LUMA EDUCATIONAL APPS

NBCRNA NCE Comprehensive Review Course

Board preparation for SRNAs and CRNAs

2026 Edition | Aligned to the 2024-2026 NCE Outline

Basic Sciences · Equipment · Pharmacology · Clinical Practice

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Educational resource for nurse anesthesia board preparation

Contents

Created through Luma Educational Apps for nurse anesthesia learners preparing for the NBCRNA National Certification Examination. Visit https://lumaeducationalapps.com/.

COURSE INTRODUCTION

How to Use This Course

This single volume consolidates Luma Educational Apps nurse anesthesia board-prep materials into one organized NCE review. Content is aligned to the 2024-2026 NBCRNA NCE outline and expanded with full A&P, physics, equipment, pharmacology math, and clinical pharmacology deep dives.

- Step 1-Benchmark weak domains against the NCE blueprint weights.
- Step 2-Study by weight: General Principles (35%), Special Populations (25%), Basic Sciences (20%), Equipment/Technology (20%).
- Step 3-Active recall after every chapter: formulas, doses, algorithms, machine failure patterns.
- Step 4-Drill pharmacology math until conversions and infusions are automatic.
- Step 5-Rehearse crisis algorithms (MH, LAST, anaphylaxis, difficult airway, high spinal) until automatic.

Recommended 8-Week Study Plan

- Weeks 1-2: A&P + physics + math foundations.
- Weeks 3-4: Clinical pharmacology deep dives and high-yield drug tables.
- Week 5: Equipment, monitors, checkout, and troubleshooting.
- Week 6: General principles-airway, regional, fluids, positioning, PACU.
- Week 7: Special populations and procedure-specific anesthesia.
- Week 8: Mixed review, crisis drills, weak-area remediation, board-day logistics.

NCE Blueprint at a Glance

- Domain I-Basic Sciences (20%): anatomy/physiology, pharmacology, physics/chemistry, applied math.
- Domain II-Equipment, Instrumentation & Technology (20%): delivery systems, airway devices, monitors, safety systems.
- Domain III-General Principles of Anesthesia (35%): preoperative care, airway, regional, fluids, positioning, pain, PACU.
- Domain IV-Surgical Procedures & Special Populations (25%): procedure-specific anesthesia and special populations.

PART I – BASIC SCIENCES: ANATOMY AND PHYSIOLOGY

Systems-based anatomy and physiology with anesthesia implications.

A Systems-Based A&P Review for the NCE This module is a focused, graduate-level review of the anatomy and physiology most frequently tested on the National Certification Examination (NCE) administered by the NBCRNA. Each of the six systems is organized identically so you can study, compare, and review efficiently.

Every chapter follows the same five-part structure: an Anatomy Overview of the structures that matter clinically, a Physiology Review of the functional concepts you must understand, a quick-reference table of Key Formulas and Normal Values, a detailed section on Anesthesia Implications & Considerations-the heart of the module-and a set of High-Yield Pearls that distill the most testable points.

Anatomy Overview Orient to the structures with direct anesthetic relevance-not an exhaustive dissection, but what changes your plan.

Physiology Review Master the mechanisms. Board questions test why a derangement occurs and how anesthetics perturb normal function.

Formulas & Normal Memorize these. Know the equation, the normal range, and the units. They Values appear in calculation and interpretation items.

Anesthesia Implications The highest-yield section. Drug effects, monitoring, and disease-specific management for induction, maintenance, and emergence.

High-Yield Pearls Rapid final-review bullets. Read these the night before-each is a discrete, testable fact.

4 Neurologic System-CNS & Autonomic Nervous System

Cardiovascular System

Anatomy Overview

The cardiovascular system comprises the heart, arterial tree, venous system, and microcirculation. Key structures with direct anesthetic relevance include:

Heart Chambers and Valves

- The left atrium receives oxygenated blood from four pulmonary veins. The left ventricle (LV) ejects into the aorta through the aortic valve.
- Four cardiac valves maintain unidirectional flow: mitral (bicuspid), tricuspid, aortic, and pulmonic. Aortic and pulmonic valves are semilunar; mitral and tricuspid are atrioventricular.

Coronary Arteries

- The right coronary artery (RCA) supplies the RV, inferior LV wall, and sinoatrial (SA) and atrioventricular (AV) nodes in ~60% of patients (right-dominant circulation).
- Coronary perfusion is diastolic: the LV coronary arteries are compressed during systole by intramyocardial pressure; therefore, perfusion of the LV subendocardium occurs almost exclusively in diastole. This makes tachycardia particularly dangerous in patients with coronary artery disease.

Conduction System

- SA node (right atrium near SVC junction) -> AV node (Koch's triangle at interatrial septum) -> Bundle of His -> left and right bundle branches -> Purkinje fibers.
- Parasympathetic innervation (vagus nerve) slows conduction; sympathetic innervation (T1-T4) accelerates conduction and increases contractility.
- Fibrous pericardium limits acute cardiac dilation. Rapid accumulation of 100-200 mL of pericardial fluid can cause tamponade. Beck's triad: hypotension, muffled heart sounds, jugular venous distension.

The Cardiac Cycle

The cardiac cycle consists of two phases:

- Systole (~1/3 of cycle): isovolumetric contraction -> rapid ejection -> reduced ejection. The aortic valve opens when LV pressure exceeds aortic diastolic pressure (~80 mmHg).
- Diastole (~2/3 of cycle): isovolumetric relaxation -> rapid filling (mitral valve opens) -> reduced filling -> atrial contraction (contributes ~20-25% of EDV). Ventricular relaxation is an active, energy-dependent process (requires ATP for calcium re-uptake into sarcoplasmic reticulum via SERCA2a). Ischemia impairs both systolic contraction and diastolic relaxation.

- S1: Closure of mitral and tricuspid valves (beginning of systole)
- S2: Closure of aortic and pulmonic valves (end of systole; physiologic splitting during inspiration)
- S3: Rapid ventricular filling-associated with CHF (volume overload)
- S4: Atrial contraction against a stiff ventricle-associated with diastolic dysfunction/hypertrophy.

Determinants of Cardiac Output

CO = HR x SV Stroke Volume (SV) is determined by three variables:

- Preload-the end-diastolic ventricular wall tension (approximated clinically by end-diastolic volume,.

EDV, or filling pressure). Increased preload -> increased SV (Frank-Starling mechanism). Clinical surrogates:

- Right ventricular preload: CVP (normal 2-8 mmHg)
- Left ventricular preload: PAOP/wedge pressure (normal 6-12 mmHg)
- Afterload-the impedance to ventricular ejection during systole. For the LV, approximated by SVR.

(systemic vascular resistance). For the RV, approximated by PVR.

- SVR = [(MAP-CVP) / CO] x 80 (normal: 800-1200 dynes-sec-cm-5)
- As afterload increases, SV decreases (inverse relationship).

The Frank-Starling Law: Within physiologic limits, the force of contraction increases as initial sarcomere length increases (i.e., increased preload -> increased SV). This operates because optimal actin-myosin overlap occurs at sarcomere lengths of 2.0-2.2 um; beyond this, force generation decreases. This law ensures that LV and RV outputs are matched over time.

Heart Rate is the most powerful acute regulator of CO. Tachycardia at >160-180 bpm reduces diastolic filling time, potentially decreasing CO. In neonates and infants, CO is predominantly rate-dependent because stroke volume is relatively fixed.

Coronary Perfusion Pressure

Coronary Perfusion Pressure (CPP) = Aortic Diastolic BP-LVEDP

- Normal: ~70-80 mmHg
- Subendocardial perfusion is at greatest risk: subendocardial blood flow = (DBP-LVEDP) x diastolic time.
- Myocardial ischemia risk increases when: DBP decreases, heart rate increases (reducing diastolic time), or LVEDP increases (elevated filling pressures in heart failure)
- The subendocardium is most vulnerable because it is compressed by the highest intramyocardial pressures during systole.

Blood Pressure Regulation

MAP = CO x SVR = DBP + 1/3 (Pulse Pressure) Arterial blood pressure is regulated by:

- Baroreceptors (carotid sinus via CN IX, aortic arch via CN X): respond rapidly to stretch; decrease in BP -> sympathetic activity -> HR, contractility, vasoconstriction.
- RAAS (kidneys): long-term BP regulation via angiotensin II-mediated vasoconstriction and aldosterone-driven sodium retention.
- Chemoreceptors (peripheral: carotid body and aortic arch; central: medullary): respond to hypoxia, hypercapnia, acidosis -> stimulate ventilation and sympathetic outflow.

Key Formulas and Normal Values

Cardiac Output (CO) CO = HR x SV 4-8 L/min

Cardiac Index (CI) CI = CO / BSA 2.5-4.0 L/min/m2

Stroke Volume (SV) SV = EDV-ESV 60-100 mL/beat

Stroke Volume Index (SVI) SVI = CI / HR x 1000 30-60 mL/beat/m2

Ejection Fraction (EF) EF = SV / EDV x 100 >=55%

Mean Arterial Pressure (MAP) MAP = DBP + 1/3 (SBP-DBP) 70-105 mmHg

SVR [(MAP-CVP) / CO] x 80 800-1200 dynes-sec-cm-5

PVR [(MPAP-PAOP) / CO] x 80 150-250 dynes-sec-cm-5

Coronary Perfusion Pressure CPP = DBP-LVEDP ~70-80 mmHg

CVP-2-8 mmHg

PAOP (wedge)-6-12 mmHg

PAP systolic/diastolic-20-30 / 5-15 mmHg 2 DO2 (oxygen delivery) CaO2 x CO x 10 550-650 mL/min/m

CaO2 (1.38 x Hgb x SaO2) + (PaO2 x 0.0031) 18-21 mL/dL

Volatile Anesthetic Effects on the Cardiovascular System

All volatile agents cause dose-dependent decreases in MAP, but by different mechanisms:

Isoflurane (reflex) 0/ (mild) 0/+

Sevoflurane 0 0/ (mild) 0

(at Desflurane 0/ (mild) 0/+ rapid)

+++ halothane 0 0/ (epinephrine)

- Isoflurane is a potent systemic vasodilator; decreases SVR, maintains CO via reflex tachycardia; isoflurane may cause coronary steal in patients with collateral-dependent myocardium (controversial)
- Desflurane at rapid increases in concentration causes sympathetic stimulation (HR, BP transiently)-potentially dangerous in cardiac patients; should not be used for induction.
- Sevoflurane has the most favorable cardiovascular profile among volatile agents; maintains cardiac output; minimal effect on heart rate.
- Volatile anesthetic preconditioning: sevoflurane and desflurane activate mitochondrial K-ATP channels and reduce ischemia-reperfusion injury-clinically relevant in cardiac surgery.

Intravenous Anesthetic Effects

- Propofol: Decreases MAP by vasodilation (SVR) and mild negative inotropy; also decreases HR. Significant hypotension may reduce coronary perfusion pressure-particularly dangerous in CAD, AS, or hypovolemia. Dose: induction 1-2.5 mg/kg IV; reduce by 30-50% in elderly/compromised patients.
- Etomidate: Most hemodynamically stable induction agent; minimal effect on HR, MAP, SVR, or CO; preferred for unstable or cardiac-compromised patients. However, adrenocortical suppression occurs even with single dose-relevant in sepsis.
- Ketamine: Sympathomimetic (stimulates catecholamine release) -> HR, MAP, CO. Paradoxically, in catecholamine-depleted patients (prolonged critical illness), ketamine can be a direct myocardial depressant.

Useful in hemodynamically unstable patients, bronchospasm, and trauma.

- Midazolam: Mild MAP via vasodilation; negative inotrope in high doses; less cardiovascular depression than propofol.
- Dexmedetomidine: alpha2-agonist; decreases HR, MAP, and sympathetic outflow; reduces anesthetic/opioid requirements; initial transient hypertension from peripheral vasoconstriction, followed by hypotension and bradycardia.

Opioid Effects

- Opioids have minimal direct cardiac effects at clinical doses.
- High-dose fentanyl/sufentanil: Used as the primary anesthetic in cardiac surgery; provides hemodynamic stability by blunting the stress response to laryngoscopy and sternotomy. May cause bradycardia via vagal stimulation.
- Morphine: Histamine release -> vasodilation; avoid in hemodynamically unstable patients or documented severe allergy history.
- Remifentanil: Ultra-short acting; causes significant bradycardia and hypotension especially at induction; infusion management is required.

Neuromuscular Blockade Effects

- Succinylcholine: Stimulates both muscarinic (bradycardia, especially in pediatrics or repeat dosing) and nicotinic receptors. Bradycardia prevented by pretreatment with atropine 0.02 mg/kg in children.
- Pancuronium: Vagolytic -> tachycardia, useful in patients who tend toward bradycardia; avoid in CAD where tachycardia may precipitate ischemia.
- Vecuronium/rocuronium: Minimal cardiovascular effects; preferred in cardiac patients.
- Cisatracurium: No cardiovascular effects; Hofmann elimination (preferred in hepatic/renal failure).

Vasoactive Drug Management

Spinal hypotension, Phenylephrine alpha1 SVR, reflex HR vasodilatory shock

Septic shock, vasoplegic Norepinephrine alpha1>beta1 SVR + contractility syndrome

HR, CO, SVR Cardiac arrest, anaphylaxis, Epinephrine alpha1, beta1, beta2 (dose-dependent) low CO states

Vasopressin V1 SVR (no sympathetic) shock, reduces NE requirement

Cardiogenic shock, Dopamine D1, beta1, alpha1 (dose-dep.) CO +/- SVR bradycardia

Cardiogenic shock, low EF Dobutamine beta1 > beta2 CO, SVR states

Ephedrine alpha, beta (indirect) HR, MAP, CO Spinal/epidural hypotension

Myocardial ischemia, Nitroglycerin -> cGMP (veins) preload, coronary dilation hypertensive crises

Hypertensive urgency, aortic Nitroprusside -> cGMP (arterial) SVR (afterload reduction) surgery

Monitoring Considerations

- Arterial line (A-line): Continuous beat-to-beat BP, ABG access; required for major cardiac/vascular surgery; placed in radial, femoral, or brachial artery.
- Pulse pressure variation (PPV) >12-13% and stroke volume variation (SVV) >12-13% predict fluid responsiveness in mechanically ventilated patients with regular rhythm.
- Central venous catheter (CVC): CVP monitoring, vasoactive drug administration, volume resuscitation access.

- Pulmonary artery catheter (PAC): Measures CO (thermodilution), PAOP, SvO2, PVR; indicated in complex cardiac surgery, severe pulmonary hypertension, high-risk cases where preload/afterload optimization is critical.
- Transesophageal echocardiography (TEE): Real-time assessment of ventricular function, volume status (hypovolemia = "kissing papillary muscles"), valvular pathology, air emboli, aortic atherosclerosis; standard of care in cardiac surgery.

Coronary Artery Disease (CAD)

- Maintain HR 50-70 bpm (avoids tachycardia-induced ischemia), DBP >=60 mmHg (preserves CPP), avoid dramatic swings in BP.
- Continue beta-blockers preoperatively; consider fentanyl-based technique to blunt laryngoscopic response.
- Signs of ischemia: new ST-segment changes, new RWMA on TEE, decreased CO

Aortic Stenosis (AS)

- Fixed, pressure-overloaded LV; narrow SV range; "the 5 no's": no tachycardia, no hypotension, no vasodilation, no bradycardia (well, maintain normal SR), no decreased preload.
- Maintain sinus rhythm (atrial kick contributes 30-40% of filling in AS)
- Phenylephrine is preferred vasopressor for treating hypotension (maintains SVR without tachycardia)

Aortic Regurgitation (AR)

- Maintain higher HR (70-90 bpm)-reduces diastolic regurgitant fraction
- Reduce SVR (afterload reduction) to promote forward flow
- Avoid phenylephrine (worsens regurgitation by increasing DBP)

Mitral Stenosis (MS)

- Maintain HR 60-80 bpm (avoid tachycardia-reduces diastolic filling time across stenotic valve)
- Maintain sinus rhythm; atrial fibrillation with rapid ventricular response is very poorly tolerated.
- Beware pulmonary hypertension and RV failure

Mitral Regurgitation (MR)

- Maintain HR 80-100 bpm (minimize diastolic regurgitant volume)
- Reduce SVR (afterload) to promote forward flow; avoid bradycardia and high SVR

Hypertrophic Obstructive Cardiomyopathy (HOCM)

- Maintain HR 50-70, high preload, high SVR-all reduce dynamic LV outflow obstruction.
- Avoid tachycardia, vasodilation, hypovolemia, positive inotropes
- Treatment of acute obstruction: IV fluids, phenylephrine, beta-blockade (NOT ephedrine or dobutamine)

Cardiac Tamponade

- Maintain HR (rate-dependent CO), SVR (to maintain MAP), and preload (adequate filling against elevated pericardial pressure)
- Avoid anything that reduces HR or preload (benzodiazepines, neuraxial, vasodilators)
- Ketamine is often the preferred induction agent
- Pericardiocentesis or surgical pericardiotomy is definitive treatment
- Be prepared for dramatic hemodynamic improvement immediately after drainage

High-Yield Pearls

Coronary perfusion occurs in diastole for the LV. CPP = DBP-LVEDP. Tachycardia reduces CPP by shortening diastolic time AND increasing LVEDP. Propofol causes hypotension through vasodilation and negative inotropy

- Reduce the induction dose in elderly, hypovolemic, or cardiac-compromised patients by 30-50%. Volatile anesthetic ischemic preconditioning (sevoflurane > desflurane > isoflurane): clinically relevant cardioprotection via mitochondrial K-ATP channels.
- May reduce troponin release in cardiac surgery. Desflurane should NOT be used for inhalational induction-rapid concentration increases cause sympathoadrenal surges (tachycardia, hypertension) that can precipitate myocardial ischemia. In HOCM, the dynamic obstruction is worsened by vasodilation, tachycardia, and hypovolemia. Treat hypotension with phenylephrine and IV fluids, NOT ephedrine or dopamine. SVV > 12-13% predicts fluid responsiveness only in patients with regular cardiac rhythm on controlled mechanical ventilation with Vt > 6 mL/kg. Spinal anesthesia causes sympathectomy -> SVR, venous return, HR (from cardiac accelerator fiber blockade at T1-T4 if block is high).
- Treat with IV fluids, phenylephrine, and atropine/ephedrine as needed. Succinylcholine causes bradycardia (especially in children or with a second dose) through muscarinic receptor stimulation.
- Pretreat with atropine in pediatric patients. Ejection fraction alone is not sufficient to assess diastolic dysfunction-patients with EF >55% can have severe heart failure (HFpEF) with markedly impaired diastolic relaxation. Beck's triad of tamponade: hypotension, muffled heart sounds, jugular venous distension. Electrical alternans on ECG is pathognomonic.

Respiratory System

Upper Airway

- Nose and nasopharynx: Filtration, humidification, warming of inspired air. Turbinates provide large mucosal surface area. Rich vascularity provides heat exchange; epistaxis risk with nasopharyngeal airways.
- The cricothyroid membrane lies between the thyroid and cricoid cartilages-the landmark for cricothyrotomy in cannot-intubate/cannot-oxygenate scenarios.
- The recurrent laryngeal nerve (branch of CN X) innervates all intrinsic laryngeal muscles except the cricothyroid (external branch of superior laryngeal nerve). RLN injury (thyroid surgery, mediastinal tumors, aortic aneurysm) causes unilateral or bilateral vocal cord paralysis.

Tracheobronchial Tree

- Trachea: 11-13 cm, bifurcates at carina (T4/T5-angle of Louis). Adult tracheal diameter ~18-22 mm.
- Right main bronchus: shorter, wider, more vertical (~25 degrees from midline) -> right main bronchus intubation most common when ETT advanced too far; foreign body aspiration occurs more often on the right.
- Left main bronchus: longer, more horizontal (~45 degrees from midline) -> used in double-lumen tube placement for one-lung ventilation (DLT with left-sided positioning is preferred in most cases).

Lungs and Pleura

- Right lung: 3 lobes (upper, middle, lower), 10 bronchopulmonary segments
- Left lung: 2 lobes (upper, lower with lingula), 8-9 bronchopulmonary segments

Respiratory Muscles

- Primary inspiratory: Diaphragm (innervated by phrenic nerve C3, C4, C5 - "C3, 4, 5 keeps the diaphragm alive"); contracts and descends during inspiration.
- Accessory inspiratory: Scalenes, sternocleidomastoid, external intercostals
- Expiration: At rest, passive recoil. Active expiration uses internal intercostals, abdominal muscles (rectus abdominis, external/internal obliques).

Alveoli and Gas Exchange Interface

- Approximately 300 million alveoli; total surface area ~70 m2. Gas exchange occurs across an ultrathin (0.2-0.5 um) alveolocapillary membrane.
- Type I pneumocytes: gas exchange (90% of surface); Type II pneumocytes: surfactant production, cell regeneration.
- Surfactant (dipalmitolyl phosphatidylcholine, DPPC): reduces surface tension; prevents alveolar collapse; production begins at 24-28 weeks gestation; mature production by ~35 weeks. Absent in RDS of the newborn.

Tidal Volume (TV) Air moved per breath at rest 500 mL (6-8 mL/kg IBW)

Inspiratory Reserve Volume (IRV) Extra air above TV 1900-3300 mL

Expiratory Reserve Volume

Extra air below TV 700-1200 mL

Remains after maximal exhalation Residual Volume (RV) 1200-1500 mL (20-25 mL/kg) (cannot be measured by spirometry)

Total Lung Capacity (TLC) TLC = TV + IRV + ERV + RV 5800-6000 mL

Vital Capacity (VC) VC = TV + IRV + ERV 4500-4800 mL (60-70 mL/kg)

Inspiratory Capacity (IC) IC = TV + IRV 3500 mL

Functional Residual Capacity FRC = ERV + RV; volume at end of 2300-2500 mL (30 mL/kg) (FRC) normal expiration

Functional Residual Capacity (FRC)-Most Important Volume in Anesthesia FRC is the resting lung volume-the balance point between outward chest wall recoil and inward lung recoil. FRC provides the oxygen reservoir during apnea (e.g., at intubation) and maintains alveolar patency.

- Supine position: ~20% decrease due to cephalad diaphragm shift
- General anesthesia: additional ~20% decrease; total reduction 400-500 mL
- Obesity, pregnancy, abdominal distension, Trendelenburg positioning: further dramatic reductions.
- Muscle paralysis: ~16% further decrease FRC is below closing capacity (CC) when small airways begin to close during normal tidal breathing. This leads to V/Q mismatch and shunting. Clinically relevant in:
- Morbid obesity (CC > FRC even when awake and supine)
- Elderly patients
- All patients when supine under general anesthesia PEEP, CPAP, lung recruitment maneuvers restore FRC.

Ventilation and Perfusion

Minute Ventilation (VE): TV x RR; normal ~5-8 L/min

Alveolar Ventilation (VA): (TV-VD) x RR; normal ~4 L/min

Physiologic Dead Space (VD)

- Anatomical dead space: Conducting airways that do not participate in gas exchange (nose through terminal bronchioles)-approximately 150 mL (2 mL/kg)
- Alveolar dead space: Ventilated alveoli that receive no perfusion (V/Q =; minimal under normal conditions)
- Physiologic dead space = anatomical + alveolar dead space
- VD/VT ratio: normal 0.33 (33%); increases in pulmonary embolism, low CO states, ARDS Bohr Equation: VD/VT = (PaCO2-PECO2) / PaCO2.

V/Q Matching

- Ideal V/Q ratio = 1.0
- Under normal, upright conditions, both ventilation and perfusion are greater at the lung bases (gravity-dependent)
- Perfusion increases more than ventilation toward the bases -> bases have lower V/Q (~0.6), apices have higher V/Q (~3.0)
- This normal V/Q heterogeneity explains the normal A-a gradient (3-16 mmHg in young adults; increases with age up to 20-30 mmHg) West's Lung Zones (upright position):

Zone 1 PA > Pa > Pv Minimal/none hypotension

Zone 2 Pa > PA > Pv Intermittent Variable

Zone 3 Pa > Pv > PA Continuous (most perfusion) Dominant in upright lung

Zone 4 Interstitial pressure > Pa Reduced Pulmonary edema

- True shunt: blood passes through the lung without contacting ventilated alveoli (V/Q = 0)
- Normal physiologic shunt 2-5% (bronchial circulation, thebesian veins)
- Unlike V/Q mismatch, true shunt does NOT respond to supplemental oxygen
- Causes in anesthesia: atelectasis (most common), endobronchial intubation, one-lung ventilation, ARDS, pneumonia Shunt Equation: Qs/Qt = (CcO2-CaO2) / (CcO2-CvO2)

Normal P50 26.7 mmHg (PaO2 at which Hgb is 50% saturated)

Normal SaO2 at PaO2 60 mmHg ~90% (critical threshold-below this, saturation drops precipitously)

Normal SaO2 at PaO2 100 mmHg ~97-99%

Right shift (affinity, tissue O2 unloading, P50):

- Temperature, PaCO2 (Bohr effect), 2,3-DPG, H+ (acidosis) Left shift (affinity, tissue O unloading, P50): 2.
- Temperature, PaCO2, 2,3-DPG, H+ (alkalosis), fetal hemoglobin (HbF), carboxyhemoglobin Bohr Effect: CO2 and acidosis cause right shift in ODC -> promotes O2 unloading in metabolically active tissues. This is a key adaptation linking metabolism to oxygen delivery.

Haldane Effect: Oxygenation of Hgb in the lungs promotes CO2 release (deoxygenated Hgb is a better CO2 carrier).

Compliance and Resistance

Compliance (C) = Volume / Pressure

- Total respiratory compliance = lung + chest wall compliance
- Normal total compliance: 70-100 mL/cmH2O
- Normal lung compliance alone: 150-200 mL/cmH2O
- Normal chest wall compliance: 150-200 mL/cmH2O Compliance decreases with: pulmonary fibrosis, ARDS, atelectasis, surfactant deficiency, pulmonary edema, obesity, increased muscle tone/bronchospasm from a mechanical standpoint when combined with dynamic effects.

Airway Resistance

- Normal resistance: 0.5-2.0 cmH2O/L/sec (spontaneous breathing)
- Resistance is governed by Poiseuille's law: R 1/r4 (radius has the greatest effect)
- Resistance increases: bronchospasm (asthma), secretions, small endotracheal tubes.
- The endotracheal tube itself significantly increases resistance-relevant during weaning.

Control of Breathing

Central (medullary) controllers:

- Dorsal respiratory group (DRG): inspiration; rhythmic breathing pattern
- Ventral respiratory group (VRG): expiration (active)
- Pre-Botzinger complex: respiratory pacemaker
- Pontine respiratory group (pneumotaxic center): fine-tunes breathing rhythm; apneustic center (lower pons) promotes prolonged inspiration Chemoreceptors:
- Central chemoreceptors (ventral medulla): respond to changes in CSF pH and PCO2. PaCO2 is the primary driver of ventilation under normal conditions. A 1 mmHg increase in PaCO2 increases VE by approximately 2-3 L/min.
- Peripheral chemoreceptors (carotid body, aortic arch): respond primarily to hypoxia (PaO2 < 60 mmHg), hypercapnia, and acidosis. Carotid bodies are more important clinically (via CN IX -> NTS). They provide the hypoxic ventilatory drive.

Hypoxic Pulmonary Vasoconstriction (HPV)

- Local pulmonary arterioles constrict in response to alveolar hypoxia (PAO2 < 60 mmHg)
- Diverts blood from hypoxic/atelectatic units to better-ventilated areas -> improves V/Q matching.
- HPV is inhibited by: volatile anesthetic agents (dose-dependent, all agents), vasodilators (nitroprusside, nitroglycerin, calcium channel blockers), high FiO2, hypothermia, acidosis.
- HPV is preserved by: IV anesthetics (propofol, ketamine, opioids-do NOT inhibit HPV)
- Critical during one-lung ventilation (OLV): attenuation of HPV by volatile agents worsens V/Q mismatch; propofol-based TIVA may improve oxygenation during OLV.

Alveolar Gas Equation PAO2 = FiO2 x (PB-PH2O)-PaCO2/RQ ~100 mmHg (room air)

A-a Gradient PAO2-PaO2 3-16 mmHg (increases with age)

VD/VT ratio (PaCO2-PeCO2) / PaCO2 0.25-0.33

PaO2 (normal)-80-100 mmHg

PaCO2 (normal)-35-45 mmHg

SaO2 (normal)-95-100%

P50-26.7 mmHg

FRC ERV + RV 2300-2500 mL (30 mL/kg)

Tidal Volume-6-8 mL/kg IBW

Minute Ventilation TV x RR 5-8 L/min

FEV1/FVC ratio - >0.70 (normal)

Respiratory Quotient (RQ) VCO2/VO2 0.8 (mixed diet)

Alveolar ventilation (TV-VD) x RR ~4-5 L/min

- Spirometry: Obstructive pattern-FEV1/FVC (<0.70), TLC (air trapping); Restrictive pattern-TLC (<80% predicted), normal FEV1/FVC.
- FEV1 < 50% predicted or FEV1 < 0.8 L: high risk of postoperative pulmonary complications; may require preoperative optimization and postoperative ventilation planning.
- Room air SpO2 < 94% on resting: assess for obstructive sleep apnea (OSA), COPD, cardiac disease, baseline V/Q mismatch.
- Six-minute walk test, VO2 max (<15 mL/kg/min -> very high risk for lung resection), and DLCO are used for thoracic surgery risk stratification.
- Smoking cessation: 8 weeks prior -> reduces pulmonary complications; 24-48 hours -> reduces carboxyhemoglobin and improves mucociliary function (short-term benefit); may temporarily increase secretions during the first 1-2 weeks.

Induction of General Anesthesia

- FRC decreases within 15-40 seconds of induction due to loss of tonic diaphragmatic activity and cephalad shift of the diaphragm.
- Formation of atelectasis (mainly in dependent lung regions) occurs almost immediately after induction-prevalent in 90%+ of patients.
- Pre-oxygenation ("denitrogenation") with 3-5 minutes of 100% FiO2 or four vital capacity breaths maximally increases the oxygen reservoir in the FRC, extending safe apnea time.

Safe Apnea Time

- Healthy adult: ~6-8 minutes after thorough pre-oxygenation
- Obese patient: ~2-3 minutes
- Pregnant patient (full-term): ~1.5-3 minutes (reduced FRC + increased O2 consumption)
- Neonate: ~1-2 minutes (high VO2, low FRC)

Volatile Agents and Respiration

- All volatile agents cause dose-dependent respiratory depression: tidal volume, compensatory RR (net alveolar ventilation), blunting of hypercapnic and hypoxic ventilatory responses.
- Ventilatory response to CO2 is progressively blunted: isoflurane > sevoflurane desflurane. At 1 MAC, hypercapnic response is reduced ~50%; at 1.5 MAC, nearly abolished.
- Volatile agents inhibit HPV (dose-dependent): all volatile agents attenuate HPV, worsening shunt during OLV; propofol-based TIVA is preferred by many centers for OLV.
- Bronchodilation: isoflurane and sevoflurane are effective bronchodilators; useful in status asthmaticus. Desflurane is airway-irritating and should be avoided in airway-reactive patients (causes bronchospasm,

coughing, laryngospasm)

Propofol and Respiration

- Respiratory depression similar to volatile agents; causes apnea at induction doses.
- Does NOT inhibit HPV-advantage during OLV
- Effective antiemetic properties (reduces PONV)
- Anti-bronchospastic: attenuates airway reflexes; useful in reactive airway disease.

Opioid Effects on Respiration

- All opioids cause dose-dependent respiratory depression via u-receptor agonism in the brainstem/pre-Botzinger complex.
- Decrease RR (the dominant opioid effect on breathing), decrease TV, blunt hypercapnic ventilatory response.
- Chest wall rigidity (wooden chest syndrome): rapid high-dose fentanyl/alfentanil/remifentanil-impairs ventilation due to thoracic/abdominal muscle rigidity; treat with neuromuscular blockade or naloxone.
- Reverse with naloxone (0.04 mg IV q2 min; avoid precipitating acute withdrawal or pain crisis)

One-Lung Ventilation (OLV)

- Used during thoracic surgery to isolate the operative lung and improve surgical exposure.
- Tools: double-lumen endotracheal tube (DLT-left-sided preferred in most cases); Univent tube; bronchial blocker.
- Physiology: non-ventilated lung continues to be perfused -> intrapulmonary shunt (Qs/Qt); HPV reduces but cannot eliminate this shunt.
- Management of hypoxemia during OLV:
- Apply CPAP (5-10 cmH O) to operative (non-ventilated) lung
- Apply PEEP

2 2 (5-10 cmH O) to dependent (ventilated) lung 4. Alveolar recruitment maneuver 5. Reduce volatile agent 2 concentration (switch to TIVA with propofol if severe) 6. Intermittent two-lung ventilation 7. Clamp pulmonary artery to operative lung (surgical option during pneumonectomy)

Mechanical Ventilation in Anesthesia

Standard ventilator settings during general anesthesia:

- TV: 6-8 mL/kg ideal body weight (IBW)-lung-protective
- RR: 10-14 breaths/min
- FiO2: titrate to SpO2 >= 95%; use lowest FiO2 that maintains adequate oxygenation.
- PEEP: 5-8 cmH2O routine; higher in obese patients or ARDS
- I: E ratio: 1:2 normal; 1:3 or 1:4 in obstructive lung disease (allow adequate expiratory time to prevent auto-PEEP) Lung-Protective Ventilation (ARDS, high-risk patients):
- TV 6 mL/kg IBW (or lower-4 mL/kg in severe ARDS)
- Plateau pressure <30 cmH2O
- PEEP per ARDS Network protocol
- Permissive hypercapnia acceptable (pH > 7.20)

Pathology-Specific Considerations

- Loss of elastic recoil -> dynamic airway collapse -> air trapping -> intrinsic PEEP (auto-PEEP)
- Prolonged expiratory time needed; avoid aggressive ventilation (risk of pneumothorax, hemodynamic compromise from excessive intrathoracic pressure)
- Avoid hypercapnic drive suppression: in severe COPD, chronic CO2 retention leads to hypoxic drive; supplemental O2 should be titrated to SpO2 88-92% (COPD exacerbation). Under anesthesia, ventilation is controlled so this is less of a concern intraoperatively.
- "Pink puffer" (emphysema predominant): thin, barrel-chested, uses accessory muscles, maintains PaO2 at cost of work of breathing.
- "Blue bloater" (chronic bronchitis predominant): obese, cyanotic, elevated PaCO2, polycythemia, cor pulmonale Asthma:
- Reversible airway obstruction from bronchospasm, inflammation, mucus plugging
- Intraoperative bronchospasm: SpO2, peak airway pressure, "shark fin" capnograph waveform (sloped expiratory upstroke)
- Treatment: deepen anesthesia (sevoflurane or propofol), inhaled beta2-agonist (albuterol, 4-8 puffs via ETT adapter), IV epinephrine if severe, IV corticosteroids, magnesium sulfate (bronchodilatory)
- Avoid desflurane, morphine (histamine release), high succinylcholine doses; prefer propofol for induction.

Obstructive Sleep Apnea (OSA)

- Increased sensitivity to opioids and sedatives; increased risk of postoperative airway obstruction.
- STOP-BANG screening tool (Score >= 3 = high risk)
- Perioperative management: minimize opioids (multimodal analgesia, neuraxial, regional blocks), CPAP perioperatively, position upright or lateral during emergence.
- Airway management may be difficult: thick neck, decreased mouth opening, Mallampati III/IV.

FRC decreases ~40% under general anesthesia (supine + anesthetic effect) -> leads to atelectasis and V/Q mismatch. PEEP partially restores FRC. Right main bronchus intubation (most common airway complication with ETT advancement): presents as unilateral breath sounds, SpO, peak airway pressure. Treat by withdrawing ETT 2 2-3 cm. Desflurane is airway-irritant-coughing, breath-holding, laryngospasm, bronchospasm. Avoid in reactive airway disease and for inhalational induction. Use sevoflurane for inhalational induction. HPV is inhibited by volatile agents (dose-dependent). Propofol-based TIVA preserves HPV-clinically relevant during one-lung ventilation. Safe apnea time is dramatically reduced in obese, pregnant, and pediatric patients due to lower FRC and higher VO

- Pre-oxygenate aggressively and consider HFNCO (high-flow nasal cannula oxygenation) during intubation. PaO2 < 60 mmHg corresponds to SpO2 90% - this is the threshold on the steep portion of the ODC where small decreases in PaO2 cause large drops in SaO.
- Oxygen saturation becomes an unreliable safety margin below this point. Capnography (EtCO2) is the most reliable monitor to confirm endotracheal tube placement; normal EtCO2 35-45 mmHg. Low EtCO2 with low CO (low perfusion): differentiate from esophageal intubation by colorimetric CO2 detector and direct laryngoscopy. Anesthesia-related atelectasis occurs in 90%+ of patients within minutes of induction. Lung recruitment with sustained inflation pressure (30 cmH2O x 30 seconds) followed by PEEP reduces atelectasis. The normal A-a gradient is approximately (Age/4 + 4) mmHg. Elevated A-a gradient indicates V/Q mismatch, shunt, or diffusion impairment. Pulse oximetry cannot detect hyperoxia, hypercapnia, or CO poisoning. Carboxyhemoglobin reads as oxyhemoglobin on standard pulse oximetry-use co-oximetry for accurate SpO2 in suspected CO poisoning.

Renal System

The kidneys are retroperitoneal organs located at T12-L3 vertebral levels. Each kidney contains ~1 million nephrons-the functional units. The nephron consists of:

Renal corpuscle (glomerulus + Bowman's capsule)-filtration occurs here

- Proximal convoluted tubule (PCT)-bulk reabsorption
- Loop of Henle (descending and ascending limbs, thick ascending limb)
- Distal convoluted tubule (DCT)-fine-tuning of electrolytes
- Collecting duct
- Final regulation under ADH and aldosterone

Vascular Supply

- Renal arteries branch from the aorta at L1-L2
- Afferent arteriole -> glomerular capillaries -> efferent arteriole -> peritubular capillaries / vasa recta.
- Renal blood flow (RBF): ~1200 mL/min (20-25% of cardiac output)
- Renal plasma flow (RPF): ~600-700 mL/min

Zones of the Kidney

- Cortex: contains glomeruli, PCT, DCT
- Medulla: contains loops of Henle and collecting ducts; medullary blood supply is sparse (vasa recta) -> medullary hypoxia is a concern with reduced renal perfusion.

Glomerular Filtration Rate (GFR)

GFR = Kf x Net Filtration Pressure Net filtration pressure = (Hydrostatic capillary pressure)-(Hydrostatic Bowman's capsule pressure)-(Oncotic capillary pressure)

Normal GFR: 120-125 mL/min (varies with age, sex, body size)

- GFR is autoregulated over a MAP range of 70-160 mmHg through two intrinsic mechanisms:

Filtration fraction (FF) = GFR/RPF = 125/625 0.20 (20%)

Clinical Assessment of GFR

- Serum creatinine: Crude marker; late indicator of GFR decline; rises when GFR has decreased by ~50%.
- BUN (Blood urea nitrogen): Elevated in renal failure, dehydration, GI bleeding (prerenal); BUN/creatinine ratio >20:1 suggests prerenal azotemia.
- Creatinine clearance (Cockcroft-Gault): CrCl = [(140-age) x weight (kg)] / (72 x SCr); multiply by 0.85 for females.
- Cystatin C: More sensitive early marker of GFR decline than creatinine
- CKD staging (KDIGO): G1 (GFR >=90), G2 (60-89), G3a (45-59), G3b (30-44), G4 (15-29), G5 (<15 or on dialysis)

Nephron Function by Segment

Reabsorbs 65% Na+, H2O, Na-K-ATPase (basolateral);

PCT 100% glucose, 100% amino Na-glucose cotransport reabsorption acids, 85% HCO3-(SGLT2, apical)

Descending Loop Freely permeable to water; Aquaporins (AQP1)-of Henle impermeable to solutes

Thick Ascending furosemide action); Aldosterone (modest); reabsorbs Na+, K+, Cl-(25% Loop of Henle generates medullary macula densa TGF of filtered load) via NKCC2 concentration gradient

NCC cotransporter (thiazide Reabsorbs Na+, Cl-(5-10%); PTH (Ca2+ reabsorption), DCT diuretic target); Ca2+ Ca2+ reabsorption under PTH aldosterone channels

RAAS (Renin–Angiotensin–Aldosterone System)

- Renin is secreted from juxtaglomerular cells in response to:
- Beta1-adrenergic stimulation (sympathetic activation during hypovolemia/stress)
- Decreased NaCl delivery to the macula densa
- Renin cleaves angiotensinogen -> Angiotensin I (inactive)
- ACE (lung) converts Angiotensin I -> Angiotensin II (active)
- Angiotensin II effects:
- Potent vasoconstriction (raises MAP)
- Stimulates aldosterone secretion from the adrenal cortex (zona glomerulosa) -> Na+ retention, K+/H+ secretion.
- Stimulates ADH release from posterior pituitary -> water retention
- Directly stimulates PCT Na+ reabsorption
- Constricts efferent arteriole preferentially -> maintains GFR despite decreased RPF (critical in heart failure) ACE inhibitors/ARBs: Block this axis -> vasodilation + reduced aldosterone -> risk of acute kidney injury when combined with reduced renal perfusion (NSAIDs, contrast, hypovolemia). ACE inhibitors should be held the morning of major surgery by many guidelines.

Acid–Base Regulation

The kidneys are the primary organs for long-term acid-base balance (minutes to days vs. immediate ventilatory response).

- Metabolic acidosis (H+): Kidneys increase H+ secretion (distal nephron), generate new HCO3-, increase ammonium (NH4+) excretion.
- Metabolic alkalosis: Kidneys decrease H+ secretion, excrete excess HCO3-in urine.
- Bicarbonate reabsorption: 85% in PCT (carbonic anhydrase-mediated); 15% in collecting duct Anion gap = Na+ - (Cl- + HCO3-); normal = 8-12 mEq/L.
- Elevated anion gap metabolic acidosis (MUDPILES): Methanol, Uremia, Diabetic ketoacidosis, Propylene glycol, Isoniazid/Infection, Lactic acidosis, Ethylene glycol, Salicylates.

Electrolyte Handling Summary

- Potassium: 98% filtered K+ reabsorbed in PCT and ascending loop; final regulation in collecting duct by aldosterone (K+ secretion). Normal serum K+: 3.5-5.0 mEq/L.
- Sodium: 99% of filtered Na+ reabsorbed. Normal serum Na+: 135-145 mEq/L.
- Calcium: Filtered Ca2+ reabsorbed in PCT (~65%), loop of Henle (~25%), DCT (~8%). PTH increases Ca2+ reabsorption at the DCT. Normal ionized Ca2+: 1.0-1.3 mmol/L.
- Magnesium: Primarily reabsorbed in the thick ascending limb. Hypomagnesemia -> hypokalemia (impairs K+ reabsorption) and hypocalcemia.
- Phosphate: PTH inhibits proximal tubule phosphate reabsorption -> urinary phosphate excretion (phosphaturic effect).

GFR Kf x Net filtration pressure 120-125 mL/min

Filtration fraction GFR / RPF ~0.20 (20%)

Creatinine clearance [(140-age) x kg] / (72 x SCr) 80-120 mL/min (males)

BUN: Creatinine ratio BUN / SCr 10-20:1 (normal); >20:1 prerenal

Serum creatinine-0.6-1.2 mg/dL

Serum BUN-8-20 mg/dL

Urine output - >=0.5 mL/kg/hr + Serum Na-135-145 mEq/L + Serum K-3.5-5.0 mEq/L + - - Anion gap Na-(Cl + HCO3) 8-12 mEq/L

RBF - ~1200 mL/min (20-25% of CO)

RPF RBF x (1-Hematocrit) 600-700 mL/min + Osmolality 2 x Na + Glucose/18 + BUN/2.8 275-295 mOsm/kg

Effects of Anesthesia on Renal Function

All anesthetic techniques reduce renal blood flow and GFR by 20-40% through a combination of:

- Decreased CO and MAP -> reduced renal perfusion pressure
- Sympathetic activation during light anesthesia -> renal vasoconstriction
- ADH release (stress response + positive pressure ventilation) -> water retention
- Redistribution of RBF away from the cortex

Specific Agent Effects

- Volatile agents generally preserve renal autoregulation but reduce RBF proportional to reductions in CO/MAP. Isoflurane, desflurane, and sevoflurane are all acceptable.
- Sevoflurane and Compound A: Interaction with soda lime desiccant produces Compound A (fluoromethyl-2,2-difluoro-1-(trifluoromethyl) vinyl ether), which is nephrotoxic in rats. In humans, the clinical relevance is controversial, but low-flow (<2 L/min) sevoflurane is generally avoided in patients with pre-existing renal disease. The FDA recommends >2 L/min fresh gas flow with sevoflurane.
- Sevoflurane and fluoride ions: Sevoflurane undergoes approximately 3-5% hepatic metabolism, releasing inorganic fluoride (F-). Peak serum fluoride concentrations are ~30-50 umol/L-generally below the nephrotoxic threshold of ~50 umol/L seen with methoxyflurane.
- Propofol: No direct nephrotoxicity. Propofol infusion syndrome (PRIS) includes metabolic acidosis, rhabdomyolysis, and renal failure at prolonged high doses (>4 mg/kg/hr for >48 hours)-most relevant in ICU settings.
- NSAIDs (ketorolac): Inhibit prostaglandin synthesis -> afferent arteriole vasoconstriction -> decreased GFR, especially in patients who are already prostaglandin-dependent for renal perfusion (heart failure, cirrhosis, dehydration, elderly). Avoid in perioperative patients with AKI risk.

Drug Dosing in Renal Failure

Pancuronium Significant renal excretion-avoid in renal failure (prolonged blockade)

Vecuronium ~30% renal excretion; mild prolongation in renal failure

Rocuronium Primarily hepatic/biliary; mild renal contribution; generally acceptable

Hofmann elimination-completely independent of renal/hepatic function; Cisatracurium drug of choice in renal failure

Active metabolite M6G accumulates in renal failure-respiratory depression Morphine risk; use with caution

Normeperidine (toxic metabolite) accumulates -> seizures; avoid in renal Meperidine impairment

Safer alternatives; minimal active metabolite accumulation; remifentanil Fentanyl/Sufentanil/remifentanil preferred in renal failure

Midazolam Active metabolite (1-hydroxymidazolam) accumulates; use with caution

Furosemide May require higher doses in CKD to overcome reduced tubular secretion

Increases K+ by ~0.5-1.0 mEq/L (normal fasciculation); may be unsafe if K+ Succinylcholine already >=5.5 mEq/L (risk of life-threatening hyperkalemia in burn, paralysis, crush injury, denervation-upregulated extrajunctional receptors)

Perioperative Renal Protection

Fluid management: Euvolemia is the primary renal protection strategy. Hypovolemia reduces RBF and GFR; hypervolemia -> abdominal compartment syndrome, pulmonary edema. Goal-directed fluid therapy using dynamic indices (PPV, SVV) may improve outcomes.

Maintenance of MAP: MAP >=65-80 mmHg is essential to maintain renal autoregulation; lower MAP thresholds in elderly or chronic hypertensive patients. Vasopressors should be used if vasodilation is the cause of hypotension.

Avoid nephrotoxins: Contrast, NSAIDs, aminoglycosides, vancomycin. N-acetylcysteine (NAC) and IV hydration for contrast-induced nephropathy prevention.

Dopamine at "renal-dose" (0.5-3 ug/kg/min) activates dopamine receptors in renal vasculature -> vasodilation, increased urine output. However, renal-dose dopamine has NOT been shown to prevent AKI or improve renal outcomes in clinical trials (critically ill or major surgery patients). Urine output is not a reliable marker of renal protection.

Mannitol (0.5-1.0 g/kg) is used as a free radical scavenger and osmotic diuretic in high-risk situations (abdominal aortic aneurysm repair, renal transplant). It maintains tubular flow and reduces cellular edema.

N-acetylcysteine: Antioxidant; evidence for renal protection in contrast nephropathy is limited in newer trials.

KDIGO AKI Criteria

- Stage 1: SCr >=1.5x baseline or >=0.3 mg/dL within 48 hours, or UO <0.5 mL/kg/hr x 6-12 hours.
- Stage 2: SCr >=2x baseline or UO <0.5 mL/kg/hr x 12 hours
- Stage 3: SCr >=3x baseline or UO <0.3 mL/kg/hr x 24 hours, or need for RRT High-risk surgical populations: Cardiac surgery (CPB), aortic cross-clamping, major vascular, hepatic resection, trauma, sepsis.

BUN: Cr ratio >20:1 10:1

Urine Na+ <20 mEq/L >40 mEq/L

Urine osm >500 mOsm/kg 290 mOsm/kg (isosthenuria)

FENa = (Urine Na+ x Plasma Cr) / (Plasma Na+ x Urine Cr) x 100

Dialysis and Anesthesia

Patients on dialysis (HD or PD) present complex challenges:

- Electrolyte disturbances: Hyperkalemia most dangerous-verify K+ before elective surgery; schedule surgery early post-dialysis; avoid succinylcholine if K+ >=5.0 mEq/L.
- Fluid status: May be significantly volume-overloaded (right after dialysis) or depleted. Recent HD may cause hypotension from rapid fluid removal.
- Coagulopathy: Uremic platelet dysfunction -> bleeding risk. Desmopressin (DDAVP) 0.3 ug/kg IV can transiently improve platelet function.
- Anemia: Normochromic normocytic anemia from reduced erythropoietin production. Hgb often maintained at 10-12 g/dL with exogenous EPO.
- Avoid: nephrotoxic agents, high-dose morphine, meperidine, NSAIDs.
- Prefer: cisatracurium, fentanyl, remifentanil, propofol, sevoflurane or desflurane in low doses.

GFR autoregulation occurs between MAP 70-160 mmHg via myogenic and tubuloglomerular feedback mechanisms. Outside this range, GFR follows MAP passively. Serum creatinine is insensitive as an early AKI marker-it does not rise until GFR has decreased by ~50% (reserve kidney function). Cystatin C is a more sensitive early marker.

Succinylcholine raises serum K+ by ~0.5 mEq/L via motor end plate depolarization. In patients with denervation injuries, burns, crush injury, or prolonged immobilization, upregulated extrajunctional receptors can cause life-threatening hyperkalemia (K+ rises by 5-10 mEq/L). Use rocuronium with sugammadex reversal instead.

Cisatracurium is the neuromuscular blocker of choice in renal (and hepatic) failure due to Hofmann elimination-organ-independent degradation at physiologic pH and temperature. Compound a from sevoflurane is formed in higher concentrations with low fresh gas flows and with desiccated soda lime.

In practice: maintain fresh gas flow >2 L/min with sevoflurane, especially in patients with pre-existing renal disease. "Renal-dose" dopamine does not protect renal function in critically ill or surgical patients-do not use it for renal protection. Maintain MAP and euvolemia instead.

ACEi/ARBs should be held the morning before major surgery to prevent intraoperative vasodilatory hypotension and reduce AKI risk. This is particularly important in cardiac, vascular, and major abdominal surgery. FENa < 1% = prerenal (intact tubular Na+ reabsorption); FENa > 2% = intrinsic renal failure (ATN). Note: FENa may be falsely low in contrast nephropathy and myoglobinuria.

Treat with DDAVP (desmopressin) and consider dialysis prior to elective major surgery.

Neurologic System

4 Neurologic System: CNS & ANS

- Cerebral cortex: Higher cognitive function, sensory processing, motor control. Divided into frontal, parietal, temporal, occipital lobes.
- Basal ganglia: Voluntary movement modulation; degeneration in Parkinson's disease.
- Thalamus: Relay station for almost all sensory information to the cortex; also involved in consciousness.
- Hypothalamus: Master neuroendocrine regulator; controls pituitary, temperature, thirst, hunger, autonomic functions; produces ADH and oxytocin (released from posterior pituitary).
- Brainstem (midbrain, pons, medulla): Houses respiratory and cardiovascular centers; origin of cranial nerves III-XII. Critical for maintaining consciousness and vital functions. Medullary respiratory center (DRG, VRG), pneumotaxic center (pons), and cardiovascular center are located here.

- Cerebellum: Coordination, balance, fine motor control. Spinal Cord: Extends from the foramen magnum to L1-L2 (conus medullaris) in adults. The spinal cord is shorter than the vertebral column, with the spinal cord ending at L1-L2 and the dural sac ending at S2 (relevant for lumbar puncture performed below L2 to avoid cord injury).

Blood-Brain Barrier (BBB)

- Formed by tight junctions between cerebral capillary endothelial cells, astrocyte end-feet, and pericytes.
- Highly lipid-soluble, non-ionized, low-molecular-weight substances cross readily (most anesthetic agents,.
- Disrupted by: inflammation, infection, traumatic brain injury, ischemia, hypertensive encephalopathy.
- Functionally important: Explains why highly lipid-soluble anesthetic agents (fentanyl, propofol) have rapid CNS onset, while large hydrophilic molecules (mannitol, contrast) do not normally cross.

Ventricular System and CSF

- CSF produced by choroid plexus (~500 mL/day); total CSF volume ~150 mL
- Circulates through lateral ventricles -> foramen of Monro -> third ventricle -> aqueduct of Sylvius -> fourth ventricle -> subarachnoid space (foramen of Magendie, Luschka)
- Absorbed by arachnoid granulations into dural sinuses
- Normal ICP: 5-15 mmHg (supine adult); ventricular CSF pressure measured at lateral ventricle is the gold standard.

Normal CBF: 50-55 mL/100 g/min (whole brain average); gray matter 80 mL/100 g/min; white matter 20 mL/100 g/min

Cerebral Metabolic Rate of Oxygen (CMRO2): 3.0-3.5 mL O2/100 g/min

CBF and CMRO2 are tightly coupled under normal conditions (flow-metabolism coupling): when metabolic activity increases, CBF increases proportionally (functional hyperemia).

Cerebral Perfusion Pressure (CPP)

CPP = MAP-ICP (or MAP-CVP if CVP > ICP)

Normal CPP: 60-100 mmHg

CPP >=60 mmHg Minimum for adequate cerebral perfusion

CPP 60-70 mmHg Target range in TBI (Brain Trauma Foundation guidelines)

CPP >70 mmHg Associated with worse outcomes in TBI (worsens cerebral edema)

Elevated ICP -> reduced CPP. Cerebral ischemia occurs when CPP < 50 mmHg (CBF < 20-25 mL/100 g/min).

Cerebrovascular Autoregulation

The cerebral vasculature maintains constant CBF over a MAP range of approximately 50-150 mmHg in healthy adults. Outside this range, CBF becomes pressure-passive (pressure-dependent).

Factors impacting autoregulation:

- PaCO2: Most potent pharmacologic regulator of CBF.
- CBF changes by 1-2 mL/100 g/min per 1 mmHg PaCO2 change (range 20-80 mmHg)
- Hypercapnia -> cerebral vasodilation -> CBF -> ICP (used therapeutically cautiously for acute ICP crises: hyperventilate to PaCO2 30-35 mmHg)
- Hypocapnia -> cerebral vasoconstriction -> CBF -> ICP (also risk of ischemia if overcorrected)

- PaO2: CBF increases when PaO2 < 50 mmHg (hypoxic vasodilation). Hyperoxia has minimal effect on CBF.
- Temperature: CBF and CMRO2 decrease ~7% per 1 degrees C decrease in body temperature (Q10 effect). Used in cardiac surgery and profound hypothermia for neuroprotection.
- Viscosity: Hemodilution (low Hct) decreases viscosity -> CBF. Severe anemia also triggers vasodilation.

Autoregulation Impairment

- High-dose volatile anesthetics (>1 MAC) impair autoregulation in a dose-dependent manner.
- TBI, severe SAH, chronic hypertension (rightward shift of the autoregulatory curve), hyperventilation for prolonged periods.

Monro-Kellie Doctrine

The cranium is a rigid box; total intracranial volume is fixed: Volume_Brain + Volume_CSF + Volume_Blood = Constant

When one component expands, the others must compensate. Initially, CSF shifts to the spinal subarachnoid space and cerebral veins are compressed (compensation). Once compensatory reserve is exhausted, small increases in volume cause exponential increases in ICP (low intracranial compliance).

