosis ± normal PaO_2, Serum lactate: reveals tissue hypoxia severity
▪**ECG + cardiac enzymes (troponin)**: to rule out the possibility of myocardial injury
▪**Neuroimaging** (if indicated): in case of delayed neurologic sequelae

Carbon Monoxide Oximetry

Cherry-red skin: pathognomonic for CO toxicity, but uncommon

Management of Carbon Monoxide toxicity

▪100% oxygen via non-rebreather oxygen mask delivery
▪Hyperbaric oxygen if:
  ¤ COHb >25% (or >15% in pregnancy)
  ¤ Depressed level of consciousness with preserved airway reflexes; intubation not yet indicated
  ¤ Cardiac ischemia
  ¤ Severe metabolic acidosis

Hyperbaric Oxygen Therapy (HBOT): Administration done by placing the patient in 100% O2 chamber pressurized to 2-3 times the atmospheric pressure, steps are:
▪Place the patient in a hyperbaric chamber
▪Administer 100% oxygen at 2–3 atmospheres absolute (ATA)
▪Typical session duration: 60–90 minutes
▪One or more sessions may be given depending on clinical response and COHb level
▪Goal: Rapidly displace carbon monoxide from hemoglobin and improve tissue oxygen delivery

Mechanism of action of Hyperbaric Oxygen: (HBO_2) helps overcome CO poisoning by:

1. Competition under pressure: At high pressure (e.g., 3 ATA), the huge amount of dissolved oxygen in plasma creates high gradient that forces CO off hemoglobin (half-life: ~20-30 min)
2. Direct life support & neuroprotection: The dissolved oxygen bypasses blocked hemoglobin, directly oxygenating tissues. It also reduces brain swelling and prevents delayed neurological damage

This concludes the comprehensive coverage of the prescribed ministerial curriculum. We hope this material serves as a valuable resource for all students and educators.