ICP Waveforms: Normal ICP waveform has P1 (percussion wave, arterial), P2 (tidal wave), P3 (dicrotic wave). When P2 > P1, intracranial compliance is reduced (pathological).

Hyperventilation (PaCO2 28-35 Cerebral vasoconstriction Rapid, transient ICP mmHg)

Osmotic gradient draws brain water into Mannitol 0.25-1 g/kg Brain water, ICP vasculature

Hypertonic saline (3% or 23.4%) Osmotherapy Cerebral edema; raises MAP

The Autonomic Nervous System (ANS)

Anatomy The ANS has two divisions with anatomically and functionally distinct pathways:

Sympathetic (Thoracolumbar, T1-L2)

- Preganglionic fibers originate in the intermediolateral cell column of the spinal cord (T1-L2)
- Short preganglionic fibers synapse in paravertebral (sympathetic chain) or prevertebral ganglia.
- Long postganglionic fibers innervate effector organs
- Preganglionic neurotransmitter: acetylcholine (ACh) at nicotinic receptors
- Postganglionic neurotransmitter: norepinephrine (NE) at adrenergic receptors (exception: adrenal medulla and sweat glands-ACh)

Parasympathetic (Craniosacral)

- Cranial component: CN III, VII, IX, X (vagus = 75% of parasympathetic outflow)
- Sacral component: S2-S4 (pelvic splanchnic nerves -> pelvic organs, bladder, colon)
- Long preganglionic fibers; short postganglionic fibers at or near target organ
- Both pre-and postganglionic neurotransmitters: acetylcholine (ACh)
- Receptors: muscarinic (postganglionic) and nicotinic (ganglionic)

Adrenergic Receptors

Vascular smooth muscle, iris, Gq -> IP3/DAG -> Vasoconstriction, mydriasis, alpha1 GU tract intracellular Ca2+ contraction

Presynaptic neurons NE release (feedback), alpha2 (inhibitory), vascular smooth Gi -> cAMP vasoconstriction, sedation, muscle, platelets analgesia

Heart (SA/AV node, HR (chronotropy), beta1 myocardium), juxtaglomerular Gs -> cAMP contractility (inotropy), cells renin release

Lungs (bronchial smooth Bronchodilation, vasodilation, muscle), vascular smooth beta2 Gs -> cAMP glycogenolysis, uterine muscle (skeletal/coronary), relaxation uterus, liver

Beta3 Adipose tissue, bladder Gs -> cAMP Lipolysis, bladder relaxation

Neuromuscular junction (skeletal Nicotinic (Nm) Depolarization -> muscle contraction muscle)

Depolarization -> impulse Nicotinic (Nn) Autonomic ganglia (both divisions) transmission

Muscarinic (M1) CNS, gastric glands Gastric acid secretion, CNS actions

Muscarinic (M2) Heart (SA/AV node) HR, conduction velocity

Bronchoconstriction, secretions, Smooth muscle (bronchi, GI, GU), Muscarinic (M3) GI motility, vasodilation (via NO from glands, endothelium endothelium)

"SLUDGE" (Muscarinic excess-cholinergic crisis): Salivation, Lacrimation, Urination, Defecation, GI upset, Emesis

Sympathetic vs. Parasympathetic effects on key organs:

Organ Sympathetic (NE/Epi) Parasympathetic (ACh)

Pupil Dilation-mydriasis (alpha1) Constriction-miosis (M3)

Bladder Retention (alpha urethral) Voiding (M detrusor) 1 3

Blood vessels Vasoconstriction (alpha1) Vasodilation (M3 -> NO, limited)

Cerebral Perfusion Pressure CPP = MAP-ICP 60-100 mmHg

Target CPP (TBI)-60-70 mmHg

Normal ICP-5-15 mmHg (supine adult)

Normal CBF-50-55 mL/100 g/min

CMRO2-3.0-3.5 mL O2/100 g/min

CBF change per PaCO2 1-2 mL/100g/min per 1 mmHg Range: PaCO2 20-80 mmHg

CMRO2 change per degrees C ~7% per 1 degrees C Q10 effect

Total CSF volume - ~150 mL

CSF production rate - ~500 mL/day (~0.35 mL/min)

CSF protein-15-45 mg/dL

45-75 mg/dL (60-70% serum CSF glucose-glucose)

Opioid Effects on Autonomic Tone

0/ 0/ 0/ Preserved Preserved dose)

Key Clinical Points

- All volatile anesthetics are cerebral vasodilators-they increase CBF despite reducing CMRO2 (uncoupling of flow and metabolism = "luxury perfusion") at >1 MAC.
- Propofol reduces CBF and CMRO2 in a coupled fashion; maintains autoregulation and CO2 reactivity.
- Ketamine is contraindicated as the sole agent in patients with elevated ICP (increases CBF, CMRO2, and ICP; however, when given with propofol or midazolam, the ICP increase may be attenuated)
- Hyperventilation to PaCO2 30-35 mmHg can counteract volatile agent-induced ICP elevation, but PaCO2 should not be lowered below 28-30 mmHg (risk of cerebral ischemia)
- Etomidate: preferred induction agent for patients with elevated ICP or reduced CPP reserve because it ICP without MAP -> maintains CPP.

Neuroanesthesia Principles

- Maintain CPP >=60 mmHg (MAP goal often 70-100 mmHg; keep MAP > ICP + 60)
- Avoid hypercapnia (increases ICP) and excessive hypocapnia (cerebral ischemia)
- Avoid hypoxia (PaO2 < 60 mmHg -> cerebral vasodilation, ICP)
- Avoid hypo-osmolality (cerebral edema); maintain serum osmolality 290-320 mOsm
- Maintain normoglycemia (hyperglycemia worsens ischemic brain injury via anaerobic glycolysis -> lactic acidosis; hypoglycemia also injurious)
- Temperature management (avoid hyperthermia; controlled hypothermia in select cases)

Induction for neurosurgery (craniotomy with elevated ICP):

- Pre-oxygenate well
- Lidocaine 1.5 mg/kg IV 3 minutes before laryngoscopy (blunts ICP spike from intubation)
- Fentanyl 1-2 ug/kg +/- esmolol to blunt hemodynamic response
- Propofol or thiopental for induction (ICP)
- Rocuronium or vecuronium (avoid succinylcholine if suspected raised ICP-though risk of ICP increase is mild and transient; for RSI, succinylcholine remains acceptable)
- Avoid high concentrations of volatile agents (use <=1 MAC; supplement with propofol or opioid infusion)
- Hyperventilate to PaCO2 35 mmHg (target 30-35 mmHg if ICP acutely elevated) Awake craniotomy (brain mapping):
- Used for resection near eloquent cortex (speech/motor areas)
- Asleep-Awake-Asleep (scalp block + propofol/dexmedetomidine)
- Scalp block covers greater/lesser occipital nerves, supratrochlear, supraorbital, auriculotemporal, zygomaticotemporal, great auricular nerves.
- Patient must be cooperative and comfortable; dexmedetomidine provides anxiolysis/sedation without respiratory depression.

Spinal Cord and Regional Anesthesia

Physiologic effects of neuraxial blockade:

- Sympathectomy: vasodilation below level of block -> SVR -> hypotension
- Cardiac accelerator fibers (T1-T4) blockade -> HR, CO ("cardiac sympathectomy")

- Respiratory: high thoracic/cervical spinal/epidural anesthesia can impair accessory respiratory muscles; true respiratory arrest only with high cervical (C3-C5) level affecting the phrenic nerve.

Autonomic Dysreflexia (ADR)

- Life-threatening in patients with spinal cord injury above T6
- Treatment: remove the noxious stimulus (empty bladder); position patient upright; antihypertensives (nitroglycerin, nitroprusside, nifedipine); general or spinal anesthesia (T10 or above) prevents the sympathetic response during surgery Succinylcholine in spinal cord injury: The risk of hyperkalemia from upregulated extrajunctional receptors begins within 24-48 hours of injury and persists for years. Avoid succinylcholine after 48 hours post-injury.

CPP = MAP-ICP. To maintain CPP >60 mmHg when ICP is elevated, MAP must be supported. Do not let MAP drop (avoid excessive hypotension). When ICP is critically elevated, even modest MAP reduction can precipitate cerebral ischemia. Ketamine increases CBF, CMRO2, and ICP-historically contraindicated as a sole agent in TBI/elevated ICP.

However, when combined with propofol or benzodiazepine, the ICP increase may be attenuated. Controversial-use with caution in elevated ICP. Autoregulation of CBF is impaired at >1 MAC of any volatile agent. Maintain <=0.5 MAC or use total IV anesthesia (propofol) in patients with poor intracranial compliance. N2O increases CMRO2 and ICP-usually avoided in neuroanaesthesia.

It should also be avoided in cases where air emboli are a risk (craniotomy in sitting position) and in patients with pneumocephalus. Etomidate is ideal when hemodynamic stability with ICP reduction is needed (induction for a hemodynamically unstable patient with TBI). However, even a single dose causes adrenocortical suppression for 8-24 hours-relevant in septic or critically ill patients.

Hyperthermia dramatically worsens cerebral ischemic injury-avoid intraoperatively, especially during carotid endarterectomy, neurovascular surgery, or in TBI. alpha2-agonists (dexmedetomidine, clonidine): Reduce anesthetic/opioid requirements (MAC by up to 50%), provide anxiolysis and sedation without respiratory depression, decrease sympathetic stress response to intubation/extubation.

Dexmedetomidine is commonly used in neurointensive care for sedation. Autonomic dysreflexia in spinal cord injury >=T6: triggered by stimuli below the level of injury; causes uncontrolled sympathetic crisis -> hypertensive emergency. Spinal or general anesthesia prevents this during surgery.

Cushing's response (reflex): Rising ICP -> hypertension, bradycardia, irregular respiration (Cushing's triad)-a late, ominous sign of brainstem compression/herniation. Succinylcholine should be avoided after 48 hours of spinal cord injury, severe burns, denervation, or prolonged immobilization due to risk of fatal hyperkalemia from upregulated extrajunctional nicotinic receptors.

Endocrine System

The endocrine system consists of glands that secrete hormones directly into the bloodstream to regulate homeostasis, metabolism, and the stress response. Key glands with direct anesthetic relevance:

Pituitary Gland (Hypophysis)

- Located in the sella turcica of the sphenoid bone; connected to the hypothalamus by the pituitary stalk.
- Anterior pituitary (adenohypophysis)-six major hormones: GH, TSH, ACTH, FSH, LH, Prolactin. Regulated by hypothalamic releasing/inhibiting hormones.
- Posterior pituitary (neurohypophysis)-stores and releases ADH (vasopressin) and Oxytocin, produced in the hypothalamus.

Thyroid Gland

- Located anterior to the trachea at C5-T1
- Two lobes connected by an isthmus
- Produces T3 (triiodothyronine) and T4 (thyroxine)-metabolic hormones requiring iodine and thyroglobulin.
- Produces calcitonin (parafollicular/C cells)-lowers serum calcium

Adrenal Glands

- Located retroperitoneally on the superior poles of both kidneys
- Adrenal cortex (80% of gland): Three zones-Zona Glomerulosa (aldosterone), Zona Fasciculata (cortisol), Zona Reticularis (androgens). Mnemonic: "GFR-Salt, Sugar, Sex" (from outside in).
- Adrenal medulla (20% of gland): Chromaffin cells produce and store catecholamines-80% epinephrine, 20% norepinephrine; a modified sympathetic ganglion (receives preganglionic ACh, releases adrenaline directly into bloodstream)
- Located retroperitoneally in the upper left abdomen; head is nestled in the duodenal C-loop.
- Islets of Langerhans (endocrine pancreas, ~1-2% of mass):
- Beta cells (beta): Insulin secretion (most abundant; ~70% of islet cells)
- Alpha cells (alpha): Glucagon secretion (~20%)
- Delta cells (delta): Somatostatin (inhibits both insulin and glucagon)
- F/PP cells: Pancreatic polypeptide

Parathyroid Glands

- Four small glands on the posterior surface of the thyroid
- PTH (parathyroid hormone): primary regulator of calcium and phosphate homeostasis-raises serum calcium (bone resorption, renal calcium reabsorption, activates vitamin D), lowers serum phosphate.

Pituitary–Hypothalamic Axis

The hypothalamic-pituitary axis regulates most endocrine organs:

- CRH (hypothalamus) -> stimulates ACTH (anterior pituitary) -> stimulates cortisol (adrenal cortex) -> negative feedback to hypothalamus and pituitary.
- TRH (hypothalamus) -> stimulates TSH (anterior pituitary) -> stimulates T3/T4 (thyroid) -> negative feedback.
- Anesthesia and surgery activate the HPA axis -> marked increases in ACTH and cortisol (stress response)

Thyroid Hormones

Synthesis: Tyrosine + Iodine -> MIT -> DIT -> T3 + T4 (stored as thyroglobulin in follicles)

- T3 is 3-4x more potent than T4; most circulating T4 is converted to T3 in peripheral tissues (liver, kidney)
- Deiodination process (T4 -> T3 by deiodinase; T4 -> rT3 [reverse T3, inactive] during illness/stress)
- Most T3/T4 is protein-bound (to TBG-thyroxine-binding globulin, albumin, transthyretin); only free hormone is biologically active (fT3, fT4)
- Thyroid hormones increase basal metabolic rate (BMR), increase oxygen consumption, increase cardiac output (HR, contractility), increase GI motility, accelerate drug metabolism.

Normal values

- TSH: 0.4-4.5 mIU/L (most sensitive for thyroid dysfunction)
- Free T4 (fT4): 0.8-1.8 ng/dL
- Free T3 (fT3): 2.3-4.2 pg/mL
- T3 is the active hormone; T4 is the prohormone (storage/transport form)

Cortisol (Glucocorticoid)

- Secreted in a diurnal rhythm (peak in morning ~8 AM, nadir at night)
- Normal secretion: 20-30 mg/day (equivalent to ~5 mg prednisone/day)
- During maximal surgical stress: cortisol secretion can increase 5-10x to 100-300 mg/day.
- Actions: anti-inflammatory, immunosuppressive, stimulates gluconeogenesis, promotes protein catabolism, permissive action on catecholamines, maintains vascular tone, increases cardiac contractility.
- Regulated by: CRH -> ACTH -> cortisol (diurnal and stress-driven)

Aldosterone (Mineralocorticoid)

- Primary regulation by RAAS (angiotensin II) and serum K+; minor ACTH effect
- Actions: promotes Na+ and water retention, K+ and H+ secretion in the collecting duct -> volume expansion, hypertension in excess Cortisol analogues and potency equivalents:

HPA Axis Suppression: Chronic steroid use (>5 mg/day prednisone equivalent for >3 weeks, or >10 mg/day for >2 weeks) leads to HPA axis suppression -> inability to mount a cortisol stress response. This is relevant in the perioperative period.

Pancreatic Hormones and Glucose Regulation

- Secreted by beta cells in response to blood glucose, GLP-1, GIP, amino acids, parasympathetic stimulation.
- Actions: promotes glucose uptake (GLUT4) by muscle and fat, glycogen synthesis, protein synthesis, inhibits gluconeogenesis, lipolysis, glycogenolysis -> anabolic hormone.
- Suppressed by: sympathetic stimulation (alpha2 receptors), somatostatin, cortisol, epinephrine.
- Normal fasting glucose: 70-100 mg/dL; post-prandial: <140 mg/dL Glucagon:
- Secreted by alpha cells in response to blood glucose, sympathetic stimulation, amino acids, stress hormones.
- Actions: promotes glycogenolysis, gluconeogenesis -> blood glucose; stimulates cardiac beta1 receptors (inotropic/chronotropic-used in beta-blocker overdose/calcium channel blocker overdose)

Surgical Stress Response and Glucose

- Surgery triggers catecholamine and cortisol release -> profound insulin resistance + increased hepatic glucose production -> hyperglycemia even in non-diabetic patients.
- Perioperative hyperglycemia (>180-200 mg/dL) is associated with increased infection, delayed wound healing, impaired immune function, and worse neurologic outcomes after cardiac surgery.
- Target: Blood glucose 140-180 mg/dL intraoperatively (avoid hypoglycemia: glucose <70 mg/dL causes cerebral ischemia)

Adrenal Medulla: Catecholamines

The adrenal medulla releases epinephrine (80%) and norepinephrine (20%) directly into the bloodstream:

- Epinephrine: "fight or flight" - HR (beta1), contractility (beta1), bronchodilation (beta2), glycogenolysis, vasodilation in skeletal/coronary vessels (beta2), vasoconstriction in skin/viscera (alpha1)

Fasting blood glucose 70-100 mg/dL

HbA1c <5.7% normal; 5.7-6.4% pre-DM; >=6.5% DM

TSH 0.4-4.5 mIU/L

Free T4 0.8-1.8 ng/dL

Serum cortisol (AM) 10-20 ug/dL

Daily cortisol secretion 20-30 mg/day (basal); up to 300 mg/day (surgical stress)

Serum calcium (total) 8.5-10.5 mg/dL

Serum ionized calcium 1.0-1.3 mmol/L

PTH 15-65 pg/mL

ADH (plasma vasopressin) 1-5 pg/mL

Adrenal Insufficiency and Steroid Stress Coverage

Patients on chronic corticosteroids or with known adrenal insufficiency cannot mount adequate cortisol response to surgical stress -> risk of adrenal crisis (cardiovascular collapse, hypotension refractory to vasopressors, fever, hypoglycemia).

Recommendations for perioperative steroid coverage (based on surgical stress):

Minor (<30 min, local Excision, colonoscopy None; usual daily dose only anesthesia)

Cholecystectomy, hip replacement, Hydrocortisone 50-75 mg IV on day Moderate (< 1-2 hr) colostomy reversal of surgery

Hydrocortisone 100-150 mg IV on day Cardiac, vascular, hepatic, esophageal Major (complex surgery) of surgery + taper over 2-3 days resection back to maintenance

Signs of adrenal crisis: unexplained hypotension unresponsive to fluids and vasopressors, low cortisol level, recent steroid use. Treatment: Hydrocortisone 100 mg IV bolus, then 50 mg q6-8h; IV fluids.

Etomidate: Inhibits 11-beta-hydroxylase -> blocks cortisol synthesis for 8-24 hours after a single induction dose. Controversial as induction agent in septic patients or patients at risk for adrenal insufficiency. For a standard elective case, one dose of etomidate is unlikely to be clinically significant, but for sepsis or critical illness, use propofol or ketamine.

Thyroid Disease

- Slowed metabolism: bradycardia, hypothermia, hyponatremia, delayed gastric emptying (aspiration risk), peripheral neuropathy, macroglossia (difficult airway)
- Cardiovascular: CO, pericardial effusion (tamponade risk), sensitivity to anesthetic/sedative drugs.
- Anesthetic management: preoperative optimization with T4 replacement; avoid deep hypothermia without cardiac protection; smaller anesthetic doses required; risk of prolonged recovery; maintain normothermia.
- Myxedema coma: extreme hypothyroidism -> coma, hypothermia, hypoventilation, cardiovascular collapse. Treatment: IV T4/T3, hydrocortisone, rewarming, airway management. Hyperthyroidism:
- Hypermetabolic state: tachycardia, hypertension, increased CO, VO2, heat intolerance, weight loss, ophthalmopathy (Graves' disease)
- Treatment of thyroid storm:
- Propylthiouracil (PTU) or Methimazole: Block thyroid hormone synthesis 2. Iodine (after PTU):

Wolff-Chaikoff effect-blocks hormone release; must be given AFTER PTU (otherwise iodine provides substrate for more T3/T4 synthesis)

- Beta-Blockers (propranolol 2 mg IV or esmolol infusion): Control HR, T4 -> T3 peripheral conversion (propranolol)
- Hydrocortisone 100 mg IV q8h: Prevents relative adrenal insufficiency; also inhibits T4 -> T3 conversion.
- Treat precipitating cause (antibiotics if infected)
- Preoperative optimization for thyroidectomy: Achieve euthyroid state with antithyroid drugs; beta-blockade for 1-2 weeks; Lugol's iodine 10 drops TID for 10-14 days preoperatively to reduce thyroid vascularity Airway considerations in thyroid disease:
- Large goiter -> tracheal deviation and compression -> potentially difficult airway.
- Pre-anesthetic imaging (CT, X-ray) to assess tracheal compression and deviation
- Awake fiberoptic intubation if significant tracheal compromise
- Tracheomalacia ("floppy trachea") may be present after large longstanding goiter is removed -> potential for post-extubation tracheal collapse; have tracheal stents or plan for delayed extubation.
- Post-thyroidectomy complications: RLN injury (hoarseness), bilateral RLN injury (stridor, respiratory arrest), hypoparathyroidism (hypocalcemia -> laryngospasm, tetany), tracheomalacia, hematoma with airway compression Post-thyroidectomy laryngospasm from hypoparathyroidism/hypocalcemia: Treat with IV calcium gluconate 1-2 g slowly. Monitor: Chvostek's sign (facial twitching with facial nerve percussion) and Trousseau's sign (carpal spasm with BP cuff).

Diabetes Mellitus–Perioperative Management

Type 1 DM: Absolute insulin deficiency (autoimmune beta-cell destruction); always requires insulin; risk of DKA if insulin withheld.

Type 2 DM: Relative insulin deficiency + insulin resistance; managed with oral agents and/or insulin.

Perioperative glucose management:

- Target blood glucose: 140-180 mg/dL intraoperatively and ICU; tighter control (80-110) associated with hypoglycemia risk without clear benefit except in cardiac surgery (some evidence for 140-180 mg/dL target)
- Hold metformin 24-48 hours before surgery (risk of lactic acidosis if AKI, contrast exposure, or prolonged.
- Hold SGLT-2 inhibitors (empagliflozin, dapagliflozin) >=3 days before surgery: Risk of euglycemic DKA-these agents promote ketosis even at normal blood glucose levels; patients may not present with typical hyperglycemia.
- Hold oral sulfonylureas the morning of surgery (hypoglycemia risk)
- Insulin-dependent patients: give 50-80% of usual long-acting insulin dose the night before; hold morning doses; monitor glucose q1hr intraoperatively.
- Glucose-containing IV fluids: avoid large volumes; may use for patients at hypoglycemia risk (NPO, thin patients, Type 1 DM) Diabetic autonomic neuropathy: Gastroparesis -> aspiration risk (impaired gastric motility); silent myocardial ischemia; hypotension with spinal/epidural; abnormal cardiovascular reflexes; temperature dysregulation.

Pheochromocytoma preoperative preparation is critical

- Alpha-blockade first: Phenoxybenzamine (irreversible alpha1, alpha2 blockade) for 10-14 days preoperatively to control hypertension and allow volume expansion (vascular compartment expands as alpha-mediated vasoconstriction is relieved)
- Beta-blockade second (only after adequate alpha-blockade): to control tachycardia and arrhythmias; Never give beta-blockers before alpha-blockers-unopposed alpha-stimulation causes severe hypertension.
- IV fluid resuscitation (patients are often volume-depleted preoperative)

- Phenoxybenzamine target: BP <120/80 sitting; orthostatic drop >=15 mmHg; no ST changes; mild nasal congestion (sign of effective alpha-blockade)
- Intraoperative: arterial line before induction; CVP or PAC; have phentolamine (IV alpha-blocker), nitroprusside, and esmolol immediately available; laparoscopic adrenalectomy is standard.

The two critical intraoperative moments:

- Tumor manipulation: catecholamine surge -> severe hypertension (treat with nitroprusside, phentolamine, nicardipine)
- Venous ligation/tumor removal: catecholamine drops abruptly -> profound hypotension (treat with fluids + norepinephrine, as the patient's receptors are now highly sensitized to catecholamines)

SIADH (Syndrome of Inappropriate ADH Secretion)

- Causes: CNS disease (TBI, SAH, tumor), pulmonary disease, drugs (carbamazepine, SSRIs, vincristine), postoperative (pain, nausea)
- Features: Euvolemic hyponatremia (Na+ <135), low serum osmolality (<275), inappropriately concentrated urine (Uosm >100 mOsm/kg, UNa >40 mEq/L)
- Treatment: Fluid restriction (600-1000 mL/day); hypertonic saline (3%) if severe (Na+ <120 or neurologic symptoms). Correct Na+ at rate <=0.5-1 mEq/L/hr to avoid osmotic demyelination (central pontine myelinolysis)-risk of permanent brain damage if corrected too rapidly.

Diabetes Insipidus (DI)

- Central DI: ADH secretion (pituitary surgery, TBI, neurosurgical procedures, hypothalamic disease)
- Nephrogenic DI: renal response to ADH (lithium, demeclocycline, hypercalcemia, hypokalemia)
- Features: Large-volume dilute urine (Uosm <200 mOsm/kg), serum Na+ >145 mEq/L, serum osmolality >295.
- Treatment: Central DI-desmopressin (DDAVP) 1-4 ug IV/SC; Nephrogenic DI-treat underlying cause, low-salt diet, thiazide diuretics.

Perioperative adrenal crisis presents as unexplained hemodynamic instability (hypotension refractory to fluids and vasopressors). Suspect in patients on chronic steroids. Treatment: hydrocortisone 100 mg IV bolus. Never start beta-blockers before alpha-blockers in pheochromocytoma-this leads to unopposed alpha-stimulation and catastrophic hypertensive crisis.

Thyroid storm precipitants in the OR: inadequate preoperative preparation, surgical stimulation, infection, trauma. Manage with PTU, iodine (after PTU), beta-blockade, hydrocortisone. Etomidate inhibits adrenal steroidogenesis (11-beta-hydroxylase block) with a single dose. In septic patients, adrenocortical suppression may be prolonged and harmful. Propofol or ketamine are alternatives.

SGLT-2 inhibitors (gliflozins) must be held >=3 days before surgery to prevent euglycemic DKA-patients can develop severe ketoacidosis with near-normal glucose, making diagnosis difficult. Hypothyroid patients need reduced anesthetic doses, careful temperature management, and perioperative supplementation if emergency surgery is needed (IV T4/T3 + hydrocortisone).

Hyperglycemia worsens ischemic neurologic outcomes; target 140-180 mg/dL intraoperatively, especially in cardiac and neurosurgical cases. Perioperative hypothyroidism is associated with delayed emergence from anesthesia, hypothermia, bradycardia, and prolonged drug effects-confirm thyroid status preoperatively in patients with suspected disease.

Hepatic System

Gross Anatomy

- The liver is the largest solid organ in the body, weighing approximately 1400-1600 g (2% of adult body weight)
- Located predominantly in the right upper quadrant; protected by the lower ribs
- Divided by the falciform ligament into right and left anatomical lobes; functional (surgical) division is by Cantlie's line (middle hepatic vein)

~75% of total hepatic blood Unregulated (passive); Portal vein ~50-60% of hepatic O2 flow (~1050 mL/min) depends on splanchnic flow

~25% of total hepatic blood Autoregulated by myogenic Hepatic artery ~40-50% of hepatic O2 flow (~350 mL/min) and metabolic mechanisms

~1400 mL/min - - blood flow

- When portal flow decreases, hepatic arterial flow increases compensatorily (mediated by adenosine washout)
- Volatile anesthetic agents and cirrhosis impair the HABR -> liver vulnerable to ischemia when portal flow decreases.
- No reciprocal buffer exists for decreases in hepatic arterial flow

Hepatic Sinusoids and Zones

- Zone 2: Intermediate zone
- Zone 3 (Centrilobular): Adjacent to central hepatic vein; receives deoxygenated blood; most susceptible to ischemic and toxic injury; primary site of drug biotransformation, ketogenesis, glycolysis, glycogen synthesis Zone 3 is the "danger zone": Site of halothane hepatitis (centrilobular necrosis from reductive metabolism under hypoxic conditions producing toxic reactive intermediates), acetaminophen toxicity, and ischemic hepatitis.

Hepatic Functions Overview

The liver performs hundreds of metabolic, synthetic, excretory, and immunological functions:

- Protein synthesis (albumin, clotting factors, binding proteins)
- Carbohydrate metabolism (glycogenesis, glycogenolysis, gluconeogenesis)
- Lipid metabolism (fatty acid oxidation, lipoprotein synthesis, ketogenesis, cholesterol synthesis)
- Bile production and secretion (500-700 mL/day; emulsification of dietary fat)
- Detoxification (ammonia -> urea; bilirubin conjugation)
- Immune function (Kupffer cells-liver-resident macrophages; pit cells-hepatic NK cells)
- Vitamin and mineral storage (A, D, E, K, B12; iron as ferritin, copper)
- Hormone metabolism (thyroid hormone deiodination; sex hormone metabolism; insulin degradation)

Drug metabolism occurs primarily in the smooth endoplasmic reticulum of Zone 3 hepatocytes:

Phase I Reactions (functionalization)

- Oxidation, reduction, hydrolysis-typically introduce or expose a reactive group (-OH, -NH2, -SH)
- Primarily catalyzed by the cytochrome P450 (CYP450) enzyme family (especially CYP3A4, CYP2D6,.
- Produce a more hydrophilic, often still pharmacologically active metabolite
- Products may be more toxic than parent compound (e.g., acetaminophen -> NAPQI via CYP2E1/3A4)

- CYP450 inducers (increase enzyme activity -> decrease drug levels): rifampin, phenytoin, carbamazepine, barbiturates, alcohol (chronic), St. John's Wort, smoking.
- CYP450 inhibitors (decrease enzyme activity -> increase drug levels / toxicity): fluconazole, ketoconazole, erythromycin, clarithromycin, grapefruit juice, amiodarone, cimetidine.

Phase II Reactions (conjugation)

- Attach a hydrophilic moiety to the Phase I product to make it readily excretable via bile or urine.
- Reactions: glucuronidation (most common, via UGT enzymes in smooth ER), sulfation (cytosol), glutathione conjugation (cytosol/mitochondria), acetylation, methylation.
- Products are typically pharmacologically inactive and water-soluble -> renal or biliary excretion Phase III: Membrane transport proteins (ABC transporters, MRP, P-glycoprotein) export metabolites out of hepatocytes into bile or sinusoids.

Both flow and enzyme Intermediate Codeine, quinidine 0.3-0.7 activity

Low extraction Warfarin, Diazepam, Enzyme activity and protein <0.3 (ER < 0.3) Phenytoin, Lorazepam binding (capacity-limited)

High-extraction drugs: Clearance depends primarily on hepatic blood flow (not enzyme capacity). CO -> hepatic blood flow -> clearance -> prolonged drug action. These drugs have a high first-pass effect.

Low-extraction drugs: Clearance depends primarily on enzyme activity and protein binding. Liver disease (enzyme activity, protein binding) significantly impairs clearance. These drugs have low first-pass effect.

Protein Synthesis

The liver synthesizes nearly all plasma proteins:

- Clotting factors (except Factor VIII and von Willebrand factor, which are endothelial/megakaryocyte-derived): Factors II (prothrombin), V, VII, IX, X, XI, XII, XIII, fibrinogen.
- Vitamin K-dependent factors: II, VII, IX, X, Protein C, Protein S-require hepatic gamma-carboxylation with vitamin K. Factor VII has the shortest half-life (~4-6 hours) -> PT/INR is the most sensitive early marker of hepatic synthetic failure and vitamin K deficiency.
- Antithrombin III, Protein C, Protein S: Anticoagulant proteins; reduced in liver failure -> paradoxical coagulopathy (both bleeding and thrombosis risk)
- Indirect (unconjugated) bilirubin: Fat-soluble; produced from heme catabolism (RBC destruction -> unconjugated bilirubin -> bound to albumin in blood -> delivered to liver)
- Direct (conjugated) bilirubin: Water-soluble; conjugated with glucuronate in hepatocytes via UGT1A1 -> excreted in bile.

Causes of jaundice

- Pre-hepatic (unconjugated hyperbilirubinemia): Hemolysis, ineffective erythropoiesis.
- Hepatocellular (mixed): Hepatitis, cirrhosis-impaired conjugation AND excretion.
- Post-hepatic (cholestatic, conjugated hyperbilirubinemia): Bile duct obstruction (gallstones, pancreatic tumor, cholangiocarcinoma)
- Glycogenesis: Liver stores ~70-100 g glycogen; glycogen synthesis after meals when glucose is high.
- Glycogenolysis: Glycogen breakdown during fasting -> raises blood glucose
- Gluconeogenesis: Synthesis of glucose from non-carbohydrate precursors (amino acids, lactate, glycerol) during prolonged fasting -> sustained blood glucose maintenance In liver failure: Hypoglycemia occurs due to inability to perform gluconeogenesis and glycogenolysis; impaired insulin metabolism also contributes (hyperinsulinemia).

With CO, hemorrhage, volatile Total hepatic blood flow ~1400 mL/min (25% of CO) agents

Reduced in portal hypertension, Portal vein blood flow ~1050 mL/min (75% of HBF) cirrhosis

Hepatic artery blood flow ~350 mL/min (25% of HBF) Only autoregulated portion

Albumin half-life 15-20 days Late marker of synthetic failure

PT/INR (normal) PT: 11-15 sec; INR: <1.2 Early synthetic function marker

Most sensitive clotting factor for Factor VII half-life 4-6 hours acute hepatic failure

Serum albumin 3.5-5.0 g/dL <2.5 = severe hypoalbuminemia

AST/ALT (normal) <40 U/L Hepatocellular injury markers

Total bilirubin 0.1-1.2 mg/dL >3 = clinical jaundice

GGT/Alk. Phos. GGT <55; ALP 30-120 U/L Cholestatic markers

Pseudocholinesterase 4,000–12,000 U/L

Child-Pugh Score A (5-6 patients), B (7-9 patients), C (10-15 patients) Risk stratification for liver surgery

90-day mortality prediction in liver 6.43 x ln(INR) + 3.78 x ln(Bili) + 9.57 x MELD Score disease; used for transplant ln(Cr) + 6.82 prioritization

Effects of Anesthesia on Hepatic Blood Flow

All anesthetic agents and techniques reduce hepatic blood flow:

- General anesthesia reduces hepatic blood flow by 20-40% primarily through reductions in CO and MAP.
- Volatile agents: Isoflurane better preserves hepatic blood flow compared to halothane (maintains HAF better); isoflurane preferred over halothane in high-risk hepatic surgery.
- Mechanical ventilation and PEEP: Positive pressure ventilation intrathoracic pressure -> venous return -> portal blood flow.
- Neuraxial anesthesia: Spinal/epidural -> sympathectomy -> vasodilation -> MAP -> hepatic perfusion; but may be beneficial in abdominal surgery by reducing intraoperative opioid needs.

Halothane Hepatitis

- Type 1 (subclinical): Mild transient elevation of LFTs; occurs in 20-30% after repeated halothane exposure; likely reductive metabolite toxicity.
- Modern volatile agents (isoflurane, sevoflurane, desflurane): Much lower metabolism rates -> far lower risk of immune-mediated hepatitis. Desflurane is least metabolized (<0.02%); isoflurane ~0.2%; sevoflurane ~2-5%; halothane ~20%.

Drug Dosing in Hepatic Disease

- Decreased albumin: Free drug fraction for highly protein-bound drugs (propofol, diazepam, phenytoin, warfarin) -> enhanced effect per given dose; titrate carefully.
- Decreased Phase I enzyme activity (CYP450): Prolonged effect of drugs with high extraction ratios and drugs metabolized by CYP450 (e.g., morphine, fentanyl, midazolam, propofol at high doses)
- Decreased pseudocholinesterase: Prolonged succinylcholine duration; prolonged ester local anesthetic hydrolysis.
- Decreased clotting factor synthesis: Coagulopathy; require FFP, cryoprecipitate, vitamin K, or platelets before invasive procedures.

- Portosystemic shunting: Bypasses first-pass hepatic metabolism -> higher bioavailability of oral drugs (clinically relevant for PO opioids, beta-blockers)

Prolonged due to pseudocholinesterase; prolonged relaxation time in severe Succinylcholine liver disease

Preferred NMB-organ-independent (Hofmann); NOT dependent on Cisatracurium hepatic metabolism

Hofmann + ester hydrolysis; acceptable; laudanosine accumulation in liver Atracurium failure (theoretical seizure risk)

Morphine Active metabolite M6G excreted renally; avoid if concurrent renal failure

Hepatic metabolism via CYP3A4; prolonged in severe liver disease; Fentanyl generally well-tolerated for short procedures

Ester hydrolysis by non-specific plasma esterases -> independent of hepatic remifentanil function; preferred in severe liver disease

Extensive CYP3A4 metabolism; significantly prolonged in liver disease; Midazolam active metabolite (1-OH midazolam)

Glucuronidation (Phase II only-less affected by hepatic disease); Lorazepam preferred benzodiazepine in liver failure

Hepatic metabolism but also extrahepatic (lung, kidney); relatively Propofol well-tolerated

Vecuronium ~30-40% biliary excretion; prolonged in hepatic failure

Pancuronium Significant biliary excretion; avoid in severe liver disease

~70% biliary excretion; markedly prolonged in liver failure; reversal with Rocuronium sugammadex reliable

Cirrhosis and Portal Hypertension

Cirrhosis represents end-stage liver fibrosis -> architectural distortion -> portal hypertension (portal pressure >12 mmHg), hyperdynamic circulation (CO, SVR), and multiorgan effects:

Cardiovascular effects

- Hyperdynamic state: CO, SVR, MAP -> nitric oxide-mediated splanchnic vasodilation.
- Cirrhotic cardiomyopathy: reduced contractile response to stress + diastolic dysfunction; normally concealed but unmasked by surgery/sepsis.
- QTc prolongation: risk of ventricular arrhythmias

Respiratory effects

- Hepatopulmonary syndrome (HPS): Intrapulmonary vascular dilation -> arteriovenous shunting -> hypoxemia (orthodeoxia-SpO2 when upright, when supine, opposite of pulmonary edema)
- Portopulmonary hypertension (PoPH): Pulmonary artery hypertension in portal hypertension -> RV overload; severe PoPH is a contraindication to liver transplant.
- Pleural effusions (hepatic hydrothorax), ascites (FRC)

Renal effects

- Hyponatremia (dilutional): due to ADH excess + impaired free water excretion; Na+ <130 in advanced cirrhosis Coagulation:
- Clotting factors (II, V, VII, IX, X, XI) -> PT/INR -> bleeding tendency

- Platelet count (splenic sequestration from portal hypertension) + platelet dysfunction.
- Fibrinogen (severe liver failure) -> hypofibrinogenemia
- Paradoxically, Protein C + Protein S -> thrombotic tendency (balanced coagulopathy); INR alone does not adequately assess hemostasis in cirrhosis.

Neurologic effects

- Hepatic encephalopathy (HE): Due to accumulation of nitrogenous waste products (ammonia, mercaptans, false neurotransmitters) -> altered mental status, asterixis (flapping tremor), confusion -> coma. Grades I-IV. Treatment: lactulose, rifaximin, low-protein diet, treat precipitants (GI bleeding, infection, sedatives).
- Avoid benzodiazepines and opioids in patients with HE or risk thereof-markedly exacerbates encephalopathy.

Esophageal and Gastric Varices

- Portal hypertension -> portosystemic collateral formation -> varices
- Rupture risk increases when portal pressure gradient (HVPG) >12 mmHg; prophylaxis with non-selective beta-blockers (propranolol, nadolol)
- Acute variceal hemorrhage: octreotide (splanchnic vasoconstriction) + endoscopic banding/sclerotherapy + blood products; balloon tamponade (Sengstaken-Blakemore tube) as bridge; TIPS procedure for refractory bleeding.

Liver Transplant Anesthesia

Liver transplantation involves three phases with distinct hemodynamic and metabolic challenges:

Phase 1-Dissection/Hepatectomy:

- Blood loss from coagulopathy, adhesions, portal hypertension collaterals
- Hemodynamic instability; aggressive blood product administration (FFP, PLT, cryoprecipitate)
- Thromboelastography (TEG) or ROTEM to guide targeted coagulation management Phase 2-Anhepatic Phase (liver removed, before reperfusion):
- Venous clamps on IVC and portal vein -> venous return -> CO; venovenous bypass may be used.
- No hepatic metabolism -> drugs accumulate; citrate-containing blood products -> hypocalcemia.
- Increasing metabolic acidosis, hypothermia, hypocoagulability Phase 3-Reperfusion:
- Unclamping of portal and hepatic vessels -> reperfusion syndrome: sudden release of cold, acidotic, hyperkalemic blood from the new liver -> bradycardia, hypotension, arrhythmia, pulmonary hypertension, cardiac arrest.
- Prophylaxis: correct acidosis/hypothermia/hyperkalemia before unclamping; have calcium, bicarbonate, epinephrine ready; maintain EF.
- Massive transfusion protocol; large-bore IV access; arterial line; PA catheter or TEE.

Child-Pugh and MELD Scoring

Child-Pugh Score-perioperative risk classification:

Bilirubin (mg/dL) <2 2-3 >3

Albumin (g/dL) >3.5 2.8-3.5 <2.8

- Class A (5-6): 10% operative mortality
- Class B (7-9): 30% operative mortality
- Class C (10-15): 70-80% operative mortality MELD Score = 3.78 x ln[Bilirubin (mg/dL)] + 11.2 x ln[INR] + 9.57 x ln[Creatinine (mg/dL)] + 6.43.

- Used for liver transplant waiting list prioritization; higher score = higher 90-day mortality.

Hepatic blood flow (1400 mL/min = 25% of CO) is divided: 75% portal vein (passive), 25% hepatic artery (autoregulated). The hepatic arterial buffer response (HABR) compensates for portal flow reduction. Volatile agents and cirrhosis impair HABR. halothane hepatitis (Type 2, immune-mediated): Results from oxidative metabolism -> TFA-hapten -> immune sensitization -> centrilobular necrosis.

Modern volatile agents (sevoflurane, desflurane, isoflurane) have much lower metabolism rates and far lower risk. Desflurane is least metabolized (<0.02%). Cisatracurium is the neuromuscular blocker of choice in hepatic failure (Hofmann elimination-independent of liver function). Rocuronium should be used cautiously (primarily biliary excretion)-if used, reversal with sugammadex is reliable.

Succinylcholine duration is prolonged in hepatic failure due to decreased pseudocholinesterase synthesis. The duration may double in severe liver disease. High-extraction ratio drugs (morphine, lidocaine, propranolol, fentanyl): Clearance is flow-dependent. Decreased CO (or decreased hepatic blood flow) -> decreased clearance -> accumulation and prolonged drug effect.

Additionally, portosystemic shunting reduces first-pass metabolism -> enhanced oral bioavailability. Factor VII has the shortest half-life (~4-6 hours) of all liver-synthesized clotting factors; INR rises earliest and most sensitively with acute liver failure. PT/INR is the most practical early assessment of hepatic synthetic function.

Albumin hypoalbuminemia in liver disease increases the free (unbound) fraction of acidic, highly protein-bound drugs (diazepam, phenytoin, warfarin, thiopental, propofol). The effect of a standard dose is amplified-titrate carefully. Hepatic encephalopathy: avoid benzodiazepines, opioids, and sedatives that exacerbate encephalopathy.

If sedation is necessary, propofol is preferred (no active metabolites, rapidly cleared). If opioids required, remifentanil (ester hydrolysis) is preferred. remifentanil is the safest opioid in severe liver failure-ester hydrolysis by non-specific plasma esterases is completely liver-independent. Organ-independent elimination also makes it useful in combined hepatic-renal failure.

Reperfusion syndrome during liver transplant: Release of cold, acidotic, hyperkalemic blood from the new liver causes cardiac depression; prepare with calcium, bicarbonate, and epinephrine immediately available. TEE and PA catheter guide management.

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PART II – ANESTHESIA PHYSICS AND CHEMISTRY

Units, gas laws, flow, electricity and safety, vaporization, humidification, and blood-gas measurement.

For SRNAs preparing for the NBCRNA National Certification Examination (NCE)

02 Gases & the Gas Laws

06 Vaporization & the Anesthesia Vaporizer

07 Humidification & the Airway

08 Gas Supply: Cylinders & Pressures

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Units and Measurement

Units, Measurement & Physical Quantities

Every physics question begins with units. The NCE expects fluency in SI base units, the pressure units used across the anesthesia workspace, and the conversions that let you move between a cylinder gauge, a ventilator, and a blood-gas report without error.

SI Base & Derived Units

Pressure is force per unit area (the pascal, Pa = N/m2). In clinical anesthesia, however, you will constantly translate between pascals, mmHg, cmH2O, atmospheres, bar, and psi.

Pressure pascal (Pa) mmHg, cmH2O, atm, bar, psi, kPa

Volume cubic metre (m3) mL, L

Temperature kelvin (K) degrees C (K = degrees C + 273.15)

Energy / work joule (J) calorie (1 cal = 4.18 J)

Millimetres of mercury 760 mmHg (torr)

Centimetres of water 1034 cmH2O

Key Conversions

1 atm = 760 mmHg = 1034 cmH2O = 101.3 kPa = 14.7 psi. Quick airway rule: 1 mmHg 1.36 cmH2O, and 1 kPa 7.5 mmHg.

Exam Pearl

Temperature in every gas-law calculation must be in kelvin. Plugging in degrees Celsius is the single most common arithmetic trap on physics items-convert first (K = degrees C + 273).

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Gases and Gas Laws

Gases & the Gas Laws

The behavior of gases under changing pressure, volume, and temperature underlies cylinder physics, ventilation, vaporizer output, and bubble/embolus behavior. Memorize which variable is held constant in each "simple" law, then see how they combine into the ideal gas law.

Figure 2.1-The three simple gas laws. Each holds one variable constant: Boyle (T), Charles (P), Gay-Lussac (V).

Boyle's PxV=k Temp. Bag/bellows ventilation; pneumothorax

Charles's V/T=k Pressure Gas expands when warmed to body temp.

Gay-Lussac's P/T=k Volume Cylinder pressure rises if a tank is heated

Combined PV / T = k-General gas state changes

Dalton's Law of Partial Pressures

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In a gas mixture, each gas exerts the pressure it would exert if it alone occupied the volume; the total pressure is the sum of the partial pressures. Partial pressure-not concentration-is the driving force for diffusion and the final determinant of anesthetic effect at the brain.3

Key Concept–Dalton's Law

Ptotal = P1 + P2 + P3. Partial pressure = total pressure x fractional concentration. Example: room air O2 0.21 x 760 = ~160 mmHg.

Exam Pearl–Altitude

A variable-bypass vaporizer delivers a nearly constant partial pressure of agent regardless of altitude, even though the volume % shown on the dial under-reads at altitude. Because the brain responds to partial pressure (MAPP), clinical effect is largely preserved. Desflurane's heated, pressurized vaporizer is the exception-it delivers a set % and so must be adjusted at altitude.4

StatPearls, "Anesthesia Vaporizers," ncbi.nlm.nih.gov/books/NBK

- StatPearls, "Gas Laws and Clinical Application," ncbi.nlm.nih.gov/books/NBK

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Vapor Pressure and States of Matter

Vapor Pressure & States of Matter

A vapor is the gaseous phase of a substance below its critical temperature-the phase that matters for volatile anesthetics. Understanding saturated vapor pressure (SVP) is the bridge to vaporizer design (Section 6).

Key Definitions

- Evaporation-a surface phenomenon: high-energy molecules escape the liquid into the gas phase.
- Saturated vapor pressure (SVP)-the pressure of vapor in equilibrium with its liquid in a closed container; depends on the agent and its temperature, and is independent of barometric pressure.
- Boiling point-the temperature at which SVP equals atmospheric pressure (760 mmHg). Boiling occurs throughout the liquid, not just at the surface.
- Latent heat of vaporization-the energy needed to convert 1 g of liquid to vapor at constant temperature; this is why a vaporizing agent cools.
- Specific heat-energy to raise 1 g of a substance by 1 degrees C; high-specific-heat vaporizer materials buffer temperature swings.

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Key Concept

SVP rises exponentially with temperature and is unique to each agent. Higher SVP -> more vapor produced -> greater risk of overdose if the wrong agent fills a vaporizer. Reference values are quoted at 20 degrees C.

Agent SVP @ 20 degrees C (mmHg) Boiling point (degrees C) MAC (%)

Liquid volume to vapor: roughly 1 mL of liquid anesthetic -> ~200 mL of vapor (agent-dependent, ~210 mL for many agents). This is why a small spill or a cross-filled vaporizer can produce a clinically enormous vapor concentration.

- StatPearls, "Anesthesia Vaporizers," ncbi.nlm.nih.gov/books/NBK559321. SVP and MAC values are standard reference figures.

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Solubility, Diffusion, and Osmosis

Solubility, Diffusion & Osmosis

Solubility governs how fast an inhaled agent reaches the brain; diffusion governs gas exchange and the behavior of gases across membranes; osmosis governs water movement across semipermeable membranes.

Henry's Law & Blood: Gas Solubility

Henry's Law: at constant temperature, the amount of gas dissolved in a liquid is proportional to its partial pressure above the liquid. Solubility falls as temperature rises-warm blood holds less dissolved gas.

Key Concept–Blood: Gas Partition Coefficient

A low blood: gas coefficient means the agent is poorly soluble in blood, so the alveolar partial pressure rises quickly -> faster induction and emergence. a high coefficient (very soluble) means slower onset.

Figure 4.1-The lower the blood: gas partition coefficient, the faster the wash-in and the speed of induction. nitrous oxide and desflurane are the fastest; halothane is the slowest.

Key Concept–Graham's Law

The rate of diffusion of a gas is inversely proportional to the square root of its molecular weight (and proportional to its solubility for diffusion through a membrane). Light gases diffuse fastest.

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Fick's Law of Diffusion

Fick's Law states that the rate of diffusion across a membrane is proportional to the surface area and the partial-pressure gradient, and inversely proportional to membrane thickness. It explains alveolar gas exchange and why thickened membranes (edema, fibrosis) impair transfer.

Exam Pearl-Concentration & Second-Gas Effects nitrous oxide's high-volume uptake concentrates the remaining alveolar gases (concentration effect) and accelerates the uptake of a co-administered volatile (second-gas effect).

Because N2O is ~34x more soluble than nitrogen, it can also expand air-filled spaces (bowel, pneumothorax, ETT cuff) and cause diffusion hypoxia on emergence-give 100% O2 as you discontinue it.

Osmosis Osmosis is the movement of solvent (water) across a semipermeable membrane from low to high solute concentration. Osmotic pressure is proportional to the number of dissolved particles (osmoles), underpinning fluid shifts with mannitol, hypertonic saline, and colloids.

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Pressure and Fluid Flow

Pressure & Fluid Flow

Flow physics appears everywhere: IV catheters, airways, flowmeters, suction, and endotracheal tubes. The central distinction is laminar versus turbulent flow.

Figure 5.1-Laminar flow is orderly and proportional to the pressure gradient; turbulent flow is chaotic and proportional to the square root of the pressure gradient, and it depends on gas density.

Key Concept–Hagen–Poiseuille

For laminar flow: Q = (- P-r) / (8 - - L) Flow is proportional to the 4th power of the radius (r) and to P, and inversely proportional to viscosity () and length (L). Radius dominates everything.

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Figure 5.2-Because flow scales with r, doubling a catheter's radius increases flow 16-fold. a short, wide cannula is the fastest route for rapid volume resuscitation.

Turbulent Flow & Reynolds Number

Turbulence develops at high velocity, in branch points, or past obstructions. The Reynolds number predicts the transition; above roughly 2000-4000, flow becomes turbulent. In turbulent flow, density (not viscosity) is the dominant fluid property.

Exam Pearl-Heliox & Bernoulli Because turbulent flow depends on density, low-density heliox reduces resistance and improves flow through obstructed airways. The Bernoulli principle (fast-moving fluid has lower lateral pressure) and the related Venturi effect explain jet ventilation, nebulizers, and fixed-performance Venturi O2 masks.

Viscosity vs. Density

- Laminar flow -> governed by viscosity (e.g., blood viscosity, IV fluid choice).
- Turbulent flow -> governed by density (e.g., heliox benefit in upper-airway obstruction).
- Laplace's Law (wall tension): for a sphere, P = 2T/r; for a cylinder, P = T/r-relevant to alveoli, surfactant, aneurysms, and the LV.

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Vaporization and Vaporizers

Vaporization & the Anesthesia Vaporizer

The vaporizer applies the physics of Sections 2-3: it must deliver a precise, temperature-stable concentration of agent despite the cooling caused by latent heat of vaporization.

Figure 6.1-a variable-bypass, agent-specific vaporizer. The concentration dial sets the splitting ratio between the bypass channel and the vaporizing chamber; the two streams recombine at the outlet.

How a Variable-Bypass Vaporizer Works

- Fresh gas splits into a large bypass stream and a small stream entering the vaporizing chamber, where it becomes fully saturated with agent at SVP.
- The concentration dial sets the splitting ratio; the streams recombine to deliver the dialed volume %.
- A bimetallic strip / temperature-compensating valve automatically increases chamber flow as the liquid cools, keeping output constant.
- Modern vaporizers are agent-specific, calibrated, variable-bypass, and temperature-compensated.
- They do not use a bubble-through design.

Output % is set by the splitting ratio, automatically corrected for temperature. Desflurane is different: its near-ambient boiling point demands a separate heated (~39 degrees C), pressurized vaporizer that injects measured vapor rather than splitting flow.

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Exam Pearl-Hazards

Cross-filling a vaporizer with the wrong agent changes output dramatically (filling a sevoflurane vaporizer with the higher-SVP isoflurane causes overdose). Tipping can flood the bypass with liquid agent. The pumping effect (intermittent back-pressure from ventilation) and changes in carrier-gas composition can also alter output.

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Humidification and the Airway

Humidification & the Airway

Humidity is water vapor in gas. Anesthetized patients lose heat and water when the upper airway is bypassed and dry medical gases are delivered.

Absolute vs. Relative Humidity

- Absolute humidity-the actual mass of water vapor per unit volume of gas (mg/L).
- Relative humidity-the percentage of the maximum water vapor the gas could hold at that temperature.
- Warmer gas holds more water, so warming gas lowers its relative humidity unless water is added.

Figure 7.1-Inspired gas is fully saturated by the time it reaches the alveoli (37 degrees C, 100% RH 44 mg/L). Dry medical gas places this entire humidifying burden on the airway when the nose is bypassed.

Key Numbers

Fully saturated gas at body temperature (37 degrees C) holds ~44 mg/L of water. Gas leaving a normal nose/upper airway is ~34 mg/L. Dry medical gas is essentially 0.

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Gas Supply: Cylinders and Pressures

Gas Supply: Cylinders & Pressures

Cylinder physics is a direct application of the gas laws and is heavily tested. The crucial distinction is between a cylinder holding a compressed gas (oxygen) and one holding a liquefied gas under its own vapor pressure (nitrous oxide).

Figure 8.1-In an oxygen cylinder, gauge pressure falls linearly with contents, so the gauge reliably estimates the remaining volume. a full E-cylinder holds ~660 L at ~1900-2200 psi.

Gauge tracks contents? Yes-linear (Boyle) No-constant until liquid gone

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Exam Pearl-Adiabatic & Joule-Thomson Rapidly opening a cylinder compresses gas downstream and generates heat (adiabatic compression)

- A fire risk with O2 and contaminants. Conversely, gas cools as it expands through a regulator (Joule-Thomson effect), which can frost N2O regulators at high flows.

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Electricity and Electrical Safety

Electricity & Electrical Safety

Ohm's Law and the difference between macroshock and microshock are reliably tested, along with the OR systems that protect patients and staff.

Key Concept–Ohm's Law

Figure 9.1-Macroshock vs. microshock current thresholds and the layered electrical protections used in the operating room.

Macroshock vs. Microshock

- Macroshock-current applied across intact skin. ~1 mA is perceptible; ~100 mA can cause ventricular fibrillation.
- Microshock-current delivered directly to the myocardium (via pacing wires, central lines, or saline-filled catheters). As little as 100 uA can induce VF.
- Any conductor that touches the heart is a microshock hazard-handle pacing wires and CVCs with insulated technique.

Operating-Room Protections

- Isolation transformer-creates an ungrounded power supply so a single fault does not complete a circuit to ground.

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- Line Isolation Monitor (LIM)-alarms (typically at 2-5 mA) when isolation is lost; it warns but does not cut power, allowing the case to continue.
- Equipotential grounding-ties conductive surfaces to the same potential to eliminate stray current paths.
- Ground-fault circuit interrupter (GFCI)-cuts power on a small leakage current; used where isolation is impractical.

If the LIM alarms, the most recently plugged-in device is the likely faulty unit-unplug it. The patient is not in immediate danger because power is not interrupted; the alarm indicates the protective isolation has been lost and a second fault could now be hazardous.

Also know: NFPA classifies an OR as a wet location, and surgical fires require the fire triad-oxidizer (O2/N2O), fuel, and ignition source.

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Measurement of Oxygen, CO2, and pH

Measurement of Oxygen, CO2 & Hydrogen Ions

The NCE physics domain includes the measurement principles behind the monitors you rely on every case.

Oxygen Measurement

- Pulse oximetry (SpO2)-uses the Beer-Lambert law and the different absorption of red (660 nm) and infrared (940 nm) light by oxy-vs. deoxyhemoglobin.
- Galvanic / fuel cell & polarographic (Clark) electrodes-electrochemical O2 analyzers in the breathing circuit.
- Paramagnetic analyzers-exploit oxygen's paramagnetism for fast inspired/expired O2 measurement.

Carbon Dioxide Measurement

- Capnography-infrared absorption spectroscopy; CO2 absorbs IR light at ~4.3 um.
- Distinguish mainstream (sensor in the circuit, fast) from sidestream (gas aspirated to a remote sensor, slight delay).

Hydrogen Ion (pH) Measurement

- PH = -log10[H] - a logarithmic scale; a one-unit pH change is a tenfold change in [H].
- Measured with a pH-sensitive glass (Sanz) electrode; the Severinghaus electrode measures PCO2 and the Clark electrode measures PO2 in a blood-gas analyzer.

Match the analyte to its physical principle: O2 -> Beer-Lambert / paramagnetic / electrochemical; CO2 -> infrared absorption; pH -> logarithmic glass electrode.

Pulse oximetry can be fooled: carboxyhemoglobin reads falsely high (looks like oxyhemoglobin), methemoglobin drives the reading toward ~85%, and motion, low perfusion, or certain dyes (methylene blue) cause errors. Co-oximetry is required to distinguish dyshemoglobins.

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High-Yield Constants and Rapid Review

High-Yield Constants & Rapid Review

A final, exam-day pass over the numbers and relationships most likely to appear.

Must-Know Constants

Constant / value Number to remember

1 atmosphere 760 mmHg = 1034 cmH2O = 101.3 kPa = 14.7 psi

Kelvin conversion K = degrees C + 273.15

Liquid -> vapor expansion ~1 mL liquid -> ~200 mL vapor

Saturated gas at 37 degrees C ~44 mg/L water (100% RH)

N2O E-cylinder ~1590 L; gauge ~745 psi until liquid gone

Relationships at a Glance

If you see. Think.

Pressure / volume / temperature change Gas laws-convert temp to kelvin first

Speed of inhaled induction Blood: gas coefficient (low = fast)

Diffusion rate of a gas Graham's Law (1/MW); Fick across membranes

IV catheter or airway flow Poiseuille-radius dominates (laminar)

Upper-airway obstruction / heliox Turbulent flow -> density matters

Cardiac catheter + current Microshock-100 uA can cause VF

SpO2 / capnography / pH Beer-Lambert / infrared / log glass electrode

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Final Reminder

The NCE rewards relationships, not rote formulas. For each topic, be able to state which variable is held constant, which direction the effect goes, and the one clinical scenario that makes it concrete. Master those and the calculation items follow.

- StatPearls. "Anesthesia Vaporizers." NCBI Bookshelf. ncbi.nlm.nih.gov/books/NBK559321.
- StatPearls. "Gas Laws and Clinical Application." NCBI Bookshelf. ncbi.nlm.nih.gov/books/NBK546592.

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PART III – PHARMACOLOGY MATH FOR ANESTHESIA

Dimensional analysis, dilutions, weight-based dosing, infusions, MAC math, pediatrics, fluids and blood loss, with practice problems.

Drug concentrations & dilutions-weight-based dosing-infusion rates-unit conversions

- MAC-pharmacokinetics-pediatrics-fluids & blood loss

Includes worked examples throughout plus a 20-question practice set with a fully worked answer key. Study reference for educational use. Always verify every calculation against institutional protocols, current drug references, and a second licensed provider before administration.

0 Foundations & The Universal Approach Nearly every anesthesia calculation reduces to one of a few patterns: converting units, relating a dose to a concentration to get a volume, or relating those to time and body weight to get a rate. If you master dimensional analysis (unit cancellation), you can derive any equation in this module from first principles rather than memorizing dozens of formulas.

The three quantities you always juggle

- Dose-the amount of drug the patient should receive (mg, mcg, units, mEq).
- Concentration-how much drug is in each mL of your syringe or bag (mg/mL, mcg/mL).
- Volume-the number of mL you draw up or infuse.

Volume (mL) = Dose Concentration

Dose = Volume x Concentration | Concentration = Dose Volume

Dimensional analysis-the one method that never fails Write what you have, multiply by conversion factors arranged so unwanted units cancel, and you are left with the unit you want. Carry units through every step; if they don't cancel cleanly, the setup is wrong.

Order: give 4 mg of ondansetron. You have a 4 mg / 2 mL vial. How many mL?

4 mg x (2 mL 4 mg) = 2 mL. The "mg" cancels, leaving mL.

Percent solutions-decode the label a percent concentration is grams of drug per 100 mL of solution. This single rule unlocks lidocaine, propofol, mannitol, calcium, magnesium, and every other "%" drug.

X% solution = X grams per 100 mL = (X x 10) mg per mL

- 1% = 10 mg/mL (e.g., lidocaine 1%, propofol 1%).
- 2% = 20 mg/mL (e.g., lidocaine 2%).
- 0.5% = 5 mg/mL (e.g., bupivacaine 0.5%).
- 0.25% = 2.5 mg/mL (e.g., bupivacaine 0.25%).

Ratio strengths (epinephrine, neostigmine) a ratio strength such as 1:1,000 means 1 gram of drug per 1,000 mL of solution.

1: 1,000 = 1 g / 1,000 mL = 1 mg/mL

1: 10,000 = 1 g / 10,000 mL = 0.1 mg/mL | 1: 100,000 = 0.01 mg/mL = 10 mcg/mL

1 Unit Conversions & Key Constants Conversion errors are among the most dangerous in anesthesia because a misplaced factor of 1,000 between mg and mcg can be lethal. Internalize these before anything else.

Core Math Conversions for Anesthesia

Mass 1 g = 1,000 mg | 1 mg = 1,000 mcg | 1 mcg = 1,000 ng

Volume 1 L = 1,000 mL | 1 mL = 1 cc

Weight 1 kg = 2.2 lb | lb 2.2 = kg

Time 1 hr = 60 min | rate/hr 60 = rate/min

Concentration 1% = 10 mg/mL | 1:1,000 = 1 mg/mL

Pressure 1 atm = 760 mmHg | 1 kPa = 7.5 mmHg | 1 cmH2O = 0.74 mmHg

Temperature degrees C = (degrees F-32) x 5/9 | degrees F = (degrees C x 9/5) + 32

A patient weighs 176 lb. Propofol induction at 2 mg/kg. What total dose?

176 lb 2.2 = 80 kg. 80 kg x 2 mg/kg = 160 mg.

Answer: 160 mg

2 Diluting Medications Diluting a drug means adding diluent (usually normal saline or sterile water) to a known amount of drug to reach a target concentration that is safer and easier to titrate. Two relationships cover essentially every dilution you will perform.

Method A-Final concentration from a known drug amount

Final concentration = Total drug (mg or mcg) Total final volume (mL)

Use this when you know how much drug you put in the syringe/bag and how big the final volume is.

Standard mix: 10 mg phenylephrine into a 250 mL bag, OR draw 10 mg into 100 mL.

Bag: 10 mg 250 mL = 0.04 mg/mL = 40 mcg/mL.

Syringe: 10 mg 100 mL = 0.1 mg/mL = 100 mcg/mL.

Answer: 40 mcg/mL (bag) or 100 mcg/mL (syringe)

Method B-The dilution equation (C1V1 = C2V2) Use this when you are diluting a stock concentration down to a target concentration. The amount of drug is conserved, so the product of concentration and volume before equals the product after.

C1 x V1 = C2 x V2

V1 = (C2 x V2) C1 Diluent to add = V2-V1

C1 = stock (starting) concentration-V1 = volume of stock needed-C2 = desired concentration-V2 = desired final volume.

Worked example-diluting epinephrine for push-dose pressor

You have epinephrine 1:10,000 = 100 mcg/mL (the code-cart 10 mL syringe). You want push-dose epi at 10 mcg/mL, 10 mL total. How much stock and how much saline?

C = 100 mcg/mL, C = 10 mcg/mL, V = 10 mL. 1 2 2

V = (10 x 10) 100 = 1 mL of stock. 1

Diluent = 10-1 = 9 mL saline.

Answer: 1 mL epinephrine + 9 mL NS = 10 mcg/mL

Concentration safety check: Epinephrine 1:1,000 = 1 mg/mL (IM/SQ), 1:10,000 = 0.1 mg/mL (IV code dose), 1:100,000 = 10 mcg/mL (often in local anesthetics). Confirm which you are holding-a 10-fold error here is a sentinel event.

Phenylephrine 10 mg / 250 mL 40 mcg/mL

Norepinephrine 4 mg / 250 mL 16 mcg/mL

Epinephrine (gtt) 4 mg / 250 mL 16 mcg/mL

Vasopressin 20 units / 100 mL 0.2 units/mL

Nitroglycerin 50 mg / 250 mL 200 mcg/mL

Dopamine 400 mg / 250 mL 1,600 mcg/mL

Dexmedetomidine 200 mcg / 50 mL 4 mcg/mL

Propofol 1% premix 10 mg/mL

Remifentanil 2 mg / 40 mL 50 mcg/mL

3 Weight-Based Dosing Most anesthesia drugs are dosed per kilogram. Always dose to the appropriate body weight: total body weight (TBW), ideal body weight (IBW), or lean body weight (LBW) depending on the drug's pharmacology.

Dose (mg) = Weight (kg) x Dose per kg (mg/kg)

Volume to draw (mL) = Dose Concentration

IBW (men) = 50 kg + 2.3 kg x (inches over 60)

IBW (women) = 45.5 kg + 2.3 kg x (inches over 60)

Dose to IBW/LBW for: propofol induction (LBW), succinylcholine is TBW, rocuronium/vecuronium (IBW), fentanyl/opioids (LBW), and most volatile agent MAC considerations are not weight-based. When unsure, consult a current reference-this distinction changes real doses.

70 kg patient, succinylcholine 1.5 mg/kg for RSI. Vial = 20 mg/mL.

Dose = 70 x 1.5 = 105 mg. Volume = 105 20 = 5.25 mL.

Answer: 105 mg = 5.25 mL

Common induction & maintenance doses (adult, verify before use)

Propofol (induction) 1.5-2.5 mg/kg 10 mg/mL

Etomidate 0.2-0.3 mg/kg 2 mg/mL

Ketamine (induction) 1-2 mg/kg IV 10 or 50 or 100 mg/mL

Fentanyl 1-3 mcg/kg 50 mcg/mL

Succinylcholine 1-1.5 mg/kg 20 mg/mL

Rocuronium (intubating) 0.6-1.2 mg/kg 10 mg/mL

Lidocaine (IV blunt) 1-1.5 mg/kg 10 mg/mL (1%) or 20 (2%)

Dexamethasone (PONV) 0.1 mg/kg (max ~8 mg) 4 or 10 mg/mL

LAST (Local Anesthetic Systemic Toxicity) is preventable with correct max-dose math. Compute the patient's ceiling in mg, then convert to a volume of the specific concentration you are using.

Max volume (mL) = (Max mg/kg x weight kg) concentration (mg/mL)

Lidocaine (plain) 4.5 mg/kg ~300 mg

Lidocaine with epi 7 mg/kg ~500 mg

Bupivacaine (+/- epi) 2-3 mg/kg ~175 mg

Ropivacaine 3 mg/kg ~200-250 mg

Mepivacaine 5-7 mg/kg ~400 mg

80 kg patient, bupivacaine 0.5% (5 mg/mL), max 2 mg/kg. Max volume?

Max mg = 80 x 2 = 160 mg. Volume = 160 5 = 32 mL.

Answer: 160 mg = 32 mL of 0.5%

Rate (mL/hr) = [Dose (mcg/kg/min) x Weight (kg) x 60] Concentration (mcg/mL)

The x60 converts minutes to hours. If the dose is ordered in mcg/kg/hr or mg/kg/hr, drop the 60 and match units. Solve for dose by rearranging:

Dose (mcg/kg/min) = [Rate (mL/hr) x Concentration (mcg/mL)] [Weight (kg) x 60]

70 kg patient, propofol 150 mcg/kg/min, concentration 10 mg/mL = 10,000 mcg/mL. Pump rate?

Rate = (150 x 70 x 60) 10,000 = 630,000 10,000 = 63 mL/hr.

Answer: 63 mL/hr

90 kg patient, norepinephrine 0.05 mcg/kg/min, mix 16 mcg/mL. Rate?

Rate = (0.05 x 90 x 60) 16 = 270 16 = 16.9 mL/hr.

Answer: ~16.9 mL/hr

Non-weight-based drips (e.g., nitroglycerin in mcg/min)

Rate (mL/hr) = [Dose (mcg/min) x 60] Concentration (mcg/mL)

NTG ordered at 50 mcg/min, mix 200 mcg/mL. Rate?

Rate = (50 x 60) 200 = 3,000 200 = 15 mL/hr.

Answer: 15 mL/hr

Gtt/min = [Volume (mL) x Drop factor (gtt/mL)] Time (min)

Common drop factors: macrodrip 10, 15, or 20 gtt/mL; microdrip 60 gtt/mL. With a 60 gtt/mL set, gtt/min equals mL/hr-a handy shortcut.

Infuse 1,000 mL over 8 hr with a 15 gtt/mL set. gtt/min?

8 hr = 480 min. gtt/min = (1,000 x 15) 480 = 15,000 480 ~ 31 gtt/min.

Answer: ~31 gtt/min

5 MAC & Volatile Agent Math Minimum Alveolar Concentration (MAC) is the alveolar concentration of a volatile agent at 1 atm that prevents movement in 50% of patients to a surgical stimulus. MAC values are additive and are modified by patient and physiologic factors.

MAC is additive

Total MAC = (volatile agent fraction of MAC) + (N2O fraction of MAC)

Approximate 1 MAC values (age ~40, no N2O):

Agent 1 MAC (vol %)

Nitrous oxide (N2O) 104%

Sevoflurane at 1.0% plus N2O at 52%. What is the total MAC delivered?

Sevo: 1.0 2.0 = 0.5 MAC. N2O: 52 104 = 0.5 MAC.

Total = 0.5 + 0.5 = 1.0 MAC.

Age adjustment

MAC peaks in infancy and decreases ~6% per decade after age 40. an useful estimate:

MACage ~ MAC40 x 10^[-0.00269 x (age-40)]

Rule of thumb: MAC decreases ~6% for every decade over 40.

Effect Factors

Chronic alcohol use, hyperthermia, hypernatremia, infancy, MAO inhibitors, acute

Increase MAC

Age, hypothermia, opioids/sedatives, pregnancy, acute alcohol, hyponatremia, lithium,

Decrease MAC

Alpha-2 agonists, severe hypotension/hypoxia

No effect Gender, duration of anesthesia, thyroid function, hyper/hypokalemia

Fresh gas flow & agent consumption (liquid mL/hr)

Liquid agent (mL/hr) = [3 x FGF (L/min) x volume %] (approx.)

Derived from the agent's vapor-to-liquid expansion (~196-210 mL vapor per mL liquid). Lower fresh gas flows dramatically cut volatile agent cost and waste-a key reason for low-flow anesthesia.

6 Pharmacokinetic Equations These relationships explain how drug concentration changes with dose, distribution, metabolism, and time-the basis for loading doses, infusions, and predicting offset.

Loading dose

LD = (Ctarget x Vd) bioavailability (F)

Fills the volume of distribution to reach a target plasma concentration quickly.

Volume of distribution

Vd = Total drug in body Plasma concentration

Apparent volume relating amount of drug to measured concentration.

CL = k x Vd = Rate of elimination Concentration

Volume of plasma cleared of drug per unit time.

Maintenance infusion

MD rate = Ctarget x CL F

Replaces drug at the rate the body removes it to hold steady state.

Elimination half-life

T1/2 = 0.693 x Vd CL

Time for plasma concentration to fall by 50%.

K = 0.693 t1/2 = CL Vd

Steady state

Time to plateau on a constant infusion without a loading dose.

Target plasma concentration 3 mcg/mL, Vd = 30 L, F = 1 (IV). Loading dose?

Convert units: 3 mcg/mL = 3 mg/L. LD = 3 mg/L x 30 L = 90 mg.

Answer: 90 mg IV

Context-sensitive half-time

The time for plasma concentration to fall 50% after stopping an infusion, which lengthens with infusion duration for most agents. remifentanil is the notable exception-its context-sensitive half-time stays ~3-4 minutes regardless of infusion length, because of rapid ester hydrolysis.

7 Pediatric Calculations Pediatric anesthesia is weight-driven and unforgiving of decimal errors. Always dose per kg, double-check concentrations, and consider diluting concentrated adult vials for accurate small-volume dosing.

Estimating weight (when not measured)

1-12 months: Weight (kg) = (age in months + 9) 2

1-5 years: Weight (kg) = 2 x age (yr) + 8

6-12 years: Weight (kg) = (3 x age yr) + 7

Maintenance fluids-the 4-2-1 rule

4 mL/kg/hr for the first 10 kg

+ 2 mL/kg/hr for the next 10 kg (11-20 kg)

+ 1 mL/kg/hr for each kg above 20 kg

A 26 kg child. Hourly maintenance fluid rate?

First 10 kg: 10 x 4 = 40. Next 10 kg: 10 x 2 = 20. Remaining 6 kg: 6 x 1 = 6.

Total = 40 + 20 + 6 = 66 mL/hr.

Answer: 66 mL/hr

Uncuffed ETT ID (mm) = (age 4) + 4 | Cuffed = (age 4) + 3.5

ETT depth at lip (cm) ~ ETT ID x 3

Premature neonate 90-100 mL/kg

Term neonate 80-90 mL/kg

Infant (<1 yr) 70-80 mL/kg

Child (1-12 yr) 70-75 mL/kg

Adult male / female 75 / 65 mL/kg

MABL = EBV x (Hi-Hf) Hi

EBV = estimated blood volume (weight x mL/kg). Hi = initial hematocrit (or Hgb). Hf = lowest acceptable hematocrit. Some references use Havg in the denominator for a more conservative estimate.

70 kg adult male (EBV 75 mL/kg), starting Hct 42%, lowest acceptable Hct 30%.

EBV = 70 x 75 = 5,250 mL.

MABL = 5,250 x (42-30) 42 = 5,250 x 0.286 ~ 1,500 mL.

Answer: ~1,500 mL

Replacement ratios

- Crystalloid (LR, NS): replace blood loss ~3 mL crystalloid per 1 mL blood lost (3:1).
- Colloid (albumin): replace ~1 mL per 1 mL blood lost (1:1).
- PRBC transfusion: 1 unit raises hemoglobin by ~1 g/dL (hematocrit ~3%) in an average adult.

Hgb (g/dL) ~ (units PRBC x ~1 g/dL) per average adult

Pediatric: 10 mL/kg PRBC raises Hgb by ~2-3 g/dL

Deficit = hourly maintenance (4-2-1) x hours NPO

Replace: 1/2 in hour 1, 1/4 in hour 2, 1/4 in hour 3 (plus ongoing maintenance)

70 kg adult, NPO 8 hours. Maintenance by 4-2-1 = 110 mL/hr (40 + 20 + 50). Total deficit?

Deficit = 110 x 8 = 880 mL. Give ~440 mL in the first hour, then 220 mL in hours 2 and 3.

Answer: 880 mL deficit

9 Practice Problems Work each problem on paper using dimensional analysis before checking the answer key in Section

- Assume standard concentrations unless stated. Round pump rates to one decimal place.

- A patient weighs 154 lb. Convert to kilograms.
- Propofol is 10 mg/mL. You need 180 mg for induction. How many mL do you draw up?
- You mix 10 mg of phenylephrine in a 250 mL bag. What is the concentration in mcg/mL?
- Using C1V1 = C2V2: dilute a 1 mg/mL stock to make 10 mL of 100 mcg/mL. How much stock and how much diluent?
- A 60 kg patient needs succinylcholine 1.5 mg/kg. The vial is 20 mg/mL. Dose in mg and volume in mL?
- Propofol infusion at 125 mcg/kg/min for a 70 kg patient, concentration 10 mg/mL. Pump rate in mL/hr?
- Norepinephrine 16 mcg/mL, ordered 0.08 mcg/kg/min for an 85 kg patient. Rate in mL/hr?
- Sevoflurane 1.5% with N2O 52%. Total MAC delivered? (1 MAC sevo = 2.0%, N2O = 104%)
- Estimate the weight of a 4-year-old child.
- Calculate maintenance fluid (4-2-1) for an 18 kg child.
- Estimate the uncuffed ETT internal diameter for a 6-year-old.
- A 70 kg male (EBV 75 mL/kg) has a starting Hct of 45% and lowest acceptable Hct of 30%.
- Loading dose: target concentration 2 mcg/mL, Vd = 40 L, F = 1. Loading dose in mg?
- If a drug has a t1/2 of 4 hours, approximately how long until steady state on a constant infusion?

1 154 2.2 = 70 kg.

2 180 mg 10 mg/mL = 18 mL.

3 2% = 20 mg/mL. 20 x 5 = 100 mg.

4 10 mg = 10,000 mcg. 10,000 250 = 40 mcg/mL.

5 1:10,000 = 1 g / 10,000 mL = 0.1 mg/mL = 100 mcg/mL.

6 V1 = (100 mcg/mL x 10 mL) 1,000 mcg/mL = 1 mL stock; diluent = 10-1 = 9 mL. (1 mL stock + 9 mL diluent.)

7 60 x 1.5 = 90 mg. 90 20 = 90 mg = 4.5 mL.

8 80 x 2 = 160 mcg. 160 50 = 160 mcg = 3.2 mL.

9 0.5% = 5 mg/mL. Max mg = 75 x 2 = 150 mg. 150 5 = 30 mL.

10 (125 x 70 x 60) 10,000 = 525,000 10,000 = 52.5 mL/hr.

11 (0.08 x 85 x 60) 16 = 408 16 = 25.5 mL/hr.

12 (30 x 60) 200 = 1,800 200 = 9 mL/hr.

13 6 hr = 360 min. (1,000 x 20) 360 = 20,000 360 ~ 56 gtt/min.

14 Sevo: 1.5 2.0 = 0.75 MAC. N2O: 52 104 = 0.5 MAC. Total = 1.25 MAC.

15 (2 x age) + 8 = (2 x 4) + 8 = 16 kg.

16 First 10 kg: 40 mL/hr. Next 8 kg: 8 x 2 = 16 mL/hr. Total = 56 mL/hr.

17 (age 4) + 4 = (6 4) + 4 = 1.5 + 4 = 5.5 mm.

18 EBV = 70 x 75 = 5,250 mL. MABL = 5,250 x (45-30) 45 = 5,250 x 0.333 ~ 1,750 mL.

19 2 mcg/mL = 2 mg/L. LD = 2 mg/L x 40 L = 80 mg.

20 Steady state ~ 4-5 half-lives x 4 hr = 16-20 hours.

PART IV – CLINICAL PHARMACOLOGY

Focused perioperative pharmacology for high-yield NCE and clinical decision-making.

Volatile Anesthetics

Volatile Anesthetics: Overview of Inhaled Agents and Anesthesia

Implications This course introduces the major inhaled anesthetic agents used in modern anesthesia practice and explains how their pharmacology translates into bedside decision-making for CRNAs.

Learners will review core concepts such as MAC, solubility, uptake, and elimination; compare commonly used agents; and examine important physiologic, safety, and recovery implications that influence anesthetic planning, maintenance, and emergence.

Why Volatile Anesthetics Still Matter

Volatile anesthetics remain central to anesthesia practice because they provide reliable hypnosis, amnesia, immobility, and titratable maintenance of general anesthesia.

Even in an era of total intravenous anesthesia, enhanced recovery pathways, and growing sustainability concerns, inhaled anesthetics continue to be widely used in adult and pediatric practice, ambulatory surgery, inpatient surgery, and selected critical care or procedural settings.

Minimum Alveolar Concentration (MAC)

MAC is the alveolar concentration at which 50% of patients do not move in response to a surgical incision. It is the standard measure of potency for inhaled anesthetics. a lower MAC means a more potent agent. MAC decreases with age and is also influenced by temperature,

Opioids, sedatives, pregnancy, and other patient factors. In everyday practice, end-tidal concentration and age-adjusted MAC help the CRNA titrate volatile depth more safely.

A practical way to apply MAC is to remember that anesthetic requirement usually falls with age. For example, an end-tidal concentration that may be reasonable for a healthy 25-year-old often represents excessive depth in a frail 75-year-old.

MAC also decreases when opioids, benzodiazepines, propofol, dexmedetomidine, and other sedatives are added, so the vaporizer dial should never be interpreted in isolation from the rest of the anesthetic plan.

Blood–gas solubility

The blood-gas partition coefficient predicts how quickly an inhaled anesthetic equilibrates between alveoli and blood. Lower solubility means faster onset and faster emergence. Desflurane and nitrous oxide have low blood-gas solubility and therefore support rapid adjustment in anesthetic depth.

Isoflurane is slower, and sevoflurane is intermediate but still fast enough to be highly practical for routine use.

Uptake and elimination

Volatile anesthetics are delivered via vaporizer and inhaled into the alveoli. Uptake is influenced by alveolar ventilation, cardiac output, inspired concentration, fresh gas flow, and blood-gas solubility. Elimination occurs primarily through exhalation, with relatively little metabolism for most modern agents compared with older inhaled drugs.

This exhaled elimination pattern is one reason emergence can often be managed quickly when ventilation and fresh gas flow are appropriate.

Overview of Common Inhaled Agents

Sevoflurane Sevoflurane is widely used because it is nonpungent, versatile, and well suited for inhalational induction, especially in pediatrics. It has a relatively low blood-gas solubility, smooth mask tolerance, and rapid clinical usability. It can cause dose-dependent hypotension and respiratory depression like other volatiles, but it is generally well tolerated.

Sevoflurane remains one of the most common maintenance agents in contemporary practice.

Desflurane Desflurane has very low blood-gas solubility and therefore offers rapid adjustment in anesthetic depth and rapid emergence. However, it is pungent, irritating to the airway, and often poorly tolerated for inhalational induction. Rapid increases in inspired concentration can trigger sympathetic stimulation with tachycardia and hypertension.

Desflurane use has also declined in many institutions because of its disproportionately high environmental impact.

Isoflurane Isoflurane is an older but still important volatile anesthetic. It is more soluble than sevoflurane or desflurane, so onset and emergence are slower. It is relatively potent and tends to produce vasodilation with dose-dependent hypotension, while often preserving cardiac output better

Than might be expected because of reflex tachycardia. Isoflurane remains relevant in some resource-conscious settings and in selected cases where cost and familiarity matter.

Nitrous oxide

Nitrous oxide is not a volatile liquid anesthetic but is often grouped with inhaled anesthetics because it is delivered as an inhaled gas and has important anesthetic implications. It has weak anesthetic potency, meaningful analgesic properties, very rapid uptake and offset, and MAC-sparing effects when combined with volatile agents.

However, it expands closed gas spaces, may worsen postoperative nausea and vomiting, and has significant environmental impact. It should be used selectively rather than reflexively.

Halothane (historical perspective) halothane is rarely used in many modern U. S. practices but remains historically important. It is associated with greater myocardial depression, catecholamine sensitization, and halothane hepatitis, which helped drive the transition toward newer fluorinated agents.

It is useful to know historically, but current CRNA practice focuses more on sevoflurane, desflurane, isoflurane, and nitrous oxide.

Volatile agent comparison (high-yield):

- Sevoflurane: MAC about 2%; relatively fast; nonpungent; useful for mask induction; watch hypotension, respiratory depression, and emergence agitation in some children.
- Desflurane: lowest blood-gas solubility and fastest titration among the common volatiles; pungent; can raise HR/BP with abrupt increases; avoid for inhalation induction.

- Isoflurane: intermediate kinetics; pungent; inexpensive and familiar; less ideal for inhalation induction.
- Nitrous oxide: MAC about 104%; low potency; second-gas effect; expands closed air spaces; increases PONV risk.

Desflurane ~6% Pungent stimulation, high fast and wake-up environmental impact

Maintenance, emergence, Isoflurane ~1.2% Slower Pungent familiar and vasodilation, cost-conscious airway irritation if option used for induction

Analgesic space expansion, Nitrous Very Generally adjunct, MAC-vitamin B12 ~104% oxide fast nonirritating sparing, rapid effects, onset and offset environmental impact

Physiologic and Anesthesia Implications

All modern volatile agents produce dose-dependent decreases in blood pressure, primarily through vasodilation and reductions in systemic vascular resistance. Cardiac output is often better preserved than arterial pressure, but hypotension can still become clinically significant, especially in older adults, hypovolemic patients, or those receiving vasodilatory adjuncts.

Desflurane and isoflurane can provoke sympathetic stimulation if concentration is increased rapidly.

Volatile anesthetics depress ventilation in a dose-dependent manner, blunt the response to hypercapnia and hypoxia, and reduce tidal volume. Sevoflurane is less irritating to the airway and is therefore useful for inhalational induction. Desflurane is pungent and may trigger coughing, breath-holding, laryngospasm, or sympathetic activation when introduced abruptly.

Volatile anesthetics reduce cerebral metabolic rate but can increase cerebral blood flow, especially at higher MAC levels, which may increase intracranial pressure in selected patients. They provide amnesia and hypnosis reliably but do not provide major analgesia, with the partial exception of nitrous oxide.

Emergence agitation, delayed recovery, or postoperative cognitive concerns may be influenced by dose, case duration, adjunct medications, and patient susceptibility.

Muscle relaxation and other implications Volatile anesthetics provide some degree of skeletal muscle relaxation and potentiate nondepolarizing neuromuscular blockade. They also reduce MAC requirements when used with opioids, nitrous oxide, benzodiazepines, propofol, and other sedatives.

This interaction is clinically useful, but it also means that oversedation and hemodynamic depression can occur quickly when agents are layered without thoughtful titration.

Special populations and pediatric considerations Volatile choice should be individualized for the patient in front of you. Older adults usually require less anesthetic because MAC declines with age, and they may develop hypotension or delayed recovery at concentrations that younger adults tolerate well.

Hemodynamically fragile patients may not tolerate abrupt increases in volatile concentration, while patients with reactive airways often benefit from sevoflurane's smoother airway profile and may do poorly with desflurane.

In obese patients, emergence planning is especially important because airway obstruction, hypoventilation, and residual drug effect can outweigh the theoretical speed advantage of a low-solubility agent. In selected neurosurgical patients, volatile dose, ventilation, and intracranial dynamics all need to be considered together rather than treating end-tidal concentration alone as the target.

In pediatric practice, sevoflurane is commonly favored for inhalational induction because it is nonpungent and better tolerated with mask induction. Desflurane is generally less suitable for inhalational induction because airway irritation can provoke coughing, breath-holding, laryngospasm, or sympathetic stimulation.

Children may also experience emergence agitation after volatile anesthesia, particularly after short sevoflurane-based anesthetics, so analgesia, timing, and adjunct medications remain important parts of a smooth wake-up plan.

Nitrous Oxide–Specific Considerations

Nitrous oxide deserves special attention because its clinical profile differs from the potent volatile liquids. It is a weak anesthetic but useful analgesic adjunct and can reduce requirements for more potent agents.

However, it diffuses into closed gas spaces faster than nitrogen can leave them, which means it can expand pneumothorax, bowel gas, middle ear spaces, intracranial air, venous air emboli, and certain ophthalmologic gas bubbles. This makes case selection important.

Nitrous oxide may also contribute to postoperative nausea and vomiting and can inactivate vitamin B12-dependent methionine synthase with prolonged or repeated exposure. For CRNAs, the practical decision is whether its MAC-sparing and analgesic effects add enough value to justify its disadvantages in the specific case.

For CRNAs, this supports a more selective approach: nitrous oxide may still offer MAC-sparing and modest opioid-sparing benefits, but those advantages should be weighed carefully against the added PONV burden, especially in patients who already have multiple emesis risk factors.

Second gas effect and diffusion hypoxia nitrous oxide is classically associated with the second gas effect, in which rapid nitrous uptake transiently increases the alveolar concentration of a concurrently administered volatile agent and may speed early uptake.

In modern practice, the concept remains important for understanding gas kinetics, but its day-to-day clinical impact is usually modest compared with ventilation, fresh gas flow, and overall anesthetic technique. During emergence, rapid nitrous washout can dilute alveolar oxygen and carbon dioxide, a phenomenon known as diffusion hypoxia.

This is why supplemental oxygen during nitrous discontinuation remains a simple and important safety step.

Cases where nitrous oxide should be avoided

- Known or suspected pneumothorax, venous air embolism, or other trapped gas spaces that could expand during anesthesia.
- Bowel obstruction or major abdominal distention, where additional bowel gas expansion may worsen surgical exposure or patient risk.
- Middle ear surgery, sinus procedures with trapped air, or recent ear pathology where pressure changes may be harmful.
- Recent retinal surgery involving an intraocular gas bubble, because nitrous oxide can rapidly expand the bubble and threaten vision.
- Neurosurgical cases or recent cranial procedures with possible intracranial air (pneumocephalus).
- Patients at high risk for postoperative nausea and vomiting, especially when the expected clinical benefit is small.
- Prolonged or repeated exposure in patients with vitamin B12 deficiency risk, megaloblastic anemia, or conditions where methionine synthase inhibition is a concern.
- Situations in which environmental impact is a major consideration and nitrous oxide offers little meaningful advantage over other techniques.

High-Yield Safety Concerns

Malignant hyperthermia (MH) All potent volatile anesthetics are triggering agents for malignant hyperthermia in susceptible patients. nitrous oxide is not a triggering agent, but sevoflurane, desflurane, and isoflurane are.

The CRNA must be able to recognize rapidly rising end-tidal CO2, tachycardia, rigidity, hyperthermia, acidosis, and hyperkalemia as possible signs of MH and respond immediately with discontinuation of triggering agents, dantrolene, hyperventilation with oxygen, active cooling, and crisis management support.

Postoperative nausea and vomiting (PONV) Volatile anesthetics are associated with a higher risk of PONV than total intravenous anesthesia, and nitrous oxide may further contribute. In high-risk patients, this may influence anesthetic choice, antiemetic planning, or preference for a propofol-based technique.

Airway irritation and emergence issues Desflurane can irritate the airway, especially during rapid increases in concentration. Emergence may be rapid with low-solubility agents, but this is not always synonymous with smooth recovery. Agitation, coughing, hemodynamic stimulation, or pain can become more visible when patients wake quickly without balanced planning.

Emergence planning

Fast wake-up is not always the same thing as a smooth wake-up. Emergence quality depends on pain control, airway reactivity, secretion burden, neuromuscular recovery, antiemetic planning, and the timing of volatile washout relative to the rest of the anesthetic.

For CRNAs, a balanced emergence often means reducing volatile concentration thoughtfully, optimizing ventilation, treating pain before the patient is fully awake, and anticipating coughing, delirium, hypertension, or nausea before they become recovery-room problems.

Renal and hepatic considerations Modern volatile agents are generally much safer than older halogenated anesthetics with respect to organ toxicity.

Sevoflurane metabolism produces inorganic fluoride and has long-standing discussion about compound an in closed-circuit systems, but routine modern use has not made this a major day-to-day clinical limitation in most settings. halothane hepatitis remains historically important but is much less relevant in current routine U. S. practice because halothane is rarely used.

Environmental Impact and Practical CRNA Guidance

Volatile anesthetics and nitrous oxide are greenhouse gases, and environmental stewardship has become an increasingly important aspect of anesthesia practice. Desflurane has the greatest climate impact among commonly used inhaled anesthetics, while nitrous oxide also contributes substantially and has ozone-related implications.

Sevoflurane and isoflurane have lower but still meaningful environmental footprints. For CRNAs, environmentally informed practice does not mean abandoning inhaled anesthetics indiscriminately.

It means choosing the right agent for the patient and procedure, minimizing unnecessary fresh gas flow when clinically appropriate, avoiding desflurane or nitrous oxide when they do not add meaningful clinical value, and understanding when intravenous or regional alternatives may reduce both exposure and emissions.

Low-flow anesthesia

Low-flow anesthesia can reduce volatile consumption, lower greenhouse gas emissions, help preserve heat and humidity, and support more efficient use of inhaled agents when the patient and circuit are stable. It also requires attention to wash-in and wash-out timing, inspired oxygen concentration, and the limits of your machine and absorber system.

In practice, low-flow strategies make the most sense when they do not compromise oxygen delivery, monitoring, or the ability to adjust anesthetic depth promptly.

Volatile anesthetics vs TIVA

Volatile anesthesia and propofol-based total intravenous anesthesia are both standard techniques, and the best choice depends on the patient, procedure, and recovery goals.

Volatile anesthesia offers simplicity, end-tidal monitoring, and easy titration, while TIVA may be preferred when minimizing postoperative nausea and vomiting is a high priority or when a propofol-based technique better fits the surgical context.

For most routine cases, the decision is less about one technique being universally better and more about which tradeoffs matter most for the specific patient.

EEG/BIS and depth monitoring End-tidal volatile concentration remains a practical anchor for estimating hypnotic dose, but it does not capture everything that matters about the patient's brain state. Clinical signs, hemodynamics, neuromuscular blockade, adjunct medications, and surgical stimulation can all complicate the picture.

Processed EEG monitors such as BIS may be helpful in selected patients,

Especially when awareness risk, frailty, or concern about excessive depth is high, but these tools should complement rather than replace end-tidal monitoring and clinical judgment.

Practical CRNA points

- Use age-adjusted MAC rather than a fixed concentration target.
- Expect dose-dependent hypotension and ventilatory depression with all potent volatile agents.
- Favor sevoflurane when mask induction or airway tolerance matters.
- Use caution with desflurane in reactive airways or when rapid inspired concentration changes may provoke sympathetic responses.
- Avoid nitrous oxide when closed gas spaces, PONV risk, or limited clinical benefit make it a poor choice.
- Always consider malignant hyperthermia susceptibility when planning a volatile-based anesthetic.

Future Directions in Volatile Anesthesia

Although no brand-new volatile anesthetic has replaced sevoflurane, desflurane, or isoflurane in routine practice, inhaled anesthesia continues to evolve. Current innovation is focused on three major goals: improving hemodynamic stability, reducing environmental impact, and refining how inhaled agents are delivered in the operating room and critical care environments.

Xenon as a future inhaled agent Xenon remains the most frequently discussed future inhaled anesthetic because it offers rapid onset and emergence, minimal metabolism, and excellent cardiovascular stability. It is often described as approaching the profile of an ideal inhaled anesthetic.

However, xenon has not become widely adopted because of high cost, limited availability, and the need for specialized closed-circuit delivery systems.

Discovery of newer compounds There is also ongoing interest in the development of new inhaled anesthetic compounds that may produce less hypotension and less cardiovascular depression than current volatile agents.

Although these efforts remain early in development, they reflect a broader research trend toward designing anesthetics that are not only effective and fast, but also more physiologically forgiving.

Sustainability and smarter delivery systems a major future direction is also the optimization of existing volatile anesthetics through low-flow techniques, end-tidal control, better scavenging systems, and potential gas-capture technologies.

These approaches are increasingly important because the future of volatile anesthesia will depend not only on pharmacology, but also on environmental stewardship and more efficient delivery.

Bottom line for CRNAs

The future of volatile anesthesia is likely to be shaped by two parallel priorities: finding inhaled agents that are gentler on patient physiology and using volatile anesthetics in ways that are gentler on the environment. For CRNAs, this means future practice may be influenced as much by advances in system design and sustainability as by the introduction of entirely new anesthetic gases.

Clinical pearls

- Lower blood-gas solubility generally means faster adjustment in anesthetic depth and faster emergence.
- Sevoflurane is nonpungent and well suited for inhalational induction, especially in children.
- Desflurane allows rapid wake-up but can irritate the airway and increase sympathetic tone when introduced abruptly.
- All potent volatile anesthetics can trigger malignant hyperthermia in susceptible patients.
- Nitrous oxide expands closed gas spaces and can increase the risk of postoperative nausea and vomiting.
- A smooth emergence depends on planning for pain, airway events, nausea, and hemodynamics, not just on choosing the fastest agent.

Key Takeaways

- Volatile anesthetics remain foundational tools in general anesthesia because they are potent, titratable, and widely applicable.
- Sevoflurane, desflurane, and isoflurane differ in potency, solubility, airway tolerance, and emergence characteristics, while nitrous oxide has a distinct role as a weak anesthetic and analgesic adjunct.
- All potent volatile agents can cause dose-dependent hypotension, ventilatory depression, and are triggering agents for malignant hyperthermia.
- Nitrous oxide should be used selectively because of closed-space expansion, PONV contribution, and environmental impact.
- CRNAs should combine age-adjusted MAC guidance, patient-specific physiology, airway considerations, and environmental stewardship when choosing and titrating inhaled anesthetics.

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Ketamine

Mechanism of Action

- NMDA receptor antagonism-primary mechanism; reduces excitatory glutamate transmission.
- Interaction with opioid, monoaminergic, and GABAergic systems contributes to analgesia, dissociation, and cardiovascular stimulation.
- Produces a unique dissociative anesthetic state with preserved airway reflexes.
- Rapid onset due to high lipid solubility.
- Hepatic metabolism via CYP450 to norketamine (active metabolite).
- Redistribution determines duration of effect.

Secondary Mechanisms

Ketamine is pharmacologically "messy" - and that's why it's so versatile.

- Opioid receptor modulation o Weak agonism at u-receptors o Potentiates endogenous opioid signaling o Explains synergy with opioids and reduced opioid tolerance.
- Monoaminergic effects o Inhibits reuptake of serotonin, norepinephrine, dopamine o Contributes to cardiovascular stimulation and antidepressant effects.
- GABAergic modulation o Enhances inhibitory tone indirectly o Supports dissociation and amnesia.
- HCN1 channel inhibition o Contributes to hypnotic effects o Shared with propofol and volatile anesthetics.
- Anti-inflammatory actions o Reduces TNF-alpha, IL-6 o May contribute to improved postoperative pain control.

Physiologic Effects

- Cardiovascular: HR, BP due to sympathetic stimulation.
- Respiratory: minimal depression; bronchodilation beneficial in asthma.
- Neurologic: increased cerebral blood flow; emergence phenomena possible.
- Endocrine: catecholamines and cortisol.
- Hemodynamic instability
- Emergency department
- Burn dressing changes
- Short painful procedures
- Acute pain (trauma, postoperative)
- Opioid-tolerant patients
- Multimodal analgesia strategies

Adjunct in Regional Anesthesia

- Low-dose infusions reduce central sensitization.
- May decrease postoperative opioid requirements.

ICU Sedation

- Hemodynamically favorable
- Useful in bronchospasm or status asthmaticus

Contraindications & Safety Considerations

- Ketamine hypersensitivity
- Severe cardiovascular disease
- Elevated intracranial pressure (evidence evolving)
- Severe psychiatric disorders (risk of emergence reactions)
- Pregnancy (limited data)

Adverse Effects

- Emergence delirium
- Transient hypertension
- Increased muscle tone

Chronic Pain

AANA's updated practice considerations emphasize CRNAs' role in safe ketamine therapy for psychiatric disorders and chronic pain.

Psychiatric Uses

- Treatment-resistant depression (TRD)
- Major depressive disorder (MDD) with suicidal ideation
- Bipolar depression

Esketamine nasal spray is FDA-approved for TRD and MDD with acute suicidal ideation.

- Neuropathic pain
- Central sensitization disorders

Safety Requirements

- Collaborative care with psychiatric-mental health professionals
- Structured screening, monitoring, and follow-up
- Evidence-based clinic policies and emergency preparedness

Administration & Monitoring

- Cardiovascular assessment
- Psychiatric history
- Substance use history
- Airway evaluation
- Continuous ECG, SpO2, BP
- Capnography for sedation
- Watch for laryngospasm (rare)
- Quiet environment to reduce emergence reactions
- Monitor for agitation, nausea, hypertension

- Ensure return of protective reflexes

Expansion) If you want, I can add full written analyses for each case:

- Trauma induction
- Opioid-tolerant surgical patient
- Psychiatric history & sedation

(All sources are from authoritative anesthesia and CRNA-specific organizations.)

- American Association of Nurse Anesthesiology. Updated Practice Considerations for Ketamine Therapy for Psychiatric Disorders and Chronic Pain Management.
- American Association of Nurse Anesthesiology. Ketamine Infusion Therapy Overview.
- Gifted Anesthesia. CRNA CEU: Ketamine Course.

If you'd like, I can now create slides, a full CE handout, or a post-test with answer key to accompany this module.

Can you redo this without the pictures

Absolutely, Nicole-here is a clean, fully rewritten ketamine & anesthesia CE module for CRNAs with no images, structured for professional CE use and ready for expansion into slides, a test bank, or a formatted handout if you want.

I've kept it comprehensive, evidence-based, and aligned with current AANA guidance.

- Primary action: NMDA receptor antagonism, reducing excitatory glutamate signaling.
- Secondary actions: opioid receptor interaction, monoamine reuptake inhibition, and mild GABAergic effects.
- Produces a dissociative anesthetic state with amnesia, analgesia, and preserved airway reflexes.
- Redistribution determines duration; elimination half-life ~2.5-3 hours.
- Cardiovascular: sympathetic stimulation -> HR, BP, CO.
- Respiratory: minimal depression; bronchodilation.
- Neurologic: cerebral blood flow and ICP (evidence evolving); emergence reactions possible.
- Asthma or bronchospasm
- Difficult IV access (IM route available)
- Emergency medicine
- Pediatric sedation
- Acute postoperative pain
- Trauma and battlefield medicine
- Opioid-tolerant or opioid-dependent patients
- Multimodal analgesia protocols
- May reduce postoperative opioid consumption.
- Hemodynamically stable alternative to propofol or dexmedetomidine.
- Useful in severe bronchospasm or status asthmaticus.
- Severe cardiovascular disease (e.g., uncontrolled hypertension, ischemic heart disease)
- Elevated ICP (controversial; use clinical judgment)
- Pregnancy (limited safety data)
- Active substance use disorder
- Emergence delirium or agitation
- Transient hypertension and tachycardia

- Increased muscle tone or myoclonus

Supported by growing evidence and AANA practice considerations:

- Major depressive disorder with suicidal ideation

Chronic Pain Applications

- Complex regional pain syndrome (CRPS)
- Central sensitization syndromes

Safety Requirements for CRNA-Led Ketamine Therapy

- Collaborative care with mental health professionals
- Standardized screening and consent
- Continuous monitoring during infusion
- Post-infusion observation and follow-up
- Emergency preparedness (airway, cardiovascular, behavioral)
- Psychiatric history and screening
- Medication review (benzodiazepines may blunt effect)
- Capnography for moderate/deep sedation
- Vigilance for laryngospasm (rare but possible)
- Titrate dosing based on effect and patient response
- Quiet, low-stimulus environment to reduce emergence reactions
- Ensure return of protective reflexes and orientation
- Provide discharge instructions if outpatient

Optional Case Studies

Trauma induction with hemodynamic instability

- Opioid-tolerant surgical patient requiring multimodal analgesia
- Sedation in a patient with psychiatric history

I can write full narrative case studies with discussion questions if you want.

- American Association of Nurse Anesthesiology (AANA). Updated Practice Considerations for Ketamine Therapy for Psychiatric Disorders and Chronic Pain Management.
- AANA. Ketamine Infusion Therapy Overview.
- Domino EF. Taming the ketamine tiger. Anesthesiology.
- Schwenk ES et al. Consensus Guidelines on the Use of Intravenous Ketamine Infusions for Acute Pain Management.
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Benzodiazepines

Pharmacology of Benzodiazepines

Benzodiazepines enhance the inhibitory effect of gamma-aminobutyric acid (GABA) at the GABA-a receptor. They do not directly open the chloride channel; instead, they increase the frequency of channel opening in the presence of endogenous GABA. This produces anxiolytic, sedative, amnestic, anticonvulsant, and muscle-relaxant effects.

In anesthesia practice, the most clinically important features are anxiolysis, anterograde amnesia, synergy with opioids and other sedatives, and dose-dependent respiratory depression. Unlike propofol or barbiturates, benzodiazepines are rarely used as sole anesthetic agents in routine practice, but they remain highly relevant as adjuncts throughout the perioperative period.

Midazolam Dosing Chart (Adults and Pediatrics)

The following doses are common educational reference ranges for perioperative use and should always be individualized to age, comorbidities, concurrent sedatives or opioids, and desired depth of sedation.

Midazolam should be titrated slowly with continuous respiratory and hemodynamic monitoring; lower initial doses are appropriate in older adults, debilitated patients, and those with obstructive sleep apnea or other causes of increased respiratory risk.

Population / Use Route Typical Dose Key Notes

- 1 to 2.5 mg slow IV.
- May repeat Give slowly and reassess Adults: in small increments after before redosing. Reduce preoperative adequate time to assess effect. initial dose in older adults, anxiolysis or light IV Total dose is often <=5 mg in frail patients, or when procedural healthy adults younger than 60 opioids or other sedatives sedation years. are also used. Adults: 0.07 to 0.08 mg/kg IM, typically Useful when IV access is preoperative IM administered up to 1 hour not yet established.
- Onset is anxiolysis before surgery. slower than IV dosing. Use as part of a balanced Premedicated: about 0.15 to anesthetic, not as an Adults: induction 0.25 mg/kg IV. substitute for full induction adjunct or light IV Unpremedicated: about 0.3 to planning. Consider dose anesthesia 0.35 mg/kg IV. Higher total reduction when combined doses may prolong recovery. with opioids or other induction agents. These patients have greater Older adults or Start with lower doses, often sensitivity to oversedation, debilitated IV 0.5 to 1 mg IV, then titrate airway obstruction, and adults carefully. delayed recovery. Often used 15 to 30 0.25 to 0.5 mg/kg PO.
- A minutes before separation Pediatrics: common preoperative dose is or induction. Watch for preoperative Oral 0.5 mg/kg PO (maximum 20 paradoxical reactions, anxiolysis mg). delayed recovery, or airway obstruction.

Anxiolysis or 0.05 to 0.1 mg/kg IV initially; reassess before redosing. procedural cumulative dosing may reach Younger children are more IV sedation, age 6 about 0.6 mg/kg, though total vulnerable to airway months to 5 dose is usually <=6 mg. obstruction and years hypoventilation.

0.025 to 0.05 mg/kg IV initially; Titrate to effect with close Pediatrics: cumulative dosing may reach airway and ventilation anxiolysis or IV about 0.4 mg/kg, though total monitoring, especially if procedural dose is usually <=10 mg. opioids are coadministered.

Sedation, age 6 to 12 years Clinical context still Pediatrics: Often dosed similarly to adults, matters; body size, adolescents 12 IV with careful titration and total comorbidities, and to 16 years dose commonly <=10 mg. concomitant medications may justify lower dosing.

Common ranges are 0.2 to 0.3 Intranasal dosing may sting Pediatrics: mg/kg IN for anxiolysis; recent and can produce variable preoperative pediatric procedural sedation absorption.

Use caution in anxiolysis or Intranasal data suggest 0.4 to 0.5 mg/kg children with copious selected IN may provide more reliable secretions or airway procedural use sedation for brief procedures in vulnerability. selected

children.

References for Midazolam Dosing Chart

Dosing ranges in this chart were adapted from official prescribing information for midazolam injection and oral syrup, with pediatric intranasal dosing and monitoring considerations supplemented by current procedural sedation literature and professional guidance.

- Midazolam Injection prescribing information (FDA and DailyMed), including adult and pediatric IV and IM dosing, titration guidance, and geriatric dose reduction recommendations.
- Midazolam Hydrochloride Syrup prescribing information (DailyMed), including pediatric oral premedication dosing and safety precautions.
- American Society of Anesthesiologists. Practice Guidelines for Moderate Procedural Sedation and Analgesia (2018), used for adult procedural sedation monitoring context.

Common Perioperative Benzodiazepines

- Midazolam: Short-acting; commonly used for preoperative anxiolysis, procedural sedation, and induction adjuncts. Rapid onset and relatively short duration make it the most familiar anesthetic benzodiazepine.
- Diazepam: Longer-acting; less commonly used perioperatively today but still relevant for seizure management and chronic outpatient therapy.
- Lorazepam: Intermediate to long duration; useful in seizure treatment, ICU practice, and chronic benzodiazepine regimens, but less favorable for brief ambulatory anesthesia because of prolonged sedative effects.
- Remimazolam: Ultra-short-acting benzodiazepine with growing use for procedural sedation and, in some settings, general anesthesia. It offers organ-independent esterase metabolism and can be antagonized with flumazenil.

Clinical Applications in Anesthesia

- Preoperative anxiolysis and amnesia: Benzodiazepines are frequently used to reduce anxiety and improve perioperative comfort, particularly before induction or invasive procedures.
- Procedural sedation: Midazolam and remimazolam are used for monitored anesthesia care and procedural sedation, often in combination with opioids or other hypnotics.
- Induction adjunct: Benzodiazepines may be used as part of a balanced anesthetic technique to reduce anesthetic requirements and support amnesia.
- Anticonvulsant therapy: Benzodiazepines remain essential in acute seizure management and status epilepticus.
- ICU sedation and withdrawal management: Selected benzodiazepines may be used in critical care, alcohol withdrawal, and other settings where sedation or anticonvulsant effects are needed.

A careful medication history is essential. Important questions include whether the patient uses benzodiazepines chronically, the specific agent and dose, frequency of use, indication, and timing of the most recent dose. Chronic benzodiazepine use may alter sedative requirements and increase the risk of withdrawal if therapy is stopped abruptly.

- Older adults may be more vulnerable to prolonged sedation, delirium, and falls.
- Patients with obstructive sleep apnea, obesity, or pulmonary disease may be more susceptible to respiratory depression.
- Patients receiving opioids, gabapentinoids, alcohol, or other sedatives may have additive central nervous system depression.

- Abrupt discontinuation of chronic benzodiazepines may precipitate agitation, tremor, autonomic instability, and withdrawal delirium. For many chronic users, perioperative continuation or thoughtful substitution is safer than unplanned discontinuation.

Intraoperative and Sedation Implications

- Respiratory effects: Benzodiazepines can cause dose-dependent respiratory depression, especially when combined with opioids or other sedatives.
- Hemodynamic profile: They generally cause less hemodynamic instability than propofol, but hypotension may still occur in hypovolemic or frail patients, particularly when co-administered with other agents.
- Synergy: Benzodiazepines reduce anesthetic requirements and can potentiate opioids, propofol, and volatile agents. Small doses may have substantial effects in susceptible patients.
- Recovery considerations: Excessive dosing may contribute to delayed emergence, residual sedation, impaired airway reflexes, or prolonged PACU recovery.

Postoperative Risks, Delirium, and Withdrawal

Postoperatively, benzodiazepines may contribute to sedation, hypoventilation, impaired cognition, and delayed mobilization. Their relationship with postoperative delirium is complex: benzodiazepines may be associated with increased delirium risk in some older or critically ill populations, yet abrupt discontinuation in chronic users may also trigger withdrawal and delirium.

A practical CRNA approach is to avoid unnecessary benzodiazepine exposure in high-risk older adults while also recognizing that chronic therapy should not be stopped suddenly without a plan. Both oversedation and withdrawal can cause harm.

Emerging neuroimaging research also suggests that prolonged benzodiazepine exposure may be associated with adverse structural brain changes.

In a 2025 diffusion MRI study of patients with benzodiazepine use disorders, long-term benzodiazepine exposure was associated with white matter microstructural abnormalities-particularly in the corpus callosum and pontine crossing tract-and these changes correlated with worse cognitive performance.

Although this does not prove that all chronic benzodiazepine use causes white matter loss, it strengthens concern that prolonged exposure, especially when associated with dependence or misuse, may contribute to disruption of white matter integrity and cognitive decline over time.

Population Considerations

However, children are also susceptible to paradoxical reactions, airway obstruction, and respiratory depression, particularly when benzodiazepines are combined with opioids or other sedatives.

Recent pediatric literature has also increased interest in remimazolam because of its rapid onset, short context-sensitive recovery profile, and reversibility with flumazenil, although pediatric evidence remains less mature than adult data and broad routine use still requires careful clinical judgment.

For the CRNA, pediatric use requires careful weight-based dosing, vigilant ventilation monitoring, and awareness that sedation depth may change quickly when benzodiazepines are combined with other agents. In ambulatory or procedural settings, the goals are reliable anxiolysis and amnesia while preserving airway patency, spontaneous ventilation, and recovery efficiency.

Older Adults

Older adults warrant particular caution because age-related pharmacodynamic sensitivity and reduced physiologic reserve may increase susceptibility to oversedation, prolonged recovery, impaired coordination, hypoventilation, and postoperative neurocognitive complications.

Although recent evidence has questioned whether perioperative benzodiazepines independently cause postoperative delirium in all older patients, many anesthesia guidelines and quality-improvement initiatives still support limiting routine benzodiazepine exposure in older adults, especially when alternative strategies are available.

In practice, CRNAs should use the lowest effective dose, avoid reflexive administration, and individualize decisions based on frailty, baseline cognition, fall risk, obstructive sleep apnea, concurrent opioid use, and the procedural context. When benzodiazepines are needed, careful titration and postoperative observation are especially important.

The clinical objective is not universal avoidance, but thoughtful use that balances anxiolysis and amnesia against the risks of prolonged sedation, respiratory compromise, and delayed recovery.

Obesity Patients with obesity may be more vulnerable to airway obstruction, hypoventilation, difficult mask ventilation, and prolonged postoperative respiratory events when benzodiazepines are administered. Excess adiposity may also increase sensitivity to the respiratory depressant effects of combined sedative and opioid regimens, particularly in ambulatory or recovery settings.

For the CRNA, benzodiazepine use in patients with obesity should be conservative, titrated to effect, and integrated into a broader plan that emphasizes airway preparation, multimodal analgesia, careful positioning, and postoperative monitoring.

Patients with known or suspected OSA are at heightened risk for upper airway collapse and ventilatory compromise when benzodiazepines are combined with opioids, other sedatives, or residual anesthetic effects. Even modest benzodiazepine doses may worsen airway collapsibility and blunt arousal responses.

CRNAs should screen for OSA risk, avoid unnecessary benzodiazepine exposure when suitable alternatives exist, and emphasize short-acting strategies, opioid-sparing analgesia, and enhanced postoperative observation. In selected patients, perioperative use of CPAP or other positive airway pressure support may help reduce respiratory complications.

Pregnancy Benzodiazepines cross the placenta and therefore require thoughtful risk-benefit assessment during pregnancy. In anesthesia practice, limited perioperative exposure may be clinically justified in selected situations, but chronic use or repeated exposure near delivery may increase concern for neonatal respiratory depression, hypotonia, or withdrawal.

When benzodiazepines are required in pregnant patients, the CRNA should use the lowest effective dose, avoid unnecessary repeated dosing, and coordinate care with the obstetric and neonatal teams when maternal exposure is expected to be clinically significant.

Breastfeeding considerations should also be addressed. Current perioperative lactation guidance indicates that most anesthetic and sedative medications do not require routine "pump and dump" after surgery; for short-term perioperative benzodiazepine exposure, breastfeeding can often resume once the patient is awake, alert, and able to safely hold the infant.

When benzodiazepines are needed in lactating patients, shorter-acting agents and the lowest effective dose are preferred, while repeated high-dose or long-acting exposure should be avoided when possible because infant sedation risk may be greater with accumulation.

If maternal benzodiazepine use is ongoing, or if the infant is premature, medically fragile, or unusually sleepy, the dyad should be monitored for poor feeding, excessive sedation, or respiratory depression and individualized counseling is appropriate.

Hepatic and Renal Impairment

Hepatic dysfunction may prolong the effects of traditional benzodiazepines that depend on hepatic metabolism, particularly in patients receiving repeated doses or infusions. Although renal impairment has less direct impact on some parent compounds, metabolite accumulation and overall sedative sensitivity may still complicate recovery in medically fragile patients.

These issues are especially relevant with longer-acting agents such as diazepam and lorazepam. In contrast, remimazolam offers a potentially useful alternative in selected patients because its metabolism is less dependent on conventional hepatic and renal clearance pathways.

For CRNAs, the practical approach is to reduce dose, lengthen intervals between administrations, monitor emergence carefully, and choose shorter-acting agents whenever feasible.

Flumazenil and Reversal

Flumazenil is a competitive benzodiazepine antagonist that can reverse sedation and respiratory depression caused by benzodiazepines. In anesthesia practice, it may be considered for residual benzodiazepine effect or delayed emergence when reversal is expected to improve safety or recovery.

Flumazenil Dosing Chart

Flumazenil should be titrated to the minimum dose needed to restore the desired level of consciousness rather than given as a large bolus. Because its duration may be shorter than the benzodiazepine being reversed, continued monitoring for re-sedation and recurrent respiratory depression is essential.

Extra caution is required in patients with chronic benzodiazepine exposure, seizure disorders, or suspected mixed overdose.

0.2 mg IV over 15 seconds, Titrate to effect rather than

Then 0.2 mg every 1 minute complete arousal if airway and procedural sedation as needed to the desired ventilation are adequate. or benzodiazepine-IV level of responsiveness; Smaller cumulative doses may associated delayed cumulative dose usually 0.6 reduce agitation and acute emergence to 1 mg, maximum 1 mg. withdrawal risk.

Adults: suspected 0.2 mg IV over 30 seconds; if If there is no meaningful IV isolated needed, give 0.3 mg after 30 response after 5 mg, ongoing

Benzodiazepine seconds, then 0.5 mg at 1-sedation is unlikely to be overdose minute intervals to an usual primarily due to maximum cumulative dose benzodiazepines. Avoid of 3 mg. Rare partial routine use when mixed responders may be titrated overdose, tricyclic up to 5 mg total. antidepressant exposure, or seizure risk is suspected.

0.01 mg/kg IV over 15 seconds (maximum 0.2 mg Use only when airway and Pediatrics (1 to 17 per dose). If needed, repeat ventilation can be closely years): reversal of after 45 seconds, then every monitored.

Safety and efficacy IV benzodiazepine 1 minute up to 4 additional in children younger than 1 sedation doses; maximum cumulative year are not established in the dose 0.05 mg/kg or 1 mg, prescribing information. whichever is lower.

Repeat the lowest effective Continue respiratory and dose if clinically necessary. hemodynamic monitoring Adults or pediatrics: In adults, repeat dosing may because recurrent sedation re-sedation after IV be given at 20-minute may outlast the antagonist initial response intervals; do not exceed 1 effect.

Reversal does not treat mg at one time or 3 mg in 1 coadministered opioids or hour. other sedatives.

Practical CRNA Guidance

- Use the lowest effective benzodiazepine dose for the intended clinical objective.
- Adjust dosing downward in older adults, frail patients, and those receiving other sedatives or opioids.
- Avoid assuming that chronic benzodiazepine users will respond normally to standard doses; tolerance and withdrawal risk must both be considered.
- Monitor ventilation carefully during procedural sedation, especially when benzodiazepines are combined with opioids.
- When considering reversal, weigh the benefits of improved emergence against the risks of withdrawal, seizures, and re-sedation.

Case 1: Older Adult With Hip Fracture and Delirium Risk

An 82-year-old patient presents for urgent hip fracture repair. The patient is anxious, mildly frail, and has baseline memory impairment. The surgical team requests preoperative midazolam for anxiety. The CRNA must balance anxiolysis with the risk of oversedation, hypoventilation, and postoperative neurocognitive complications.

Discussion: This case highlights the importance of individualized benzodiazepine use in older adults. Although a small benzodiazepine dose may reduce distress, older adults are more

Susceptible to prolonged sedation and postoperative confusion. a CRNA may reasonably choose a reduced dose, use nonpharmacologic anxiolysis, or avoid routine benzodiazepine administration altogether depending on frailty, baseline cognition, and the overall anesthetic plan.

Clinical Pearl: In older adults, the question is often not whether benzodiazepines are absolutely contraindicated, but whether the anticipated benefit clearly outweighs the risk of oversedation and postoperative cognitive complications.

Case 2: Obesity, OSA, and Procedural Sedation

A 54-year-old patient with obesity and known obstructive sleep apnea presents for endoscopy under monitored anesthesia care. The patient takes chronic opioids for back pain. a benzodiazepine is requested for anxiolysis before sedation begins. Discussion: This scenario illustrates cumulative respiratory risk.

Even small benzodiazepine doses may worsen airway collapsibility and reduce ventilatory responsiveness when combined with opioids and sedative-hypnotics. The CRNA should anticipate a narrower safety margin, consider avoiding benzodiazepines if not clearly necessary, and emphasize airway positioning, capnography, opioid-sparing strategies, and enhanced recovery observation.

Clinical Pearl: In patients with obesity and OSA, benzodiazepines should be viewed as risk-amplifying rather than benign premedication.

Case 3: Pregnancy and Limited Perioperative Exposure

A 29-year-old pregnant patient in the second trimester presents for urgent nonobstetric surgery. She is extremely anxious at induction and asks for medication to help her relax. The CRNA must decide whether a limited perioperative benzodiazepine exposure is justified. Discussion: This case requires a risk-benefit approach rather than rigid avoidance.

Benzodiazepines cross the placenta, but limited maternal exposure may be clinically reasonable when anxiety reduction improves procedural safety or facilitates induction. The prudent approach is to use the lowest effective dose, avoid unnecessary repeated administration, and communicate with the obstetric and neonatal teams when clinically significant exposure is anticipated.

Clinical Pearl: Pregnancy does not automatically preclude perioperative benzodiazepine use, but it does require more deliberate justification and team communication.

Case 4: Chronic Benzodiazepine Use and Withdrawal Risk

A 46-year-old patient takes clonazepam daily for panic disorder and presents for elective abdominal surgery. On the morning of surgery, the patient has not taken the usual dose and is tachycardic, anxious, and tremulous. The surgical team asks whether preoperative benzodiazepines should be avoided because the patient will receive anesthetic medications soon.

Discussion: This case emphasizes that withdrawal risk may be more dangerous than continuation. Chronic benzodiazepine users may require continuation of baseline therapy or

Substitution planning to prevent perioperative agitation, autonomic instability, and withdrawal delirium. Standard premedication assumptions do not apply when the patient is benzodiazepine-dependent, and reversal with flumazenil later in the course may be especially hazardous.

Clinical Pearl: In chronic benzodiazepine users, the perioperative question is often how to maintain stability safely, not how to eliminate exposure completely.

- Benzodiazepines remain important for anxiolysis, amnesia, procedural sedation, seizure control, and selected critical care indications.
- Midazolam is the most familiar perioperative agent, while remimazolam is expanding interest in ultra-short-acting benzodiazepine techniques.
- The major anesthesia concerns are additive respiratory depression, delayed recovery, postoperative cognitive effects, and withdrawal in chronic users.
- Older adults and patients with comorbid respiratory disease or polypharmacy require especially careful dosing and monitoring.
- CRNA practice should emphasize individualized dosing, thoughtful monitoring, and a balanced approach to continuation, avoidance, or reversal.

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Benzodiazepines and Anesthesia for Nurse Anesthetists

Explain the pharmacology, receptor effects, and major clinical properties of benzodiazepines used in anesthesia practice. Differentiate common perioperative benzodiazepines, including midazolam, diazepam, lorazepam, and remimazolam. Identify appropriate uses of benzodiazepines for anxiolysis, amnesia, procedural sedation, induction adjuncts, seizure management, and ICU sedation.

Apply CRNA-focused strategies for safe dosing, monitoring, reversal, and perioperative management of benzodiazepines across diverse patient populations, and use case-based reasoning to support clinical decision-making in patients receiving chronic or acute benzodiazepine therapy.

Statement 1 2 3 4 5 The information presented on benzodiazepines in anesthesia is accurate and evidence-based. The content reflects current clinical practice and recent advances in perioperative benzodiazepine use. The material is relevant to anesthesia and CRNA practice.

The module adequately addresses practical benzodiazepine considerations such as dosing, adverse effects, reversal, and patient selection.

Statement 1 2 3 4 5 The information is presented in a clear and understandable manner. The content is logically organized. Complex concepts are well explained. Tables, quick-reference sections, and case pearls improved the usability of the module.

Neuromuscular Blocking Agents and Sugammadex

Overview and Classification of Neuromuscular Blocking Agents

Neuromuscular blocking agents (NMBAs) interrupt transmission at the neuromuscular junction and produce skeletal muscle paralysis. They are used to facilitate tracheal intubation, improve surgical conditions, and support immobility or ventilator synchrony in selected settings. NMBAs do not provide hypnosis, amnesia, or analgesia and should never be used as a substitute for adequate anesthesia.

Clinically, NMBAs are classified as depolarizing or nondepolarizing. Succinylcholine is the only depolarizing NMBA in common anesthesia practice. Nondepolarizing agents agents are further divided into aminosteroid compounds, such as rocuronium and vecuronium, and benzylisoquinolinium compounds, such as cisatracurium and atracurium.

Succinylcholine is a depolarizing NMBA with rapid onset and ultrashort duration, which historically made it the classic drug for rapid sequence intubation. It acts as an acetylcholine receptor agonist, causing persistent depolarization and temporary paralysis.

- Advantages: Very rapid onset, predictable intubating conditions, brief duration.
- Important adverse effects: Hyperkalemia, bradycardia, myalgias, increased intraocular/intragastric pressure, triggering of malignant hyperthermia, and prolonged block in pseudocholinesterase deficiency.

- Key contraindications: Known or suspected hyperkalemic conditions, major burns after the acute phase, prolonged immobilization, neuromuscular disease, certain stroke or spinal cord injury states, and susceptibility to malignant hyperthermia. In many practices, high-dose rocuronium with planned sugammadex reversal has reduced reliance on succinylcholine, but succinylcholine remains clinically relevant when its advantages clearly outweigh its risks.

Nondepolarizing agents NMBAs competitively antagonize acetylcholine at nicotinic receptors at the neuromuscular junction. In routine anesthesia practice, the most important agents are rocuronium, vecuronium, cisatracurium, and atracurium.

- Rocuronium: Rapid onset, intermediate duration, aminosteroid compound. Commonly used for intubation and maintenance; can approximate RSI conditions at higher doses.
- Vecuronium: Intermediate duration, aminosteroid compound. Reliable maintenance agent but slower onset than rocuronium.
- Cisatracurium: Intermediate duration, benzylisoquinolinium compound. Undergoes Hofmann elimination and is especially useful when hepatic or renal dysfunction is present.
- Atracurium: Intermediate duration, benzylisoquinolinium compound. Also undergoes organ-independent breakdown but may produce histamine release and laudanosine. Older or less commonly used agents, such as pancuronium or mivacurium, remain pharmacologically relevant but are less central to contemporary CRNA practice in many settings.

Dosing Chart for Common Neuromuscular Blocking Agents

The following chart summarizes usual adult anesthesia dosing ranges and practical characteristics of commonly used neuromuscular blocking agents. Institutional practice, procedure type, patient comorbidities, anesthetic depth, and quantitative monitoring should guide final dosing decisions.

Typical Intuba Ons al sm /

Tion et Durat Eliminati ance Dose ion on 1-1.5 Rapid onset; mg/kg Not Plasma hyperkalemia, IV; 3-4 typically 30-cholinest MH triggering,

Depolarizing mg/kg used for 60 erase bradycardia, oline min IM if mainten sec metabolis pseudocholine no IV ance m sterase access deficiency 0.1-0.2 0.6-1.2 mg/kg Hepatic mg/kg Common RSI Nondepolarizing agents bolus or uptake / Rocuroniu IV 1-2 30-70 alternative; ng infusion biliary m (higher min min reversible with aminosteroid 4-16 eliminatio end for sugammadex mcg/kg/ n

- Min 0.01 Useful mg/kg Hepatic maintenance 0.08-boluses metabolis Nondepolarizing agents agent.
- Slower Vecuroniu 0.12 or 2-3 30-45 m.
- Biliary ng onset than m mg/kg infusion min min and renal aminosteroid rocuronium.
- IV about 1 eliminatio reversible with mcg/kg/ n sugammadex min 0.01-Organ-Nondepolarizing agents 0.1-0.2 0.03 Hofmann independent Cisatracuri ng 2-4 40-75 mg/kg mg/kg eliminatio elimination.
- Um benzylisoquin min min IV bolus or n useful in olinium infusion hepatic/renal.

1-3 dysfunction mcg/kg/ and ICU min paralysis

0.08-0.1 histamine mg/kg

0.4-0.5 eliminatio laudanosine Atracuriu ng or 2-3 20-35 mg/kg n and may m benzylisoquin infusion min min IV ester accumulate olinium 5-10 hydrolysis with mcg/kg/ prolonged min exposure 0.01 mg/kg boluses Long-acting; 0.06-Primarily Nondepolarizing agents or 60-vagolytic/tachy Pancuroni 0.1 2-3 renal ng infusion 120+ cardic profile; um mg/kg min eliminatio aminosteroid about min less common

0.1 today mg/kg/h r Short-acting Plasma Nondepolarizing agents 0.15-Infusion but not widely cholinest Mivacuriu ng 0.25 4-10 2-3 15-30 available; erase m benzylisoquin mg/kg mcg/kg/ min min histamine metabolis olinium IV

min release may m occur

Practical note: Dosing ranges vary with anesthetic technique, patient factors, and whether intubation versus maintenance paralysis is the clinical goal. Quantitative neuromuscular monitoring should guide maintenance dosing and timing of reversal whenever a NMBA is used.

Pediatric dosing note: Pediatric NMBA dosing is weight based and may differ from adult onset and duration because of developmental physiology. When these agents are used in children, age-specific references, institutional policy, and quantitative monitoring should guide final dosing and reversal decisions.

Choosing Among Agents in Clinical Practice

Selection of a NMBA depends on urgency, desired onset and duration, patient comorbidities, metabolism, and the reversal strategy available. Rocuronium is often favored when rapid onset is needed and sugammadex is available. Cisatracurium is especially attractive in critically ill patients and those with significant hepatic or renal dysfunction.

Vecuronium remains useful for maintenance but may accumulate with repeated dosing. Succinylcholine may still be reasonable for RSI when contraindications are absent and a very brief block is desired.

The CRNA must also consider patient-specific variables that alter sensitivity to NMBAs, including age, temperature, acid-base status, electrolyte abnormalities, neuromuscular disease, obesity, burn injury, chronic anticonvulsant therapy, and concurrent medications such as magnesium or certain antibiotics.

Monitoring Neuromuscular Blockade and Residual Weakness

Residual neuromuscular blockade remains common and clinically important. It is associated with upper airway obstruction, hypoxemia, impaired pulmonary function, reintubation, and other postoperative respiratory complications. Contemporary practice guidelines strongly support quantitative neuromuscular monitoring whenever NMBAs are used.

- Qualitative assessment with a peripheral nerve stimulator can estimate block depth but cannot reliably exclude residual weakness.
- Quantitative monitoring with acceleromyography or electromyography is preferred.
- Extubation should follow documented recovery to an acceptable train-of-four ratio, generally at least 0.9. Sugammadex improves reversal reliability for aminosteroid block, but it does not eliminate the need for objective monitoring.

Reversal of Neuromuscular Blockade

Traditional reversal of nondepolarizing block uses an acetylcholinesterase inhibitor such as neostigmine, typically paired with an antimuscarinic agent such as glycopyrrolate. Neostigmine is most appropriate when recovery is already underway and a shallow or minimal block is present.

It is slower and less predictable than sugammadex, and it may be associated with bradycardia, secretions, bronchospasm, or inadequate reversal if given at an inappropriate depth of block. Sugammadex is a selective binding agent that encapsulates aminosteroid NMBAs, especially rocuronium and vecuronium.

It provides rapid and more predictable reversal across moderate and deep levels of aminosteroid block and has changed routine practice in many operating rooms.

Sugammadex: Practical Considerations for CRNAs

- What it reverses: Rocuronium and vecuronium; it does not reverse succinylcholine, cisatracurium, or atracurium.
- Why it matters: Faster recovery, reduced residual paralysis, and fewer cholinergic side effects than neostigmine-based reversal.
- Important safety issues: Bradycardia, rare severe hypersensitivity or anaphylaxis, and the possibility of inadequate reversal if underdosed relative to block depth.
- Special populations: Use requires additional judgment in severe renal impairment because the sugammadex-NMBA complex is renally cleared. Evidence continues to evolve in obstetric, pediatric, and critically ill populations.
- Drug interaction pearl: As a steroid-binding agent, sugammadex may reduce the effectiveness of hormonal contraceptives; patients should receive appropriate counseling per product labeling.

In practice, CRNAs should distinguish between common adverse effects and uncommon but high-acuity reactions. Reported side effects include nausea, vomiting, pain, dizziness, headache, dry mouth, and occasional hypotension.

More serious concerns include marked bradycardia, recurrent or incomplete recovery when dosing does not match block depth, and hypersensitivity reactions that may range from rash or flushing to anaphylaxis. Transient laboratory prolongation of PT or aPTT has also been described, so caution is reasonable when perioperative bleeding risk is already a concern.

- Common: nausea, vomiting, dizziness, headache, dry mouth, pain, mild hypotension.
- Serious: marked bradycardia, hypersensitivity, anaphylaxis, incomplete or recurrent recovery if underdosed.
- Practical caution: continue quantitative monitoring and use extra caution in severe renal impairment.

Although sugammadex is highly effective, best practice still combines appropriate dosing with quantitative monitoring rather than relying on empiric reversal alone.

Sugammadex and Hormonal Contraception

Because sugammadex can bind steroidal compounds, it may reduce the effectiveness of hormonal contraceptives, including oral contraceptive pills, transdermal patches, vaginal rings, injectable formulations, implants, and some intrauterine systems that rely on hormonal release. Product labeling advises that exposure to sugammadex should be treated similarly to a missed hormonal contraceptive dose.

For CRNAs, this creates an important perioperative counseling responsibility. Patients using hormonal contraception should be informed that a nonhormonal backup method or abstinence is recommended for 7 days after sugammadex administration, consistent with current labeling.

This counseling is especially important in ambulatory surgery, where the patient may otherwise be unaware of the interaction after discharge.

A practical documentation pearl is to note that contraceptive counseling was provided when sugammadex is administered to a patient of reproductive potential who uses hormonal contraception.

Sugammadex Dosing and Reversal Quick Reference

Dose Rapid reversal of Confirm block depth with

Moderate block

2 mg/kg rocuronium or quantitative monitoring; (e.g., 2 twitches on IV vecuronium; recovery underdosing may leave

Often within a few minutes. Residual weakness Deep block (e.g., Use only for rocuronium or post-tetanic counts 4 mg/kg Predictable reversal of vecuronium; continue present, no TOF IV deeper aminosteroid block monitoring until full recovery twitches) is documented Very rapid reversal when Reserved for specific Immediate rescue 16 immediate return of circumstances; dosing should after high-dose mg/kg neuromuscular function is match a known recent high-rocuronium RSI IV required dose rocuronium exposure

Sugammadex does not reverse succinylcholine or benzylisoquinolinium neuromuscular blockers. Severe renal impairment, bradycardia, hypersensitivity, and contraceptive counseling remain important practical considerations.

Special Populations and High-Risk Situations

Pediatrics Children may demonstrate variable onset and duration of neuromuscular blockade depending on age, cardiac output, and distribution characteristics. Succinylcholine use in pediatrics requires particular caution because unrecognized myopathies may increase the risk of life-threatening hyperkalemia.

When nondepolarizing agents are used, careful weight-based dosing and quantitative monitoring remain essential. Sugammadex use in pediatric practice continues to expand, but clinicians should follow current institutional guidance and age-specific dosing recommendations.

Older adults may have prolonged NMBA duration because of reduced physiologic reserve, changes in organ function, altered body composition, and increased sensitivity to anesthetic drugs overall. Residual weakness can be especially consequential in this population because even modest impairment may worsen airway protection, cough strength, and postoperative

Respiratory recovery. For CRNAs, this means conservative dosing, objective monitoring, and ensuring full recovery before extubation are especially important.

Obesity and Obstructive Sleep Apnea (OSA)

Patients with obesity and OSA may experience more serious consequences from residual neuromuscular weakness because upper airway collapsibility and reduced pulmonary reserve can magnify even mild postoperative weakness.

Drug dosing strategy should be based on the specific NMBA and the patient's dosing weight considerations, while recovery decisions should rely on quantitative monitoring rather than clinical impression alone. Full reversal and careful postoperative respiratory observation are critical.

Pregnancy Pregnancy alters pharmacokinetics, airway risk, and aspiration risk, which may influence NMBA selection and the urgency of airway control. Succinylcholine and rocuronium both remain clinically relevant in obstetric anesthesia, but reversal strategy and timing must be matched to the procedure and the maternal airway plan.

Evidence for sugammadex in obstetric practice continues to evolve, and local policy, urgency, and fetal considerations should guide decision-making.

Hepatic and Renal Dysfunction

Organ dysfunction can substantially alter the duration of aminosteroid NMBAs such as rocuronium and vecuronium. In these patients, cisatracurium is often advantageous because it undergoes organ-independent Hofmann elimination. Sugammadex also requires additional caution in severe renal dysfunction because the sugammadex-aminosteroid complex is cleared renally.

The practical CRNA approach is to choose the most pharmacologically appropriate agent, monitor quantitatively, and avoid assuming standard recovery times.

Neuromuscular Disorders

Patients with myasthenia gravis, muscular dystrophies, motor neuron disease, and other neuromuscular disorders may demonstrate marked sensitivity or resistance to different NMBAs. Succinylcholine may be particularly hazardous, and nondepolarizing agents often require individualized dosing with meticulous monitoring.

In these patients, quantitative monitoring is not optional; it is central to safe practice.

Burns, Denervation, and Prolonged Immobility

These conditions increase extrajunctional acetylcholine receptor expression and can markedly increase the risk of hyperkalemia with succinylcholine. They may also alter response to nondepolarizing agents. CRNAs should be particularly cautious about succinylcholine timing in relation to burn injury, neurologic injury, and prolonged immobilization.

Critical Care and Prolonged Paralysis

In critical care, prolonged NMBA exposure may contribute to accumulation, residual weakness, and difficulty separating sedation from paralysis. Cisatracurium is often favored for infusion because of organ-independent elimination. Even in ICU settings, depth of blockade and

Recovery should be approached systematically, with careful attention to ongoing sedation, analgesia, and reassessment of the ongoing need for paralysis.

Allergic Reactions and NMBA Anaphylaxis

Neuromuscular blocking agents are among the most common causes of perioperative immediate hypersensitivity and anaphylaxis. Reactions may range from cutaneous manifestations to severe cardiovascular collapse and bronchospasm. Because these events often occur shortly after induction, rapid recognition is essential.

Cross-reactivity among NMBAs is clinically important, especially because quaternary ammonium structures may trigger sensitization across agents. a history of prior perioperative anaphylaxis or unexplained severe reaction during anesthesia warrants careful review, avoidance of suspected agents when possible, and referral for formal allergy evaluation when appropriate.

For the CRNA, immediate priorities are to stop potential triggers, call for help, support the airway, administer oxygen, give epinephrine as indicated, treat hypotension aggressively with fluids and vasopressors, and document the event clearly for postoperative follow-up.

After stabilization, the suspected trigger should be communicated to the patient and the perioperative team, because future anesthetic planning may depend on formal testing and drug avoidance strategies.

Case: Severe Hypotension and Bronchospasm After Induction

A 44-year-old patient presents for elective laparoscopic surgery. General anesthesia is induced with an intravenous hypnotic and opioid, followed by rocuronium for intubation. Within minutes of induction, the patient develops profound hypotension, tachycardia, difficulty ventilating, increasing peak airway pressures, and generalized erythema.

Oxygen saturation begins to fall, and the surgical procedure has not yet started. Discussion: This case is highly concerning for perioperative anaphylaxis, with a NMBA among the leading suspected triggers. For the CRNA, rapid recognition is critical because cutaneous signs may be subtle or delayed, while cardiovascular collapse and bronchospasm may dominate the presentation.

Immediate priorities include discontinuing potential triggers, calling for help, administering 100% oxygen, treating with epinephrine, rapidly supporting circulation with intravenous fluids and vasopressors as needed, and managing the airway and bronchospasm aggressively.

Once the patient is stabilized, the event should be documented clearly, the suspected trigger communicated to the patient and perioperative team, and referral for formal allergy evaluation should be recommended before future anesthetics.

Clinical Pearl: In the operating room, unexplained hypotension with bronchospasm shortly after induction should prompt immediate consideration of NMBA-related anaphylaxis, even if skin findings are absent or minimal.

Case 2: Residual Paralysis in the PACU

A 67-year-old patient undergoes robotic abdominal surgery with rocuronium used intermittently for maintenance relaxation. At the end of the case, extubation occurs after apparent clinical recovery, but quantitative neuromuscular monitoring was not used. In the PACU, the patient develops shallow respirations, weak cough, difficulty sustaining head lift, and intermittent oxygen desaturation.

Discussion: This scenario is highly concerning for residual neuromuscular blockade. The case emphasizes that clinical signs alone do not reliably exclude residual weakness and that objective recovery assessment is central to safe extubation practice. For the CRNA, the key lesson is that quantitative monitoring should guide both maintenance dosing and timing of reversal.

When residual weakness is suspected postoperatively, immediate priorities include airway support, oxygenation, reassessment of neuromuscular function, and appropriate reversal or ventilatory support as indicated. Clinical Pearl: Apparent wakefulness and simple bedside strength tests do not reliably exclude residual paralysis; objective train-of-four recovery remains the safer standard.

A 36-year-old patient with a history of prolonged immobilization after spinal cord injury presents for emergent airway management. Succinylcholine is administered for rapid sequence intubation. Shortly after administration, the patient develops widening QRS complexes, peaked T waves, and then pulseless ventricular arrhythmia.

Discussion: This case illustrates one of the most feared complications of succinylcholine: life-threatening hyperkalemia in a susceptible patient.

Conditions such as burns after the acute phase, denervation injuries, prolonged immobility, and certain neuromuscular disorders can upregulate extrajunctional acetylcholine receptors and create a profound potassium release response after succinylcholine exposure. For the CRNA, recognition must be immediate.

Management priorities include treatment of hyperkalemia and associated arrhythmia according to resuscitation standards while avoiding future succinylcholine exposure in similar patients. Clinical Pearl: Succinylcholine is fast, but in patients with denervation, prolonged immobility, burns, or certain neuromuscular disorders, speed is not worth the risk of catastrophic hyperkalemia.

- Neuromuscular blocking agents are essential tools in anesthesia, but they require thoughtful selection, monitoring, and reversal.
- Succinylcholine remains useful in selected cases, but rocuronium plus sugammadex has changed modern practice.
- Cisatracurium is particularly valuable when organ-independent metabolism is desired.
- Quantitative neuromuscular monitoring is central to preventing residual weakness and improving patient safety.
- Sugammadex is a major advance, but it does not replace the need for appropriate drug selection, proper dosing, and objective monitoring.
- Extubation decisions should be based on documented quantitative recovery rather than clinical impression or simple bedside strength tests alone.
- Sugammadex dosing should match the depth of aminosteroid block to reduce the risk of incomplete or recurrent paralysis.
- In patients with significant hepatic or renal dysfunction, drug choice and expected recovery time may differ substantially from routine cases.
- Severe bradycardia, hypersensitivity, and contraceptive interaction counseling are important practical considerations whenever sugammadex is administered.
- Clear documentation of reversal strategy, monitoring findings, adverse reactions, and patient counseling strengthens continuity of care and future anesthetic planning.

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Classify neuromuscular blocking agents as depolarizing or nondepolarizing and distinguish aminosteroid from benzylisoquinolinium compounds. Compare commonly used agents including succinylcholine, rocuronium, vecuronium, cisatracurium, and atracurium with respect to onset, duration, metabolism, adverse effects, and usual adult dosing ranges.

Explain evidence-based monitoring of neuromuscular blockade, including the importance of quantitative monitoring and prevention of residual weakness. Differentiate reversal strategies using neostigmine/glycopyrrolate and sugammadex, including appropriate clinical use, usual reversal dosing by block depth, and important limitations.

Apply CRNA-focused decision-making for agent selection, monitoring, reversal, and management of special populations or high-risk situations, including case-based recognition and management of NMBA anaphylaxis.

Statement 1 2 3 4 5 The information presented on neuromuscular blocking agents and sugammadex is accurate and evidence-based. The content reflects current clinical practice and recent advances in neuromuscular blockade management and reversal.

The material is relevant to anesthesia and CRNA practice. The module adequately addresses practical NMBA considerations such as dosing, adverse effects, monitoring, reversal, and patient selection.

Statement 1 2 3 4 5 The discussion demonstrates critical analysis of neuromuscular blocking agent selection, monitoring, and reversal. Benefits and risks of neuromuscular blocking agents and sugammadex are adequately balanced and discussed. The content encourages clinical reasoning rather than memorization.

The module helped me apply NMBA principles to complex scenarios such as residual paralysis, severe renal dysfunction, or perioperative anaphylaxis.

Statement 1 2 3 4 5 The material increases my confidence in understanding neuromuscular blocking agents and sugammadex. The presentation is useful for graduate-level anesthesia education. I would recommend this content as a learning resource for other students or clinicians.

The module improves my confidence in making patient-specific decisions about neuromuscular blocker selection, monitoring, and reversal.

Non-Opioid and Multimodal Analgesia

Why Non-Opioid Pain Management Matters in Anesthesia

Pain after surgery remains common, and opioid-centered analgesia alone is often insufficient or undesirable. Although opioids remain important rescue and breakthrough agents in selected situations, they are associated with respiratory depression, nausea, ileus, sedation, urinary retention, delirium risk, opioid-induced hyperalgesia, and persistent postoperative use in some patients.

Contemporary perioperative care increasingly emphasizes opioid-sparing and non-opioid strategies that target multiple pain pathways simultaneously.

For CRNAs, the practical goal is not simply to eliminate opioids at all costs, but to build effective multimodal analgesia plans that reduce reliance on opioids while preserving comfort, safety, mobility, and recovery quality.

This often means combining systemic non-opioid medications, regional anesthesia techniques, local infiltration strategies, and nonpharmacologic interventions in a procedure-specific and patient-specific way.

Core Principle: Multimodal Analgesia

Multimodal analgesia uses different medications and techniques with different mechanisms of action to improve pain control while reducing opioid requirements. Rather than depending on a

Single drug class, this approach combines therapies that act at peripheral, spinal, and central levels of pain processing.

- It often provides better analgesia than opioid-only strategies.
- It can reduce opioid-related adverse effects such as PONV, ileus, sedation, and respiratory compromise.
- It supports enhanced recovery pathways and earlier mobilization.

The most effective multimodal regimen depends on procedure type, expected pain intensity, patient comorbidities, contraindications, and the availability of regional techniques. Not every patient needs every medication, and thoughtful selection is more important than simply adding more drugs.

Foundational Non-Opioid Medications

Acetaminophen Acetaminophen is one of the most consistently useful non-opioid analgesics in perioperative care. It has central analgesic and antipyretic effects, reduces postoperative opioid use, and is generally well tolerated when dosing limits are respected.

Oral acetaminophen is often sufficient, while intravenous acetaminophen may be used when enteral administration is not feasible, although outcome advantages over oral dosing are often limited.

Recent OFIRMEV cost and benefits Intravenous acetaminophen (OFIRMEV and generic equivalents) remains substantially more expensive than oral acetaminophen, even after broader generic availability, so many hospitals restrict its routine perioperative use.

Its main practical advantages are rapid delivery, predictable absorption, and usefulness when the patient is NPO, nauseated, vomiting, or has unreliable gastrointestinal absorption. However, when oral acetaminophen can be given reliably, comparative studies often show little or no meaningful superiority of the IV formulation for overall pain scores, opioid consumption, or recovery outcomes.

For CRNAs, the best value approach is usually selective use of IV acetaminophen for patients who cannot take PO medication or when rapid early dosing is clinically important, rather than automatic routine substitution for oral acetaminophen.

NSAIDs and COX-2-selective agents

Nonsteroidal anti-inflammatory drugs are major components of multimodal analgesia because they reduce inflammatory pain and provide clinically meaningful opioid-sparing benefit. Common perioperative examples include ketorolac, ibuprofen, celecoxib, and diclofenac.

They are especially useful in orthopedic, abdominal, gynecologic, and ambulatory surgery when bleeding, renal, and gastrointestinal risks are acceptable.

The main cautions are renal dysfunction, bleeding risk in selected surgeries, peptic ulcer history, uncontrolled heart failure, and patient-specific concerns about anastomotic healing or bone-healing controversies in selected contexts. These risks should be balanced rather than overstated universally.

When ketorolac (Toradol) should be avoided Ketorolac deserves particular caution among NSAIDs. It should generally be avoided in patients with active peptic ulcer disease, recent gastrointestinal bleeding or perforation, a strong history of ulcer-related bleeding, advanced renal impairment, or volume depletion with risk of acute kidney injury.

It is also inappropriate when bleeding risk is high, hemostasis is incomplete, or platelet inhibition could create procedural harm; it is contraindicated as prophylactic analgesia before major surgery and in the setting of CABG surgery.

Additional situations to avoid ketorolac include concurrent aspirin or other NSAID use, labor and delivery, and prior serious NSAID hypersensitivity such as bronchospasm or anaphylactoid reactions. Even when appropriate, ketorolac should be limited to a short course and not continued beyond 5 total days in adults.

Dexamethasone Dexamethasone is best known perioperatively as an antiemetic, but it also has useful analgesic and opioid-sparing effects. a single perioperative dose may reduce pain, inflammation, and PONV, making it a common adjunct in enhanced recovery pathways.

Practical cautions include hyperglycemia, especially in diabetic patients, and selective concern for infection or wound-healing issues, although single-dose use is commonly accepted in routine perioperative practice.

Dexamethasone in spine surgery In spine surgery, dexamethasone may be especially helpful because postoperative pain, tissue edema, and nausea can all interfere with early recovery. In lumbar procedures, a

single perioperative dose has been associated with lower early pain scores, delayed need for rescue analgesia, and reduced opioid use.

In anterior cervical spine surgery, the literature is particularly supportive for reducing postoperative dysphagia and odynophagia, likely by limiting soft-tissue inflammatory swelling; some studies also report shorter length of stay and improved early comfort.

Current evidence suggests that brief perioperative dexamethasone exposure does not clearly worsen long-term fusion outcomes, although clinicians should still individualize use in patients at higher risk for hyperglycemia, infection, or wound complications.

Adjuvant Non-Opioid Analgesics

Ketamine Low-dose ketamine remains one of the most important opioid-sparing analgesic adjuncts, especially in major surgery, opioid-tolerant patients, and procedures with high pain burden. By reducing central sensitization and NMDA-mediated wind-up, ketamine may improve analgesia and reduce postoperative opioid requirements.

It is particularly useful when pain is expected to be severe or when opioid minimization is especially important.

Intravenous lidocaine

Intravenous lidocaine is used selectively as an opioid-sparing analgesic strategy, especially in abdominal and laparoscopic surgery. Potential benefits include reduced pain, reduced opioid use, improved bowel recovery, and shorter hospital stay in some pathways. It requires

Thoughtful dosing, awareness of local anesthetic systemic toxicity risk, and caution in patients with significant conduction disease or severe liver dysfunction.

Alpha-2 agonists: dexmedetomidine and clonidine Alpha-2 agonists can reduce sympathetic activation, improve analgesia, and decrease opioid requirements. Dexmedetomidine is especially useful when the team wants sedation plus opioid-sparing benefit, but it can also cause bradycardia and hypotension.

Clonidine has similar opioid-sparing relevance in some settings, including selected regional techniques and perioperative adjunctive use.

Magnesium Magnesium may provide modest analgesic and opioid-sparing benefit through NMDA-related mechanisms and is sometimes incorporated into multimodal pathways. Its role is generally adjunctive rather than foundational, and clinicians should remain aware of hypotension, weakness, and potentiation of neuromuscular blockade at higher exposure levels.

Gabapentinoids Gabapentin and pregabalin have historically been used for perioperative multimodal analgesia, but current evidence has become more cautious. They may reduce opioid use in selected settings, especially neuropathic-pain-prone procedures, but they also increase dizziness, sedation, visual disturbance, and respiratory risk when combined with opioids or other sedatives.

Many clinicians now use gabapentinoids more selectively rather than routinely.

Regional, Neuraxial, and Local Analgesic Techniques

Some of the most effective non-opioid pain strategies are procedural rather than systemic. Regional and neuraxial techniques can dramatically reduce perioperative opioid requirements while improving pain scores, mobilization, and patient satisfaction.

- Peripheral nerve blocks: essential in extremity surgery, many orthopedic procedures, breast surgery, and other procedure-specific pathways.

- Neuraxial analgesia: spinal and epidural techniques provide powerful non-opioid or opioid-minimized analgesia, especially in abdominal, thoracic, obstetric, and lower-extremity surgery.
- Local infiltration and wound infiltration: useful in many ambulatory and minimally invasive cases, often as part of surgeon-administered multimodal pathways.
- Liposomal or extended-release local anesthetic strategies: may be used in selected protocols, although cost-effectiveness and comparative benefit vary.

For CRNAs, these techniques are often the most powerful way to reduce postoperative opioid exposure because they address pain transmission directly rather than relying only on systemic rescue medication.

Nonpharmacologic and Recovery-Focused Strategies

Non-opioid pain management is not limited to medications and blocks. Recovery quality also depends on patient education, expectation-setting, physical support, and symptom prevention.

- Preoperative education can improve pain expectations and reduce anxiety-driven analgesic escalation.
- Early mobilization, physical therapy, splinting, and positioning can reduce pain amplification and improve function.
- Ice, compression, and elevation remain useful after many orthopedic and soft-tissue procedures.
- Good PONV prevention, bowel recovery planning, and sleep support also indirectly improve perceived pain burden. These measures may seem less dramatic than medications, but in enhanced recovery pathways they are often what makes multimodal analgesia sustainable and patient-centered.

Special Populations and Important Cautions

- Older adults: greater sensitivity to sedating adjuncts, delirium risk, renal vulnerability, and the need for mobility-focused planning.
- Obesity and OSA: particularly strong reason to favor opioid-sparing strategies, while also using caution with sedating adjuncts such as gabapentinoids and alpha-2 agonists.
- Renal dysfunction: affects NSAID use, gabapentinoid dosing, magnesium accumulation, and broader medication selection.
- Hepatic dysfunction: requires caution with acetaminophen, lidocaine infusions, and broader drug metabolism issues.
- Bleeding-risk or renal-risk surgery: may limit NSAIDs despite otherwise favorable analgesic benefit.
- Chronic pain or opioid tolerance: often strengthen the rationale for ketamine, regional anesthesia, and stronger multimodal planning rather than relying on escalating postoperative opioids. T he practical lesson is that non-opioid does not automatically mean low-risk. Each medication and technique still requires patient-specific judgment.
- Build pain plans around the procedure, not around a default opioid order set.
- Use acetaminophen and NSAIDs as foundational agents when not contraindicated.
- Reserve sedating adjuncts such as gabapentinoids and dexmedetomidine for situations where benefits clearly outweigh respiratory or recovery risks.
- Think early about regional anesthesia and local infiltration because these may provide the greatest opioid-sparing impact.
- Use ketamine, lidocaine, magnesium, and alpha-2 agonists selectively according to procedure, patient factors, and institutional comfort.
- Remember that successful non-opioid pain management also depends on communication, expectation-setting, mobility support, and recovery planning.

The following adult perioperative dosing ranges are intended as a practical educational reference rather than a substitute for institutional policy, product labeling, procedure-specific pathways, or patient-specific clinical

judgment.

Renal function, hepatic function, age, frailty, pregnancy status, obesity, obstructive sleep apnea, bleeding risk, and the total sedative burden should all influence final dosing decisions.

Dosing Pattern

- 650-1,000 mg PO or IV every 6 hours as scheduled in many Use lower maximum daily pathways.
- Total daily exposure totals in liver disease, low body Acetaminophen commonly limited to 3-4 g/day in weight, alcohol misuse, or adults, with lower limits often prolonged use. used in frailty or hepatic dysfunction. Avoid or use great caution with 15-30 mg IV once or every 6 renal dysfunction, active hours for a limited short course.
- Bleeding risk, peptic ulcer Ketorolac many clinicians favor 15 mg in disease, or high-risk older adults or renal-risk patients anastomotic or bone-healing when used at all. concerns depending on procedure. Ibuprofen 400-800 mg PO.
- Procedure-specific bleeding Ibuprofen / celecoxib 200-400 mg PO risk, kidney function, GI Celecoxib preoperatively or postoperatively history, and cardiovascular in selected ERAS pathways. history should guide selection.

4-10 mg IV once perioperatively is consider patient-specific Dexamethasone common for antiemetic and infection, wound-healing, or analgesic adjunct effect. endocrine issues.

Bolus 0.1-0.3 mg/kg IV; infusion Titrate cautiously in Ketamine (opioid-commonly 0.1-0.3 mg/kg/hr, with cardiovascular disease, sparing analgesic some pathways extending to 0.5 psychiatric vulnerability, and range) mg/kg/hr in selected high-pain or when emergence effects are an opioid-tolerant patients. concern.

Often 1-1.5 mg/kg IV bolus Requires local anesthetic followed by infusion about 1-2 Intravenous systemic toxicity awareness; mg/kg/hr during the case in lidocaine use caution with conduction selected abdominal or disease, severe liver laparoscopic pathways.

Dysfunction, or concurrent local anesthetic exposure. Common intraoperative adjunct infusion range about 0.2-0.7

Bradycardia and hypotension

Mcg/kg/hr; some clinicians use a Dexmedetomidine are the major practical small loading dose or avoid limitations. loading entirely to reduce hemodynamic instability. Often 0.1-0.2 mg PO preoperatively in selected Sedation, bradycardia, and Clonidine pathways, or small regional hypotension can limit routine adjunct doses according to block use. protocol.

Common adjunct regimens Use caution with renal include 30-50 mg/kg IV bolus dysfunction, hypotension, and

Magnesium sulfate

Followed by lower-rate infusion in potentiation of neuromuscular selected protocols. blockade. Gabapentin 100-600 mg PO or Dose conservatively in older Gabapentin / pregabalin 25-150 mg PO in adults, renal dysfunction, OSA, Pregabalin selective pathways rather than and when opioids or sedatives routine use for all patients. will also be used.

Practical CRNA note: The safest dosing strategy for non-opioid analgesics is not the largest regimen, but the most appropriate combination for the procedure and the patient in front of you. Regional anesthesia, local infiltration, and procedure-specific ERAS pathways should still guide the overall pain plan.

- Non-opioid pain management is a core part of modern multimodal perioperative analgesia.
- Acetaminophen, NSAIDs, and dexamethasone are common foundational agents.

- Ketamine, intravenous lidocaine, alpha-2 agonists, magnesium, and selected gabapentinoids may provide additional opioid-sparing benefit when used thoughtfully.
- Regional and neuraxial techniques are among the most effective non-opioid pain strategies available.
- CRNAs should individualize pain plans using procedure-specific, patient-specific, and recovery-specific reasoning rather than one universal regimen.

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Integrate nonpharmacologic and recovery-focused pain-management strategies into perioperative care plans.

Statement 1 2 3 4 5 The information presented on non-opioid pain management and multimodal analgesia is accurate and evidence-based. The content reflects current clinical practice related to multimodal analgesia, opioid-sparing strategies, and perioperative use of non-opioid medications and techniques.

The material is relevant to anesthesia and CRNA practice. The module adequately addresses practical anesthesia considerations such as procedure-specific analgesic planning, medication contraindications, dosing considerations, regional techniques, and patient risk stratification.

Statement 1 2 3 4 5 The discussion demonstrates critical analysis of non-opioid analgesics, multimodal analgesia, and perioperative anesthesia implications. Risks, benefits, and clinical management considerations are adequately balanced and discussed across different non-opioid medications, adjuvants, and regional analgesic strategies.

Statement 1 2 3 4 5 The material increases my confidence in understanding non-opioid pain management and multimodal perioperative analgesia. The presentation is useful for graduate-level anesthesia education. I would recommend this content as a learning resource for other students or clinicians.

The module improves my confidence in making patient-specific perioperative decisions involving multimodal analgesia, non-opioid medication selection, regional techniques, and recovery-focused pain planning.

Hypotension is one of the most common physiologic disturbances encountered during anesthesia. It may occur because of vasodilation from anesthetic agents, sympathectomy from neuraxial anesthesia, hypovolemia, reduced cardiac contractility, distributive shock, vasoplegia, or combinations of these mechanisms.

Untreated or prolonged hypotension is associated with organ injury, including myocardial injury, acute kidney injury, stroke, and poor postoperative outcomes. For CRNAs, hemodynamic support requires more than remembering a list of drug names. The central clinical question is why the blood pressure is low.

A patient with pure vasodilation may respond well to phenylephrine or norepinephrine, whereas a patient with hypotension and bradycardia may be better served by ephedrine, and a patient with catecholamine-resistant vasoplegia may require vasopressin, angiotensin II, or methylene blue rather than escalating the same adrenergic drug endlessly.

First Principles: Match the Drug to the Physiology

A practical hemodynamic framework begins by deciding which physiologic problem is dominant:

- Low systemic vascular resistance (SVR): common with volatile anesthesia, propofol, neuraxial sympathectomy, sepsis, and vasoplegia.
- Low cardiac output or impaired contractility: may occur with myocardial dysfunction, severe beta-blockade, advanced shock, or excessive anesthetic depth.
- Bradycardia-dominant hypotension: often requires a drug that supports heart rate as well as pressure.
- Hypovolemia: fluids or blood are primary; vasopressors are only adjuncts until volume is restored.
- Catecholamine-resistant vasoplegia: may require non-adrenergic rescue such as vasopressin, methylene blue, or angiotensin II.

The hemodynamic agent should be chosen to correct the dominant mechanism, not simply the monitor number.

Phenylephrine and Ephedrine: Common First-Line Bolus Vasopressors

Phenylephrine Phenylephrine is a pure alpha-1 agonist that increases arterial and venous tone, raises systemic vascular resistance, and increases blood pressure without direct beta-mediated inotropy. It is often an useful choice when the primary problem is anesthetic-or neuraxial-induced vasodilation.

However, because it may cause reflex bradycardia and can reduce cardiac output in selected patients, it is not ideal when hypotension is accompanied by low heart rate or when forward flow is already limited.

Ephedrine Ephedrine has mixed indirect and direct sympathomimetic effects, increasing blood pressure while also supporting heart rate and contractility. It is often useful for transient hypotension with bradycardia or relatively low cardiac output, especially in neuraxial anesthesia or brief intraoperative episodes.

Its effect can become less reliable in catecholamine-depleted states or after repeated dosing.

Practical contrast

- Use phenylephrine when vasodilation is dominant and heart-rate reduction is acceptable or even beneficial.
- Use ephedrine when hypotension is accompanied by bradycardia or when a small boost in cardiac output is desirable.

Norepinephrine Norepinephrine provides predominantly alpha-adrenergic vasoconstriction with modest beta-1 support. This makes it one of the most physiologically versatile vasopressors for perioperative hypotension, especially when the patient needs blood pressure support without the reflex bradycardia or cardiac-output reduction that may be seen with pure phenylephrine.

It is increasingly favored by many clinicians for infusion-based treatment of vasodilatory intraoperative hypotension.

Vasopressin Vasopressin acts on V1 receptors and increases vascular tone through a non-adrenergic pathway. This makes it especially valuable when catecholamine responsiveness is poor, such as in vasoplegia, septic shock physiology, or hypotension associated with chronic ACE inhibitor or ARB exposure.

Vasopressin does not depend on adrenergic receptors and may restore vascular tone when escalating phenylephrine or norepinephrine is producing diminishing returns.

- Norepinephrine is often preferred when hypotension reflects vasodilation but maintenance of cardiac output matters.
- Vasopressin is especially useful as an adjunct in catecholamine-resistant vasodilation or vasoplegia.

Angiotensin II

Angiotensin II is a non-catecholamine vasopressor that restores vascular tone through the renin-angiotensin system. It is most relevant in vasoplegic shock and catecholamine-resistant vasodilation, especially after cardiopulmonary bypass or in severe distributive states.

Current perioperative interest in angiotensin II is growing because it may reduce dependence on high-dose adrenergic vasopressors in refractory vasoplegia.

Methylene blue

Methylene blue is not a routine first-line vasopressor. Instead, it is a rescue therapy for selected vasoplegic states, particularly post-cardiopulmonary bypass vasoplegia and other distributive conditions where nitric oxide-mediated vasodilation is a major driver. By interfering with the nitric oxide-cyclic GMP pathway, it may improve vascular tone when conventional catecholamines are failing.

However, it has important limitations, including risk of serotonin toxicity with serotonergic medications and hemolysis risk in glucose-6-phosphate dehydrogenase deficiency.

CRNA perspective

For the CRNA, both angiotensin II and methylene blue should be thought of as physiology-targeted rescue tools for refractory vasoplegia rather than routine OR pressors for ordinary anesthetic hypotension.

Epinephrine has mixed alpha-and beta-adrenergic effects and can function as both a vasopressor and inotrope. It is especially useful when hypotension coexists with poor contractility or severe shock physiology, but it can increase lactate, tachycardia, and myocardial oxygen demand.

Dopamine is used far less often in modern perioperative practice because of arrhythmia risk and less favorable comparative performance versus other agents.

Dobutamine and milrinone are primarily inotropes rather than pure vasopressors. They are relevant when low cardiac output and ventricular dysfunction are dominant and afterload support alone is not the right answer.

Hydroxocobalamin has also emerged as a rescue adjunct in selected vasoplegic states, although it is not a standard first-line perioperative vasopressor. The practical lesson is that "vasopressor" and "hemodynamic agent" are not always the same. Some patients need vascular tone, some need contractility, and some need both.

High-yield agent comparison (receptor action to clinical effect):

- Phenylephrine: strong alpha-1 agonist; increases SVR and MAP; may cause reflex bradycardia; best for pure vasodilation-dominant hypotension.
- Ephedrine: indirect sympathomimetic with direct effects; raises BP while also increasing HR and modestly supporting CO; useful when hypotension is accompanied by bradycardia.
- Norepinephrine: alpha-1 with modest beta-1 activity; excellent first-line infusion vasopressor when vascular tone support is needed with better preservation of CO than pure alpha agonists.
- Epinephrine: beta-1, beta-2, and alpha-1; supports contractility, HR, and vascular tone; most useful when hypotension coexists with poor pump function or peri-arrest physiology.
- Vasopressin: non-adrenergic V1 receptor agonism; restores vascular tone independent of catecholamine receptors; useful in ACE inhibitor/ARB-related vasodilatory states and catecholamine-resistant vasoplegia.

- Angiotensin II: RAAS/AT1 pathway activation; option for refractory vasoplegic shock when catecholamines are failing.
- Dobutamine: mainly beta-1 with some beta-2; increases contractility and CO and may lower SVR; useful when low output is the main problem rather than pure vasodilation.
- Milrinone: PDE-3 inodilator (not a receptor agonist); increases contractility and reduces afterload/PVR, but may worsen hypotension if SVR is already low.

Bottom line: Agents with similar blood-pressure effects can have very different receptor profiles and very different consequences for heart rate, cardiac output, and afterload.

Adult perioperative dosing patterns (practical reference only; always confirm with institutional policy and patient factors):

- Phenylephrine: often 50-200 mcg IV bolus; infusion commonly about 0.25-1.5 mcg/kg/min. Best for vasodilation-dominant hypotension; may cause reflex bradycardia.
- Ephedrine: often 5-10 mg IV bolus, repeated as needed. Useful when hypotension is accompanied by bradycardia.
- Norepinephrine: often started around 0.02-0.1 mcg/kg/min and titrated. Strong choice when vascular tone support is needed without sacrificing too much cardiac output.
- Vasopressin: protocol-dependent rescue dosing for catecholamine-resistant vasodilatory states.
- Methylene blue: reserved for refractory vasoplegia; typical dosing about 1-2 mg/kg IV over several minutes; screen for serotonergic interactions and G6PD deficiency.

Practical note: Final dosing should be guided by arterial pressure targets, end-organ perfusion, route of administration, and the specific clinical environment.

Inotropes: When the Problem Is Forward Flow, Not Just Pressure

Inotropes are hemodynamic agents used when inadequate cardiac output or impaired ventricular contractility is a major driver of shock or perioperative instability. Unlike pure vasopressors, which mainly increase vascular tone, inotropes improve stroke volume, cardiac output, or both.

They are most helpful when the patient has hypotension with pump failure, low-output shock after cardiac surgery, ventricular dysfunction, significant beta-blockade, or poor forward flow despite adequate filling pressure and vascular tone.

The key clinical distinction is simple: if the number on the monitor is low because the heart is not generating enough forward flow, more vasoconstriction alone may worsen afterload and tissue perfusion rather than fix the problem.

Dobutamine is a predominantly beta-1 agonist with some beta-2 activity. It increases contractility and cardiac output and may lower filling pressures, but the beta-2 effect can also reduce SVR and worsen hypotension if vascular tone is already poor.

This makes dobutamine most useful when low cardiac output is dominant and blood pressure is still adequate enough to tolerate some vasodilation, or when it is paired with a vasopressor such as norepinephrine.

Milrinone is a phosphodiesterase-3 inhibitor that increases intracellular cyclic AMP independent of beta-receptor stimulation. It improves contractility and relaxation while also reducing afterload and pulmonary vascular resistance, making it an useful inodilator when ventricular dysfunction coexists with elevated afterload or right-sided strain.

Milrinone can be attractive in patients receiving chronic beta-blockade, but it has a longer half-life than dobutamine and may produce prolonged hypotension, especially in renal dysfunction.

Epinephrine is best thought of as a mixed inopressor rather than a pure inotrope. At lower doses, beta effects support contractility and heart rate; as dose rises, alpha-mediated vasoconstriction becomes more prominent.

Epinephrine is useful when the patient needs both inotropy and pressure support, such as severe low-output shock with hypotension, peri-arrest states, or profound myocardial depression. The tradeoffs are tachycardia, arrhythmia risk, increased myocardial oxygen demand, and lactate elevation that can complicate interpretation of shock progression.

Levosimendan and isoproterenol deserve brief mention as more specialized agents. Levosimendan is a calcium-sensitizing inodilator that can improve contractility without relying on beta-receptor stimulation and may be discussed in advanced cardiac or ICU practice, although it is not a routine perioperative first-line agent in many U. S. settings.

Isoproterenol is a potent beta agonist with strong chronotropic and inotropic effects and essentially no alpha support; it is most relevant when the major need is heart-rate augmentation or beta-mediated support, such as selected bradyarrhythmic or right-ventricular/pulmonary vascular scenarios, but it can worsen tachyarrhythmias and hypotension if used indiscriminately. Practical use principles

- Choose an inotrope when low cardiac output is the dominant problem: signs include poor contractility, rising filling pressures, low mixed venous oxygen saturation, cool extremities, worsening lactate, or echo evidence of ventricular dysfunction.
- Do not rely on MAP alone: a higher pressure produced by pure vasoconstriction can still leave the patient underperfused if stroke volume remains poor.
- Expect combination therapy in unstable patients: dobutamine or milrinone is often paired with norepinephrine or vasopressin when the heart needs help but SVR cannot be allowed to fall.
- Watch for tradeoffs: inotropes can improve flow but may also cause tachyarrhythmias, hypotension, ischemia, or increased myocardial oxygen consumption.

Commonly 2-10 mcg/kg/min Improves contractility but may Dobutamine infusion, titrated to cardiac worsen hypotension if SVR is output and perfusion response already low.

Longer-acting inodilator; reduce mcg/kg/min infusion; loading Milrinone dose in renal dysfunction and dose often avoided in unstable or expect slower titration. hypotensive patients Often 0.01-0.1 mcg/kg/min Useful when both pressure and infusion depending on the degree contractility support are needed, Epinephrine of shock and pressure support but monitor for tachyarrhythmias needed and lactate rise.

Specialized agent selection and Useful to recognize conceptually, Levosimendan / dosing are typically protocol-but usually managed in advanced isoproterenol based and context-specific rather cardiac, ICU, or rhythm-specific than routine OR first-line practice settings.

Bottom line: Inotropes are for flow problems. When cardiac output is the major issue, they may restore perfusion more effectively than escalating a pure vasoconstrictor. The safest approach is still physiology first: determine whether the patient needs more vascular tone, more contractility, or both.

Choosing the Best Agent for the Patient in Front of You

Routine anesthetic vasodilation: Phenylephrine or norepinephrine are often reasonable, depending on whether cardiac output preservation is an important concern.

Hypotension with bradycardia: Ephedrine is often more physiologically appropriate than phenylephrine because it supports both pressure and heart rate.

Neuraxial hypotension: Phenylephrine and ephedrine remain common choices, with selection guided by maternal heart rate and the dominant physiology.

Distributive shock or vasoplegia: Norepinephrine is often foundational, with vasopressin commonly added when catecholamine needs rise. Angiotensin II or methylene blue may be considered in refractory cases.

Low cardiac output with hypotension: a mixed inopressor or inotrope may be more appropriate than a pure vasoconstrictor alone.

ACE inhibitor or ARB-associated refractory hypotension: Vasopressin often becomes more useful because the usual sympathetic compensatory pathway is blunted.

Shock and Vasopressor Decision Chart

The following quick-reference chart is designed to help match the dominant hemodynamic physiology to the most appropriate first-line vasopressor or rescue strategy. It is intended as a clinical decision aid, not a substitute for full assessment of volume status, cardiac function, source control, or institutional protocol.

Check depth, Low SVR from ventilation, and

Anesthetic volume first; hypotension norepinephrine vasodilation phenylephrine may worsen bradycardia.

Physiologic than pure Hypotension with inadequate heart Ephedrine alpha agonism when bradycardia rate/cardiac chronotropy is output needed. Treat positioning,

Neuraxial uterine displacement, with vasodilation +/- adequate; ephedrine hypotension and volume issues as bradycardia if bradycardic appropriate.

Marked low SVR and source control still Distributive shock / with variable Norepinephrine matter; pressure vasodilatory shock cardiac output alone is not the full endpoint.

ACE inhibitor or Blunted renin-where non-adrenergic ARB-associated angiotensin support may Vasopressin refractory response with outperform repeated hypotension vasodilation ephedrine or phenylephrine.

Consider a pure vasoconstrictor Pump failure / Low cardiac output epinephrine, may worsen forward impaired with hypotension dobutamine, or flow if contractility is contractility milrinone depending the real problem.

Bottom line: The best vasopressor is the one that matches the dominant physiology. Pressure improvement without improvement in perfusion, forward flow, or underlying cause is not enough.

Special Scenarios

Vasoplegic syndrome after cardiopulmonary bypass Vasoplegic syndrome is characterized by severe low-SVR hypotension with preserved or high cardiac output and poor responsiveness to conventional catecholamines. In this setting, vasopressin is often used early, while methylene blue and angiotensin II are increasingly discussed as adjunctive rescue options in refractory cases.

Obstetric hypotension

Spinal-induced hypotension in obstetrics is a common and clinically important scenario. Phenylephrine is often favored when tachycardia is not needed, whereas ephedrine may be more appropriate when bradycardia is present or when additional chronotropy is desired. The practical principle remains the same: treat the dominant physiology.

Refractory distributive states Patients with severe distributive physiology may require a layered approach using norepinephrine, vasopressin, and sometimes non-adrenergic rescue agents when escalating one catecholamine alone is failing.

Calcium as a targeted rescue adjunct in hypotension Calcium is not a routine first-line vasopressor for ordinary anesthetic hypotension, but it can be an useful targeted adjunct when reduced ionized calcium or

calcium-dependent cardiovascular dysfunction is contributing to hemodynamic collapse.

In practice, this is most relevant with acute hypocalcemia, citrate load during massive transfusion, hyperkalemia with cardiac

Instability, hypermagnesemia, and calcium-channel blocker toxicity. In these settings, calcium may improve myocardial contractility, vascular smooth muscle tone, or membrane stability while the underlying cause is corrected.

- Massive transfusion or rapid blood-product administration: citrate can lower ionized calcium and contribute to hypotension, impaired contractility, and coagulopathy; calcium replacement may be important during active resuscitation.
- Documented or strongly suspected hypocalcemia: consider calcium when hypotension is accompanied by low ionized calcium, prolonged QT, myocardial depression, or refractory vasopressor requirements.
- Calcium-channel blocker toxicity: calcium can provide temporary hemodynamic support and is commonly used along with fluids, vasopressors, and other antidotal therapies.
- Hyperkalemia or hypermagnesemia with instability: calcium is valuable primarily for cardiac membrane stabilization rather than as a classic pressor, but that stabilization can be lifesaving in shock or peri-arrest physiology.

Practical pearl: think of calcium as a physiology-specific rescue medication, not a substitute for treating the underlying cause of hypotension. It is most helpful when calcium-dependent myocardial or vascular dysfunction is part of the problem, and less helpful for routine low-SVR hypotension alone.

Calcium chloride provides more elemental calcium and is often favored in emergencies, whereas calcium gluconate is less irritating to peripheral veins.

- Treat the cause of hypotension first whenever possible: depth, ventilation, bleeding, volume status, and surgical factors still matter.
- Choose the hemodynamic agent based on physiology, not habit.
- Avoid reflexive escalation of the same adrenergic pressor when vasoplegia is clearly resistant; think early about vasopressin or other rescue pathways.
- Use invasive monitoring and infusion titration when instability is sustained or severe.
- Remember that pressure is not the only endpoint-organ perfusion, heart rate, cardiac output, and trend matter.
- Phenylephrine and ephedrine remain important first-line perioperative bolus vasopressors, but they are not interchangeable.
- Norepinephrine is increasingly central to infusion-based support of perioperative vasodilatory hypotension.
- Vasopressin is especially valuable in catecholamine-resistant vasodilation and vasoplegia.
- Angiotensin II and methylene blue are advanced rescue tools for selected refractory vasoplegic states rather than routine first-line OR pressors.
- The best hemodynamic agent is the one that matches the dominant physiology of the patient in front of you.
- Inotropes such as dobutamine and milrinone are most useful when poor contractility and low forward flow are the dominant problems; epinephrine can function as a mixed inopressor when both pressure and contractility support are needed.
- Levosimendan and isoproterenol are more specialized agents worth recognizing: levosimendan as an advanced inodilator and isoproterenol as a potent chronotropic/inotropic beta agonist used in selected rhythm-or right-heart-focused scenarios.
- Calcium is a targeted rescue adjunct-not a routine first-line pressor-and is most useful when hypotension is driven by hypocalcemia, massive transfusion/citrate load, calcium-channel blocker toxicity, or membrane instability from hyperkalemia or hypermagnesemia.

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Perioperative Antihypertensives

Why Perioperative Antihypertensives Matter

Perioperative hypertension is common during induction, intubation, incision, emergence, and in the post-anesthesia care unit. It may reflect pain, anxiety, inadequate anesthetic depth, hypercarbia, hypoxia, bladder distention, medication withdrawal, volume overload, or poorly controlled chronic hypertension.

If severe or sustained, it may contribute to myocardial ischemia, stroke, surgical bleeding, aortic stress, heart failure, and other end-organ complications.

For CRNAs, the key principle is that hypertension should not be treated reflexively with the same drug every time. The first step is to identify and correct the likely cause, then use a short-acting IV agent when drug therapy is truly needed. The best agent depends on the patient's heart rate, ventricular function, comorbidities, and the specific clinical scenario.

First Principles: Treat the Cause Before the Number

Acute perioperative hypertension is often a physiologic response rather than a primary disease event. Before giving an antihypertensive, the CRNA should ask whether the elevation is being driven by inadequate anesthesia, pain, agitation, bladder distention, hypoventilation, hypercarbia, hypoxemia, medication withdrawal, or surgical stimulation. Correcting these

Triggers may be more effective and safer than simply lowering blood pressure pharmacologically.

- Deepen anesthesia if sympathetic stimulation from inadequate depth is likely.
- Improve ventilation if hypercarbia or hypoxia is contributing.
- Treat pain, emergence agitation, bladder distention, or medication withdrawal when present.

Once reversible causes are addressed, persistent hypertension can be managed more safely with titratable IV medication tailored to the clinical picture.

Perioperative Hypertension Caused by Laparoscopic Insufflation

A common intraoperative cause of acute hypertension is laparoscopic insufflation.

Creation of pneumoperitoneum increases intra-abdominal pressure, which can raise systemic vascular resistance, stimulate catecholamine release, reduce venous return in selected patients, and produce abrupt increases in blood pressure and sometimes heart rate-especially during initial insufflation or when insufflation pressures are high.

The practical CRNA response is to treat the cause before reflexively escalating antihypertensives: confirm adequate anesthetic depth and analgesia, assess end-tidal CO2 because absorbed carbon dioxide and hypercarbia may amplify sympathetic response, and communicate with the surgeon about lowering insufflation

pressure or slowing insufflation when clinically feasible.

If hypertension persists after these corrective steps, a short-acting titratable agent matched to the physiology is usually preferred-for example, esmolol when tachycardia is prominent, or nicardipine/clevidipine when increased systemic vascular resistance is the dominant issue and heart-rate reduction is not desired.

The key principle is that pneumoperitoneum-related hypertension often improves most effectively when insufflation dynamics, ventilation, and anesthetic depth are corrected rather than by using long-acting antihypertensives alone.

Common Perioperative Antihypertensive Agents and Drug Properties

Labetalol Labetalol is a combined alpha-and beta-adrenergic blocker. It lowers blood pressure while also reducing heart rate and blunting sympathetic stimulation. It is useful when hypertension is accompanied by tachycardia, but its longer clinical effect makes it less titratable than ultra-short-acting options.

It should be used cautiously in patients with asthma or other reactive airway disease because beta-blockade can precipitate bronchospasm, especially in those with active wheezing, poor baseline control, or recent bronchodilator need. Additional precautions include bradycardia, heart block, and decompensated heart failure.

In practice, if significant bronchospasm risk is present or the patient is already wheezing, a titratable vasodilator such as nicardipine or clevidipine may be safer than reflexive beta-blockade.

Esmolol Esmolol is an ultra-short-acting beta-1 selective blocker. It is particularly useful for transient sympathetic surges such as laryngoscopy, intubation, or emergence when tachycardia is prominent. Because it is rapidly titratable and wears off quickly, it is ideal when the CRNA wants heart-rate control without a long tail of effect.

Diltiazem (Cardizem)

Diltiazem (Cardizem) is a non-dihydropyridine calcium channel blocker that slows AV nodal conduction and can also lower blood pressure modestly. In perioperative care, its main value is usually rate control rather than primary treatment of isolated hypertension.

It may be useful when hypertension coexists with supraventricular tachyarrhythmia or rapid atrial fibrillation/flutter and the CRNA wants both ventricular-rate slowing and some blood-pressure reduction. However, it should be used cautiously in bradycardia, second-or third-degree AV block without pacing, hypotension, reduced ventricular function, or decompensated heart failure.

Because it is more of a chronotropic and dromotropic drug than a pure titratable antihypertensive, nicardipine or clevidipine are usually better choices when the primary problem is elevated systemic vascular resistance without a rate-control need.

Nicardipine Nicardipine is a dihydropyridine calcium channel blocker that acts as an arterial vasodilator. It is useful when hypertension is driven by high systemic vascular resistance and when heart rate does not need to be slowed. It is commonly favored in neurologic and stroke-related blood pressure control and in patients where beta-blockade is undesirable.

Clevidipine Clevidipine is an ultra-short-acting dihydropyridine calcium channel blocker formulated as a lipid emulsion. It is highly titratable and particularly attractive for perioperative hypertension because of its rapid onset and very short half-life. It is often considered one of the most controllable agents for blood pressure reduction when smooth, fast adjustment is desired.

Hydralazine Hydralazine is a direct arterial vasodilator with less predictable onset and a longer duration than many modern titratable agents. It can be useful in selected postoperative or obstetric situations, but it is less ideal when tight minute-to-minute control is needed.

Nitroglycerin Nitroglycerin is primarily a venodilator and is most useful when hypertension is accompanied by myocardial ischemia, pulmonary edema, or preload-sensitive cardiac conditions. It is not usually the strongest choice for isolated vasoconstrictive hypertension without a cardiac ischemic component.

Nitroprusside Nitroprusside is a potent arterial and venous vasodilator with immediate onset. It can reduce blood pressure very rapidly, but because of overshoot hypotension risk and cyanide or

Thiocyanate toxicity with prolonged use, it is generally reserved for highly monitored settings rather than casual routine use.

Phentolamine Phentolamine is a nonselective alpha-blocker most relevant when catecholamine excess is suspected, such as pheochromocytoma or severe sympathomimetic crisis. It is not a routine first-line OR antihypertensive for ordinary perioperative hypertension.

Perioperative Antihypertensive Dosing Quick Reference

The following adult dosing patterns are intended as a practical educational reference. Institutional protocols, arterial-line monitoring, patient comorbidities, and the urgency of control should guide final dosing decisions.

5-20 mg IV bolus, repeated as needed; some protocols escalate in Useful when hypertension and Labetalol 10-20 mg increments. Infusion tachycardia coexist; longer effect strategies are also used in selected than esmolol. settings. 10-50 mg IV bolus in many OR Best for brief sympathetic surges settings, or 0.5-1 mg/kg bolus

- Followed by infusion about 50-300 hypertension. mcg/kg/min when needed. For IV rate control, common Best thought of as a rate-control patterns include 0.25 mg/kg over 2 drug with secondary blood-pressure Diltiazem minutes, then 0.35 mg/kg if benefit.
- Avoid reflexive use for (Cardizem) needed.
- Infusion often begins isolated perioperative hypertension around 5 mg/hr and may be in bradycardic or low-output titrated upward by protocol. patients. Begin around 2.5-5 mg/hr infusion Good for vasoconstrictive and titrate upward by protocol.
- Hypertension and neurologic BP Nicardipine many pathways use a ceiling near control.
- Does not directly slow heart 15 mg/hr. rate. Start around 1-2 mg/hr and titrate One of the most titratable every few minutes.
- Many protocols perioperative options.
- Lipid Clevidipine double early, then fine-tune more emulsion formulation matters in gradually. allergy and infusion planning. 2.5-10 mg IV bolus, with careful reassessment because effect may Less predictable and less titratable Hydralazine outlast the immediate than nicardipine or clevidipine. perioperative moment.

Common infusion range about 5-Most useful when myocardial 200 mcg/min, titrated to ischemia, Nitroglycerin ischemia or pulmonary congestion is preload, and blood pressure present. response. Very potent; avoid casual use Often 0.3-10 mcg/kg/min infusion Nitroprusside without close monitoring and in tightly monitored environments. awareness of toxicity risk.

Practical note: The best antihypertensive regimen is not the one that lowers pressure fastest, but the one that matches the cause of hypertension and avoids overshoot hypotension.

How to Choose the Best Antihypertensive for the Patient

If tachycardia is prominent When hypertension is accompanied by tachycardia, especially during laryngoscopy, emergence, or acute sympathetic stimulation, beta-blocking approaches are often best. Esmolol is ideal when the episode is brief or when the CRNA wants tight moment-to-moment control. Labetalol is useful when a somewhat longer effect is acceptable.

If heart rate is normal or low When the patient is already bradycardic or when heart-rate reduction would be undesirable, vasodilator strategies such as nicardipine or clevidipine are often preferable. These drugs lower systemic vascular resistance without the same degree of direct bradycardia.

If myocardial ischemia or pulmonary edema is present Nitroglycerin becomes more attractive when hypertension coexists with chest pain, demand ischemia, pulmonary congestion, or preload-sensitive cardiac physiology. Beta-blockade may still be helpful, but nitroglycerin directly addresses ischemic and filling-pressure physiology better than a pure arteriolar vasodilator alone.

If neurologic blood pressure control is needed Nicardipine and clevidipine are often favored when careful smooth control is required in neurologic or cerebrovascular contexts because they are titratable and avoid the longer tail of effect seen with some bolus drugs. Overshoot hypotension should still be avoided because cerebral perfusion may be pressure-dependent.

If pheochromocytoma or catecholamine excess is suspected an alpha-blocking strategy such as phentolamine may be more appropriate than reflexive beta-blockade alone. In catecholamine-driven states, the wrong drug choice may worsen physiology rather than improve it.

If the need is brief versus prolonged For transient events, esmolol or clevidipine often provide the greatest control. For more sustained postoperative hypertension, nicardipine or carefully chosen bolus strategies may be more practical. Hydralazine is usually less desirable when rapid fine-tuning is necessary.

Chronic Antihypertensive Medications in the Perioperative Period

Perioperative blood pressure control is influenced not only by rescue IV medications, but also by whether chronic antihypertensive drugs are continued or withheld before surgery.

Current practice generally supports continuing beta-blockers, calcium channel blockers, alpha-blockers, and centrally acting antihypertensives through the day of surgery because abrupt withdrawal may trigger rebound hypertension or tachycardia.

Renin-angiotensin system inhibitors such as ACE inhibitors and angiotensin receptor blockers are more nuanced. Recent evidence suggests that continuing them may increase intraoperative hypotension, while withholding them may increase postoperative hypertension.

A reasonable approach is individualized: continuation may be acceptable in lower-risk or poorly controlled patients, while temporary interruption may be preferred when significant intraoperative hypotension would be especially harmful or likely.

The key CRNA implication is that untreated perioperative hypertension may sometimes reflect medication withdrawal rather than disease progression. Asking what home medications were actually taken matters.

Blood Pressure Reduction Goals and Avoiding Overshoot

When perioperative hypertension requires treatment, the goal is controlled reduction rather than immediate normalization. Patients with chronic hypertension may have shifted autoregulatory ranges, so an abrupt drop in pressure can reduce cerebral, coronary, and renal perfusion even when the monitor shows a "normal" blood pressure.

Recent consensus guidance emphasizes that when intraoperative hypertension is treated, it should be treated carefully to avoid hypotension and related end-organ risk. In practical CRNA decision-making, it is usually better to lower pressure gradually while correcting the underlying cause than to chase a rapid return to baseline with large boluses.

Short-acting, titratable agents are preferred because they allow reassessment after changes in anesthetic depth, ventilation, analgesia, and surgical stimulation. This is especially important in patients with cerebrovascular

disease, coronary disease, chronic severe hypertension, or other conditions in which perfusion may be pressure dependent.

- Do not reflexively attempt to make the blood pressure "normal" within minutes if the patient appears perfusing adequately and the cause is still being corrected.
- Reassess after each intervention to avoid cumulative dosing and overshoot hypotension.
- Use higher caution in neuro, cardiac, renal, and chronically hypertensive patients, where excessive reduction can be more dangerous than modest transient hypertension.

Clinical Scenarios Where Tight Blood Pressure Control Is Imperative

Although many perioperative hypertensive episodes can be managed by treating the cause and using titratable rescue therapy, some procedures and disease states demand especially tight blood-pressure control because both hypertension and hypotension can cause immediate harm.

In these settings, the CRNA should think in terms of maintaining a narrow physiologic window, using continuous arterial-line monitoring whenever appropriate, and choosing agents that can be adjusted minute to minute.

TCAR and Other Carotid Revascularization Procedures

Transcarotid artery revascularization (TCAR), carotid artery stenting, and carotid endarterectomy are classic examples of procedures in which hemodynamic instability can translate quickly into stroke, cerebral hypoperfusion, neck hematoma risk, or cerebral hyperperfusion injury.

These patients may be vulnerable both during carotid manipulation and in the post-procedural period because baroreceptor disturbance, reperfusion, and changes in cerebrovascular resistance can produce abrupt shifts in pressure.

The practical CRNA goal is smooth control rather than dramatic swings: avoid severe hypertension that could promote bleeding or hyperperfusion syndrome, but also avoid hypotension that could compromise cerebral perfusion across a previously flow-limited vascular bed.

In TCAR specifically, many anesthesia pathways aim for systolic blood pressure roughly 140-160 mm Hg during active flow reversal to support cerebral reverse-flow dynamics, then transition to a lower postoperative systolic target such as about 120-150 mm Hg while avoiding both hypotension and marked hypertension.

Short-acting titratable agents such as nicardipine, clevidipine, esmolol, or carefully dosed labetalol are generally more useful than long-acting boluses because the target may need to change rapidly as the surgical phase changes.

Intracranial Aneurysm Clipping and Other Neurovascular Procedures

In neurovascular anesthesia, blood pressure directly affects aneurysm wall stress, cerebral perfusion pressure, surgical exposure, and the risk of hemorrhage or ischemia.

During aneurysm clipping, sudden hypertension may increase transmural pressure and rupture risk, whereas excessive hypotension may jeopardize perfusion to vulnerable brain tissue, especially during temporary clipping or when autoregulation is impaired. Similar principles apply in arteriovenous malformation surgery and other intracranial vascular procedures.

The key is not simply "lower is better"; the key is controlled, phase-specific management. The CRNA should maintain smooth induction and emergence, avoid coughing or sympathetic surges, and use titratable agents that permit rapid response to surgical events, temporary vessel occlusion, or signs that perfusion support is needed.

Acute Aortic Syndromes and Major Aortic Surgery

Few conditions make blood-pressure control more urgent than acute aortic syndromes. In acute aortic dissection and other high-risk aortic pathology, the immediate goal is anti-impulse therapy: reducing aortic wall stress by controlling both blood pressure and heart rate while definitive treatment is arranged.

Excessive hypertension can propagate dissection or worsen rupture risk, but profound hypotension may reflect tamponade, rupture, malperfusion, or

Decompensation and requires a different response than routine antihypertensive escalation. Beta-blocking strategies are often central because they reduce shear force as well as pressure; vasodilators may then be added if needed after impulse control is established.

In the operating room, abrupt swings should be avoided during induction, line placement, incision, and emergence because each surge can increase aortic stress.

Microvascular Free-Flap Reconstruction and Perfusion-Dependent Surgery

In microvascular free-flap surgery, blood pressure is not just a number-it can influence graft perfusion, venous drainage, and the interpretation of flap-monitoring data. Hypotension may reduce perfusion across the anastomosis and jeopardize a flap that depends on adequate driving pressure, whereas uncontrolled hypertension may increase bleeding, edema, or strain at the surgical site.

The practical implication is to avoid prolonged hypotension and large uncorrected swings. These cases often benefit from invasive monitoring, careful volume assessment, and thoughtful titration of vasoactive medications rather than reflexive deepening of anesthesia alone. The goal is stable organ and flap perfusion, not simply a conventional cuff target.

- Recent stroke, intracranial hemorrhage, or patients with pressure-dependent cerebral perfusion.
- Coronary ischemia, acute heart failure, or severe pulmonary edema, where hypertension may worsen myocardial oxygen demand but hypotension may reduce coronary perfusion.
- Major vascular clamps and unclamps, where abrupt afterload and perfusion changes are expected.
- Procedures with a high bleeding consequence, where surges in pressure can worsen surgical field visibility or blood loss.

Chronic Antihypertensive Continuation/Withholding Quick Chart (Pre-op)

Chronic Usually Key concern if medication Key concern if withheld continue? continued class Bradycardia or Rebound tachycardia,

Beta-blockers hypotension in hypertension, and patients susceptible patients ischemic risk

Loss of baseline control Calcium channel Yes, in most conduction effects and postoperative blockers patients depending on agent and hypertension comorbidity Clonidine and Yes, strongly Sedation, bradycardia,

Other centrally consider or hypotension in some that may be severe acting agents continuation patients

Intraoperative Alpha-blockers Usually yes possible rebound vasodilation in selected sympathetic symptoms patients postoperative

Hypertension or ACE inhibitors / intraoperative Individualize interruption of therapy ARBs hypotension, sometimes in selected high-risk vasopressor-requiring patients Worsening fluid overload

Often or loss of blood-pressure Diuretics electrolyte disturbance individualized control in selected depending on context patients

Practical note: Contemporary reviews support continuing beta-blockers and most other chronic antihypertensives, while ACE inhibitor and ARB management remains patient specific. If these agents are withheld, they should generally be restarted promptly when clinically appropriate after surgery.

Contraindications, Precautions, and Agent-Specific Pearls

Use beta-blockade cautiously in baseline bradycardia or heart block; it is most useful when tachycardia and hypertension coexist Labetalol decompensated depress cardiac output; coexist and a slightly heart failure, reactive bronchospasm risk longer effect is airway disease remains relevant acceptable Even short-acting beta-Bradycardia, heart blockade can cause Excellent for transient block, poor major heart-rate or surges such as Esmolol contractility, pressure drops if the laryngoscopy or bronchospasm risk in patient is preload emergence when rapid sensitive patients dependent or already reversibility is valuable conduction limited

Can reduce afterload stenosis, marked Useful when blood quickly but may reflex tachycardia, pressure is SVR driven Nicardipine increase heart rate and advanced heart and heart-rate slowing is can be poorly tolerated failure in some not desired in fixed outflow settings obstruction

It is formulated as an Allergy to soy or lipid emulsion, may One of the best options eggs, defective lipid cause reflex when minute-to-minute metabolism, severe tachycardia with rapid Clevidipine titration is needed and aortic stenosis, heart titration, and does not heart rate is already failure requiring protect against abrupt normal or low close monitoring beta-blocker withdrawal

Onset and peak effect More useful when titration, are less predictable, slower postoperative tachycardia-prone Hydralazine and reflex tachycardia control is acceptable states, myocardial can worsen myocardial than for dynamic ischemia, some oxygen demand intraoperative swings neuro settings Venodilation can drop

Preload significantly Nitroglycerin is useful for hypertension with myocardial ischemia; avoid when severe hypotension limits coronary perfusion pressure or preload-dependent isolated arteriolar pulmonary congestion states vasoconstriction It can lower pressure Limited monitoring, almost immediately, Reserve for highly prolonged infusion, but overshoot monitored renal or hepatic Nitroprusside hypotension and environments when a dysfunction, elevated cyanide or thiocyanate very potent agent is intracranial pressure toxicity make casual truly needed in some settings use risky

Without Think of this agent when blockade can cause catecholamine pheochromocytoma or Phentolamine dramatic vasodilation if excess, hypovolemia, sympathomimetic crisis the physiology is not tenuous coronary is on the differential catecholamine driven perfusion

Common Perioperative Antihypertensive Pitfalls

- Treating pain, inadequate anesthetic depth, hypercarbia, hypoxia, or bladder distention with antihypertensives alone instead of correcting the cause.
- Using long-acting bolus drugs for a short-lived stimulus such as laryngoscopy, emergence, or temporary insufflation-related sympathetic activation.
- Lowering pressure too aggressively in patients with chronic hypertension, cerebrovascular disease, or coronary disease and causing avoidable hypoperfusion.
- Choosing beta-blockade when bradycardia, conduction disease, or poor ventricular function already limit physiologic reserve.
- Forgetting that postoperative hypertension may reflect missed home beta-blocker or clonidine doses rather than a need for escalating rescue IV therapy.
- Ignoring cuff artifact or failing to confirm the pressure trend before giving medication, especially during positioning, shivering, or arrhythmia.

- Allowing repeated doses from multiple team members to accumulate before the first drug has reached peak effect.

Approx Heart-rate

Agent duration / Best use case Major downside onset effect titratability

1-2 Decreases sympathetic Esmolol highly depressed minute heart rate surges with titratable cardiac output s tachycardia Hypertension with About Intermediate; tachycardia Prolonged effect 2-5 Decreases Labetalol less titratable when some if overshoot minute heart rate than esmolol carryover occurs s effect is acceptable SVR-driven Usually About hypertension Can cause reflex

5-15, neuro tachycardia and Nicardipine titratability by mildly minute blood-is not infusion increases s pressure instantaneous heart rate control Dynamic Usually perioperative Lipid emulsion

Neutral to hypertension restrictions and 2-4 short; Clevidipine mildly requiring allergy-related minute exceptionally increases minute-to-contraindication s titratable heart rate minute s control

5-20 postoperativ Hydralazine less increase onset and minute e or obstetric predictable heart rate prolonged tail s situations

1-2 titration for isolated Nitroglycerin increase ischemia or minute straightforwar afterload-driven heart rate pulmonary s d hypertension edema Highly

Nitroprussid Ultra-fast but reflex settings s to 1 hypotension and e unforgiving tachycardi requiring minute toxicity concerns a possible rapid potent vasodilation

- Do not treat the monitor before treating the cause. Correct pain, depth, ventilation, and reversible triggers first.
- Use short-acting, titratable IV agents whenever possible rather than long-lasting bolus therapy when the pressure may normalize quickly.
- Match the agent to the physiology: beta-blockers when tachycardia drives the problem, calcium channel blockers when vasoconstriction dominates, and nitrates when ischemia or pulmonary edema is present.
- Avoid overshoot hypotension. The goal is controlled reduction, not rapid normalization at any cost.
- Remember that postoperative hypertension often improves when pain, agitation, bladder distention, or missed home medications are addressed.
- Perioperative hypertension should be approached by identifying and correcting the cause, not by reflexively reaching for one favorite drug.
- Esmolol and labetalol are especially useful when tachycardia is part of the problem.
- Nicardipine and clevidipine are strong choices when vasoconstrictive hypertension requires titratable arterial vasodilation.
- Nitroglycerin is especially valuable when hypertension is tied to myocardial ischemia or pulmonary edema rather than isolated SVR elevation.
- In TCAR, a practical target is often systolic blood pressure about 140-160 mm Hg during active flow reversal, then about 120-150 mm Hg after the procedure while avoiding both hypotension and marked hypertension.
- In acute aortic dissection, the immediate goal is anti-impulse therapy: control both heart rate and blood pressure to reduce aortic wall stress, and avoid abrupt sympathetic surges during induction, line placement, and emergence.
- In microvascular free-flap cases, prioritize stable flap-driving perfusion and avoid prolonged hypotension or large pressure swings that can threaten anastomotic flow and flap viability.
- The best perioperative antihypertensive is the one that fits the physiology, the procedure, and the patient's comorbidities.

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Airway and Pulmonary Pharmacology

Beta2-Adrenergic Agonists

Representative drugs: albuterol (salbutamol), levalbuterol, terbutaline, epinephrine (nonselective sympathomimetic, reserved for severe or refractory bronchospasm/anaphylaxis).

Mechanism: stimulation of beta2 receptors increases cyclic AMP in bronchial smooth muscle, producing bronchodilation and reducing mediator release.

Clinical role: first-line rescue therapy for perioperative bronchospasm and an important pre-induction optimization strategy in reactive airway disease.

Drug Typical adult perioperative dose Key implications Albuterol 4-8 puffs via MDI/spacer or inline adapter; Rapid onset; common first-MDI may repeat based on response line treatment for

- Bronchospasm during anesthesia 2.5-5 mg nebulized.
- Severe cases may Useful in preop holding, Albuterol require repeated or continuous PACU, or intraoperatively nebulized nebulization when feasible Useful when inhaled 0.25 mg subcutaneous.
- May repeat Terbutaline delivery is ineffective or not cautiously if needed possible 10-50 mcg IV bolus for severe Most useful when bronchospasm with hemodynamic bronchospasm is severe, Epinephrine instability.
- Larger doses may be required in refractory, or part of anaphylaxis according to clinical context anaphylaxis.

Adverse effects and anesthesia implications: tachycardia, tremor, hypokalemia, hyperglycemia, and lactic acidosis with high-dose therapy. Intraoperatively, escalating airway pressure should prompt evaluation for mechanical causes before attributing findings to bronchospasm.

Frequent beta-agonist use may improve expiratory flow but can also increase heart rate and myocardial oxygen demand, which is especially relevant in ischemic heart disease.

Anticholinergic Bronchodilators

Representative drug: ipratropium bromide.

Mechanism: muscarinic receptor antagonism reduces vagally mediated bronchoconstriction and decreases secretions.

Clinical role: adjunct to beta-agonists in asthma or COPD exacerbation and useful when bronchospasm has a significant vagal component.

Typical adult dose: 0.5 mg nebulized, often combined with albuterol; may be repeated in acute treatment protocols.

Adverse effects: dry mouth, tachycardia, thickened secretions, and blurred vision if aerosol contacts the eyes.

Anesthesia implications: particularly helpful in COPD patients and in refractory bronchospasm when combined with beta-agonists. It should be viewed as an adjunct, not a replacement for first-line beta-agonist therapy.

Corticosteroids

Representative drugs: dexamethasone, methylprednisolone, hydrocortisone.

Mechanism: suppression of airway inflammation, reduced mucosal edema, and decreased late-phase inflammatory response.

Clinical role: prevention and treatment of airway edema, adjunct management of asthma/COPD exacerbation, and reduction of postoperative nausea and vomiting when dexamethasone is selected.

Drug Typical adult dose Clinical pearls 4-10 mg IV; 8-10 mg often used Long duration; useful for post-when airway edema or Dexamethasone extubation airway swelling and significant reactive airway risk is

PONV prophylaxis

Present Often used for acute Methylprednisolone 40-125 mg IV bronchospasm or

COPD/asthma exacerbation

Reasonable option when Hydrocortisone 100 mg IV stress-dose steroid coverage is also desired

Adverse effects and anesthesia implications: delayed onset relative to bronchodilators, hyperglycemia, impaired wound healing, psychiatric effects, and immunosuppression with repeated dosing. Steroids are not immediate rescue drugs for acute bronchospasm but are important adjuncts that reduce progression and recurrence.

Consider glucose monitoring in diabetic patients and those receiving high doses.

Agents for Upper Airway Edema and Post-Extubation Stridor

Representative drugs: nebulized epinephrine (including racemic epinephrine where available), dexamethasone, and supportive humidified oxygen.

Mechanism: alpha-adrenergic vasoconstriction reduces mucosal edema; corticosteroids reduce inflammatory swelling.

Typical adult dosing: nebulized epinephrine regimens vary by formulation and institution; common practice is to use a diluted dose via nebulizer for temporizing reduction in upper-airway swelling, while dexamethasone 8-10 mg IV is frequently used as adjunct therapy.

Anesthesia implications: monitor for rebound symptoms, tachycardia, hypertension, and the need for reintubation in severe airway compromise.

Mechanism: smooth muscle relaxation through calcium antagonism and reduced acetylcholine release.

Typical adult dose: 2 g IV over approximately 15-20 minutes for severe or refractory bronchospasm.

Clinical role: adjunct in status asthmaticus or severe perioperative bronchospasm when inhaled therapy and anesthetic deepening are insufficient.

Adverse effects: hypotension, flushing, weakness, and potentiation of nondepolarizing neuromuscular blockade.

Anesthesia implications: closely monitor blood pressure and train-of-four response, especially if rocuronium, vecuronium, or cisatracurium has been used.

Mechanism: NMDA antagonism with sympathetic stimulation and direct bronchodilatory properties.

Typical adult dose: 0.25-0.5 mg/kg IV as adjunct for bronchospasm, 1-2 mg/kg IV for induction when severe reactive airway disease is a concern.

Clinical role: useful for induction in patients at risk for bronchospasm and as an adjunct in refractory bronchospasm.

Adverse effects: tachycardia, hypertension, increased secretions, and dysphoric emergence phenomena.

Anesthesia implications: consider glycopyrrolate if secretions are problematic; ketamine may be especially useful when hypotension limits propofol use.

Methylxanthines

Representative drug: aminophylline/theophylline.

Mechanism: phosphodiesterase inhibition and adenosine receptor antagonism causing bronchodilation and mild diaphragmatic stimulation.

Current role: limited because of narrow therapeutic index and frequent adverse effects.

Typical adult dose: if specifically indicated and levels are not therapeutic, institutional loading strategies are required; routine empiric perioperative administration is uncommon.

Adverse effects: tachyarrhythmias, nausea, vomiting, seizures, and numerous drug interactions.

Anesthesia implications: review home theophylline use carefully because toxicity may mimic sympathetic overactivity and can complicate anesthetic management.

Mucolytics and Secretion Management

Representative drugs: N-acetylcysteine, hypertonic saline (institution-specific), glycopyrrolate as secretion control rather than a mucolytic.

Mechanism: N-acetylcysteine disrupts disulfide bonds in mucus, reducing viscosity.

Typical adult dose: inhaled N-acetylcysteine is most often used outside the OR; perioperative use is selective due to the risk of provoking bronchospasm.

Anesthesia implications: ensure adequate hydration, humidification, and suctioning; consider glycopyrrolate 0.1-0.2 mg IV for problematic secretions when clinically appropriate, balancing the risk of excessively thick secretions.

Reversal Agents and Airway Consequences

Drug Typical adult dose Airway/Pulmonary implications Effective for shallow to moderate Neostigmine Neostigmine 0.03-0.07 mg/kg block

- Excess muscarinic activity with IV with glycopyrrolate 0.01-may increase secretions or bronchial glycopyrrolate 0.02 mg/kg IV tone if not properly paired with anticholinergic 2 mg/kg for moderate block.
- 4 Rapid reversal of aminosteroid mg/kg for deep block.
- 16 neuromuscular blockade.
- May Sugammadex mg/kg for immediate rescue reduce risk of residual weakness and after high-dose rocuronium in postoperative respiratory select situations complications.

Residual neuromuscular blockade is a major contributor to postoperative hypoventilation, upper airway obstruction, and aspiration risk. Quantitative monitoring and timely reversal are airway management interventions as much as they are pharmacologic decisions.

Sugammadex is particularly valuable when rapid, reliable reversal of rocuronium or vecuronium is needed in patients with limited pulmonary reserve.

Inhaled Pulmonary Vasodilators

Representative drugs: inhaled nitric oxide and inhaled epoprostenol.

Clinical role: in anesthesia practice they are most often used as rescue or bridging therapies for pulmonary hypertensive crisis, acute right ventricular dysfunction or failure, difficulty separating from cardiopulmonary bypass, or refractory hypoxemia in selected patients.

Inhaled nitric oxide (iNO): nitric oxide activates soluble guanylate cyclase in pulmonary vascular smooth muscle, increasing cyclic GMP and causing rapid vasodilation. In adults, a common perioperative starting dose is 20 parts per million, with titration to the lowest effective dose based on oxygenation, pulmonary artery pressure, right ventricular performance, and institutional protocol.

CRNAs should recognize that in the United States the FDA-approved indication for nitric oxide for inhalation is term and near-term neonates (>34 weeks gestation) with hypoxic respiratory failure associated with clinical or echocardiographic evidence of pulmonary hypertension, used with ventilatory support to improve oxygenation and reduce the need for extracorporeal membrane oxygenation.

Adult perioperative use for pulmonary hypertension, right ventricular failure, or refractory hypoxemia is therefore off-label, although it is widely used in critical care and cardiac anesthesia settings.

Monitoring and safety: abrupt discontinuation of inhaled nitric oxide can precipitate rebound pulmonary hypertension with worsening hypoxemia and right ventricular strain, so it should be weaned gradually. Important monitoring includes oxygenation, hemodynamics, inspired nitrogen dioxide concentrations, and methemoglobin levels.

Additional concerns include pulmonary edema in patients with significant left ventricular dysfunction and occasional systemic hypotension.

Inhaled epoprostenol, a prostacyclin analogue, is commonly started around 50 ng/kg/min depending on device setup and institutional policy. It is often used as a lower-cost alternative to iNO and may provide similar short-term pulmonary vasodilation, but delivery systems and dosing approaches vary by institution.

For the CRNA, the key practical point is to coordinate initiation, titration, transport, and weaning carefully with respiratory therapy, perfusion, and ICU teams so therapy is not interrupted during critical transitions of care.

Sotatercept

Sotatercept (Winrevair): sotatercept is an activin signaling inhibitor used as add-on therapy for pulmonary arterial hypertension (PAH). Rather than acting primarily as an acute vasodilator, it targets pulmonary vascular remodeling by rebalancing signaling within the transforming growth factor-beta superfamily, with downstream effects that may reduce pathologic vascular proliferation.

The current FDA-approved indication is for the treatment of adults with pulmonary arterial hypertension (PAH, WHO Group 1 pulmonary hypertension) to improve exercise capacity and WHO functional class, and to reduce the risk of clinical worsening events, including hospitalization for PAH, lung transplantation, and death.

The recommended starting dose is 0.3 mg/kg subcutaneously, with a target dose of 0.7 mg/kg subcutaneously every 3 weeks. Key adverse effects and monitoring concerns include erythrocytosis, thrombocytopenia, serious bleeding, epistaxis, telangiectasia, headache, rash, dizziness, and embryo-fetal toxicity.

Hemoglobin and platelet counts should be checked before each dose for the first 5 doses, or longer if unstable, and then periodically thereafter.

Anesthesia implications: CRNAs should recognize that sotatercept is a chronic disease-modifying therapy, not a rescue drug for acute decompensation. Preoperatively, review the timing of the last dose, baseline hemoglobin, platelet count, bleeding history, concomitant prostacyclin or antithrombotic therapy, and overall PAH severity.

Elevated hemoglobin may increase thrombotic or hyperviscosity risk, while thrombocytopenia and concomitant anticoagulants may increase perioperative bleeding risk. Its presence on the medication list signals advanced PAH that warrants meticulous avoidance of hypoxemia, hypercarbia, acidosis, pain, and systemic hypotension.

Flolan (Epoprostenol)

Flolan (epoprostenol sodium): Flolan is an intravenous prostacyclin vasodilator used in patients with advanced pulmonary arterial hypertension (PAH). It is the intravenous formulation of epoprostenol and should be distinguished from inhaled epoprostenol, which may be used perioperatively as a selective rescue pulmonary vasodilator.

Mechanism: epoprostenol is a prostacyclin (PGI2) analogue that increases cyclic AMP, causing pulmonary and systemic vasodilation and inhibition of platelet aggregation. The FDA-approved indication is the treatment of pulmonary arterial hypertension (PAH, WHO Group 1) to improve exercise capacity.

The labeled starting dose is 2 ng/kg/min by continuous intravenous infusion through a central venous catheter, with titration in 1-2 ng/kg/min increments at intervals of at least 15 minutes based on clinical response and dose-limiting adverse effects.

Adverse effects and warnings: hypotension, flushing, headache, jaw pain, nausea, musculoskeletal pain, increased bleeding risk, and catheter-related complications.

Important label warnings include pulmonary edema during initiation in susceptible patients, rebound pulmonary hypertension if abruptly interrupted, and contraindication in patients with heart failure caused by reduced left ventricular ejection fraction.

Anesthesia implications: CRNAs should verify whether the patient is receiving chronic IV epoprostenol preoperatively and ensure that the infusion is never interrupted during transport, induction, procedure, or postoperative handoff. Abrupt discontinuation can cause life-threatening decompensation.

Because Flolan also inhibits platelet aggregation and causes vasodilation, anticipate potential bleeding risk and hypotension, especially when combined with anesthetics, anticoagulants, or regional techniques. The presence of chronic Flolan therapy signals severe PAH physiology and a high-risk anesthetic requiring meticulous avoidance of hypoxemia, hypercarbia, acidosis, and systemic hypotension.

Practical Anesthesia Implications

- Preoperative: assess asthma/COPD control, recent exacerbations, rescue inhaler use, smoking history, baseline oxygen needs, and prior intubation difficulty. Continue most chronic inhaled therapies and consider pre-treatment with inhaled bronchodilator before airway manipulation in reactive patients.
- Induction: avoid light anesthesia during airway instrumentation; propofol and ketamine are commonly favored in reactive airway disease, while desflurane may irritate the airway during lighter planes.
- Intraoperative bronchospasm: increase FiO2, hand ventilate, exclude circuit or tube problems, deepen anesthesia, administer inhaled beta-agonist, and escalate to epinephrine, magnesium, ketamine, or other adjuncts when needed.
- Ventilation strategy: allow adequate expiratory time, avoid breath stacking, and accept permissive hypercapnia when appropriate to reduce dynamic hyperinflation.
- Emergence and PACU: ensure complete neuromuscular recovery, adequate analgesia, and readiness to treat laryngospasm, edema, bronchospasm, or secretion burden.
- Pulmonary hypertension: avoid hypoxemia, hypercarbia, acidosis, pain, and hypotension; maintain right ventricular perfusion and have a plan for rescue pulmonary vasodilator therapy when indicated.

Scenario Likely helpful drugs Key note Reactive airway Optimize before airway Albuterol, dexamethasone, patient before manipulation when adequate induction depth intubation possible Acute intraoperative Albuterol,

ipratropium, epinephrine, Rule out mechanical bronchospasm magnesium, ketamine causes first

Post-extubation Nebulized epinephrine, rebound obstruction and stridor/airway edema dexamethasone possible reintubation Residual weakness Use quantitative

With poor pulmonary monitoring whenever neostigmine/glycopyrrolate strategy reserve available Pulmonary Inhaled nitric oxide, inhaled Avoid abrupt withdrawal hypertensive crisis or epoprostenol and correct triggers

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Antiemetics and PONV Prevention

Antiemetics for CRNA Practice

This module provides an evidence-based review of antiemetics used in contemporary nurse anesthesia practice, with emphasis on prevention and treatment of postoperative nausea and vomiting (PONV) and post-discharge nausea and vomiting (PDNV).

Current consensus guidance supports a multimodal strategy that combines risk reduction, opioid-sparing anesthetic techniques, and antiemetics from different pharmacologic classes rather than reliance on a single drug.

The module reviews commonly used agents such as dexamethasone, 5-HT3 antagonists, dopamine antagonists, anticholinergics, and NK1 antagonists, as well as newer or increasingly discussed options such as amisulpride and olanzapine.

Practical considerations for CRNAs include timing of administration, patient selection, rescue therapy after failed prophylaxis, adverse-effect profiles, QT concerns, and integration of antiemetic planning into enhanced recovery pathways.

Why Antiemetics Still Matter in Anesthesia Practice

Despite advances in anesthetic technique and antiemetic therapy, PONV remains one of the most common and disliked complications after anesthesia. It affects recovery quality, delays discharge, increases unanticipated admissions in ambulatory surgery, and may contribute to wound disruption, dehydration, electrolyte derangements, and aspiration risk in vulnerable patients.

Recent consensus recommendations emphasize that effective PONV prevention is not

Simply a matter of choosing one antiemetic; it requires risk stratification, reduction of baseline emetogenic exposures, multimodal prophylaxis, and a disciplined rescue plan. For CRNAs, antiemetic management should be planned as part of the overall anesthetic, not as an afterthought in the PACU.

Risk Assessment and Baseline Risk Reduction

Common adult risk factors include female sex, nonsmoking status, history of PONV or motion sickness, and expected postoperative opioid use. Procedure-related risk can also be meaningful, particularly with laparoscopic, gynecologic, bariatric, breast, middle ear, and strabismus procedures. Pediatric risk models differ, but this module focuses primarily on adult CRNA practice.

Baseline risk reduction strategies are as important as drug choice and include minimizing volatile anesthetic exposure when feasible, considering propofol-based total intravenous anesthesia for higher-risk patients, reducing perioperative opioids through multimodal analgesia, avoiding nitrous oxide when appropriate, maintaining adequate hydration, and using regional or neuraxial approaches when they can reduce systemic opioid requirements.

Apfel Score for Adult PONV Risk

The simplified Apfel score is one of the most widely used tools for estimating adult risk of postoperative nausea and vomiting. It assigns 1 point for each of four predictors: female sex, nonsmoking status, history of PONV or motion sickness, and expected postoperative opioid use.

The total score helps clinicians estimate baseline risk and match prophylaxis intensity to the patient's likelihood of PONV. It is most useful as a quick bedside framework rather than a perfect prediction model, because procedure type, anesthetic technique, and other clinical factors still matter.

History of PONV or motion sickness 1 Expected postoperative opioid use 1

0 About 10% 1 About 20% 2 About 40% 3 About 60% 4 About 80%

In practice, the Apfel score helps CRNAs decide how aggressive prophylaxis should be. Patients with lower scores may need only limited prophylaxis and attention to baseline risk reduction, while patients with higher scores generally benefit from multimodal strategies and efforts to reduce volatile anesthetic and opioid exposure. The score should guide, but not replace, clinical judgment.

For example, a patient with a modest Apfel score may still merit stronger prophylaxis if the procedure is highly emetogenic or if post-discharge vomiting would be especially problematic.

Suggested Prophylaxis Approach

/ Risk Level Emphasize baseline risk reduction. Consider 0 to 1 antiemetic 0-1 (Lower intervention depending on procedure risk, anesthetic plan, and risk) discharge concerns. 2 (Moderate Use 2 antiemetic strategies from different classes, combined with risk) opioid-sparing and anesthetic risk-reduction measures. 3-4 (Higher Use 3 or more complementary strategies.

Consider propofol-based risk) anesthesia, dexamethasone early in the case, a 5-HT3 antagonist near

Emergence, and selective use of scopolamine or a NK1 antagonist when delayed symptoms or vomiting are major concerns. This algorithm is a practical guide rather than a rigid protocol.

CRNAs should increase prophylaxis intensity when procedure-related risk is high, when postdischarge vomiting would be especially disruptive, or when the patient has a strong history of severe PONV despite a modest risk score.

Similarly, clinicians may scale back when an anesthetic plan already includes major risk-reducing features such as TIVA, regional analgesia, and minimal postoperative opioid exposure.

Major Antiemetic Classes in Current Practice

5-HT3 Receptor Antagonists 5-HT3 antagonists remain central to perioperative antiemetic prophylaxis. Ondansetron is widely used because of familiarity, availability, and effectiveness, especially when administered near the end of surgery.

Palonosetron has a longer half-life and may provide more durable protection into the postdischarge period, which can be useful in ambulatory surgery or patients at risk for delayed symptoms. Class adverse effects are generally modest but include headache, constipation, and dose-related QT prolongation, particularly with older first-generation agents.

In practice, 5-HT3 antagonists are often paired with dexamethasone as a first-line multimodal approach.

Dexamethasone Dexamethasone is one of the most studied and commonly used antiemetics in anesthesia practice. Although its antiemetic mechanism is not fully defined, it consistently improves prophylaxis when given early in the anesthetic and is especially effective when combined with a 5-HT3 antagonist. It is inexpensive, long-acting, and useful in enhanced recovery pathways.

CRNAs should remain attentive to patient-specific concerns such as perioperative hyperglycemia, potential steroid sensitivity, and the broader context of infection risk or wound-healing concerns, although single perioperative doses are generally well tolerated in most patients.

Dopamine Antagonists

Dopamine antagonists continue to play an important role, particularly when clinicians want to diversify receptor targets. Droperidol is effective at low doses for prophylaxis and rescue, but use still requires attention to QT issues, patient comorbidities, electrolyte abnormalities, and coadministration of other QT-prolonging drugs.

Metoclopramide is familiar and inexpensive but tends to be less robust as a primary prophylactic antiemetic at commonly used doses and carries a risk of extrapyramidal symptoms. Intravenous amisulpride is a newer option with

Evidence supporting both prevention and treatment of PONV, including rescue after failed prophylaxis when used from a different pharmacologic class than prior agents. Its availability varies by institution, but it is especially relevant in discussions of contemporary PONV rescue strategies.

Anticholinergic Therapy

Transdermal scopolamine is useful when longer-duration prophylaxis is needed, particularly for ambulatory surgery or patients with prior PDNV. Because onset is not immediate, it is most helpful when applied well before symptoms are expected. Benefits include prolonged effect and a mechanism distinct from serotonin and dopamine antagonists.

Limitations include dry mouth, blurred vision if medication is inadvertently transferred to the eye, and anticholinergic burden in susceptible patients. Careful patient counseling and hand hygiene remain important practical steps when this medication is used.

Antihistamines (H1 Antagonists)

H1 antihistamines have antiemetic effects because histamine receptors participate in vestibular and central emetic pathways.

For perioperative practice, they are not usually the first agents chosen for routine modern PONV prophylaxis, but they remain relevant as adjuncts or rescue options, especially when motion sensitivity, vestibular contributions, or a need for receptor diversification is suspected.

Common examples include dimenhydrinate, diphenhydramine, hydroxyzine, and promethazine, although promethazine also has phenothiazine properties beyond simple H1 blockade. These drugs may be useful in selected patients, but their antiemetic value must be weighed against sedation, anticholinergic effects, and delayed recovery.

Dimenhydrinate has evidence for PONV reduction, particularly as part of combination prophylaxis, while promethazine is more often used as a rescue medication because of its sedating profile and the tissue-injury risk associated with intravenous extravasation.

In CRNA practice, H1 antagonists are best viewed as secondary or adjunctive agents rather than routine front-line prophylaxis, with particular caution in older adults, patients at risk for delirium, and ambulatory patients in whom excessive sedation may delay discharge.

Neurokinin-1 Receptor Antagonists

NK1 antagonists reduce emesis by blocking substance P at neurokinin-1 receptors within central emetic pathways. This mechanism is complementary to serotonin, dopamine, and anticholinergic approaches, which is why NK1 agents are most valuable as part of multimodal prophylaxis rather than as stand-alone therapy.

In perioperative practice, the class is best known for aprepitant and the intravenous prodrug fosaprepitant. Aprepitant has been used most commonly as an oral preoperative medication, while fosaprepitant offers an intravenous option in institutions that stock it. Compared with several traditional antiemetics, NK1

Their longer duration can fill an important gap when clinicians are concerned that the protection from shorter-acting agents may fade after discharge.

For CRNAs, the practical question is not whether NK1 antagonists work, but when they add enough value to justify selective use. Oral aprepitant is commonly incorporated preoperatively for high-risk patients and is typically given before induction so adequate drug absorption occurs before the emetogenic stimulus of anesthesia and surgery.

Fosaprepitant has also shown benefit when added to established multimodal regimens in high-risk surgical populations. These drugs are usually paired with dexamethasone, a 5-HT3 antagonist, or both. They are not generally first-line rescue drugs for established early PONV in the PACU, because their greatest value is prophylactic and sustained rather than immediate symptom reversal.

Important cautions include cost, formulary variation, and drug-interaction issues. Aprepitant is a CYP3A4 inhibitor and can alter exposure to other CYP3A4-dependent medications; it may also reduce the effectiveness of hormonal contraceptives for several weeks and may affect warfarin response through CYP2C9-related mechanisms.

In short, NK1 antagonists are best reserved for patients in whom prevention of vomiting and delayed symptoms is especially important, and they are most effective when deliberately integrated into a broader multimodal antiemetic plan.

Olanzapine and Other Emerging or Selective Options

Recent reviews and meta-analyses suggest that olanzapine may reduce PONV when used prophylactically, likely because of its broad receptor activity. However, perioperative evidence remains smaller and less standardized than for established antiemetics, so most CRNAs will view it as a selective or off-label option rather than routine first-line prophylaxis.

Sedation and patient selection are important considerations. Other nonpharmacologic or adjunctive strategies, such as acupuncture or acupressure at the P6 point, may be considered in selected settings, but the strongest perioperative evidence remains with multimodal pharmacologic prophylaxis paired with anesthetic risk reduction.

Several other agents are sometimes discussed as helpful for nausea even though they are not core first-line perioperative antiemetics. Propofol has direct antiemetic properties in addition to its anesthetic role, which is one reason propofol-based total intravenous anesthesia reduces PONV compared with volatile-based techniques.

Some clinicians also use small subhypnotic doses or brief low-dose infusions as a rescue strategy, although this approach is selective, short-acting, and may be limited by sedation or the need for close monitoring. Ginger is a complementary option that has shown some benefit in reducing postoperative nausea in meta-

Analyses, but the evidence is more mixed for vomiting and for reducing the overall incidence of PONV. As a result, ginger is best viewed as an adjunct rather than a substitute for standard prophylaxis in at-risk patients. Trimethobenzamide (Tigan) is an older antiemetic with activity thought to involve the chemoreceptor trigger zone.

It may still be encountered in discussions of postoperative nausea treatment, but it is used far less often in modern anesthesia practice than agents such as ondansetron, dexamethasone, droperidol, or amisulpride. Practical limitations include sedation, extrapyramidal reactions, and the need for caution in older adults or patients with renal impairment.

For CRNAs, these options are best considered selective adjuncts when they match a specific clinical scenario rather than routine front-line therapy.

Applying Multimodal Prophylaxis in CRNA Practice

Current guidance favors broader multimodal prophylaxis than older stepwise models because risk scores are imperfect and standard antiemetic doses are generally well tolerated. a reasonable CRNA framework is to match baseline risk reduction with two or more antiemetic interventions for most patients who have meaningful risk.

Lower-risk patients may do well with one or two measures, while higher-risk patients often benefit from three or more complementary strategies such as propofol-based anesthesia, dexamethasone early in the case, and a 5-HT3 antagonist near emergence, with consideration of scopolamine or a NK1 antagonist when prolonged protection is desirable.

The key principle is to combine therapies that target different receptors and to integrate the plan into the anesthetic from induction through discharge.

When PONV occurs despite prophylaxis, rescue treatment should generally come from a different pharmacologic class than the prophylactic drug already given, particularly if symptoms occur in the early postoperative period. Repeating the same agent too soon is less likely to be effective.

This is where dopamine antagonists, including amisulpride where available, may be especially valuable if prophylaxis relied on dexamethasone and a 5-HT3 antagonist. Rescue planning should also consider the timing of symptom onset, hydration status, opioid exposure, ongoing triggers such as swallowed blood or motion, and whether nausea, retching, or vomiting is the predominant problem.

Rescue Treatment Algorithm

Choose a different class for rescue, such as droperidol, PONV occurs soon after amisulpride, promethazine, or a H1 antihistamine if prophylaxis with appropriate for the patient and setting.

Dexamethasone and/or a 5-

PONV occurs after Consider rescue with a 5-HT3 antagonist if not already prophylaxis that already used recently, or another non-dopamine option such as included a dopamine promethazine or a H1 antihistamine, while weighing antagonist sedation and discharge implications.

Favor agents with lower QT liability and correct reversible PONV occurs in a patient contributors such as hypokalemia, hypomagnesemia, with significant QT risk dehydration, or ongoing emetogenic triggers before stacking additional QT-sensitive medications. Control acute symptoms, then consider whether longer-

Acting strategies or discharge counseling are needed ambulatory patient at risk for because recurrence after leaving the facility may be delayed symptoms more problematic than PACU breakthrough alone.

Use a different rescue class, reassess analgesia to PONV occurs despite reduce opioid burden if possible, optimize hydration, and multimodal prophylaxis and look for ongoing triggers such as swallowed blood, ongoing opioid exposure gastric distention, or motion.

A practical rescue rule is to avoid simply repeating the same drug class in the early postoperative period if it was already used for prophylaxis.

Rescue treatment works best when the CRNA considers what has already been given, how long ago it was administered, the patient's major safety risks such as QT prolongation or sedation sensitivity, and whether nausea is being driven by ongoing factors that also need correction. In ambulatory patients, the rescue plan should also anticipate the possibility of recurrent symptoms after discharge.

Post-discharge Nausea and Vomiting

PDNV deserves special attention because patients lose access to rapid intravenous rescue once they leave the facility. Agents with longer duration, such as palonosetron, scopolamine, dexamethasone, and NK1 antagonists, may be particularly useful in selected ambulatory patients.

CRNAs should identify patients with prior severe PDNV, high opioid requirements, or long travel times home and consider a discharge plan that anticipates delayed symptoms. Prevention is usually more effective than attempting to manage established PDNV after discharge.

Special Populations and Clinical Scenarios

Some patients warrant more tailored antiemetic planning than a general adult approach suggests. Older adults may be more vulnerable to sedation, delirium, anticholinergic

Effects, and delayed discharge, so excessively sedating rescue medications should be used cautiously. Patients with diabetes may still benefit from dexamethasone, but CRNAs should anticipate transient hyperglycemia and weigh this against the drug's strong prophylactic value.

In patients with prolonged QT interval, significant electrolyte abnormalities, or concomitant QT-prolonging medications, clinicians should be more selective with agents such as droperidol and some 5-HT3 antagonists and should correct reversible risk factors when possible.

Bariatric and ambulatory surgery patients often merit particularly aggressive prophylaxis because vomiting, dehydration, or delayed recovery may have outsized consequences. These are the settings in which longer-acting strategies such as scopolamine, palonosetron, or NK1 antagonists may be especially helpful.

Obstetric patients have unique considerations related to neuraxial opioids, aspiration risk, and maternal comfort, while pediatric patients should be assessed with pediatric-specific risk models rather than the adult Apfel score.

Even when this module is focused on adult CRNA practice, it is important to recognize that antiemetic choices should be individualized to the surgical population, discharge setting, and the consequences of breakthrough symptoms.

Safety, Adverse Effects, and Clinical Judgment

No antiemetic is ideal for every patient. QT prolongation remains a practical concern with certain dopamine antagonists and some 5-HT3 antagonists, especially when multiple QT-prolonging medications, electrolyte disturbances, structural heart disease, or baseline conduction abnormalities are present. Sedation can be relevant with olanzapine, promethazine, or other centrally acting agents.

Anticholinergic effects matter with scopolamine, especially in older or sensitive patients. Dexamethasone may worsen perioperative hyperglycemia, and dopamine antagonists can cause akathisia or other extrapyramidal symptoms in susceptible individuals.

The CRNA's task is to balance efficacy, duration, patient comorbidities, drug interactions, and discharge setting while building a rational multimodal plan.

Case Studies for Clinical Application

Case 1: High-risk ambulatory laparoscopy. A 34-year-old nonsmoking woman with a strong history of motion sickness is scheduled for ambulatory laparoscopic gynecologic surgery and is expected to need postoperative opioids. Her Apfel score is 4, and she is at high risk for both PONV and PDNV.

A reasonable plan would include aggressive baseline risk reduction, consideration of propofol-based anesthesia, dexamethasone early in the case, a 5-HT3 antagonist near emergence, and selective addition of scopolamine or aprepitant because delayed symptoms after discharge would be particularly problematic.

Case 2: QT-sensitive patient. A 68-year-old man with structural heart disease, baseline QT prolongation, and diuretic-associated hypokalemia is scheduled for abdominal surgery. Although he may still need prophylaxis, the antiemetic plan should minimize QT liability, correct reversible electrolyte abnormalities, and avoid stacking multiple QT-prolonging agents without a compelling reason.

In this scenario, dexamethasone and careful selection among lower-risk companion drugs may be preferable to heavy reliance on droperidol or repeated QT-sensitive rescue medications.

Case 3: PACU rescue after failed prophylaxis. a patient received dexamethasone after induction and ondansetron near emergence but arrives in the PACU with persistent nausea and retching. Because early rescue from the same class is less likely to succeed, a different pharmacologic class should be chosen.

Depending on patient factors and institutional availability, this might include a dopamine antagonist such as droperidol or amisulpride rather than repeating ondansetron immediately.

Case 4: Older ambulatory patient with sedation concerns. A 76-year-old patient is scheduled for ambulatory hernia repair and is worried about nausea but also wants a rapid, clear-headed recovery.

In this setting, the CRNA may favor low-sedation prophylaxis such as dexamethasone and a 5-HT3 antagonist while avoiding unnecessary reliance on promethazine or other sedating rescue drugs unless clearly needed. Discharge planning should consider PDNV risk and the patient's ability to manage symptoms at home.

Key Practice Takeaways

- PONV prevention should begin with risk assessment and reduction of baseline emetogenic exposures.
- Multimodal prophylaxis using different receptor targets is now preferred for many at-risk patients.
- Dexamethasone plus a 5-HT3 antagonist remains a common foundation, but dopamine antagonists, scopolamine, and NK1 antagonists expand options for individualized care.
- Rescue therapy should usually come from a different class than the prophylactic agent already administered.
- PDNV requires longer-acting planning because treatment options become more limited after discharge.

- Drug selection should account for QT risk, sedation, anticholinergic burden, glucose effects, and procedure-specific needs.

Agent/Class Important

- M Perioperati Timing ions for Side ve Dosing CRNA Effects Practice Common first-line prophylacti Blocks c agent.
- Headache serotonin at often paired Near the, 5-HT3 with end of constipati Ondansetron (5-receptors in dexametha 4 mg IV surgery or on, dose-HT3 antagonist) central and sone.
- Avoid at related QT peripheral repeating emergence prolongati emetic early as on pathways rescue if already used for prophylaxis Headache, constipati Useful for on.
- Induction strong 4-8 mg IV perineal (corticosteroid) likely or early in combinatio discomfort central anti-the case n partner if given inflammato with 5-HT3 rapidly, ry and antagonists steroid-neurotrans.

As primary Dopamine prophylaxis antagonism Usually Metoclopramide Akathisia,; may help with near the (dopamine dystonia, when prokinetic 10 mg IV end of antagonist / sedation, delayed effects at surgery or prokinetic) diarrhea gastric higher as rescue emptying is doses also a concern

At rescue from induction Infusion-a different Selective 5 mg IV for or site pain, class after

Prophylaxis; intraoperat QT failed (dopamine D2/D3 10 mg IV for ively for prolongati prophylaxis antagonist) receptor rescue prophylaxi on; antagonism s; PACU for potential institutional rescue availability varies

- Dimenhydrinate 25-50 mg IV/IM may be useful as an H1 antihistamine adjunct; watch for dry mouth, sedation, and dizziness.
- Dimenhydrinate, intraoperat blurred vestibular blockade in diphenhydra diphenhydramine, ively, or as vision, or motion-vestibular mine 12.5-hydroxyzine (H1 rescue urinary related and central 25 mg IV.
- Antihistamines) depending retention, triggers.
- Emetic hydroxyzine on agent anticholin caution in pathways varies by and setting ergic older adults route burden and ambulatory patients Usually Marked reserved for sedation, rescue.

6.25-12.5 Usually because of blockade injury risk Promethazine mg IV rescue in sedation plus with IV (phenothiazine diluted PACU or and phenothiazi extravasati antihistamine/anti cautiously, later administrati ne on, emetic) or IM where postoperati on antiemetic anticholin appropriate ve setting concerns; effects ergic avoid effects, careless IV dystonia use Strong

Reactions, when oral of headache, premedicati aprepitant constipati on is less

Some antiemetics act at multiple receptors (dopamine, serotonin, histamine, muscarinic). Choose based on Apfel risk, prior response, and side-effect profile rather than using every agent routinely.

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Perioperative Antibiotics and Anaphylaxis

Perioperative Antibiotics and Anaphylaxis for the CRNA

This module is designed for nurse anesthesia learners and practicing CRNAs who need a practical review of antibiotics commonly used in the perioperative setting and the anesthesia implications of allergic reactions, especially anaphylaxis.

Antibiotic prophylaxis is one of the most frequent medication responsibilities in the operating room, and timing, drug selection, redosing, and allergy assessment directly influence surgical site infection prevention and patient safety.

Because antibiotics are also among the most common triggers of perioperative hypersensitivity reactions, CRNAs must be prepared to distinguish expected drug effects from evolving anaphylaxis and respond rapidly to airway, hemodynamic, and cutaneous findings.

This module emphasizes clinically useful dosing, stewardship principles, current evidence on beta-lactam allergy labels, and practical management of perioperative anaphylaxis.

Why Perioperative Antibiotic Prophylaxis Matters

Perioperative antibiotic prophylaxis is intended to reduce the risk of surgical site infection by ensuring adequate antimicrobial tissue concentrations at the time of incision and throughout the period of greatest contamination risk.

Successful prophylaxis depends on choosing an antibiotic active against the likely organisms for the planned procedure, administering it at the correct time before incision, redosing when appropriate, and discontinuing it when prophylaxis is no longer beneficial. For the CRNA, this is both a patient-safety and stewardship issue: incorrect timing, unnecessary broad-spectrum

Coverage, or inappropriate substitution because of an unverified allergy label can increase infection risk, drug toxicity, resistance, and cost.

Cefazolin: The First-Line Perioperative Antibiotic

Cefazolin is the preferred prophylactic antibiotic for many clean and clean-contaminated procedures because it has reliable activity against common skin flora and selected gram-negative organisms, achieves good tissue concentrations, has a favorable safety profile, and is inexpensive. Typical adult dosing is 2 g IV for most adults and 3 g IV for patients weighing 120 kg or more.

It should usually be administered within 60 minutes before incision and is commonly redosed every 4 hours intraoperatively if the procedure is prolonged or there is major blood loss. For many CRNAs, cefazolin is the most commonly administered antibiotic in the OR, making familiarity with its timing, dosing, and allergy considerations essential.

Antibiotic Common use/notes

2 g IV; 3 g IV if >=120 kg; redose Cefazolin about every 4 hours when First-line for many procedures indicated

Alternative for some beta-lactam-900 mg IV; redose about every Clindamycin allergic patients; less ideal for MSSA 6 hours when indicated prophylaxis than cefazolin

Used for MRSA risk or selected true 15 mg/kg IV, infused slowly; beta-lactam allergy situations; Vancomycin usually no intraoperative should begin earlier because of long redose for routine prophylaxis infusion time

Added when anaerobic coverage is Metronidazole 500 mg IV needed, such as selected colorectal or head and neck procedures

Often 5 mg/kg IV as a single Occasionally combined with other Gentamicin prophylactic dose when agents in selected allergies or specifically indicated procedure-specific protocols

Timing, Redosing, and Duration

Most prophylactic antibiotics should be started within 60 minutes before incision so that effective tissue concentrations are present when contamination begins. Vancomycin and fluoroquinolones require longer infusion times and are often started within 120 minutes before incision.

If a procedure is prolonged beyond the expected redosing interval or there is major blood loss, redosing may be needed to maintain adequate tissue levels. By contrast, for most clean and clean-contaminated procedures, prophylaxis should not continue after incision closure unless there is a documented infection or a procedure-specific exception.

CRNAs are often the clinicians who best control timing in real time, so clear coordination with the surgical team is important.

Beta-Lactam Allergy Labels and Cross-Reactivity

A large number of patients report a "penicillin allergy," but only a minority have a confirmed immediate hypersensitivity. Mislabeling matters because it often leads to second-line prophylaxis, which can increase surgical site infections, antimicrobial resistance, and costs.

Current evidence increasingly supports the use of cefazolin in many patients with a reported penicillin allergy because cefazolin has unique side chains and very low clinically relevant cross-reactivity with penicillins.

Contemporary reviews and perioperative literature generally place the true cross-sensitivity/dual-allergy risk at well under 1% for most patients, with older estimates having substantially overstated the risk. Some educational and perioperative sources still quote a broader "less than 1%-2%" range, but the overall message is that the risk is low, especially when the history is nonsevere or vague.

However, this does not mean all beta-lactam reactions are equivalent. a careful history should distinguish remote childhood rash, gastrointestinal intolerance, unknown reactions, and isolated nonsevere reactions from true immediate anaphylaxis or severe delayed reactions such as Stevens-Johnson syndrome/toxic epidermal necrolysis, DRESS, or AGEP.

Severe delayed hypersensitivity syndromes should generally steer clinicians away from beta-lactams unless allergy specialists advise otherwise.

4A. When Cefazolin Is Still Appropriate For many patients with a reported penicillin allergy label, cefazolin may still be appropriate after a focused history review.

Histories that are often considered lower risk include a vague childhood rash, gastrointestinal upset, headache, yeast infection, family history of penicillin allergy, or an unknown remote reaction without features of immediate

hypersensitivity.

Contemporary perioperative guidance and quality-improvement literature increasingly support direct cefazolin use in many such patients because clinically meaningful cross-reactivity is low and avoiding cefazolin may increase reliance on less effective alternatives. Greater caution is warranted when the history suggests a true

Immediate reaction to cefazolin or another beta-lactam with hypotension, bronchospasm, angioedema, or generalized urticaria soon after administration, and cefazolin should generally be avoided in patients with severe delayed reactions such as Stevens-Johnson syndrome/toxic epidermal necrolysis, DRESS, or AGEP unless allergy specialists advise otherwise.

Alternatives to Cefazolin and Their Implications

Clindamycin and vancomycin are common alternatives when cefazolin is not appropriate, but each has limitations. Clindamycin lacks the same reliability as cefazolin for MSSA prophylaxis in many settings and may be associated with higher infection rates when substituted broadly.

Vancomycin is useful for selected patients with true beta-lactam contraindications or specific MRSA considerations, but it requires longer infusion times, has slower onset, and does not replace the gram-negative coverage cefazolin may provide in some procedures. Gentamicin, metronidazole, or other agents may be added in selected procedure-specific protocols.

For the CRNA, using an alternative antibiotic should be a thoughtful decision based on reaction history and surgical indication rather than a reflexive response to any reported allergy label.

Perioperative Anaphylaxis: Recognition

Perioperative anaphylaxis is a rapidly developing, potentially life-threatening hypersensitivity reaction that may present with hypotension, bronchospasm, increased airway pressures, difficulty ventilating, hypoxemia, tachycardia or bradycardia, urticaria, flushing, angioedema, and cardiovascular collapse.

Because patients are draped, ventilated, and often unable to report symptoms, diagnosis can be delayed. Antibiotics, especially cefazolin, are among the most common identified perioperative triggers, although neuromuscular blocking agents, latex, chlorhexidine, and dyes are also important causes.

The CRNA must maintain a high index of suspicion whenever sudden cardiovascular instability or bronchospasm occurs shortly after antibiotic administration or another major drug exposure.

Initial Management of Perioperative Anaphylaxis

Initial management priorities are to stop the suspected trigger, announce concern for anaphylaxis, call for help, deliver 100% oxygen, and support the airway and circulation immediately. In the OR, where IV access and physiologic monitoring are already present, treatment is often titrated intravenously. a practical approach is to think in steps: (1) stop the antibiotic or other suspected trigger and halt any nonessential infusions

- (2) deepen oxygen delivery and assess the airway, ventilation, and end-tidal carbon dioxide.
- (3) give epinephrine early for hypotension, bronchospasm, or evolving multisystem involvement.
- (4) give rapid IV crystalloid because profound vasodilation and capillary leak are common.

(5) add adjuncts for bronchospasm or refractory shock; and (6) document the event and arrange post-event evaluation. Delay in epinephrine is associated with worse outcomes, so treatment should favor early intervention rather than waiting for skin findings or complete diagnostic certainty.

Step Practical OR action

Stop the suspected antibiotic or other trigger, notify the surgeon,

Stop exposure

Request assistance, and prepare emergency medications and and call for help vasopressor infusion capability.

Give 100% oxygen, hand-ventilate if needed, evaluate for rising

Airway pressure or poor compliance, and prepare for airway airway support edema or severe bronchospasm.

For moderate hypotension, a common OR approach is 10-20 mcg IV boluses titrated to response. For more severe reactions, 50-

100 mcg IV boluses may be needed. If repeated boluses are line treatment required, start an epinephrine infusion and titrate to blood pressure, heart rate, ventilation, and overall response.

Give rapid isotonic crystalloid boluses because vasodilation and

IV Fluid Resuscitation

Capillary leak can be profound. Escalate quickly if hypotension resuscitation persists.

Deepen anesthesia as appropriate, use inhaled albuterol for

Bronchospasm and treats both bronchospasm and hemodynamic collapse. Consider airway edema corticosteroids as secondary therapy and antihistamines as adjuncts after stabilization.

Consider vasopressin for refractory vasoplegia. In patients taking

- Refractory shock beta-blockers who respond poorly to epinephrine, glucagon may or special be considered. If cardiovascular collapse occurs, follow ACLS situations principles while continuing to treat anaphylaxis as the likely cause.

After stabilization, consider serum tryptase testing, document

Post-Event Actions

The timing of every suspected exposure and treatment, workup and communicate the event clearly during handoff, and recommend handoff formal allergy evaluation before future anesthesia.

7A. Case Vignette A 64-year-old patient presents for elective total knee arthroplasty. After induction of general anesthesia and before incision, cefazolin is administered. Within minutes, the

Blood pressure falls to 62/34 mmHg, peak inspiratory pressures rise, ventilation becomes more difficult, and diffuse flushing is noted on the upper chest. The CRNA notes that the end-tidal carbon dioxide has decreased and there has been no major blood loss.

In this setting, the most important next step is to suspect perioperative anaphylaxis early, stop the suspected trigger, call for help, deliver 100% oxygen, support the airway and ventilation, begin rapid IV crystalloid administration, and give epinephrine promptly while reassessing the differential diagnosis.

This scenario highlights how perioperative anaphylaxis may present primarily with cardiovascular and respiratory findings rather than cutaneous signs alone.

- What features in this case make perioperative anaphylaxis more likely than isolated hypotension from anesthetic depth?
- Why is epinephrine the first-line treatment in this scenario?

- What details should be documented before the patient leaves the OR or PACU?

Adjunctive Therapy, Differential Diagnosis, and Follow-Up

Additional practical points: antihistamines and corticosteroids may be useful adjuncts, but they do not replace epinephrine and should not delay it. Albuterol may help persistent bronchospasm, especially after hemodynamics begin to improve.

The differential diagnosis includes hemorrhage, high spinal or epidural block, pulmonary embolism, tension pneumothorax, severe bronchospasm of another cause, myocardial ischemia, and sepsis. a serum tryptase level obtained after stabilization can help support later diagnosis, but it should never delay immediate treatment.

Tryptase is a protease released primarily from mast cells, so an elevated acute level provides supportive evidence that mast cell activation occurred during the event.

In suspected perioperative anaphylaxis, tryptase is most useful when it is interpreted as paired testing: an acute sample drawn ideally within about 30 minutes to 2 hours of symptom onset and a later baseline sample obtained after recovery, often at least 24 hours after symptoms resolve.

Comparing those values is more informative than looking at a single number alone because some patients have naturally higher baseline tryptase levels. Importantly, tryptase is a supportive biomarker, not a bedside rule-in or rule-out test.

A normal tryptase does not exclude perioperative anaphylaxis, especially if sampling was delayed, the reaction was less severe, or the mechanism did not produce a large tryptase rise. Its main value is helping confirm the reaction later, guiding referral to allergy specialists, and improving the chances of identifying the culprit exposure before a future anesthetic.

8A. Documentation and Handoff After Suspected Perioperative Anaphylaxis After stabilization, documentation should clearly identify the suspected trigger(s), the time each medication or exposure occurred, the onset and sequence of symptoms, the

Hemodynamic and airway findings, the treatments given, and the patient's response. The record should note whether serum tryptase was sent, ideally with an acute sample obtained within roughly 30 minutes to 2 hours of symptom onset and a later baseline sample collected after recovery, because paired sampling can support later diagnosis.

Handoff to the PACU, ICU, or receiving team should explicitly describe the reaction, the suspected exposures that must be avoided pending evaluation, and the need for formal allergy referral before future anesthesia. Accurate documentation helps prevent both unsafe re-exposure and unnecessary long-term labeling with imprecise allergy information.

Current Evidence and Practice Trends

Recent literature increasingly supports better perioperative beta-lactam allergy assessment and broader use of cefazolin in patients with penicillin allergy labels when the history is low risk.

Studies and quality improvement projects published in 2024-2026 have shown increased cefazolin use without a meaningful increase in severe allergic reactions, while reducing reliance on clindamycin and vancomycin.

Contemporary guidance also emphasizes that cefazolin-associated perioperative anaphylaxis is rare, even though cefazolin remains one of the most commonly identified causes simply because it is used so frequently.

For CRNA practice, this means antibiotic selection should increasingly be driven by accurate reaction history, stewardship principles, and procedure-specific microbiology rather than broad avoidance of beta-lactams.

- Confirm the antibiotic plan: know the procedure, likely pathogens, MRSA considerations, allergy history, and intended timing before incision.
- Own the timing: prophylaxis is most effective when started within the correct pre-incision window and before tourniquet inflation if relevant.
- Clarify allergies: a vague history of "penicillin allergy" should not automatically exclude cefazolin, but severe delayed reactions require caution.
- Watch the clock for redosing: prolonged cases and major blood loss may require repeat dosing to preserve adequate tissue concentrations.
- Be ready for anaphylaxis: sudden hypotension, bronchospasm, flushing, or airway edema after antibiotic administration should trigger immediate reassessment and early epinephrine use.
- Document clearly: if a perioperative allergic reaction occurs, record suspected exposures, timing, signs, treatment, and follow-up recommendations.

Routine clean Correct first-line Cefazolin is often preferred; administer procedure without prophylaxis and in the pre-incision window major allergy history timing

Reported penicillin Avoid unnecessary Many such patients can still receive allergy with vague second-line cefazolin after careful history review childhood rash antibiotics

Known severe delayed to potentially Consider alternative prophylaxis and beta-lactam reaction unsafe beta-involve allergy guidance when needed lactam

Sudden hypotension Stop the trigger, call for help, give 100% and bronchospasm Perioperative oxygen, support airway and ventilation, after antibiotic anaphylaxis give IV epinephrine early, and start rapid administration crystalloid resuscitation

Long procedure with Consider redosing based on agent, prophylactic major blood loss duration, and blood loss tissue levels

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Tranexamic Acid

Overview and History

Tranexamic acid (TXA) is a synthetic lysine analog antifibrinolytic that reduces bleeding by stabilizing formed clot. It does not create new clot; rather, it limits fibrin breakdown by inhibiting plasminogen activation and plasmin binding to fibrin.

Since its development by Japanese researchers in the 1960s, TXA has expanded from niche hemostatic use to a cornerstone medication in blood conservation and hemorrhage management across surgery, trauma, and obstetrics.

Its modern relevance to CRNA practice is substantial. TXA is now commonly used to reduce perioperative blood loss, decrease allogeneic transfusion exposure, and support structured patient blood management programs.

Large trials and contemporary reviews support its favorable benefit-risk profile in many settings, especially trauma, postpartum hemorrhage, and surgeries with expected major blood loss. However, benefit is indication-specific, and TXA should not be viewed as universally helpful in every bleeding condition.

Pharmacology of Tranexamic Acid

TXA reversibly binds lysine-binding sites on plasminogen, preventing its conversion to plasmin and reducing plasmin interaction with fibrin. The practical result is inhibition of fibrinolysis and preservation of clot integrity. In high concentrations, TXA may also directly inhibit plasmin activity.

- Intravenous onset is rapid, which is why TXA is favored when active bleeding or imminent surgical blood loss is a concern.
- The elimination half-life is approximately 2 to 3 hours in patients with normal renal function.
- Renal elimination is the dominant route, with most drug excreted unchanged in urine; accumulation can occur in renal impairment and increases the risk of neurotoxicity, including seizures.
- TXA is available in intravenous, oral, and topical/local formulations or applications, depending on the clinical setting.

Pharmacodynamic and Clinical Implications

- TXA is most useful when hyperfibrinolysis or fibrinolytic activation contributes meaningfully to bleeding.
- It supports blood conservation but does not replace surgical hemostasis, resuscitation, correction of coagulopathy, or source control.
- High systemic exposure, especially in cardiac surgery or renal dysfunction, is associated with a greater seizure signal and warrants dose awareness.

Trauma and Hemorrhagic Shock

TXA has one of its strongest evidence bases in trauma. Mortality benefit is time-sensitive: it should be given as early as possible and no later than 3 hours after injury in patients with clinically significant hemorrhage or hemorrhagic shock. Contemporary trauma guidance continues to support early use, with the greatest benefit appearing when treatment occurs very early after injury.

Postpartum Hemorrhage

TXA is now a standard adjunct in postpartum hemorrhage management when bleeding is clinically diagnosed. As in trauma, timing matters; administration within 3 hours of birth is the key evidence-based window. It should be viewed as an adjunct to uterotonic therapy, resuscitation, and source-specific management rather than a replacement for them.

Orthopedic and Spine Surgery

TXA is widely used in joint arthroplasty and many spine procedures to reduce perioperative blood loss and transfusion. Intravenous, topical, and combined approaches are all used. For CRNAs, this is one of the most common perioperative TXA exposures in elective practice.

Cardiac Surgery

TXA is a major component of blood conservation in adult cardiac surgery. Benefit is well established for reducing bleeding and transfusion, but this is also the setting in which dose-related postoperative seizures are most discussed. Dosing strategy and renal function matter considerably.

Other Surgical and Procedural Uses

- Major noncardiac surgery with anticipated substantial blood loss
- ENT and epistaxis protocols in selected settings
- Oral or dental bleeding in hemophilia-related indications
- Selected topical or irrigation uses where institutions have established protocols, though route-specific safety must be respected rigorously.

Current evidence does not support routine TXA use for all bleeding conditions. Benefit has not been consistently demonstrated in spontaneous intracranial hemorrhage, subarachnoid hemorrhage, or gastrointestinal bleeding, and these settings should not be treated as automatic indications.

3A. TXA and Cesarean Delivery For CRNAs, tranexamic acid is especially relevant in cesarean delivery in two distinct contexts: treatment of postpartum hemorrhage after cesarean birth and prophylactic use during cesarean delivery to reduce blood loss. These are not equivalent indications, and the strength of evidence differs between them.

Treatment of Postpartum Hemorrhage After Cesarean Delivery

When clinically diagnosed postpartum hemorrhage occurs after cesarean delivery, TXA is an important adjunct to uterotonics, uterine massage, surgical hemostasis, resuscitation, and blood-component therapy when needed. The strongest evidence supports administration as early as possible and within 3 hours of birth.

For the CRNA, the practical priority is early recognition of significant bleeding and prompt integration of TXA into the obstetric hemorrhage pathway rather than waiting until hemorrhage becomes refractory.

Prophylactic TXA at the time of cesarean delivery is increasingly discussed and used in some institutions to reduce measured blood loss and transfusion exposure, especially in patients at higher hemorrhage risk. However, this remains more protocol dependent than universal, and practice varies regarding timing such as before skin incision versus after cord clamping. CRNAs

Should follow institutional obstetric anesthesia and hemorrhage protocols rather than assuming one routine prophylactic regimen applies to every cesarean delivery.

Because spinal and epidural techniques are central to cesarean delivery care, TXA deserves special medication-safety attention in obstetric anesthesia. Injectable TXA is for intravenous use only and must never be administered neuraxially.

In labor and delivery and operating-room workflows, strict separation of neuraxial medications from intravenous TXA is essential to prevent catastrophic wrong-route errors.

Dosing and Practical Regimens

TXA dosing varies by indication, institutional protocol, route, and bleeding risk. CRNAs should follow local policy, but several high-yield patterns are worth knowing.

Usual Adult Dose

Pattern As early as Do not treat delayed Trauma 1 g over 10 min, then 1 possible; use beyond 3 hr as IV hemorrhage g over 8 hr within 3 hr of routine trauma injury practice 1 g over about 10 min; As soon as

May repeat 1 g if PPH is Postpartum uterotonics, IV bleeding continues diagnosed; hemorrhage resuscitation, and after 30 min or restarts within 3 hr of source control within 24 hr birth Often 10-15 mg/kg IV preincision, with or

Orthopedic or IV +/- without repeat dose or Usually before protocol for IV vs spine surgery topical infusion; topical or incision topical approach intra-articular protocols vary

Many centers use a Before

Loading dose plus incision when seizure risk or Cardiac surgery IV infusion with lower-to and/or during renal dysfunction is moderate-dose bypass per a concern strategies increasingly protocol favored Dental 10 mg/kg immediately

Extraction in before extraction, then Per extraction IV reduce hypotension hemophilia 10 mg/kg three to four schedule risk (labeled IV use) times daily for 2-8 days

Use only according Institution specific to established Topical or local Topical / At the surgical concentration and institutional surgical use irrigation field volume protocol and route-specific safety rules

Before Any Reduce dose and/or seizure-risk

Systemic extend interval based reduction and impairment dosing or route on renal function avoidance of drug infusion accumulation Quick-reference only: final dose selection should follow the indication, patient-specific factors, renal function, and institutional protocol. Injectable TXA is for intravenous use only and must never be administered neuraxially. Trauma

- Traditional regimen: 1 g IV over 10 minutes, followed by 1 g infused over 8 hours.
- Key point: administer as early as possible and avoid late use beyond 3 hours after injury in routine trauma hemorrhage care.
- 1 g IV over about 10 minutes as soon as postpartum hemorrhage is diagnosed.
- A second 1 g dose may be used if bleeding continues after 30 minutes or restarts within 24 hours, per common obstetric guidance.

Orthopedic or Spine Surgery

- Common IV strategies include a preincision bolus such as 10 to 15 mg/kg IV, with or without a maintenance infusion or repeat dose.
- Topical or intra-articular protocols are common in arthroplasty and vary by surgeon and institution.
- The practical principle is consistency with institutional pathways rather than one universal regimen.
- Protocols differ widely. Low-to moderate-dose regimens are increasingly favored to balance efficacy with seizure risk.
- Many protocols use a loading dose followed by infusion during surgery or cardiopulmonary bypass, but the exact regimen should follow cardiac-team standards.

Hemophilia Dental Indication (FDA-Labeled IV Use)

- 10 mg/kg IV immediately before extraction, then 10 mg/kg IV three to four times daily for 2 to 8 days.
- Infuse slowly to reduce hypotension risk.

Renal Dose Adjustment

Because TXA is renally cleared, dose reduction is important in kidney dysfunction. In practice, the more impaired the renal function, the more conservative the dose or interval should be. This is especially relevant in repeated dosing, infusions, and cardiac surgery. Failure to reduce the dose in renal impairment increases the likelihood of accumulation and neurotoxicity.

Common Adverse Effects

- Nausea, vomiting, diarrhea
- Dizziness or giddiness
- Hypotension when given too rapidly intravenously
- Occasional visual or ocular symptoms that should prompt discontinuation and evaluation.

High-Importance Adverse Effects

- Seizures: most emphasized in high-dose cardiac surgery, renal dysfunction, or catastrophic neuraxial misadministration. Mechanistically, TXA can antagonize inhibitory glycine and GABA-a pathways at high concentrations.
- Thromboembolic concern: despite theoretical concern, major trials generally have not shown a major increase in thromboembolic events when TXA is used appropriately; however, caution remains warranted in patients with active intravascular clotting or selected high-risk circumstances.
- Hypersensitivity reactions: rare but clinically important.

Contraindications and Strong Precautions

- Neuraxial administration is contraindicated. TXA is for intravenous use only when using the injectable product.
- Active intravascular clotting is a contraindication.
- Subarachnoid hemorrhage is a contraindication in product labeling because of risk of cerebral edema and infarction.
- Severe hypersensitivity to TXA or formulation components is a contraindication.
- Use added caution in renal impairment, prior seizure disorder, and settings where very high doses may be considered.

5A. TXA and Coronary Stents / Antiplatelet Therapy a history of coronary stent placement alone is not generally considered an automatic contraindication to tranexamic acid. For the CRNA, the key issue is not simply whether a stent is present, but whether the patient is currently in a high-risk thrombotic state.

Prior remote stent placement in a clinically stable patient does not necessarily preclude TXA when bleeding reduction is important and the overall indication is strong.

More caution is warranted when the patient has had recent percutaneous coronary intervention, recent acute coronary syndrome, interruption of dual antiplatelet therapy, active ischemia, or suspected active intravascular thrombosis.

In these settings, the balance between bleeding reduction and thrombotic risk is more complex and should be individualized with the surgical, anesthesia, and cardiology teams when possible.

Terms, elective noncardiac surgery is generally delayed at least 30 days after bare-metal stent placement, ideally 6 months after drug-eluting stent placement for chronic coronary disease, and about 12 months after drug-eluting stent placement for acute coronary syndrome when feasible.

If antiplatelet therapy must be interrupted, aspirin is often continued when possible and the P2Y12 inhibitor restarted as soon as surgical bleeding risk allows.

For the CRNA, this means a remote, stable stent history should be distinguished clearly from active ischemia, recent PCI, recent ACS, interrupted DAPT, or suspected active intravascular thrombosis, which are the situations that warrant greater caution when TXA is being considered.

- Remote, stable stent history: TXA may still be reasonable when clinically indicated.
- Recent stent placement or recent ACS: use heightened caution and individualized multidisciplinary judgment.

- Interrupted aspirin or P2Y12 therapy: recognize that stent-thrombosis risk may be higher, especially early after PCI.
- Active thrombosis or active ischemia: this is a fundamentally different and more concerning situation than a remote prior stent.

Clinical Pearl: a prior coronary stent is not the same as active clotting. The safer question is whether the patient is in a high-risk coronary thrombotic window when TXA is being considered.

High-Importance Safety Issue: Wrong Drug-Wrong Route Errors

One of the most important contemporary TXA safety topics for anesthesia professionals is inadvertent neuraxial administration. Catastrophic cases have occurred when intravenous TXA was mistaken for local anesthetic and injected intrathecally or epidurally. Consequences include severe seizures, paraplegia, cardiovascular collapse, permanent neurologic injury, and death.

Recent labeling updates have strengthened warnings and explicitly contraindicate neuraxial use of injectable TXA.

CRNA Safety Actions

- Treat injectable TXA as an intravenous medication only.
- Do not place TXA where neuraxial medications are drawn up or handed off interchangeably with local anesthetics.
- Use careful syringe and ampule or vial labeling, barcode scanning when available, and route-focused read-backs.
- Assume this error is possible in any perioperative area and build workflow safeguards accordingly.

CRNA Implications and Practical Decision-Making

- Preoperative planning: Identify procedures with meaningful bleeding risk and know whether TXA is part of the service-line pathway.
- Patient selection: Assess renal function, seizure history, active thrombosis risk, procedure type, and timing-sensitive indications such as trauma or postpartum hemorrhage.
- Intraoperative integration: Use TXA as one part of a broader hemostatic strategy that also includes normothermia, surgical hemostasis, resuscitation, coagulation assessment, and transfusion stewardship.
- Communication: Confirm dose, route, and timing with the operative team, especially during trauma activation, obstetric emergencies, and handoffs from EMS or emergency department teams.
- Postoperative vigilance: Monitor for persistent bleeding, neurologic change, seizure activity in higher-risk patients, and any evidence of medication-route error.

Clinical Pearl: TXA is best thought of as a clot-preserving drug, not a rescue substitute for definitive hemorrhage control. The earlier it is used in the right indication, the more value it usually provides.

- Tranexamic acid is a synthetic lysine analog antifibrinolytic that stabilizes formed clot by inhibiting fibrinolysis.
- Its most important CRNA-relevant uses include trauma, postpartum hemorrhage, orthopedic and spine surgery, cardiac surgery, and other operations with expected substantial blood loss.
- Timing is crucial in trauma and obstetric hemorrhage: early administration matters, and routine delayed administration in trauma beyond 3 hours should be avoided.
- Renal impairment requires dose awareness, and seizure risk increases with high exposure or accumulation.
- The injectable product is for intravenous use only. Inadvertent neuraxial administration is a catastrophic never event.

- TXA supports patient blood management, but it must be integrated with sound anesthetic, surgical, and resuscitative practice.

Case 1: Trauma Activation With Suspected Hemorrhagic Shock

A 27-year-old patient presents after a high-speed motor vehicle collision with tachycardia, hypotension, pelvic instability, and concern for major internal bleeding. The patient arrives within 45 minutes of injury and requires rapid operative and resuscitative planning. Discussion: This case highlights the time-sensitive value of TXA in trauma.

For the CRNA, the key question is not only whether the patient is bleeding, but whether the patient is within the therapeutic window in which antifibrinolysis is most likely to help. Early administration can be incorporated alongside balanced resuscitation, airway management, blood product preparation, and definitive hemorrhage control.

Delayed administration beyond the accepted treatment window should not be treated as routine trauma practice. Clinical Pearl: In trauma, TXA should be thought of as an early adjunct to hemorrhage management, not a rescue drug after prolonged uncontrolled bleeding.

Case 2: Postpartum Hemorrhage During Emergent Cesarean Delivery

A 33-year-old patient undergoing urgent cesarean delivery develops brisk uterine bleeding after placental delivery with ongoing hemodynamic instability despite uterotonics and uterine massage. The anesthesia and obstetric teams are escalating resuscitative measures. Discussion: This scenario illustrates the role of TXA as a standard adjunct in postpartum hemorrhage.

For the CRNA, the decision-making priority is prompt recognition of clinically significant hemorrhage and rapid integration of TXA while other treatments continue. TXA does not replace uterotonics, surgical evaluation, blood component therapy, or source-specific intervention, but it can support hemostatic management when given early in the obstetric emergency.

Clinical Pearl: In postpartum hemorrhage, TXA is most useful when it is administered promptly and integrated into a broader hemorrhage protocol rather than delayed until bleeding becomes refractory.

Case 3: High-Risk Cesarean Delivery With Anticipated Major Blood Loss

A 36-year-old patient with placenta previa and two prior cesarean deliveries presents for scheduled repeat cesarean birth. The obstetric and anesthesia teams anticipate increased hemorrhage risk. The CRNA must decide whether TXA should be available only for treatment of postpartum hemorrhage or incorporated prophylactically according to the institution's obstetric hemorrhage pathway.

Discussion: This case highlights a common cesarean-delivery question: treatment use of TXA is clearly supported when postpartum hemorrhage is diagnosed, but prophylactic use during cesarean delivery remains more protocol dependent.

For the CRNA, the practical priorities are to identify hemorrhage risk preoperatively, confirm whether prophylactic TXA is part of the local cesarean or placenta-accreta-spectrum pathway, coordinate timing with the obstetric team, and ensure that uterotonics, blood availability, and hemorrhage-response planning are already in place.

TXA should be integrated into structured preparation, not treated as a substitute for surgical hemostasis or uterine-directed therapy.

Clinical Pearl: In high-risk cesarean delivery, the most important TXA question is often not whether the drug works, but whether the team has clearly defined when it will be used prophylactically, when it will be used therapeutically, and how medication-route safety will be maintained in an obstetric neuraxial environment.

Case 3: Cardiac Surgery Patient With Renal Dysfunction

A 71-year-old patient presents for complex cardiac surgery with chronic kidney disease and a history of postoperative confusion after a prior procedure. The surgical team wants TXA for blood conservation, but the anesthesia team is concerned about accumulation and postoperative seizure risk. Discussion: This case emphasizes that TXA is not a one-size-fits-all drug.

In cardiac surgery, the benefits for reducing bleeding and transfusion are well recognized, but the CRNA must also account for dose intensity, renal clearance, and the greater seizure signal associated with

Higher exposure. The practical takeaway is to follow cardiac-service protocols carefully, confirm whether renal adjustment is needed, and maintain a lower threshold for postoperative neurologic vigilance in higher-risk patients. Clinical Pearl: When renal dysfunction is present, the safest TXA plan is the one that preserves efficacy while deliberately limiting accumulation.

During setup for spinal anesthesia, a syringe labeled for neuraxial use is discovered to contain tranexamic acid that had been drawn up from an intravenous vial placed next to local anesthetic ampules. The error is identified before injection, and the case is paused for a team safety review. Discussion: This near miss reflects one of the most important TXA safety issues in anesthesia practice.

The CRNA implication is immediate and practical: route separation, clear labeling, medication organization, and deliberate read-back processes are not optional safeguards. Because catastrophic neuraxial misadministration continues to occur in real practice, every perioperative setting should treat TXA storage and preparation as a high-alert medication workflow issue.

Clinical Pearl: a prevented TXA route error is not just a near miss; it is evidence that medication-system design matters as much as pharmacology knowledge.

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Apply practical dosing strategies for intravenous, topical, and oral tranexamic acid while recognizing when renal dose adjustment is required. Recognize adverse effects, contraindications, precautions, and major drug-safety issues, including seizure risk and the danger of neuraxial misadministration.

Integrate tranexamic acid into CRNA-focused blood-management and patient-safety planning using evidence-informed clinical judgment.

Statement 1 2 3 4 5 The information presented on tranexamic acid is accurate and evidence-based. The content reflects current clinical practice and recent evidence regarding tranexamic acid use.

The material is relevant to anesthesia practice and CRNA decision-making. The module adequately addresses practical tranexamic acid considerations such as dosing, adverse effects, timing, and patient selection.

Statement 1 2 3 4 5 The discussion demonstrates critical analysis of tranexamic acid use across different clinical settings. Benefits and risks of tranexamic acid are adequately balanced and discussed. The content encourages

clinical reasoning rather than memorization.

The module helped me apply tranexamic acid principles to complex scenarios such as trauma, postpartum hemorrhage, cardiac surgery, or renal impairment.

Statement 1 2 3 4 5 The material increases my confidence in understanding tranexamic acid. The presentation is useful for graduate-level anesthesia education. I would recommend this content as a learning resource for other students or clinicians. The module improves my confidence in making patient-specific decisions about tranexamic acid administration.

Contrast Media and Surgical Dyes

Why Contrast Media and Operative Dyes Matter in Anesthesia

Contrast agents and operative dyes are increasingly used in perioperative care, not only in radiology suites but also in hybrid ORs, interventional settings, endovascular procedures, robotic and laparoscopic surgery, transplant surgery, urology, and selected neurosurgical or ophthalmic procedures.

For the CRNA, these agents matter because they can alter hemodynamics, trigger acute hypersensitivity or physiologic reactions, complicate kidney risk assessment, and require rapid recognition and coordinated response when adverse events occur.

An important practical distinction is that not all "contrast" in the OR is the same. iodinated contrast media are commonly used for fluoroscopy and angiographic imaging. Gadolinium-based contrast agents are primarily associated with MRI but may appear in selected interventional workflows.

Indocyanine green and fluorescein function as optical or fluorescent imaging agents rather than conventional radiographic contrast media. Methylene blue is technically a dye rather than a radiographic contrast agent, but it is relevant to anesthesia

Because it is used intraoperatively for tissue identification and has distinctive pharmacologic and safety implications.

Iodinated Contrast Media

These are the most common intravascular contrast agents encountered perioperatively. They are used for angiography, venography, CT-based procedures, intraoperative fluoroscopy, and many endovascular or interventional cases. Modern low-osmolality nonionic agents have improved safety compared with older high-osmolality media, but acute reactions and kidney considerations remain clinically important.

Gadolinium–Based Contrast Agents

These are most closely associated with MRI and MR angiography. They are less common in the conventional OR but remain relevant when anesthetizing patients for MRI-guided or peri-MRI workflows and when reviewing recent contrast exposure in patients with advanced kidney disease.

Their major unique safety concern is nephrogenic systemic fibrosis in selected patients with severe renal dysfunction, especially with higher-risk agents.

Indocyanine Green (ICG)

ICG is an optical imaging agent used with near-infrared fluorescence systems to assess tissue perfusion and identify anatomy. In the OR it is increasingly used in robotic, laparoscopic, transplant, reconstructive, gastrointestinal, hepatobiliary, vascular, and gynecologic procedures. It is especially useful for perfusion assessment and biliary visualization.

Fluorescein Fluorescein is a fluorescent dye historically associated with ophthalmic angiography but also relevant to selected neurosurgical, spinal, or tissue-visualization applications. Although many CRNAs encounter it less often than iodinated contrast or ICG, it still deserves familiarity because it can produce nausea, discoloration, and occasional severe reactions.

Methylene blue is used in the OR for tissue marking, leak testing, urologic and gynecologic identification, parathyroid or sentinel-node workflows in selected settings, and treatment of specific pathophysiologic states such as vasoplegia or methemoglobinemia.

Although not a conventional imaging contrast agent, it belongs in perioperative dye education because its adverse-effect profile and drug interactions are anesthesia-relevant.

- Endovascular and vascular procedures: iodinated contrast for angiography, stent placement, embolization, thrombectomy, and vascular roadmap imaging.
- Hybrid OR cases: real-time imaging during transcatheter, aortic, vascular, and cardiac interventions.
- Urology and gynecology: contrast studies, ureteral assessment, sentinel-node mapping, and dye-based leak or structure identification.
- GI, hepatobiliary, and colorectal surgery: ICG for perfusion assessment, biliary anatomy, anastomotic evaluation, and lymphatic mapping in selected workflows.
- Plastic, reconstructive, and transplant surgery: ICG for flap perfusion, tissue viability, and graft perfusion assessment.
- Neurosurgery and ophthalmology: fluorescein or ICG in selected visualization applications, often with microscope or specialized imaging systems.

For the CRNA, the unifying principle is that these agents are usually administered to improve surgical or procedural visualization, but their physiologic and safety implications extend beyond the imaging system itself.

Acute Reactions, Adverse Effects, and Safety Concerns

- Acute reactions are commonly described as allergic-like or physiologic. Mild symptoms can include warmth, flushing, nausea, vomiting, pruritus, or limited urticaria.
- More serious reactions include bronchospasm, laryngeal edema, hypotension, severe urticaria, cardiovascular collapse, and rarely cardiac arrest.
- Extravasation can cause pain and local tissue injury; severe injury is uncommon but requires attention.
- Immediate reactions are less common than with iodinated contrast but still possible.
- The highest-yield CRNA concern is not routine immediate allergy, but rather renal-risk assessment for nephrogenic systemic fibrosis in susceptible patients with severe kidney dysfunction.

Indocyanine Green

- Generally well tolerated, but hypersensitivity reactions can occur.
- Dose limits matter, and repeated intraoperative dosing should remain within product labeling and procedural guidance.

Fluorescein and Methylene Blue

- Fluorescein can cause nausea, vomiting, skin and urine discoloration, and occasional serious hypersensitivity or respiratory reactions.
- Methylene blue can cause hypertension, serotonin toxicity when combined with serotonergic drugs, hemolysis risk in glucose-6-phosphate dehydrogenase deficiency, and local tissue injury if extravasated.

CRNA Safety Pearl: The patient who reacts to contrast may present like an anaphylaxis patient, a bronchospasm patient, or a sudden unexplained hypotension patient. Early recognition matters more than labeling the reaction perfectly in the first seconds.

- Kidney Considerations: Contrast-Associated Acute Kidney Injury and Renal Risk

The terminology around kidney injury has evolved. Many contemporary sources prefer the term contrast-associated acute kidney injury rather than assuming every episode is directly caused by contrast. This matters because perioperative patients often have multiple competing renal insults, including hypotension, sepsis, nephrotoxic medications, blood loss, and underlying chronic kidney disease.

For iodinated contrast, risk is greatest in patients with significantly reduced kidney function, especially those with advanced chronic kidney disease, recent acute kidney injury, or major hemodynamic instability.

Practical risk-reduction strategies include thoughtful patient selection, avoidance of unnecessary repeat contrast exposure, hemodynamic optimization, and adequate hydration when clinically appropriate. The current direction of guideline-based practice is toward targeted rather than indiscriminate screening and prevention.

For gadolinium-based contrast agents, the classic concern is nephrogenic systemic fibrosis rather than the more familiar iodinated-contrast kidney injury discussion. The highest-risk scenario is severe renal dysfunction with certain higher-risk gadolinium agents.

In practice, anesthetizing patients for MRI or peri-MRI workflows still requires awareness of recent kidney function and the type of contrast being used.

Metformin, Premedication, and Other Practical Considerations

Metformin Metformin management around iodinated contrast is no longer handled with a one-size-fits-all rule. The practical concern is not the contrast itself creating metformin toxicity, but the possibility of acute kidney injury leading to metformin accumulation and lactic acidosis in selected patients.

Current guidance generally individualizes management according to renal function, the route of contrast administration, and the likelihood of hemodynamic or renal instability. CRNAs should know their local policy and communicate with the procedural team when significant kidney risk is present.

Premedication for Prior Contrast Reactions

A prior allergic-like reaction to the same class of contrast medium is the most important historical risk factor for recurrence. However, routine premedication for every patient with unrelated allergies is not recommended. Contemporary guidance has become more selective, particularly for patients with only mild prior reactions.

Even when premedication is used, it does not eliminate the possibility of a reaction, so readiness to treat an acute event remains essential.

Fasting and Volume Status

"Iodine Allergy" Clarification: a reported shellfish allergy, povidone-iodine sensitivity, or a generic label of "iodine allergy" does not, by itself, establish a true contrast allergy. The most clinically useful history is whether the patient previously reacted to the same class of contrast agent and what the reaction looked like.

Contrast administration does not usually require an anesthesia-specific fasting deviation by itself, but perioperative dehydration, diuretic use, bowel prep, or poor oral intake can worsen kidney risk and hemodynamic tolerance. In practical CRNA care, volume status matters as much as the contrast order.

CRNA Implications and Practical First Steps

- Before the case: clarify which agent is being used, why it is needed, the expected route, and whether the patient has a history of prior contrast or dye reaction, advanced kidney disease, or high-risk serotonergic medication exposure if methylene blue may be used.
- During administration: maintain vigilance for sudden flushing, bronchospasm, hypotension, tachycardia, unexplained desaturation, or local extravasation.
- If a reaction occurs: stop exposure when possible, call for help, support airway and circulation, treat the physiologic syndrome promptly, and document the reaction clearly for future care.
- After the case: communicate any reaction, extravasation event, renal-risk concern, or medication interaction issue during handoff and postoperative planning.

Clinical Pearl: The most useful CRNA mindset is to treat contrast exposure as part of the anesthetic environment, not as a radiology-side detail. If it is being injected around your patient, it is part of your perioperative risk landscape.

Methylene Blue and Serotonergic Medications

Methylene blue can inhibit monoamine oxidase activity and may precipitate serotonin toxicity when combined with serotonergic medications such as selective serotonin reuptake inhibitors, serotonin-norepinephrine reuptake inhibitors, certain tricyclic antidepressants, monoamine oxidase inhibitors, linezolid-like regimens, and some migraine therapies.

In the perioperative setting, the practical implication is not simply whether a patient takes an antidepressant, but whether methylene blue is being considered and whether the team has screened for meaningful serotonergic exposure.

If methylene blue is used, the anesthesia professional should remain alert for agitation, hyperthermia, clonus, autonomic instability, or unexplained rigidity in the appropriate clinical context.

G6PD Deficiency

Methylene blue may worsen hemolysis and may be ineffective in patients with glucose-6-phosphate dehydrogenase deficiency. For CRNAs, this matters both when methylene blue is used as a surgical dye and when it is considered therapeutically for methemoglobinemia or vasoplegia-related workflows.

A history of G6PD deficiency should prompt extra caution, explicit team communication, and avoidance of assumptions that methylene blue is benign in all patients.

Advanced Chronic Kidney Disease and Recent Acute Kidney Injury

Patients with advanced chronic kidney disease, recent acute kidney injury, or major hemodynamic instability warrant closer assessment before iodinated contrast exposure and careful agent selection when gadolinium is being considered.

The perioperative kidney question should not be reduced to a single laboratory value alone; recent trends, volume status, planned contrast burden, and competing renal insults all matter.

Prior Contrast Reaction, Asthma, and Multiple Allergies

The most clinically important risk factor for recurrent iodinated contrast reaction is a prior reaction to the same class of agent. Asthma and multiple allergy histories may increase concern, but they do not carry the same predictive value as a documented prior contrast event.

This distinction matters because overgeneralizing "iodine allergy" or unrelated allergy history can lead to poor risk labeling rather than focused planning.

Fluoroscopy, Usually IV or flushing after contrast reaction; kidney endovascular intra-arterial injection as a real media risk in susceptible imaging perioperative patients emergency until proven otherwise.

Know recent kidney Nephrogenic Gadolinium-status and do not MRI or selected systemic fibrosis based assume all contrast interventional IV risk in severe contrast agents share the workflows kidney agents same renal risk dysfunction profile. ICG is usually well Perfusion tolerated, but assessment, increasing surgical Rare Indocyanine biliary use means it should

Green visualization, flap be treated as an anaphylaxis or graft possible perfusion perioperative allergen. Selected Nausea, Warn the team that ophthalmic, discoloration, rare visible urine or skin

Neurosurgical, or severe discoloration may tissue-hypersensitivity occur and is not, by

Clinical Response Pearls: Rapid-Response Checklist

- Stop administration when possible: identify the agent, route, and timing of the event immediately.
- Call for help early: adverse reactions can escalate quickly, especially in hybrid OR and endovascular settings.
- Support oxygenation and ventilation: treat bronchospasm, airway edema, or deteriorating respiratory mechanics promptly.
- Treat the physiologic syndrome in front of you: hypotension, tachycardia, severe flushing, or cardiovascular collapse should be addressed without waiting for perfect reaction labeling.
- Assess for extravasation or wrong-route problems: local tissue injury and route errors require immediate recognition and documentation.
- Document clearly: record the exact agent, reaction timing, manifestations, treatment, and clinical course.
- Communicate during handoff: future anesthetic planning depends on accurate transfer of contrast-or dye-related events.

Case 1: Iodinated Contrast Reaction During Endovascular Repair

Discussion: This case highlights the perioperative challenge of distinguishing hemorrhage, anaphylaxis, and contrast reaction in a high-acuity environment. For the CRNA, the practical response is to stop the exposure when possible, support oxygenation and hemodynamics, call for help, and treat the physiologic syndrome immediately rather than waiting for diagnostic

Certainty. The key lesson is that contrast reactions often present like anesthesia emergencies, not like a radiology side issue. Clinical Pearl: In hybrid OR and endovascular cases, unexplained bronchospasm or hypotension immediately after injection should place contrast reaction high on the differential.

Case 2: Methylene Blue in a Patient Taking an SSRI

Discussion: This scenario emphasizes that methylene blue is pharmacologically active and not simply a benign operative dye. The CRNA implication is to screen medication history before use, communicate serotonergic risk clearly, and recognize that postoperative autonomic or neuromuscular changes may reflect serotonin toxicity rather than routine emergence behavior.

Clinical Pearl: Methylene blue should prompt the same level of medication-reconciliation attention as many therapeutic agents used during anesthesia care.

Case 3: ICG Use During Robotic Colorectal Surgery

During robotic colorectal resection, indocyanine green is administered to assess bowel perfusion. Within minutes, the patient develops generalized erythema, increasing airway pressures, and hypotension. Discussion: Because ICG is often perceived as low risk, teams may not immediately identify it as the trigger. This case teaches that rare does not mean irrelevant.

With growing intraoperative use of ICG, CRNAs should consider it among possible perioperative allergens and respond with the same urgency applied to other suspected intraoperative hypersensitivity reactions. Clinical Pearl: Increasing use of fluorescence-guided surgery means ICG belongs in the anesthesia mental checklist of possible intraoperative reaction triggers.

- Not all perioperative contrast agents and dyes behave the same; each has distinct uses, risks, and perioperative implications.
- Acute reactions may mimic anaphylaxis, bronchospasm, hemodynamic instability, or other anesthesia emergencies and require immediate action.
- Kidney risk should be individualized using current renal status, hemodynamics, contrast burden, and the specific agent involved.
- Methylene blue deserves special caution because of meaningful serotonergic interactions and concern in G6PD deficiency.
- ICG is increasingly common in the OR and should be recognized as a possible, though uncommon, perioperative allergen.
- CRNA vigilance, preparation, and clear communication are essential whenever contrast media or operative dyes are part of the anesthetic environment.

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The OR: Evaluation

Recognize acute hypersensitivity, physiologic reactions, extravasation concerns, and organ-specific toxicities associated with contrast administration. Apply current guidance on contrast-associated acute kidney injury risk reduction, metformin management, and perioperative screening.

Integrate CRNA-focused preparation, monitoring, communication, and emergency response principles when contrast or operative dyes are used in or around the OR.

Statement 1 2 3 4 5 The information presented on IV contrast media and surgical fluorescent dyes is accurate and evidence-based. The content reflects current clinical practice and recent advances in contrast media and fluorescence-guided imaging in the OR. The material is relevant to anesthesia and CRNA practice.

The module adequately addresses practical contrast and dye considerations such as renal risk, acute reactions, medication interactions, and patient-specific assessment.

Statement 1 2 3 4 5 The discussion demonstrates critical analysis of contrast media and operative dye use in perioperative care. Benefits and risks of contrast agents and surgical dyes are adequately balanced and discussed. The content encourages clinical reasoning rather than memorization.

The module helped me apply contrast and dye safety principles to complex scenarios such as renal impairment, prior reactions, serotonergic drug exposure, or hybrid OR procedures.

Statement 1 2 3 4 5 The material increases my confidence in understanding IV contrast media and surgical fluorescent dyes used in the OR. The presentation is useful for graduate-level anesthesia education. I would recommend this content as a learning resource for other students or clinicians.

The module improves my confidence in making patient-specific decisions about contrast or operative dye use during perioperative care.

GLP-1 Receptor Agonists

GLP-1 Receptor Agonists: Current Guidelines and Anesthesia

Implications This module provides a practical, evidence-informed overview of (Glucagon-like peptide 1)GLP1 receptor agonists and pramlintide in the perioperative setting, with emphasis on current guidance, delayed gastric emptying, and aspiration-risk implications for anesthesia care.

It reviews which patients are at higher risk, outlines key considerations for preoperative evaluation and intraoperative planning, and highlights postoperative management issues such as nausea, hydration, glycemic control, and medication resumption.

The content is designed to help CRNAs apply individualized, risk-based decision-making for elective and urgent procedures in patients receiving these therapies.

Why GLP-1 Receptor Agonists Matter in Anesthesia

GLP-1 receptor agonists are now common in patients presenting for surgery and procedural sedation. These medications are prescribed for type 2 diabetes, obesity, and in some cases cardiovascular risk reduction. Common agents include semaglutide, liraglutide, dulaglutide, tirzepatide, and similar incretin-based therapies.

- Semaglutide (Ozempic, Wegovy, Rybelsus)
- Liraglutide (Victoza, Saxenda)
- Dulaglutide (Trulicity)
- Exenatide (Byetta, Bydureon)
- Lixisenatide (Adlyxin)
- Tirzepatide (Mounjaro, Zepbound) Daily vs. weekly formulations: Some GLP-1 receptor agonists are taken daily (for example, liraglutide, lixisenatide, and oral semaglutide), while others are taken weekly (for example, injectable semaglutide, dulaglutide, and tirzepatide). This distinction matters because recent.

Guidance and perioperative planning often reference whether the patient is using a daily or weekly formulation.

From an anesthesia perspective, the major concern is delayed gastric emptying. Although this effect often diminishes with long-term therapy, some patients continue to have nausea, vomiting, bloating, early satiety, or retained gastric contents despite guideline-based fasting. This raises concern for regurgitation and pulmonary aspiration during general anesthesia and deep sedation.

Pramlintide and Gastric Emptying

Pramlintide is an amylin analog used as an adjunct to mealtime insulin in selected patients with diabetes. Like GLP-1 receptor agonists, it can slow gastric emptying, reduce postprandial glucagon release, and increase satiety.

Although it is prescribed far less commonly than GLP-1 receptor agonists, it remains relevant to anesthesia because delayed gastric emptying may increase the risk of retained gastric contents despite routine fasting.

For the CRNA, the practical implication are similar to other medications that impair gastric motility: ask specifically about pramlintide during medication reconciliation, especially in insulin-treated patients with diabetes who report nausea, bloating, early satiety, or symptoms of gastroparesis.

When concern for delayed gastric emptying is high, use individualized aspiration-risk planning rather than relying only on standard fasting intervals. Key point: GLP-1 receptor agonists remain the most common perioperative concern, but pramlintide is another diabetic medication that may meaningfully slow gastric emptying and should not be overlooked during preoperative assessment.

Current Guidance: What Changed

Earlier guidance advised holding daily GLP-1 receptor agonists on the day of surgery and weekly formulations for 1 week before elective procedures. More recent multi-society guidance favors individualized risk assessment rather than routine discontinuation for every patient. For most patients at low risk for delayed gastric emptying, continuation before elective surgery is considered appropriate.

Current practice emphasizes identification of patients at highest risk for delayed gastric emptying and use of targeted risk-reduction measures, such as a liquid-only diet for 24 hours, modification of the anesthetic plan, and point-of-care gastric ultrasound when available and interpreted by trained clinicians.

In selected cases, elective procedures may need to be postponed until the anticipated risk has improved.

Which Patients Are Higher Risk?

Patients are more likely to have delayed gastric emptying or increased residual gastric contents when one or more of the following are present:

- Early treatment or dose-escalation phase
- Higher medication doses
- Active gastrointestinal symptoms such as nausea, vomiting, abdominal pain, bloating, constipation, reflux, or early satiety.
- Comorbid conditions that may impair gastric motility, including diabetic autonomic dysfunction, known gastroparesis, Parkinson disease, or prior significant gastric emptying problems.
- Procedures requiring general anesthesia or deep sedation, where aspiration risk is greatest.

From a practical gastric ultrasound standpoint, an estimated residual gastric volume of less than 1.5 mL/kg of clear fluid is often considered more consistent with lower aspiration risk, whereas volumes greater than 1.5 mL/kg or the presence of thick fluid or solid contents should prompt greater caution.

This threshold is best viewed as a risk-stratification tool rather than a guarantee of safety, and ultrasound findings should always be interpreted in the context of the patient's symptoms, comorbidities, medication timing, and planned anesthetic depth.

Anesthesia Implications for CRNAs

- Aspiration risk: The key issue is whether the patient may still have significant gastric contents despite fasting.
- Airway planning: Patients with concerning symptoms or high-risk features may require a "full stomach" approach.
- Case selection: Minimal or moderate sedation may not eliminate aspiration risk if airway reflexes are blunted or conversion to deeper anesthesia becomes necessary.

- Glycemic considerations: Holding therapy in diabetic patients may worsen glycemic control, complicate scheduling, or require bridging strategies coordinated with the prescribing team.
- Bias avoidance: Medication interruption should not be based solely on whether a patient is using the drug for obesity versus diabetes.

Additional Anesthesia Implications of GLP–1 Receptor Agonists

Beyond delayed gastric emptying and aspiration risk, GLP-1 receptor agonists have several additional perioperative implications that are relevant to CRNA assessment, anesthetic planning, and postoperative management. These considerations do not affect every patient equally, but they may alter perioperative risk stratification and should be integrated into a comprehensive anesthesia evaluation.

- Postoperative nausea and vomiting (PONV): Because GLP-1 receptor agonists commonly cause nausea, bloating, and early satiety, some patients may enter the.

Perioperative period with an elevated baseline risk for PONV and delayed tolerance of oral intake.

- Volume status and hemodynamic response: Reduced oral intake, intermittent vomiting, and progressive weight loss may contribute to relative hypovolemia in selected patients, which may increase susceptibility to peri-induction or post-induction hypotension.
- Perioperative glycemic management: When therapy is withheld or delayed, patients with diabetes may require closer glucose surveillance and temporary adjustment of other antihyperglycemic agents. Coordination with the prescribing clinician may be warranted in patients with more complex diabetes regimens.
- Sedation-related risk: GLP-1 receptor agonist use remains relevant in monitored anesthesia care and deep sedation because aspiration risk is not limited to general anesthesia. This is particularly important when airway reflexes may be blunted or when procedural sedation may unexpectedly deepen.
- Associated comorbidity burden: Many patients treated with GLP-1 receptor agonists also have obesity, obstructive sleep apnea, gastroesophageal reflux disease, hypertension, or other cardiometabolic comorbidities that independently influence anesthetic management and airway planning.
- Postoperative recovery and medication resumption: Appetite suppression, nausea, or delayed return of normal gastrointestinal function may affect readiness for diet advancement, discharge planning, and the timing of medication resumption after surgery. Electrolyte and acid-base considerations: GLP-1 receptor agonists are not typically associated with a primary electrolyte disturbance; however, clinically significant nausea, vomiting, dehydration, and poor oral intake may secondarily contribute to hypovolemia, hypokalemia, hyponatremia, hypomagnesemia, acute kidney injury, and hypochloremic metabolic alkalosis in selected patients. For continuing education purposes, the key clinical point is that GLP-1 receptor agonists should be viewed not only as potential contributors to aspiration risk, but also as medications that may influence perioperative symptoms, hemodynamics, glycemic management, and recovery pathways.

Key elements of the preoperative assessment include the following:

- Which medication that may affect gastric emptying is the patient taking (GLP-1 receptor agonist or pramlintide), and when was the most recent dose administered?
- What is the dose, and has the dose recently been increased?
- Why is the patient taking it (diabetes, obesity, cardiometabolic indication)?
- Does the patient have active GI symptoms?
- Are there other risk factors for poor gastric emptying? Has the patient had significant nausea, vomiting, poor oral intake, or dehydration that would warrant review of recent laboratory data (electrolytes, glucose, renal function) and closer assessment of volume status?

When gastrointestinal symptoms or reduced oral intake have been substantial, the preoperative evaluation should include attention to hydration status, recent basic or comprehensive metabolic panel results when available, and evidence of acute kidney injury or acid-base disturbance.

This is particularly relevant in patients with persistent vomiting, frailty, advanced age, or coexisting diuretic use. Suggested approach for elective procedures:

- Low-risk patient: Continue the GLP-1 receptor agonist or pramlintide and follow standard fasting instructions.
- Higher-risk patient: Consider a liquid-only diet for 24 hours preoperatively, gastric ultrasound when available, and case-by-case discussion with the proceduralist, surgeon, and prescribing clinician.
- Symptomatic or clearly unsafe patient: Postpone the elective procedure when feasible until symptoms improve or the highest-risk phase has passed. If a patient was instructed under older protocols to hold a daily dose on the day of surgery or a weekly dose for 1 week, that history should still be documented, but current decision-making should prioritize real-time risk assessment over a single hold interval alone. Clinical Pearl for CRNAs: Patients at highest perioperative risk are those in the dose-escalation phase, those with active gastrointestinal symptoms, those with suspected dysmotility or gastroparesis, and those with clinically significant poor intake, dehydration, or recent laboratory abnormalities. In these patients, preoperative planning should extend beyond fasting times alone and include aspiration-risk mitigation, hydration assessment, and review of recent laboratory data when available.

Intraoperative Considerations

- If aspiration risk is low: Proceed with the planned anesthetic and routine airway management.
- If aspiration risk is uncertain: Gastric ultrasound may help determine whether the stomach appears empty, contains clear liquid, or contains thick liquid/solid material.
- If aspiration risk is elevated: Consider rapid-sequence induction, tracheal intubation, minimizing bag-mask insufflation when appropriate, and avoiding deep sedation without a protected airway.
- If urgent or emergent surgery is required: Treat the patient as potentially having a full stomach when significant concern remains. The anesthetic plan should match the patient's symptoms, timing of therapy initiation or dose increase, procedure type, and the team's ability to mitigate aspiration risk.

Postoperative Considerations

- Resume therapy according to the surgical course, return of oral intake, and the prescribing clinician's plan.
- Be alert for postoperative nausea and vomiting, ileus-like symptoms, dehydration, or poor oral tolerance.
- In patients with diabetes, coordinate glucose monitoring and medication adjustments if therapy was interrupted. Clear discharge instructions are important when the perioperative plan required temporary medication changes.

Practical CRNA Algorithm

Step 4: In higher-risk elective cases, consider a 24-hour liquid diet, gastric ultrasound when available, and aspiration-risk mitigation strategies. Step 5: If symptoms are significant or gastric contents remain concerning, postpone the elective procedure when clinically feasible.

Step 6: For urgent or emergent procedures, assume increased aspiration risk when uncertainty remains and protect the airway accordingly.

- Most patients may continue GLP-1 receptor agonist therapy before elective surgery, but universal continuation is not appropriate for every patient.
- Risk is greatest in patients with recent initiation, dose escalation, higher doses, or active gastrointestinal symptoms.
- Standard fasting intervals may not reliably exclude residual gastric contents in selected patients receiving GLP-1 receptor agonists.
- CRNAs should individualize management using symptom assessment, medication timing, procedure-specific risk, aspiration-mitigation strategies, and gastric ultrasound when available.

- Clear communication among the anesthesia professional, procedural team, patient, and prescribing clinician is essential when considering delay or perioperative medication adjustment.
- 2026 Practice Update

As of 2026, no single new standard has fully replaced the 2024 multi-society guidance. Instead, perioperative management has evolved toward a more individualized, risk-based approach.

The 2024 multi-society position remains influential: most low-risk patients may continue GLP-1 receptor agonist therapy before elective surgery, whereas higher-risk patients may require a 24-hour liquid diet, modification of the anesthetic plan, gastric ultrasound, or postponement of the procedure when risk is expected to improve.

At the same time, later statements-particularly the 2025 SPAQI multidisciplinary consensus-have adopted a more cautious stance. These recommendations emphasize that delayed gastric emptying may occur even in asymptomatic patients and discuss adjustments to fasting for solids and liquids in addition to medication management.

A 2026 overview of international guidance further underscores variability across regions, particularly with respect to how long therapy should be withheld, whether fasting should be extended routinely, and which patients warrant postponement.

For CRNAs, the practical implication in 2026 is to continue careful screening for recent initiation, dose escalation, weekly formulations, active gastrointestinal symptoms, and comorbid dysmotility

- To consider a 24-hour liquid diet for higher-risk patients.
- To use point-ofcare gastric ultrasound when available.
- And to apply full-stomach precautions when clinically significant uncertainty remains. Contemporary practice is therefore less dependent on a universal medication-hold interval and more focused on individualized aspiration-risk mitigation.

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Cannabis and Anesthesia Implications

Why Cannabis Matters in Anesthesia

Cannabis use is increasingly relevant to anesthesia practice because more patients now present for surgery using cannabis medically, recreationally, or both. Over the past decade, legalization and medical approval have expanded substantially across the United States, and this changing legal landscape has increased both access and social acceptance.

As of mid-2025, medical cannabis is authorized in 40 states plus the District of Columbia and several U. S. territories, and recreational adult use is legal in 24 states plus the District of Columbia. As legalization has expanded, anesthesia professionals have encountered more patients who use cannabis for chronic pain, anxiety, sleep, nausea, recreation, and other reasons.

For CRNAs, the practical implication is simple: cannabis is no longer an uncommon or niche exposure. It is now part of routine perioperative assessment. Patients may use smoked cannabis, vaporized products, concentrates, edibles, tinctures, capsules, or prescription cannabinoid-derived products. Frequency of use varies widely, from occasional recreational use to heavy daily consumption.

Because cannabis can affect cardiovascular physiology, airway reactivity, anesthetic requirements, pain control, cognition, and postoperative recovery, it deserves the same deliberate preoperative attention as alcohol, opioids, nicotine, and other sedating or psychoactive substances.

Key cannabinoids

The two most clinically important plant-derived cannabinoids are tetrahydrocannabinol (THC) and cannabidiol (CBD). THC is the principal psychoactive compound and is primarily responsible for intoxication, altered perception, impaired cognition, tachycardia, and many of the acute behavioral effects associated with cannabis.

CBD is not intoxicating in the same way as THC and is often perceived as therapeutically benign, but it still has pharmacologic activity and potential drug interaction relevance.

Cannabinoids interact with the endocannabinoid system, especially CB1 and CB2 receptors. CB1 receptors are concentrated in the central nervous system and influence memory, mood, pain processing, appetite, and autonomic tone. CB2 receptors are more associated with immune and inflammatory pathways.

The perioperative significance is that cannabis may influence neurologic state, cardiovascular responses, pain experience, and interactions with anesthetic drugs.

Routes of administration

- Inhaled (smoked or vaporized): rapid onset, variable peak effect, and airway irritation or hyperreactivity relevance.
- Oral (edibles, capsules, beverages): slower onset, longer duration, and more unpredictable absorption.
- Sublingual or tincture products: intermediate onset and frequent use in medical cannabis populations.
- Concentrates and high-potency products: may deliver very high THC exposure and raise concern for stronger physiologic effects, intoxication, and withdrawal risk.

Because route, dose, potency, and ratio of THC to CBD vary so widely, perioperative responses are often unpredictable. This is one reason detailed screening is more useful than simply asking whether the patient "uses marijuana."

Cardiovascular considerations

Acute cannabis exposure may produce tachycardia, hypertension, anxiety, and variable hemodynamic responses. Some patients may later develop hypotension, especially when sedatives or anesthetic agents are added. In patients with significant cardiovascular disease, recent cannabis use may increase concern for ischemia, dysrhythmia, or hemodynamic instability during induction and emergence.

Airway and respiratory considerations Inhaled cannabis can irritate the airway and may be associated with chronic cough, wheeze, sputum production, and airway hyperreactivity.

This matters during anesthesia because airway stimulation, instrumentation, and deep sedation may be less well tolerated in some regular smokers or vapers. bronchospasm and increased secretions are reasonable concerns in susceptible patients.

Anesthetic and sedative requirements Emerging evidence suggests that regular cannabis users may require higher or less predictable doses of some anesthetic or sedative agents, including propofol and possibly volatile anesthetics. The evidence is not yet strong enough to support a universal dosing rule, but it is strong enough to justify expectation of variability.

Acute intoxication, however, may increase risk of oversedation, altered responsiveness, and impaired ability to provide informed consent.

Pain and postoperative recovery Contrary to what many patients believe, regular cannabis use is not clearly associated with better postoperative pain control. Several reviews and observational studies suggest that chronic users may report higher postoperative pain scores and may require greater opioid exposure after surgery.

Cannabis use may also be associated with more postoperative nausea, agitation, or delayed recovery in selected patients. Abrupt cessation in heavy users can lead to withdrawal symptoms such as irritability, anxiety, sleep disturbance, nausea, and restlessness, usually beginning within 1 to 2 days after cessation and potentially lasting up to 2 weeks.

Current perioperative guidance emphasizes universal preoperative screening for cannabis use rather than selective questioning based on appearance, age, or assumptions.

The ASRA Pain Medicine consensus recommendations advise that all patients be asked specifically about cannabis use, including whether use is medical or recreational, the product type, route, frequency, typical amount, time of last use, and any prior adverse effects. Routine toxicology testing is not recommended for all patients, but evaluation for acute intoxication is important.

The preoperative interview should clarify:

- What product the patient uses and whether it is THC-dominant, CBD-dominant, or mixed.
- How it is taken (smoked, vaped, edible, tincture, capsule, concentrate)
- How often it is used and whether use is occasional, daily, or multiple times per day.
- When the last exposure occurred
- Whether the patient has symptoms of intoxication, withdrawal, cannabis hyperemesis, chest pain, palpitations, or impaired cognition.
- Whether cannabis is being used alongside alcohol, opioids, benzodiazepines, stimulants, or other sedating or psychoactive substances.

Guideline-level themes are consistent on one key point: acute intoxication is the most important immediate perioperative concern. a patient who is intoxicated may have impaired decision-making capacity, unpredictable hemodynamic responses, and greater risk of agitation or difficult recovery.

Elective procedures should be postponed when the patient is clinically intoxicated or unable to participate appropriately in informed consent and perioperative planning.

When Should Cannabis Be Stopped Before Surgery?

This is one of the most common clinical questions, and the answer requires nuance. Current guidance does not support a single universal long-term hold interval for all cannabis users in the same way that older medication protocols sometimes used a fixed preoperative stop date.

Instead, current recommendations focus on avoiding surgery during acute intoxication and allowing time for resolution of immediate physiologic effects.

The ASRA Pain Medicine recommendations support postponing elective surgery in patients with altered mental status or impaired decision-making related to cannabis use.

For smoked cannabis, several summaries of the guidance advise delaying elective surgery for at least 2 hours after use because acute smoking increases heart rate, blood pressure, and airway irritation during the period when anesthesia risk may be highest. That 2-hour threshold should be understood as a minimum immediate safety interval rather than proof that recent use is otherwise risk-free.

Quick Clinical Checklist for CRNAs

- Ask specifically about product type, route, frequency, and last use.
- Do not proceed electively if the patient appears intoxicated or cannot participate meaningfully in consent.
- Avoid same-day smoked cannabis before elective surgery; use extra caution if smoking occurred recently.
- Anticipate airway irritation, variable hemodynamics, and potentially altered anesthetic requirements.
- Use multimodal analgesia and monitor for withdrawal, agitation, or delayed recovery in heavy users.

Use the following practical algorithm when counseling patients and determining whether to proceed:

- Step 1: Is the case elective or urgent/emergent? If the procedure is urgent or emergent, do not delay solely because of recent cannabis exposure; instead, treat the patient according to current physiologic risk. If the case is elective, continue to Step 2.
- Step 2: Is the patient acutely intoxicated? Look for impaired judgment, confusion, slowed responses, agitation, tachycardia, hypertension, anxiety, or inability to participate meaningfully in consent. If yes, postpone elective surgery until the patient is clinically sober. If no, continue to Step 3.
- Step 3: What was used, how was it taken, and when was it last used? Clarify whether the product was smoked, vaped, eaten, taken sublingually, or used as a high-potency concentrate, and document the time of last exposure. Smoked cannabis on the same day of surgery deserves particular caution because of short-term cardiovascular stimulation and airway irritation.
- Step 5: Is the patient a heavy or daily user? If yes, anticipate possible tolerance, altered anesthetic requirements, airway irritation if inhaled products are used, and potential withdrawal if abrupt cessation has occurred. For elective procedures, counsel the patient to avoid cannabis on the day of surgery and preferably longer when feasible, but do not assume a universal multi-day hold is evidence-based for every patient.
- Step 6: Is cannabis being used medically? If yes, determine the indication, product type, and whether abrupt cessation may worsen symptoms such as pain, nausea, anxiety, or sleep disturbance. Individualize the plan rather than applying a punitive stop rule.
- Step 7: Final disposition Proceed with elective surgery if the patient is not intoxicated, is able to participate in care decisions, and has avoided immediate preoperative smoked cannabis exposure. Postpone if intoxication, impaired consent capacity, persistent tachycardia or hypertension, significant airway concerns, or unresolved uncertainty makes proceeding unsafe.

Simple counseling language for patients: "Do not use cannabis on the day of surgery. If you smoked it recently, tell us exactly when. If you feel high, intoxicated, or not yourself, your surgery may need to be delayed for safety."

For regular or heavy users, many clinicians advise longer abstinence when feasible-often at least the day of surgery and preferably longer for smoked or intoxicating THC-containing products-because recent use may still affect cognition, hemodynamics, airway reactivity, and anesthetic requirements even when the patient is no longer obviously intoxicated.

However, current evidence is not strong enough to mandate a universal several-day or several-week cessation period for every patient.

Practical CRNA approach

- Never proceed electively with acute intoxication. Postpone until the patient is clinically sober and able to participate in care decisions.
- Avoid same-morning smoked cannabis before elective surgery. a minimum 2-hour delay after smoking is guideline-consistent, but longer avoidance is safer when possible.
- Counsel patients to avoid cannabis on the day of surgery whenever feasible, especially THC-dominant products.
- In heavy daily users, do not assume abrupt preoperative cessation is always benign. Withdrawal, anxiety, irritability, sleep disturbance, and nausea may complicate care if a patient stops suddenly.
- Medical cannabis users should be counseled individually. The goal is not reflexive punishment for use, but safer timing, honest disclosure, and individualized anesthetic planning. In short, current best practice is to stop intoxicating cannabis use before surgery long enough to avoid acute physiologic effects and intoxication, with at least a same-day avoidance strategy and a strict no-intoxication rule for elective procedures. Longer cessation may be prudent in heavy users, but the evidence base remains insufficient for a universal long abstinence mandate.

Intraoperative and postoperative Management Considerations

- Airway planning: Be prepared for airway irritation or hyperreactivity in chronic smokers or vapers, especially during induction and airway instrumentation.
- Hemodynamic vigilance: Monitor carefully for tachycardia, hypertension, or unexpected hypotension depending on timing of use and other anesthetic agents.
- Dose flexibility: Expect that some chronic users may have altered anesthetic or sedative requirements, but titrate to physiologic effect rather than relying on assumptions.
- Pain planning: Use multimodal analgesia and do not assume cannabis users will have lower postoperative analgesic needs. Some patients may need more analgesic support, not less.
- Recovery monitoring: Watch for agitation, dysphoria, delayed emergence, nausea, or withdrawal symptoms in chronic users who have abruptly stopped.

Patients using cannabis chronically may benefit from clear postoperative counseling, including realistic pain expectations and avoidance of combining cannabis with prescribed opioids, sedatives, or alcohol during the immediate recovery period unless specifically addressed by the treating team.

Cannabis Hyperemesis Syndrome (CHS)

Cannabis hyperemesis syndrome is a paradoxical condition seen mainly in chronic heavy cannabis users and is characterized by recurrent nausea, vomiting, abdominal discomfort, dehydration, and electrolyte abnormalities.

It is especially relevant in the perioperative setting because it may increase aspiration risk, complicate fluid status, and be mistaken for routine postoperative nausea and vomiting or other surgical causes. CRNAs should

ask about cyclic vomiting patterns, heavy long-term use, and any history of symptom relief with hot showers or bathing.

Management is primarily supportive and includes hydration, electrolyte correction, aspiration risk awareness, and consideration of alternative antiemetic strategies when standard postoperative nausea and vomiting medications are ineffective.

Decision-Making Capacity and Informed Consent During Intoxication

Acute cannabis intoxication may impair attention, short-term memory, judgment, and the ability to understand information, appreciate consequences, reason about options, or clearly communicate a choice. For that reason, intoxicated patients may not have adequate decision-

Making capacity to provide valid informed consent for elective anesthesia and surgery. If a patient appears clinically intoxicated, confused, overly sedated, highly anxious, or unable to participate meaningfully in discussion, elective procedures should be postponed until the patient is clinically sober and able to engage appropriately in consent and perioperative planning.

In urgent or emergent situations, care may still need to proceed based on clinical necessity, but the team should clearly document the concern for impaired capacity, the rationale for proceeding, and any available surrogate or emergency consent pathway used.

Patient Education: Combining Cannabis With Anesthesia, Opioids, and Other postoperative Medications

Patients should be taught that cannabis can interact with anesthesia medications and may also intensify the sedating effects of prescribed opioids, benzodiazepines, sleep aids, muscle relaxants, and alcohol during recovery.

Postoperative counseling should emphasize honest disclosure of cannabis use, including product type, route, and timing of last use, so the anesthesia and surgical team can provide safer care.

Patients should be advised not to combine cannabis with opioid pain medicine or other sedating medications unless specifically discussed with their treating team, because the combination may increase drowsiness, dizziness, impaired judgment, falls, slowed breathing, and difficulty recognizing complications.

Education should also include realistic expectations that regular cannabis users may still experience significant postoperative pain or nausea despite believing cannabis will help, and that they should contact the care team if pain control is poor, nausea and vomiting are persistent, or they develop concerning symptoms such as chest pain, severe sedation, confusion, or shortness of breath.

- Cannabis use is increasingly common in perioperative patients because of expanding medical approval and legalization.
- THC-containing products can affect cognition, hemodynamics, airway reactivity, anesthetic requirements, and postoperative pain experience.
- All patients should be screened specifically for cannabis use during preoperative evaluation.
- Elective surgery should be postponed in patients who are acutely intoxicated or unable to participate appropriately in informed consent and perioperative planning.
- Current guidance supports avoiding smoked cannabis immediately before surgery, with at least a 2-hour delay after smoking and preferably no cannabis use on the day of elective surgery.
- Cannabis hyperemesis syndrome should be recognized in chronic heavy users because it may increase dehydration, electrolyte abnormalities, aspiration risk, and diagnostic confusion with routine postoperative nausea and vomiting.
- Acute cannabis intoxication may impair decision-making capacity and informed consent, so elective procedures should be delayed until the patient is clinically sober and able to participate appropriately in care

decisions.

- Patients should be educated not to combine cannabis with prescribed opioids, benzodiazepines, sleep aids, muscle relaxants, or alcohol during recovery unless specifically discussed with the treating team.
- CRNAs should individualize care using honest screening, airway and cardiovascular assessment, flexible anesthetic titration, and multimodal pain planning.

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Reversal, Rescue, and Emergency Medications

Reversal, Rescue, and Emergency Medications for the CRNA

This module is designed for nurse anesthesia learners and practicing CRNAs who need a practical review of reversal, rescue, and emergency medications used during anesthetic care. These drugs are often administered under time pressure and have direct implications for airway protection, cardiovascular stability, neurologic recovery, and perioperative survival.

CRNAs must understand not only what these drugs are used for, but also when they should be given, how they work, how they are dosed, what complications they address, and what adverse effects they may cause.

Dantrolene for Malignant Hyperthermia

Dantrolene is the definitive treatment for malignant hyperthermia (MH). It works by inhibiting abnormal calcium release from the sarcoplasmic reticulum through the ryanodine receptor in skeletal muscle, thereby reducing the hypermetabolic crisis. Current practice commonly uses an initial IV dose of 2-2.5 mg/kg, repeated rapidly until signs

Improve, with many sources citing a cumulative dose up to 10 mg/kg or more if clinically required. dantrolene should be administered immediately when MH is suspected while simultaneously discontinuing triggering agents, hyperventilating with 100% oxygen, treating acidosis, managing hyperkalemia, initiating active cooling if indicated, and monitoring for recrudescence.

Anesthesia implications: every location delivering triggering anesthetics should have immediate access to dantrolene and a practiced MH response plan. Recrudescence may occur, so ongoing ICU-level observation and additional dantrolene may be needed after the initial crisis is controlled.

Intravenous Lipid Emulsion for Local Anesthetic Systemic Toxicity

Intravenous lipid emulsion (ILE; 20% intralipid) is a key rescue therapy for local anesthetic systemic toxicity (LAST). It is thought to work through a combination of lipid partitioning ("lipid sink"), improved fatty acid delivery to the myocardium, and direct beneficial cardiovascular effects.

A common adult dosing strategy is 1.5 mL/kg IV bolus over about 1 minute, followed by an infusion of 0.25 mL/kg/min. If cardiovascular collapse persists, the bolus may be repeated and the infusion increased to 0.5 mL/kg/min, with many references recommending an approximate upper limit of 10 mL/kg over the first 30 minutes.

Anesthesia implications: LAST management also requires airway support, seizure suppression, avoidance of large vasopressin doses, and modified resuscitation principles. Because fascial plane blocks, peripheral nerve blocks, and tumescent local anesthetic techniques remain common, CRNAs should know where lipid emulsion is stored and how to initiate it without delay.

Epinephrine is the first-line medication for anaphylaxis because it treats vasodilation, capillary leak, bronchospasm, and mucosal edema through alpha-and beta-adrenergic effects. In anesthetized patients with IV access, a common OR approach is to give 10-20 mcg IV boluses for moderate hypotension, escalating to 50-100 mcg IV in more severe reactions.

Refractory cases may require an epinephrine infusion. Outside closely monitored settings, intramuscular dosing remains standard.

Sodium Bicarbonate

Sodium bicarbonate is not a general-purpose resuscitation drug, but it remains important in selected anesthesia emergencies. It is commonly used for severe hyperkalemia with ECG changes, tricyclic antidepressant or sodium-channel blocker toxicity, and occasionally severe metabolic acidosis when clinically justified.

A common adult emergency dose is 1-2 mEq/kg IV or a practical bolus of 50 mEq IV, repeated based on blood gas analysis, ECG response, and clinical context. In sodium-channel blocker toxicity, repeated boluses and infusion strategies may be used to narrow the QRS and achieve mild alkalinization.

Anesthesia implications: bicarbonate can increase sodium load, shift the oxyhemoglobin curve, and worsen intracellular acidosis if ventilation is inadequate. It should therefore be used thoughtfully and with appropriate monitoring rather than reflexively during every resuscitation.

Calcium Gluconate vs Calcium Chloride

Calcium 1-3 g IV, commonly over 5-Less tissue injury if extravasated; often gluconate 10 minutes depending on preferred for peripheral administration 10% indication

Contains about 3 times more elemental Calcium 1 g IV, generally via central calcium than calcium gluconate and is chloride 10% line when possible more irritating to veins

Both formulations are used to stabilize the cardiac membrane in hyperkalemia with ECG changes, to treat significant hypocalcemia, and in selected toxicologic emergencies such as calcium channel blocker overdose.

The major practical difference is that calcium chloride provides more immediately available elemental calcium but carries a greater risk of tissue necrosis if extravasated, making it better suited for central access or critical emergencies. Calcium gluconate is less caustic and often preferred for peripheral administration.

Anesthesia implications: choose the formulation based on urgency, access, and tissue safety; do not mix calcium with bicarbonate in the same line because precipitation may occur.

Cyanide Antidotes

Cyanide toxicity should be considered in smoke inhalation, industrial exposure, and prolonged/high-dose sodium nitroprusside administration. The preferred antidote in many modern protocols is hydroxocobalamin, which binds cyanide to form cyanocobalamin. The common adult dose is 5 g IV over 15 minutes, with a second 5 g dose if needed.

An alternative kit includes sodium nitrite followed by sodium thiosulfate; a typical adult dose is 10 mL sodium nitrite IV followed immediately by 50 mL sodium thiosulfate IV.

Anesthesia implications: hydroxocobalamin is generally favored in smoke inhalation because nitrites may worsen oxygen delivery through methemoglobinemia. CRNAs should suspect cyanide when severe lactic acidosis, hypotension, and neurologic collapse occur despite apparently adequate oxygenation, especially during nitroprusside exposure.

Neuromuscular Reversal: Sugammadex and Neostigmine

2 mg/kg for moderate block; 4 Rapid encapsulation of mg/kg for deep block; 16 rocuronium or vecuronium; Sugammadex mg/kg for immediate reversal particularly useful when residual after high-dose rocuronium weakness would be dangerous

Requires some spontaneous Neostigmine Neostigmine 0.03-0.07 mg/kg recovery; muscarinic effects with IV with glycopyrrolate 0.01-require anticholinergic glycopyrrolate 0.02 mg/kg IV coadministration

Current anesthesia practice increasingly emphasizes quantitative neuromuscular monitoring and reversal tailored to the depth of blockade. Sugammadex is generally preferred for aminosteroid neuromuscular blockers when rapid, predictable reversal is needed, whereas neostigmine remains a reasonable option from minimal blockade when adequate spontaneous recovery is present.

Anesthesia implications: residual neuromuscular blockade is a preventable cause of postoperative respiratory failure, airway obstruction, aspiration, and reintubation.

Naloxone, Flumazenil, and Protamine

Naloxone reverses opioid-induced respiratory depression by competitive antagonism at opioid receptors. Small titrated doses such as 40 mcg IV increments are often used to improve ventilation while minimizing abrupt pain or withdrawal; larger doses may be required in overdose.

Flumazenil reverses benzodiazepine effects at the GABA-a receptor complex and is commonly given as 0.2 mg IV, repeated in small increments up to effect. However, it can precipitate seizures in benzodiazepine-dependent patients or mixed overdoses.

Protamine reverses unfractionated heparin; a common adult dose is approximately 1 mg protamine per 100 units of heparin remaining in circulation, with dose adjustment based on timing and total heparin exposure.

Anesthesia implications: all three agents can create secondary problems if used too aggressively. Naloxone may precipitate severe pain, sympathetic surge, or pulmonary edema; flumazenil may unmask seizures; protamine may cause hypotension, pulmonary hypertension, or anaphylactoid reactions, especially with rapid administration or prior sensitization.

Vasopressin, Glucagon, and Methylene Blue

Vasopressin may be considered in refractory vasodilatory shock when catecholamine responsiveness is inadequate.

Glucagon is particularly useful in patients on beta-blockers who have severe bradycardia or hypotension and respond poorly to catecholamines; common emergency dosing is 1-5 mg IV, followed by infusion when needed.

Methylene blue may be used as a rescue medication in severe vasoplegia or methemoglobinemia; dosing varies by indication, but a common dose is 1-2 mg/kg IV.

Anesthesia implications: these are not first-line medications for every shock state, but they become important in selected refractory situations, especially after cardiopulmonary bypass, in drug-induced vasoplegia, or in toxin-mediated hemodynamic collapse.

Other High-Yield Rescue Medications in Anesthesia

Atropine remains useful for symptomatic bradycardia, commonly at 0.5 mg IV repeated to effect.

Phenylephrine, ephedrine, and norepinephrine are not reversal agents in the classic sense, but they are core anesthesia rescue vasopressors when hypotension develops.

Albuterol and magnesium sulfate are valuable rescue agents for bronchospasm.

Insulin with dextrose is commonly used alongside calcium and albuterol in severe hyperkalemia.

Anesthesia implications: a CRNA's emergency medication knowledge should include not only antidotes, but also the supporting rescue drugs that keep the patient oxygenated and perfused while the underlying crisis is being reversed.

- Know where rescue drugs are stored: availability matters as much as knowledge in emergencies such as MH, LAST, and anaphylaxis.
- Dose by scenario, not memory alone: many emergency medications are weight-based or severity-dependent, so crisis checklists and cognitive aids are valuable.
- Treat the underlying cause while giving the drug: dantrolene without stopping triggers, lipid without airway support, or epinephrine without fluid resuscitation may be insufficient.
- Reversal drugs can create new problems: naloxone, flumazenil, protamine, and neostigmine all require careful titration and monitoring.
- Use quantitative monitoring whenever possible: objective data help guide reversal of neuromuscular blockade, electrolyte therapy, and resuscitation response.
- Document and hand off clearly: emergency medication use should be followed by clear postoperative communication, monitoring plans, and specialty follow-up when indicated.

Malignant Stop triggers immediately dantrolene, bicarbonate, calcium, hyperthermia and treat complications in cooling adjuncts crisis parallel

20% lipid emulsion, Airway support and

Benzodiazepines, vasopressors as modified resuscitation systemic toxicity needed remain essential

Epinephrine, crystalloid, Perioperative Use epinephrine early and bronchodilators, vasopressin if anaphylaxis do not wait for skin findings refractory

Calcium gluconate or calcium Hyperkalemia with myocardium while chloride, bicarbonate, ECG changes definitive potassium-insulin/dextrose, albuterol lowering therapies work

Residual Match the reversal agent to

Rocuronium block the depth of blockade and neostigmine/glycopyrrolate at emergence monitor objectively

Think of cyanide when

Severe lactic acidosis and associated thiosulfate, supportive collapse occur during cyanide toxicity resuscitation nitroprusside exposure

Pitfalls and Pearls

- Dantrolene: do not delay administration while trying to confirm the diagnosis. Treat malignant hyperthermia based on clinical suspicion, and remember that recrudescence can occur hours later, so continued monitoring and post-crisis dosing may be necessary.
- Lipid emulsion: it is an adjunct to, not a replacement for, airway management and modified resuscitation in LAST. Avoid large epinephrine doses and vasopressin, and be prepared for recurrent instability after initial improvement.
- Epinephrine: in perioperative anaphylaxis, delayed epinephrine is more dangerous than giving a cautious titrated IV dose early. Severe reactions may present primarily with hypotension or bronchospasm and without obvious skin findings.
- Sodium bicarbonate: this is not a routine arrest medication for every scenario. It is most useful in selected situations such as severe hyperkalemia, sodium-channel blocker toxicity, or marked acidemia when ventilation and the underlying cause are being addressed.
- Calcium chloride vs calcium gluconate: calcium chloride delivers more elemental calcium and acts quickly, but it is more caustic to veins and surrounding tissue. Calcium gluconate is often safer through peripheral access.
- Sugammadex and neostigmine: neither drug replaces objective monitoring. Quantitative train-of-four assessment is still needed to match reversal strategy to block depth and confirm adequate recovery before extubation.
- Naloxone: titrate to ventilation, not to complete wakefulness. Abrupt full reversal can precipitate severe pain, hypertension, tachycardia, agitation, and in some cases noncardiogenic pulmonary edema.
- Flumazenil: use carefully in benzodiazepine dependence, mixed overdose, or seizure-prone patients. Re-sedation can occur, so brief improvement after reversal does not eliminate the need for continued observation.
- Protamine: rapid administration can cause hypotension, pulmonary vasoconstriction, and anaphylactoid reactions. Dose carefully to estimated circulating heparin and infuse slowly with close hemodynamic monitoring.
- Glucagon and methylene blue: these are niche rescue therapies that become important in selected refractory states, particularly beta-blocker-associated hemodynamic collapse, vasoplegia, or methemoglobinemia. They should not distract from first-line stabilization and correction of the underlying cause.

Primary Typical

Drug Onset adverse CRNA pearl indication adult dose effects

Based on 2-2.5 suspicion Muscle mg/kg IV, and monitor Malignant weakness,

Hyperthermia phlebitis, GI rapidly to recrudescen upset effect ce after initial stabilization

Severe LAST, 1.5 mL/kg Fat overload, but continue Local bolus, then Immedi lab 20% lipid airway anesthetic 0.25 ate to interference, emulsion support and systemic toxicity mL/kg/min minutes pancreatitis modified infusion is rare resuscitatio n

10-20 mcg IV boluses Do not wait

Severe reactions; hypertension while giving e s hypotension, 50-100, myocardial fluids and bronchospasm mcg IV for ischemia securing the severe airway reactions

With ECG 1 g IV urgent chloride minutes injury, changes, membrane bradycardia if hypocalcemia, stabilization

Calcium pushed when channel blocker rapidly central toxicity access is available

1-3 g IV through gluconate changes, minutes elemental peripheral IV hypocalcemia calcium per access gram

Mg/kg minutes hypersensitiv Sugamma rocuronium or reversal is deep dependi ity, cost dex vecuronium needed, but block; 16 ng on consideratio blockade still confirm mg/kg depth ns TOF ratio at immediate or above 0.9 reversal

Neostigmi Reversal of ne 0.03-Do not give Neostigmi nondepolarizing 0.07 mg/kg Bradycardia, too early or ne with block when IV with 5-15 secretions, after full glycopyrrol spontaneous glycopyrrol minutes bronchospas recovery; ate recovery is ate 0.01-m, PONV timing present 0.02 mg/kg matters IV

40 mcg IV Aim for Opioid-induced Pain, increments 1-2 adequate Naloxone respiratory agitation, titrated to minutes breathing, depression sympathetic ventilation not a surge, sudden fully

Use cautiously 0.2 mg IV, and repeat in Seizures, Benzodiazepine 1-2 continue Flumazenil small agitation, re-oversedation minutes observation increments sedation because the to effect patient may sedate again

Infuse slowly and Approxima Hypotension, reassess tely 1 mg pulmonary

Per 100 hypertension Protamine unfractionated about 5 ics units of, heparin minutes continuousl circulating anaphylactoi y during heparin d reactions administrati on

Early when Beta-blocker-1-5 mg IV, Nausea, catecholami associated then vomiting, nes seem

Bradycardia or infusion if hyperglycemi ineffective in hypotension needed an a beta-blocked patient

Hemolysis in Methylene vasoplegia or 1-2 mg/kg cases and

Blue methemoglobin IV make sure deficiency, emia the blue indication is discoloration clear

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PART V – EQUIPMENT, INSTRUMENTATION AND TECHNOLOGY

The Anesthesia Machine

Medical gas systems, anesthesia machine, breathing circuits, airway equipment, ventilators, monitors, regional and vascular equipment.

Pipeline Gas Supply

Hospital pipeline systems supply medical gases directly to the anesthesia machine at a working pressure of approximately 50-55 psi (pounds per square inch). This is the primary gas source during normal operation. Pipeline gases include oxygen (O2), nitrous oxide (N2O), air, and nitrogen. The pipeline connection at the anesthesia machine uses the Diameter Index Safety System (DISS)

- A standardized, non-interchangeable threaded connector system that prevents misconnection of different gas hoses.

Pipeline pressure to anesthesia machine: ~50-55 psi for all gases

Gas Pipeline Pressure (psi) Color Code (USA) Primary Use

Cylinder Gas Supply (E-Cylinders)

E-cylinders serve as the backup gas supply when the pipeline is unavailable, or as the primary source in locations without pipeline access. They are mounted on the yoke of the anesthesia machine and secured with a retaining screw. The Pin Index Safety System (PISS) prevents attachment of the wrong cylinder to the wrong yoke-each gas has a unique pin configuration that only fits the correct yoke.

E-Cylinder Specifications

Gas Full Pressure (psi) Volume (Liters) Color (USA) Storage State

Nitrous oxide (N2O) ~745 ~1590 L Blue Liquid + vapor

CRITICAL: Oxygen is stored as a COMPRESSED GAS-pressure is directly proportional to remaining volume. a half-full O2 E-cylinder reads ~1100 psi.

CRITICAL: nitrous oxide is stored as a LIQUID-pressure remains constant at ~745 psi until all liquid is vaporized. You CANNOT estimate remaining N2O volume by pressure alone; you must WEIGH the cylinder.

The first-stage pressure regulator reduces E-cylinder oxygen pressure from ~2200 psi down to approximately 45 psi, matching pipeline pressure. a check valve (Bodok seal / one-way valve) prevents backflow of gases between the cylinder and pipeline and between cylinders.

Duration of an E-cylinder can be estimated using:

Oxygen: Duration (min) = [Pressure (psi) x 0.3] Flow rate (L/min)

Example: 1000 psi O2 at 5 L/min -> (1000 x 0.3) 5 = 60 minutes

Fail-Safe System & Low-Pressure Alarms

- It only monitors pressure, not concentration.

A low O2 pressure alarm (audible) activates when O2 pipeline pressure falls below approximately 30 psi. Modern machines also include a minimum oxygen ratio controller (e.g., Link-25 or Ratio-Master) that prevents setting a hypoxic N2O/O2 ratio-typically maintaining at least 25% O2 in the fresh gas mixture.

The fail-safe system protects against hypoxic MIXTURES but does NOT protect against a hypoxic gas being supplied in the pipeline (e.g., if O2 and N2O pipelines are accidentally crossed during hospital construction).

H-Cylinders (Large Cylinders)

H-cylinders are large, free-standing cylinders stored in the hospital's central supply area. They supply gas to the pipeline system via manifolds. a H-cylinder of oxygen contains approximately 6,900 liters at ~2200 psi. Regulators on H-cylinders reduce pressure to pipeline levels (~50-55 psi) before entering the distribution system.

Overview & Gas Flow Path

The anesthesia machine (also called the anesthesia workstation) is a complex medical device that delivers precise, controlled mixtures of anesthetic gases and vapors to the patient. Gas travels through the machine in a logical, sequential path from the high-pressure gas supply to the patient's airway.

Gas Flow Through the Anesthesia Machine

Reduces cylinder pressure to ~45 psi (pipeline pressure 1st-Stage Regulator -> bypass)

Shuts off N2O/Air if O2 pressure drops below threshold

Calibrated glass tubes measuring gas flow in L/min Flowmeters (Rotameters) ->

Ensures minimum 25% O2 in fresh gas mixture

Agent-specific; adds volatile anesthetic vapor to gas Vaporizer -> stream

Combined gas mixture exits machine Common Gas Outlet (Fresh Gas Outlet) ->

Delivers gas to patient; CO2 absorber if circle system

Flowmeters (Rotameters)

Flowmeters are precision-calibrated, gas-specific glass or acrylic tubes containing a lightweight float (bobbin or ball). Gas flowing upward lifts the float; the flow rate is read at the top of the float (ball) or midpoint of the bobbin. They are agent-specific and non-interchangeable.

Flowmeter tubes are arranged in a specific order on the manifold. On North American machines, OXYGEN is always positioned on the RIGHT (closest to the common gas outlet)-this ensures that even if there is a crack or leak in the manifold, oxygen will preferentially contaminate the fresh gas mixture rather than a hypoxic gas. nitrous oxide is typically on the left.

Oxygen flowmeter is ALWAYS on the RIGHT (downstream) in North American machines-a critical safety feature preventing hypoxic mixtures in case of flowmeter tube cracks.

At low flows, the annular space between float and tube is primarily determined by tube diameter (viscosity-dependent). At high flows, the float height is primarily determined by gas density. This is why flowmeters are gas-specific-a flowmeter calibrated for oxygen cannot be used for nitrous oxide.

Pressure Regulators on the Anesthesia Machine

First-Stage At ~2200 psi (O2 ~45 psi Reduces cylinder pressure to match (High-Pressure) cylinder cylinder) pipeline yoke

Second-Stage Within ~50 psi (pipeline/1st ~14-16 psi Provides stable, low pressure to machine stage) flowmeters

Oxygen Flush Valve Direct 50 psi 50 psi -> Bypasses all regulators; delivers 100% pipeline 35-75 L/min O2 directly

Oxygen Flush Valve

The oxygen flush valve delivers 100% oxygen at 35-75 L/min directly from the pipeline source to the common gas outlet, bypassing the flowmeters AND vaporizer. It is used for emergencies and to rapidly fill the breathing bag.

CAUTIONS with the O2 flush valve:

- Barotrauma risk-pressures can exceed 75 cmH2O if used during inspiration
- Dilutes volatile agent-can cause awareness if used carelessly during maintenance.
- Valve sticking-a stuck flush valve delivers continuous high O2 flow, potentially causing barotrauma.

Vaporizers add precise concentrations of volatile anesthetic vapor to the fresh gas flow. Modern vaporizers are variable-bypass, temperature-compensated, agent-specific devices (e.g., Datex-Ohmeda Tec 7, Draeger Vapor 2000). They split the total fresh gas flow between a bypass chamber and a vaporizing chamber.

The vaporizing chamber is saturated with anesthetic vapor; the two streams are recombined downstream. Turning the concentration dial increases the proportion of gas flowing through the vaporizing chamber.

Agent Vaporizer Boiling Point SVP at 20 degrees C Special Notes Type (degrees C) (mmHg)

Sevoflurane Tec 7 / Vapor 58.5 degrees C 157 mmHg Standard variable-bypass; most common in USA ane 2000S

Desflurane Tec 6 Plus / 22.8 degrees C 664 mmHg Electrically heated & pressurized; NOT standard ne D-Vapor variable-bypass

Isoflurane Tec 5 / Vapor 48.5 degrees C 238 mmHg Standard variable-bypass

Halothane Fluotec series 50.2 degrees C 243 mmHg Largely obsolete in USA ne

Desflurane requires a SPECIAL electrically-heated, pressurized vaporizer (Tec 6) because its boiling point (22.8 degrees C) is near room temperature and its SVP is very high. a standard variable-bypass vaporizer cannot be used.

Agent-filling safety: Each vaporizer uses a keyed, agent-specific filler (Quik-Fil or Saf-T-Fil) to prevent filling with the wrong agent. Vaporizers are interlocked-only one can be active at a time (interlock system prevents simultaneous use).

Pumping effect: When the breathing bag is squeezed, increased back-pressure in the circuit can force gas back into the vaporizer, temporarily increasing vapor output. Modern vaporizers have a pressure-compensating mechanism that minimizes this effect.

Tipping effect: Tilting a vaporizer can allow liquid anesthetic to enter the bypass chamber, causing a massive overdose. Vaporizers must be transported upright.

Before every anesthetic, the anesthesia machine must be inspected. The FDA-recommended machine check (or manufacturer-specific check) includes verifying:

- E-cylinder backup pressure adequate (O2 >1000 psi)
- Low-pressure circuit leak test (negative pressure leak test or positive pressure test depending on machine)
- Monitors and alarms active and properly calibrated

The negative pressure (Madison) leak test checks the low-pressure circuit (from flowmeters through vaporizer to common gas outlet). The anesthesia machine must pass this test before every case.

Breathing Circuits and CO2 Absorption

Circle Breathing System

The circle system is the most commonly used breathing circuit in the USA. It allows rebreathing of exhaled gases after CO2 removal, conserving heat, moisture, and volatile agents. Components include: fresh gas inlet, inspiratory unidirectional valve, inspiratory limb, Y-piece, expiratory limb, expiratory unidirectional valve, CO2 absorber canister, APL valve, and reservoir bag.

Fresh Gas Inlet Enters between absorber and inspiratory valve; delivers fresh O2/agent mix

Inspiratory Unidirectional Valve Ensures one-way gas flow toward patient (opens on inspiration)

Expiratory Unidirectional Valve Ensures one-way gas flow away from patient (opens on expiration)

CO2 Absorber Canister Contains soda lime or Amsorb; removes CO2 from exhaled gas

APL Valve (Pop-off) Limits maximum circuit pressure; vents excess gas to scavenging

Y-Piece Connects inspiratory and expiratory limbs to patient airway device

Low-flow anesthesia (total fresh gas flow <1 L/min) is possible with the circle system due to CO2 absorption. Benefits include conservation of agent, heat, and humidity. Risks include accumulation of metabolic byproducts (compound a with sevoflurane at very low flows, CO production with desflurane/isoflurane and desiccated absorbent).

CO2 Absorbents Comparison

Soda Lime Ca(OH)2 + White -> Yes (with Low-Mo Most common; water content NaOH/KOH + Pink/Violet sevoflurane) derate important water

Baralyme Ba(OH)2 + White -> Yes (higher Higher Higher CO production; largely Ca(OH)2 Violet than soda lime) discontinued

Amsorb Ca(OH)2 + Ca(Cl)2 White -> Minimal Minimal Safer with all agents; does not Plus (no NaOH/KOH) Violet produce compound A

Dragersorb Ca(OH)2 + NaOH White -> Moderate Low Manufacturer-specific / Medisorb Violet formulation

A violet/purple color in soda lime = EXHAUSTED absorbent. Replace immediately. Note: color may partially revert to white after resting (regeneration)-this does NOT restore function. Replace based on color during use, not after resting.

Desiccated absorbent (dried out) + desflurane or isoflurane -> carbon monoxide (CO) production. This is more common on Monday mornings when machines have had high O2 flows all weekend without patient use. Turn off fresh gas flows when machine is not in use.

Mapleson Circuits

Mapleson circuits are non-rebreathing (or minimal rebreathing) systems used for pediatric anesthesia, transport, and specific clinical situations. They are classified A-F based on the position of the fresh gas inlet, APL valve, and reservoir bag.

Mapleson Circuit Classification

Mapleso Magill / Lack Spontaneous Equal to 2-3x Most efficient for spontaneous; nA ventilation MV MV inefficient for controlled

Mapleso Bain Circuit Controlled 2-3x MV 70 mL/k Most common Mapleson for adults; FGI nD (coaxial) ventilation g/min inside expiratory tube

Mapleso Ayre's T-piece Pediatric (no 2-3x MV 2-3x Open-ended; no APL valve or bag; used nE bag) MV for <10 kg

Mapleso Jackson-Rees Pediatric 2-3x MV 2-3x T-piece with open-ended reservoir bag; nF (modified T-piece) MV allows manual ventilation

Bain circuit check: Before use, occlude the inner fresh gas tube while applying a low flow-if the flowmeter bobbin drops, the inner tube is intact (Pethick test).

Scavenging Systems

The anesthesia gas scavenging system (AGSS) captures waste anesthetic gases from the APL valve and ventilator relief valve, preventing OR pollution. Chronic exposure to trace anesthetic gases is associated with increased risk of spontaneous abortion, hepatotoxicity, and neurological effects in healthcare workers.

Components: gas-collecting assembly -> transfer tubing -> scavenging interface -> disposal assembly (active vacuum or passive flow). The interface contains pressure-relief valves to prevent both positive pressure (barotrauma) and negative pressure (lung collapse) from being transmitted to the breathing circuit.

OSHA recommends trace N2O levels <25 ppm and traLuma Educational Appsgenated agents <2 ppm (0.5 ppm when used with N2O) in the OR environment.

Airway Equipment: Laryngoscopes

Direct Laryngoscopy: Blades

Macintosh Curved 0-4 Tip in vallecula (epiglottis Most common adult blade; wider (adult: indirectly lifted) flange displaces tongue easily 3-4)

Miller Straight 0-4 Tip under epiglottis Pediatrics, anterior airways, long (adult: (directly lifts it) floppy epiglottis 2-3)

Wisconsin / Straight 1-2 Tip under epiglottis Pediatric; similar to Miller Wis-Foregge r

Phillips Straight with 0-2 Tip under epiglottis Pediatric anterior airways curved tip

McCoy Curved with 3 Tip in vallecula; lever lifts Difficult/anterior airways; improves articulating tip epiglottis grade by 1-2

Oxyscope Modified Adult Varies Delivers O2 during laryngoscopy to (Oxilite) Miller/Mac extend safe apnea time

Laryngoscopic view is graded by the Cormack-Lehane (C-L) classification:

Grade I: Full glottis visible

Grade II: Only posterior commissure visible

Grade III: Only epiglottis visible

Grade IV: No laryngeal structures visible

BURP maneuver (Backward, Upward, Rightward Pressure on the thyroid cartilage) applied by an assistant can improve C-L grade during difficult laryngoscopy.

Video Laryngoscopy

Video laryngoscopes (VL) use a camera mounted at the blade tip to project a magnified, indirect view of the glottis onto a screen. They improve the laryngoscopic view by 1-2 grades compared to direct laryngoscopy and are invaluable for anticipated and unanticipated difficult airways.

Video Laryngoscope Comparison

GlideSc Hyperangulated No Most widely studied VL; Requires stylet; translating from ope (Ver (60 degrees) excellent view view to intubation can be athon) challenging

McGRAT Standard curved No Familiar Mac blade angle; Good for routine & difficult H MAC geometry easier to intubate once view airways obtained

C-MAC Mac shape (sizes No DL + VL in same blade; best D-Blade for difficult airways; (Karl 2-4) + D-Blade of both worlds standard blade for easy airways

King Channeled or Yes (cha Disposable; channel guides Channel can limit ETT size; Vision non-channeled nneled) ETT requires specific tube type

Airtraq Optical/camera Yes Disposable; no external Good for limited mouth opening channeled screen needed (optical)

AWS Channeled, Yes Guides ETT with stylet Widely used in Japan; good for (Pentax) moderately channel anterior airways angulated

An excellent VL view does NOT guarantee easy intubation. The hyperangulated blade creates a sharp curve that requires a matching rigid stylet. Inability to navigate the ETT through the curve despite a great view is a recognized failure mode.

Flexible Bronchoscopy and Fiberoptic Intubation

Flexible Fiberoptic Bronchoscope (FOB)

The flexible fiberoptic bronchoscope (FOB)-also called a flexible intubating bronchoscope-is an essential tool for awake fiberoptic intubation (AFOI) and diagnostic/therapeutic bronchoscopy. It transmits light and images via thousands of bundled optical fibers (fiberoptic) or via a CCD camera chip at the tip (videoscope/videobronchoscope).

Flexible Bronchoscope Components

Insertion cord (shaft) Flexible shaft containing fiberoptic bundles, working channel, and control wires

Bending section (distal tip) Angulates up/down (180 degrees /130 degrees typical) via control lever; some offer 4-way movement

Working channel Allows suction, oxygen delivery, local anesthetic injection, and instrument (suction/biopsy) passage

Light source connector Connects to external xenon or LED light source

Eyepiece / Camera port Optical eyepiece for direct viewing OR connects to video processor/monitor

Angulation control lever Up/down deflection of distal tip

Body (handle) Held in non-dominant hand; contains working channel port, suction button, angulation lever

Sizes: Intubating bronchoscopes have an outer diameter (OD) of 3.5-6.0 mm. The ETT must have an internal diameter (ID) at least 1 mm larger than the bronchoscope OD. Most adult AFOI is performed with a 4.0-5.5 mm OD scope through a >=6.0 mm ID ETT.

Awake Fiberoptic Intubation (AFOI)

AFOI is the gold standard technique for managing the anticipated difficult airway. The patient is kept awake with topical anesthesia and light sedation (maintaining airway reflexes) while the scope is passed nasally or orally into the trachea, then the ETT is railroaded over the scope.

- Lidocaine 4% - atomized to oropharynx, larynx, trachea
- Benzocaine spray (caution: methemoglobinemia risk)
- Transtracheal block: 2-3 mL lidocaine 4% injected through cricothyroid membrane
- Glossopharyngeal nerve block (bilateral): 1-2 mL lidocaine 2% lateral to base of tongue.
- Superior laryngeal nerve block (bilateral): 2-3 mL lidocaine 2% at superior cornu of thyroid cartilage Sedation for AFOI: Dexmedetomidine (provides sedation + mild analgesia without suppressing airway reflexes; ideal), midazolam (amnesia/anxiolysis), low-dose ketamine, or remifentanil infusion (caution: can suppress airway reflexes at higher doses).

AFOI is indicated for: anticipated difficult airway with a full stomach, unstable C-spine, restricted mouth opening, large neck mass/mediastinal mass, airway pathology (tumor, hematoma, angioedema), or any situation where loss of airway could be catastrophic.

Nasal AFOI tips: Decongest with oxymetazoline (Afrin), lubricate nasal passage, choose wider nostril, use a nasal airway to guide the scope and ETT. Oral AFOI: use a Berman or Ovassapian intubating airway to guide and protect the scope.

Video Bronchoscopes & Portable Devices

Modern videobronchoscopes (e.g., Ambu aScope, Karl Storz FLEX-IT, Olympus BF-H190) integrate a CCD chip at the tip, providing superior image quality compared to fiberoptic systems. Disposable videoscopes (e.g., Ambu aScope 4) eliminate the need for reprocessing and reduce cross-contamination risk.

The Ambu aScope is a single-use, disposable flexible scope widely used for AFOI and diagnostic bronchoscopy. It connects to the reusable Ambu aView monitor. Its disposable nature is advantageous in emergency situations and remote locations where reprocessed scopes may not be available.

Endotracheal Tubes (ETTs)

Standard ETT Anatomy & Sizing

Endotracheal tubes are sized by their internal diameter (ID) in millimeters. The external diameter varies by wall thickness. Standard adult sizes are 7.0-8.0 mm ID for women and 7.5-9.0 mm ID for men. ETTs are typically made of polyvinyl chloride (PVC), which softens at body temperature and conforms to the airway.

Age/Patient ETT ID (mm) Depth at Lips Notes (cm)

Premature 2.5-3.0 6-8 cm Uncuffed preferred in very small neonate neonates

Neonate 3.0-3.5 9-10 cm (term)

6 months 3.5-4.0 11-12 cm

1 year 4.0 12 cm

Pediatric (>1 Age/4 + 4 (uncuffed); Age/4 + 3.5 Age/2 + 12 Cuffed tubes increasingly used in yr) (cuffed) (oral) peds

Adult Female 7.0-7.5 21-23 cm

Adult Male 7.5-9.0 23-25 cm

ETT cuff: The high-volume, low-pressure (HVLP) cuff is the standard in modern ETTs. It is inflated until a slight air leak is eliminated during positive pressure ventilation. Cuff pressure should be maintained at 20-30 cmH2O-higher pressures cause ischemia to the tracheal mucosa (capillary pressure ~30 cmH2O).

Specialized Endotracheal Tubes

RAE Tube Pre-formed oral or nasal curve; keeps Oral/facial surgery (oral RAE), rhinoplasty, (Ring-Adair-Elwyn) circuit away from surgical field sinus surgery (nasal RAE)

Reinforced (Armored / Stainless steel wire spiral embedded Prone positioning, head-and-neck Anode) ETT in PVC wall; kink-resistant surgery, neurosurgery (head rotation), Trendelenburg

Double-Lumen Tube Two parallel lumens (bronchial + Thoracic surgery, one-lung ventilation (DLT) tracheal); allows independent lung (OLV); requires FOB confirmation of ventilation position

Microlaryngoscopy Tube Long, narrow ID (4.0-5.0 mm ID); Laryngeal/glottic surgery, (MLT) allows vocal cord visualization microlaryngoscopy

Laser-Safe ETT (e.g., Metal foil or silicone wrapping; CO2, Nd: YAG, KTP laser surgery on/near Laser-Flex, Lasertubus) reflects laser energy; saline-filled cuff the airway-prevents airway fire

Subglottic Suction ETT Additional dorsal suction lumen above ICU ventilated patients; aspirates (e.g., Mallinckrodt HI-LO cuff subglottic secretions, reduces VAP Evac)

Parker Flex-Tip ETT Flexible, curved, tapered tip; reduces Difficult intubation over FOB or stylette; resistance during intubation reduces nasal trauma

Intubating LMA Short, reinforced, right-angle ETT; fits Blind or FOB-guided intubation through (Fastrach) ETT through LMA Fastrach channel the LMA Fastrach

Endobronchial Blocker Separate blocker advanced through OLV when DLT cannot be used; useful in (e.g., Arndt, Cohen, ETT into mainstem bronchus patients already intubated EZ-Blocker)

Double-Lumen Tubes (DLTs)

DLTs are the most commonly used device for one-lung ventilation (OLV) in thoracic surgery. They consist of two lumens-one ending in the trachea and one extending into a mainstem bronchus (usually left, as left-sided DLTs are safer due to longer left mainstem bronchus length).

Sizing: Left DLTs come in sizes 26Fr, 28Fr, 32Fr, 35Fr, 37Fr, 39Fr, 41Fr. General guide:

Women <160 cm: 35Fr | Women >160 cm: 37Fr

Men <170 cm: 39Fr | Men >170 cm: 41Fr

CT measurement of left mainstem bronchus diameter is the most accurate sizing method.

Positioning is confirmed by fiberoptic bronchoscopy (FOB) after placement. With a left-sided DLT:

- Via tracheal lumen: tracheal carina should be visible; blue bronchial cuff just below carina in left mainstem bronchus.
- Via bronchial lumen: left upper lobe takeoff and left lower lobe bronchus should be visible.

ALWAYS confirm DLT position with FOB after initial placement AND after patient repositioning (lateral decubitus position can cause DLT migration).

Supraglottic airway devices (SGAs) sit above the glottis, forming a low-pressure seal against the periglottic structures. They are used for airway management during anesthesia when endotracheal intubation is not required, as rescue devices in difficult/failed intubation, and as conduits for fiberoptic intubation.

Supraglottic Airway Devices (SGAs)

SGA Generations Comparison

First-ge LMA Classic, LMA No No Limited Simple bowl-shaped cuff; neration Unique, Soft Seal reusable or disposable

Second LMA Supreme, LMA Yes Yes (via Better-allows Integral drain tube reduces-genera ProSeal, i-gel, AirQ, drain gastric aspiration risk; higher seal tion SLIPA tube) decompression pressure

Intubati LMA Fastrach (iLMA), No No Limited Designed to facilitate ETT ng AirQ (ILA) passage (blind or FOB-guided)

LMA 1st gen, PVC inflatable ~20 Gold standard; 8 uses before replacement; sizes 1-6

LMA 1st gen, d PVC inflatable ~20 Single-use version of Classic

LMA 2nd gen, Dual cuff ~30 Highest seal of all LMAs; drain tube for gastric ProSeal reusable (dorsal+ventral) suctioning

LMA Su 2nd gen, Elliptical PVC, rigid ~25 Pre-curved rigid airway tube, integrated bite block, preme disposabl shaft drain tube e

I-gel 2nd gen, Thermoplastic ~25-30 No inflation required; non-inflatable cuff conforms to disposabl elastomer anatomy; integral drain channel e (non-inflatable)

LMA Fas Intubatin PVC inflatable ~20 Rigid, handle-equipped; allows blind or FOB-guided trach g, ETT insertion; size 3-5 (iLMA) reusable

AirQ Intubatin Inflatable ~20-25 Detachable connector; allows standard ETT removal (ILA) g, dispos while SGA remains in place able

King LT Extraglot Dual cuff (pharyng N/a Blind insertion; no mask seal needed; esophageal cuff / King tic eal+esophageal) seals esophagus; second-generation has suction port

I-gel advantages: No cuff inflation, no cuff pressure concerns, fast insertion, integral drain channel. Consider for difficult cuff management or when speed of insertion is critical.

Contraindications to SGA use: full stomach (relative), pharyngeal pathology, restricted mouth opening <2.5 cm, morbid obesity (relative), prolonged prone positioning, airway pressures >20 cmH2O needed.

Airway Adjuncts and Related Equipment

Airway Adjuncts

Oropharyn Sized from center of Displaces tongue anteriorly; Tolerated only in deeply unconscious geal mouth to earlobe; maintains pharyngeal patency patients-stimulates gag reflex if Airway sizes 60-110 mm patient too awake; causes (OPA / (adult: 80-100 mm) laryngospasm risk Guedel airway)

Nasophary ID 6-9 mm; length = Maintains nasal patency; Tolerated in lightly ngeal nostril to earlobe bypasses tongue sedated/semi-conscious patients; Airway (~15-20 cm) lubricate well; avoid in skull base (NPA / fracture, coagulopathy, nasal polyps nasal trumpet)

Stylet Fits inside ETT; bent Gives rigidity and shape to ETT Tip should NOT extend beyond ETT (malleable to desired angle for intubation tip; lubricate to allow easy intubating) withdrawal after intubation

Magill Angled metal Direct nasal ETT or foreign body Used during nasotracheal intubation Forceps forceps into glottis during laryngoscopy and foreign body removal

Light Illuminated stylet Transtracheal glow guides blind Largely replaced by VL but useful in Wand (Tra oral intubation in dark room limited resource settings chlight)

Cricothyrotomy Devices

Cricothyrotomy (surgical or needle) is the rescue technique for the 'cannot intubate, cannot oxygenate' (CICO) emergency. It provides oxygenation by accessing the airway through the cricothyroid membrane (CTM)-located between the thyroid and cricoid cartilages.

Melker Per Melker kit-Modera Modera Provides oxygenation AND ventilation; can connect cutaneous guidewire + dilator + te (~60 te to standard circuit (Seldinger) cuffed airway-90 catheter (4-6 mm ID) sec)

The 'Scalpel-Bougie' technique is the recommended eFONA method in the DAS (Difficult Airway Society) 2015 guidelines for CICO: Stab -> dilate (caudal traction on trachea) -> insert bougie -> railroad 6.0 ETT -> inflate cuff -> confirm.

Bite block / oral airway Prevents patient from biting and occluding ETT on emergence post-intubation

Tube holder / Umbilical tape Secures ETT at correct depth; prevents displacement / Thomas Tube Holder

End-tidal CO2 (ETCO2) Disposable chemical detector that changes color in presence of CO2; confirms colorimetric detector tracheal intubation

Esophageal detector device Aspirates air from tracheal tube; esophagus collapses (no refill) = esophageal; (EDD / bulb syringe) trachea resists collapse (refills) = tracheal

Tube exchanger (airway Hollow, flexible catheter; can be left in trachea while ETT is changed over it; exchange catheter) maintains airway during tube exchange

HME (Heat and Moisture Passive humidifier/filter; conserves heat and moisture; placed between circuit

Bacterial/viral filter Filters microorganisms in the breathing circuit; placed at the circuit-patient interface

Monitoring Devices Integrated with Airway Management

Capnography (ETCO2) is mandatory during intubation to confirm tracheal placement and is the gold standard for ETT confirmation. a colorimetric CO2 detector is a backup tool. Pulse oximetry provides real-time desaturation monitoring during airway management.

High-Flow Nasal Oxygenation (HFNO / THRIVE): Delivery of heated, humidified oxygen at 30-70 L/min via specialized nasal cannula. Creates apneic oxygenation via mass-flow effect and generates low levels of PEEP. Used during preoxygenation and to extend safe apnea time during airway management (especially in obese, pediatric, and difficult airway patients).

THRIVE (Transnasal Humidified Rapid-Insufflation Ventilatory Exchange) has been shown to extend safe apnea time up to 65+ minutes in some studies-valuable during complex airway management and AFOI.

Anesthesia Ventilators and Ventilation Modes

Anesthesia Machine Ventilators

Modern anesthesia machines (e.g., GE Aisys, Drager Zeus, Mindray WATO) include integrated electronic ventilators that have largely replaced the older bellows-in-a-box piston-style ventilators. They offer multiple ventilation modes similar to ICU ventilators.

Common Ventilation Modes

Volume Control VCV Tidal volume (fixed); Standard mode; predictable tidal volumes; Ventilation pressure varies risks barotrauma with high airway resistance

Pressure Control PCV Peak airway pressure Improved gas distribution; reduced Ventilation (fixed); volume varies barotrauma risk; tidal volume varies with compliance changes

Pressure Support PSV Patient-triggered; pressure Weaning; spontaneous breathing support; Ventilation support boosts patient reduces work of breathing effort

SIMV (Synchronized SIMV Mandatory breaths + Weaning; allows some patient control Intermittent Mandatory patient spontaneous

PEEP (Positive PEEP Maintains positive pressure Prevents alveolar collapse; improves End-Expiratory at end-expiration oxygenation; standard 5 cmH2O in most

Pressure-Regulated PRVC / Dual-control; targets set Combines benefits of VCV and PCV; Volume Control VC+ volume with lowest available on newer anesthesia machines possible pressure

Ventilator Settings & Targets

Tidal Volume (Vt) 6-8 mL/kg IBW Lung-protective ventilation; lower in ARDS (4-6 mL/kg IBW)

Respiratory Rate (RR) 10-14 breaths/min Adjust to maintain ETCO2 35-45 mmHg

I: E Ratio 1:2 (standard) Lengthen expiratory time (1:3-1:4) in obstructive lung disease (COPD, asthma)

PEEP 5 cmH2O (routine) Higher in obese patients (8-10 cmH2O); individualized in

ARDS Ventilation Targets

Peak Inspiratory Monitor; ideally <30 High PIP = increased airway resistance or decreased Pressure (PIP) cmH2O compliance

Plateau Pressure Keep <28-30 cmH2O Reflects alveolar pressure; driving pressure = Pplat-PEEP; (Pplat) target <15 cmH2O

FiO2 Start 1.0; titrate to Minimize FiO2 to avoid absorption atelectasis and O2 SpO2 >95% toxicity

ETCO2 35-45 mmHg Adjust RR or Vt; ETCO2 PaCO2-5 mmHg in normal lungs

Anesthesia Monitors and Safety Systems

ASA Standard Monitors

The American Society of Anesthesiologists (ASA) Standards for Basic Anesthetic Monitoring require the following monitors for all anesthetics:

Pulse Oximetry Continuous throughout anesthetic Peripheral O2 saturation; arterial pulsations (SpO2)

Capnography Continuous when intubated; strongly Confirms ETT placement; monitors ventilation; (ETCO2) recommended for all GA/MAC detects MH (rising ETCO2)

ECG Continuous throughout anesthetic Heart rate, rhythm, ischemia (ST changes)

Blood Pressure At least every 5 minutes Systolic, diastolic, MAP

Temperature When clinically significant change Core temperature (esophageal, bladder, rectal, expected nasopharyngeal)

Inspired O2 Continuous; low O2 alarm must be Confirms minimum FiO2 delivered; analyzes Analyzer enabled inspired O2 concentration

Ventilator Required during mechanical ventilation Detects circuit disconnection; low Disconnect pressure/volume alarm Alarm

Specialized Anesthesia Monitors

Volatile Agent Analyzer Inspired and expired anesthetic Confirms agent delivery; guides MAC agent concentration maintenance

Neuromuscular Monitor Train-of-four (TOF) ratio; PTC; Quantifies NMB; guides reversal; confirms (TOF Watch, StimPod) DBS; single-twitch adequate recovery (TOF >=0.9)

Bispectral Index (BIS) Processed EEG (0-100 scale) Depth of hypnosis; target 40-60 for GA; reduces awareness and oversedation

Invasive Arterial Line Continuous beat-to-beat BP + Hemodynamic instability, cardiac surgery, (A-line) arterial blood gas access anticipated large fluid shifts

Central Venous Pressure Right atrial/central venous Gross volume status; drug delivery; PA catheter (CVP) pressure via CVC insertion guide

Cerebral Oximetry Regional cerebral O2 saturation Cardiac surgery, carotid endarterectomy, CEA, (NIRS) (rSO2) via near-infrared prone spine cases spectroscopy

Transesophageal Echo Real-time cardiac structure and Cardiac surgery, hemodynamic instability, valve (TEE) function imaging evaluation, volume assessment

Pulmonary Artery CO, PCWP, PVR, mixed venous O2 Complex cardiac and pulmonary cases; largely Catheter (PA Catheter / replaced by TEE + arterial waveform analysis Swan-Ganz)

Arterial Waveform Stroke volume variation (SVV), Goal-directed fluid therapy; predicts fluid Analysis (FloTrac, pulse pressure variation (PPV), CO responsiveness in mechanically ventilated

The OR environment poses unique electrical safety risks due to the presence of wet conditions, multiple electrical devices, and anesthetized patients who cannot respond to electrical shock.

Line Isolation Monitor (LIM): The OR uses an isolated power system in which neither conductor is connected to ground. This prevents single-fault current (macroshock) from flowing through a patient.

The LIM monitors the impedance between the isolated power system and ground-an alarm (usually >2 mA of fault current) indicates that the isolation has been compromised and the next fault could cause macroshock. The procedure should not necessarily be stopped when the LIM alarms, but the faulty device should be identified and removed.

- Macroshock: Current applied to the skin; requires >100 mA to cause VF; protected by skin resistance.
- Microshock: Current applied directly to the heart (e.g., via pacing wires or intracardiac catheters); as little as 10 uA (microamps) can cause VF-patient is 10,000x more sensitive.

Any patient with an intracardiac catheter (pacemaker wire, PA catheter) is at risk for microshock. All equipment near such patients must be grounded and in good repair.

Regional Anesthesia Equipment

Spinal & Epidural Needle Types

Quincke Cutting-t 22-27G Beveled cutting Higher (cuts Traditional spinal; fast CSF flow; ip spinal tip dural fibers) good for diagnostic LP

Whitacre Pencil-p 24-27G Pencil-point with Lower Most common for spinal anesthesia; oint side orifice (separates dural reduced PDPH spinal fibers)

Sprotte Pencil-p 24-27G Larger side orifice Lower Faster injection; reduced PDPH oint than Whitacre spinal

Touhy Epidural 17-18G Curved Huber tip N/A (epidural) Standard epidural needle; curved (Tuohy) (90 degrees curve) tip directs catheter cephalad

Crawford Epidural 17-18G Short bevel, no N/a Caudal epidural; IV catheter curve insertion

Weiss Epidural 17-18G Wings for grip N/an Easier grip during loss-of-resistance (winged during LOR technique Tuohy)

Ultrasound guidance (USG) has revolutionized regional anesthesia by enabling real-time visualization of nerves, adjacent structures, and needle tip position, while observing local anesthetic spread. This reduces block failure rates, LA doses required, and complication rates (vascular puncture, pneumothorax).

High-frequency 10-15 Superfici Superficial nerve blocks (brachial plexus above clavicle, linear (hockey stick) MHz al (<4 saphenous, sural, femoral nerve), vascular access cm)

Curved/convex (low 2-5 Deep (>6 Deep nerve blocks (sciatic, lumbar plexus, paravertebral), frequency) MHz cm) abdominal blocks in obese patients

Phased array 1-5 MHz Variable TEE, point-of-care cardiac assessment; not typically used for (cardiac probe) peripheral nerve blocks

Nerve stimulator: a peripheral nerve stimulator (PNS) can be used alone or in conjunction with ultrasound. It delivers a controlled electrical current (0.5 mA, 0.1 ms) through an insulated needle tip. a motor response at <0.5 mA confirms needle proximity to the nerve. Current <0.2 mA with motor response may indicate intraneural placement-STOP and reposition.

Vascular Access and Infusion Equipment

IV Catheter Sizes & Flow Rates

14G Orange ~340 mL/min Massive hemorrhage, rapid resuscitation, level 1 infuser

16G Gray ~210 mL/min Major surgery, blood transfusion, rapid fluid administration

18G Green/Pi ~100 mL/min Standard adult IV; most surgeries; blood products nk

20G Pink/Ros ~60 mL/min Standard adult IV; most infusions and medications e

22G Blue ~35 mL/min Pediatric, elderly, difficult access; drug infusions

24G Yellow ~22 mL/min Neonates, very small pediatric patients, fragile veins

Flow rate is inversely proportional to catheter length and directly proportional to the 4th power of the radius (Poiseuille's Law). a short, large-bore catheter (14-16G) provides dramatically higher flow than a long central line for rapid resuscitation.

Central Venous Catheters & Arterial Lines

Central venous catheters (CVCs) are placed in large central veins (internal jugular, subclavian, femoral) for CVP monitoring, drug delivery (vasopressors, TPN, vesicants), and venous access when peripheral access is unavailable. Most modern CVC placement uses ultrasound guidance to reduce complications.

Complications of CVC placement: arterial puncture, pneumothorax (highest risk with subclavian approach), air embolism, catheter malposition, infection (CLABSI), thrombosis, and nerve injury.

Arterial lines (A-lines) are placed in the radial artery (most common-perform Allen's test first), femoral, brachial, or dorsalis pedis arteries. They provide continuous beat-to-beat blood pressure monitoring and arterial blood sampling access.

The waveform is transduced via a pressure transducer zeroed at the level of the phlebostatic axis (right atrium-4th intercostal space, midaxillary line).

Phlebostatic axis: The reference point for zeroing all hemodynamic pressure transducers. Located at the intersection of the 4th intercostal space and the mid-axillary line-approximates the level of the right atrium.

Infusion Devices

Syringe pump Drug infusions (vasopressors, Precise, low-volume delivery; 10-60 mL syringe; TIVA, insulin, heparin) programmable rates

IV infusion pump IV fluids and blood products Controls flow rate; air-in-line and occlusion (volumetric) alarms

Patient-controlled postoperative opioid analgesia Patient-triggered bolus doses + optional analgesia (PCA) pump continuous basal rate; lockout interval

Level 1 Fluid Warmer / Rapid warmed fluid infusion Warms fluid to 38-41 degrees C; high-flow; used for Hotline massive transfusion

Belmont Rapid Infuser Massive hemorrhage Up to 1,000 mL/min at body temperature; resuscitation pressure-driven; integrates warming

TCI (Target-Controlled TIVA (propofol, remifentanil) Pharmacokinetic model-driven; targets plasma or Infusion) pump effect-site concentration

PART I SUPPLEMENT – HIGH-YIELD BASIC SCIENCE TABLES FROM THE NCE OUTLINE

This domain tests foundational knowledge that underpins all anesthesia practice. It covers anatomy and physiology across organ systems, pathophysiology, pharmacology, and applied physics/chemistry. Pharmacology is the highest-yield sub-domain-it comprises 31 specific drug classes on the content outline.

- Frank-Starling law: increased preload -> increased stroke volume (to a point)
- Cardiac output (CO) = Heart rate (HR) x Stroke volume (SV)
- SVR = (MAP-CVP) / CO x 80; normal SVR 800-1200 dynes-s-cm
- Coronary perfusion pressure (CPP) = Aortic diastolic pressure-LVEDP
- Right coronary artery dominance in 85% of population; supplies SA and AV nodes
- Determinants of myocardial O2 demand: HR, contractility, wall tension (afterload x preload)
- Functional residual capacity (FRC) = ERV + RV; FRC is the volume at rest after passive exhalation.
- Hypoxic pulmonary vasoconstriction (HPV): diverts blood from atelectatic lung-volatile agents blunt HPV.
- Oxyhemoglobin dissociation curve: right shift (more O2 release) with increased CO2, temp, H+,.
- Closing capacity increases with age, obesity, supine position-exceeds FRC causing V/Q mismatch.
- Alveolar gas equation: PAO2 = (FiO2)(PB-PH2O)-PaCO2/0.8
- Dead space (Vd/Vt): normal 0.33; increases with PE, emphysema, high PEEP, low CO
- Cerebral blood flow (CBF): normal 50 mL/100g/min; maintained by autoregulation MAP 60-150 mmHg.
- CBF directly proportional to PaCO2 (4% per mmHg); minimal effect of PaO2 above 50 mmHg.
- ICP: normal <15 mmHg; CPP = MAP-ICP; target CPP >60 mmHg in neuro injury
- Blood-brain barrier: tight junctions, impermeable to ions; permeable to lipid-soluble drugs.
- MAC: minimum alveolar concentration to prevent movement in 50% of patients at 1 atm.
- Renal: GFR normal ~125 mL/min; kidneys receive 20% CO; ATN most common cause of acute renal failure in OR.
- Hepatic: Liver receives 25% CO; hepatic blood flow reduced by volatile agents, positive pressure ventilation, and hemorrhage.
- Hematologic: Normal Hgb 12-16 g/dL; coagulation cascade-extrinsic (PT/INR), intrinsic (PTT), common pathway (fibrin)
- Endocrine: Stress response activates HPA axis-cortisol, catecholamines, ADH, glucagon increase glucose and fluid retention.
- Musculoskeletal: Neuromuscular junction (NMJ): motor neuron releases ACh -> binds nicotinic receptors -> muscle contraction.

Aortic Stenosis Fixed CO; avoid tachycardia, Maintain sinus rhythm, SVR; phenylephrine hypotension, vasodilation for hypotension

Aortic Regurgitation Benefits from mild tachycardia, reduced Avoid bradycardia; vasodilators help reduce afterload regurgitation

Mitral Stenosis Fixed CO; avoid tachycardia, A-fib with Slow HR, avoid pulmonary hypertension RVR, fluid overload triggers

HOCM Obstruction worsens with decreased Volume, beta-blockade, avoid vasodilators preload, decreased afterload, increased and tachycardia HR, increased contractility

COPD Auto-PEEP risk; blunted hypoxic drive; Prolonged expiratory time, low RR, avoid air trapping high FiO2 in chronic hypercapnia

Pulmonary HTN RV failure risk; avoid hypoxia, Inhaled NO, sildenafil, avoid triggers; hypercarbia, acidosis, N2O vasopressors for RV support

Malignant Life-threatening; triggered by volatile STOP trigger, dantrolene 2.5 mg/kg IV; Hyperthermia agents + succinylcholine cooling; treat acidosis; avoid Ca channel blockers

Pheochromocytoma Hypertensive crisis risk; catecholamine Alpha-block first (phenoxybenzamine), then surge on tumor manipulation beta; phentolamine for crisis

Myasthenia Gravis Sensitivity to NDNMBs; may be resistant Avoid or minimize NDNMBs; sugammadex to succinylcholine preferred for reversal

The NCE content outline lists 31 drug categories under pharmacology. Master mechanism, clinical uses, key adverse effects, and reversal agents for each.

Sevoflurane 0.65 2.0 Sweet smell; used for inhalation induction; compound a with low-flow; hepatic metabolism 3-5%

Desflurane 0.42 6.0 Fastest onset/offset; pungent-cannot use for induction; sympathetic stimulation; requires heated vaporizer

Isoflurane 1.4 1.15 Coronary steal controversy; good muscle relaxation; pungent; still widely used

Nitrous oxide 0.47 104 Analgesic, not complete anesthetic alone; diffusion hypoxia; expands air-filled cavities; avoid in PTX, bowel obstruction, middle ear, severe pulmonary HTN

IV Anesthetics and Induction Agents

- Propofol: Lipid emulsion; onset 30-45 sec; decreases CBF, ICP, CMRO2; antiemetic properties; pain on injection (lidocaine pretreatment); propofol infusion syndrome (PRIS) with high doses >48h.
- Etomidate: Cardiostable; adrenal suppression with single dose; myoclonic movements; PONV; used in hemodynamically unstable patients.
- Ketamine: Dissociative; bronchodilator; increases HR, BP, ICP; preserves airway reflexes; emergence delirium (minimize with midazolam, quiet recovery)
- Dexmedetomidine: Alpha-2 agonist; sedation, analgesia, anxiolysis without respiratory depression; hemodynamic effects (bradycardia, hypotension); reduces MAC.
- Midazolam: Benzodiazepine; anxiolysis, amnesia, anticonvulsant; water-soluble; reversal with flumazenil (short acting-re-sedation risk)

Fentanyl 1-2 min 30-60 min 100x morphine potency; highly lipid soluble; chest wall rigidity at high doses

Sufentanil 1-2 min 60-90 min 1000x morphine potency; most potent clinical opioid; used in cardiac anesthesia

Remifentanil 1 min 3-5 min Ester hydrolysis-organ-independent metabolism; ideal for TIVA; hyperalgesia risk

Morphine 15-30 min 4-5 h Histamine release; active metabolite M6G accumulates in renal failure

Methadone Slow 24-36 h NMDA antagonist; QT prolongation; useful in opioid-tolerant patients

Neuromuscular Blocking Agents (NMBAs)

Succinylcholine Depolarizing 45-60 sec / 8-12 Phase I (depolarizing) then Phase II block; min hyperkalemia risk; MH trigger; bradycardia in children; avoid in burns, crush injury, denervation >72h post-injury

Rocuronium Non-depolarizi 60-90 sec / 30-60 Fastest onset NDNMB; 1.2 mg/kg for RSI; reversed ng min by sugammadex 16 mg/kg for immediate reversal

Vecuronium Non-depolarizi 3-5 min / 25-40 Hepatic elimination; accumulation in liver failure; ng min no cardiovascular effects

Cisatracurium Non-depolarizi 3-5 min / 35-45 Hofmann elimination-organ-independent; no ng min histamine; ideal in hepatic/renal failure

Atracurium Non-depolarizi 2-3 min / 25-35 min Hofmann elimination + ester hydrolysis; histamine ng release; laudanosine accumulation in renal failure

Reversal Agents

- Neostigmine: Anticholinesterase; reversal of non-depolarizing NMBs; must pair with glycopyrrolate (0.2 mg per 1 mg neostigmine) to block muscarinic effects; avoid if TOF ratio <0.9.
- Sugammadex: Selective binding of rocuronium/vecuronium; 2 mg/kg routine reversal; 4 mg/kg at 1-2 twitches; 16 mg/kg immediate reversal; may reduce hormonal contraceptive efficacy; anaphylaxis risk.
- Flumazenil: Benzodiazepine antagonist; short duration (30-60 min)-re-sedation risk; may precipitate seizures in chronic BZD users.
- Naloxone: Opioid antagonist; 0.04-0.4 mg IV; can precipitate acute withdrawal and pulmonary edema in opioid-dependent patients; shorter duration than most opioids-re-narcotization risk.

Local Anesthetics

- Mechanism: Sodium channel blockade-block in order: autonomic > sensory pain/temp > sensory touch/pressure > motor.
- Amides (lidocaine, bupivacaine, ropivacaine, mepivacaine): Liver metabolism; onset faster than esters; 'amides have 2 i's in their name'.
- Esters (procaine, chloroprocaine, tetracaine, cocaine): Plasma cholinesterase hydrolysis; para-aminobenzoic acid (PABA) metabolite-allergies.
- LAST (Local Anesthetic Systemic Toxicity): CNS (tinnitus, metallic taste, seizures) then CV collapse; treatment: Intralipid 20% 1.5 mL/kg bolus then infusion; AVOID propofol as substitute.
- Maximum doses: Lidocaine 4.5 mg/kg plain, 7 mg/kg with epi; Bupivacaine 2.5 mg/kg; Ropivacaine 3 mg/kg.
- Bupivacaine cardiotoxicity: Most cardiotoxic; binds cardiac Na channels in 'fast-in, slow-out' pattern; avoid for IV regional (Bier block)

Cardiovascular Drugs–High–Yield

Epinephrine Alpha + Beta Anaphylaxis, 1 mg IV for cardiac arrest; 0.1 mcg/kg/min for agonist cardiac arrest, anaphylaxis bronchospasm

Norepinephrin Alpha > Beta Vasodilatory shock Increases SVR and MAP; preferred in septic e agonist (sepsis) shock

Phenylephrine Pure Alpha agonist Spinal hypotension, Increases SVR; reflex bradycardia; no increase in hypotension in AS HR or contractility

Ephedrine Mixed Spinal hypotension Increases HR and BP; crosses placenta; direct/indirect preferred in obstetrics (though phenylephrine sympathomimetic now preferred for FHR)

Vasopressin V1 receptor; Refractory 0.04 units/min infusion; adjunct to NE in sepsis; non-adrenergic vasodilatory shock no dose titration vasoconstriction

Labetalol Alpha + Beta Hypertensive Reduces SVR and HR; useful in OB hypertension; blocker emergency avoid in asthma

Nicardipine CCB (L-type) Hypertensive Peripheral vasodilation; minimal negative emergency, inotropy; useful in neurosurgery cerebral vasospasm

Dantrolene Ryanodine Malignant 2.5 mg/kg IV; repeat q5-10 min up to 10 mg/kg; receptor hyperthermia diluted in sterile water only antagonist

- Boyle's Law: P1V1 = P2V2 (constant temp); pressure and volume inversely proportional-relevant to compressed gas cylinders.
- Henry's Law: Gas solubility in liquid proportional to partial pressure-basis for blood: gas partition coefficients.
- Graham's Law: Diffusion rate inversely proportional to square root of molecular weight-CO2 diffuses faster than O2 across membranes.
- Laplace's Law: T = P x r / 2w (tension in hollow sphere); smaller alveoli tend to collapse-countered by surfactant.
- Bernoulli Principle: As fluid velocity increases, pressure decreases-relevant to entrainment in.

Venturi Devices

- Poiseuille's Law: Flow = (Pr4)/(8l); resistance inversely proportional to radius-doubling tube radius increases flow 16x.
- Ohm's Law analogy: CO = MAP / SVR (like I = V/R); drives hemodynamic calculations.
- Critical temperature of O2: -119 degrees C-O2 must be stored as compressed gas, not liquid, at room temperature.
- Fick Principle: CO = O2 consumption / (CaO2-CvO2); normal SvO2 75%, CaO2 ~20 mL/dL, CvO2 ~15 mL/dL.

High-Yield Calculation Checklist

- Drug dose calculations: dose (mg) = concentration (mg/mL) x volume (mL)
- Infusion rates: mcg/kg/min x weight (kg) / concentration (mcg/mL) x 60 = mL/hr
- Allowable blood loss (ABL): EBV x (Hi-Hf) / Hi; EBV = 65-70 mL/kg adult
- Oxygen content: CaO2 = (Hgb x 1.34 x SaO2) + (0.003 x PaO2); normal ~20 mL/dL
- Alveolar gas equation: PAO2 = (FiO2)(713)-PaCO2/0.8 (at sea level)
- Anion gap: AG = Na-(Cl + HCO3); normal 8-12; elevated in MUDPILES

PART V SUPPLEMENT – NCE EQUIPMENT PEARLS AND TROUBLESHOOTING

This domain tests your mastery of the tools of anesthesia practice-from the gas machine to advanced monitoring. Equipment questions frequently use clinical scenarios with troubleshooting. Know the fail-safe hierarchy, circuit physics, and all alarm types cold.

Gas Machine-Pressure Hierarchy (High to Low Pressure)

- High-pressure system: Cylinder -> yoke/pin index safety system (PISS) -> cylinder regulator (reduces ~2000 psig O2 -> 45 psig)
- Intermediate-pressure system: Reduced pipeline gas (50 psig) -> master switch -> O2 flush (bypasses flowmeters, delivers 35-75 L/min pure O2)
- Low-pressure system: Flowmeters -> vaporizer -> common gas outlet -> breathing circuit.

- Failsafe valve: Shuts off N2O (and other gases) if O2 pipeline falls below threshold (~25 psig); does NOT prevent hypoxic mixture if pure N2O is in the O2 pipeline.
- Proportioning system: Links N2O and O2 flows to maintain minimum 25% O2 in delivered gas mixture.
- O2 Flush: Bypasses vaporizer and flowmeters; NEVER activate during inspiration (barotrauma risk); dilutes volatile agent.
- Variable-bypass vaporizer (e.g., Datex-Ohmeda Tec 6/7): Agent-specific, temperature-compensated; fills only with agent-specific key-fill device.
- Desflurane requires heated vaporizer (Tec 6): Boiling point 22.8 degrees C-would vaporize unpredictably at room temp in standard vaporizer.
- Tipping hazard: Sevoflurane/isoflurane vaporizers may deliver elevated concentrations if tilted; allow 30 min before use if tipped.
- Vaporizer out-of-circuit: Placed between flowmeters and common gas outlet; output concentration is NOT affected by fresh gas flow changes within design range.

Breathing Circuits

Circle system Yes Required Standard adult/ped; economical; allows low fresh (closed/semi-closed) gas flow

Mapleson A (Magill) Some No Most efficient for spontaneous ventilation; FGF = MV

Mapleson D (Bain) Some No Most efficient for controlled ventilation; FGF 2x MV; coaxial design

Non-rebreathing None No Pediatric; high FGF required to prevent rebreathing (Jackson-Rees)

- Soda lime: NaOH + Ca(OH)2; most common; can produce compound A (nephrotoxic) with sevoflurane and CO with desflurane/isoflurane if desiccated.
- Amsorb / Dragersorb: calcium hydroxide only; does NOT produce compound an or CO; safe with all volatiles.
- Color change: purple/violet when exhausted (ethyl violet indicator); may revert color on standing.
- Do not trust color reversal
- Miller blade (straight): Lifts epiglottis directly; preferred in pediatric patients, anterior airways.
- Macintosh blade (curved): Sits in vallecula; lifts epiglottis indirectly via hyo-epiglottic ligament.
- Video laryngoscopy (GlideScope, McGrath, C-MAC): Improves glottic view; may not improve intubation success without appropriate technique; tube delivery can be more difficult despite improved view.
- LMA sizing: Size 1 (<5 kg), 1.5 (5-10 kg), 2 (10-20 kg), 2.5 (20-30 kg), 3 (30-50 kg), 4 (50-70 kg), 5 (70-100 kg), 6 (>100 kg)
- Intubating LMA (ILMA/Fastrach): Allows blind intubation through device; fiberoptic-guided preferred.
- Cricothyrotomy: Landmark between thyroid and cricoid cartilage; needle first then surgical; rescue airway for 'cannot intubate, cannot oxygenate' (CICO) scenario.
- Bougie (Eschmann stylet): Use when grade 3-4 view; feel for tracheal rings; 10-cm rule from teeth to hub.

Pulse Oximetry Functional O2 Cannot detect hyperoxia or CO poisoning (falsely high); (SpO2) saturation of Hgb unreliable in poor perfusion, nail polish (dark colors), motion artifact

Arterial Line Continuous Overdamped waveform: falsely low systolic, high diastolic; beat-to-beat BP, underdamped (ringing): falsely high systolic; Allen test before waveform, blood radial placement draws

PA Catheter PCWP, CO, SvO2 PCWP estimates LVEDP; normal 6-12 mmHg; risks: PA rupture, (Swan-Ganz) arrhythmia, air embolism; largely replaced by TEE and less-invasive monitoring

BIS Monitor Processed EEG-0=isoelectric, 100=awake; target 40-60 for general anesthesia; depth of anesthesia 65-85 for sedation; reduces awareness risk

TEE Transesophageal Superior to TTE intraoperatively; diagnoses wall motion echo-cardiac abnormalities, valve pathology, air embolism, volume status structure/function

Nerve Stimulator Neuromuscular TOF ratio <0.9 = residual block; 4/4 with fade = partial block; (TOF) blockade depth Post-tetanic count (PTC): 1-2 = profound block

Cerebral Oximetry Regional cerebral O2 Normal 55-80%; drop >20% from baseline = intervention (NIRS) saturation threshold; used in carotid, cardiac surgery

Equipment Troubleshooting–High-Yield Scenarios

- High peak pressure + normal plateau pressure: airway obstruction (bronchospasm, ETT kink, secretions, biting)
- High peak AND plateau pressure: decreased compliance (pneumothorax, endobronchial intubation, pulmonary edema, ARDS)
- Sudden ETCO2 drop to zero: esophageal intubation, circuit disconnect, cardiac arrest.
- Gradual ETCO2 decline: pulmonary embolism, decreased cardiac output, hyperventilation.
- SpO2 unreliable: carbon monoxide poisoning (falsely high ~95%), methemoglobinemia (falsely ~85%), severe anemia, poor perfusion.
- O2 cylinder E-tank: full at ~2000 psig; flow rate estimate: 650 L at full; calculate duration = remaining psig x 0.3 / FGF rate.

PART VI – GENERAL PRINCIPLES OF ANESTHESIA

Preoperative evaluation, airway, regional anesthesia, fluids, positioning, pain management, and PACU care.

This is the largest domain on the NCE-35% of your exam. It covers the entire perioperative process from preoperative assessment through PACU discharge. Focus especially on airway management, regional anesthesia, fluid management, and the difficult airway algorithm.

ASA I Normal healthy patient No systemic disease, non-smoker, no/minimal alcohol

ASA II Mild systemic disease Well-controlled DM, HTN, mild lung disease, BMI 30-40, smoker, pregnancy

ASA III Severe systemic disease Poorly controlled DM/HTN, COPD, morbid obesity, active hepatitis, alcohol dependence, ESRD, CVA history, CABG history, CAD

ASA IV Severe systemic disease-Recent MI (<3 mo), CVA, TIA, severe valve disease, sepsis, constant threat to life DIC, ARD

ASA V Moribund-not expected to Ruptured AAA, massive trauma, intracranial bleed with survive 24h without surgery herniation

ASA VI Brain-dead for organ donation -

Clear liquids (water, juice without pulp, 2 hours black coffee, tea)

- Cardiac testing: No routine preop ECG needed in asymptomatic patients; indicated for known CAD, arrhythmia, or new symptoms.
- Pulmonary function tests: Not routinely indicated; useful if surgery-specific lung resection planning (predicted postop FEV1)
- Beta-blockers: Continue perioperatively in patients already taking them; initiating new BB day of surgery increases stroke risk.
- ACE inhibitors/ARBs: Hold morning of surgery-increased risk of refractory intraoperative hypotension.

- Clopidogrel: Hold 5-7 days before elective surgery with neuraxial; hold 5 days for coronary stent patients only if medically safe.
- Herbal supplements: Garlic (bleeding), ginkgo (bleeding), ginseng (hypoglycemia), St. John's Wort (drug interactions, prolonged volatile effect), kava (sedation enhancement)

Difficult Airway Prediction–LEMON Assessment

- L-Look: Facial trauma, obesity, micrognathia, retrognathia, large incisors
- E-Evaluate 3-3-2 rule: Mouth opening >3 fingers, hyoid-chin distance >3 fingers, hyoid-thyroid notch >2 fingers.
- M-Mallampati score: I (full pillars, uvula visible) -> IV (only hard palate visible); score III-IV associated with difficult intubation.
- O-Obstruction: Stridor, foreign body, abscess, angioedema, tumor
- N-Neck mobility: Cervical spine disease, halo, obesity; reduced extension = difficult laryngoscopy.

ASA Difficult Airway Algorithm–Key Decision Points

- Awake intubation: preferred when difficult airway is anticipated AND patient cannot tolerate apnea safely.
- Awake fiberoptic: gold standard for anticipated difficult airway in cooperative patient; topicalize with nebulized lidocaine + superior laryngeal nerve block.
- RSI indications: full stomach, GERD, trauma, bowel obstruction, pregnancy; succinylcholine 1.5-2 mg/kg OR rocuronium 1.2 mg/kg + sugammadex available.
- CICO (Cannot Intubate, Cannot Oxygenate): declare emergency; attempt supraglottic device; proceed immediately to cricothyrotomy if SGA fails.
- Extubation of difficult airway: consider using airway exchange catheter; extubate fully awake; have equipment immediately available.

Dose Small (1.5-3 mL) Large (10-20 mL)

Duration Fixed (agent-dependent) Continuous with catheter

PDPH risk Yes (inadvertent dural Headache from inadvertent dural puncture-80% puncture) incidence with 17g needle

Max sensory level T4 (nipple line) for cesarean T4-T6 for abdominal surgery safe

- High spinal: Block above T4-hypotension, bradycardia, loss of intercostal breathing; if reaches C3-C5, phrenic nerve paralysis and apnea; treatment: pressors, atropine, intubation.
- Spinal headache (PDPH): Positional (worse upright); conservative: caffeine, hydration, analgesics; definitive: epidural blood patch (15-20 mL autologous blood); onset 24-48h after inadvertent dural puncture.
- Total spinal after epidural test dose: 3 mL of 2% lidocaine with 1:200,000 epi; if epidural inadvertently in intrathecal space-will cause rapid high block.
- Brachial plexus roots: C5-T1; interscalene (shoulder/upper arm), supraclavicular (arm/elbow), infraclavicular/axillary (forearm/hand)
- Peripheral nerve blocks-high-yield: TAP block (T10-L1, abdominal wall), femoral/adductor (knee), popliteal sciatic (foot), paravertebral (unilateral breast/thorax)

Normal Saline Isotonic 154 Hyperchloremic metabolic acidosis with large volumes; (0.9%) crystalloid use in head trauma, hyperkalemia

Lactated Ringer's Balanced 130 Most physiologic; preferred for most surgical cases; (LR) crystalloid contains K, Ca; avoid in severe hyperkalemia

Plasmalyte / Balanced 140 Most balanced pH; good for large volume resuscitation; Normosol crystalloid no calcium

Albumin 5% Colloid ~145 Volume expansion; higher cost; no mortality benefit over crystalloid (SAFE trial); useful in hepatic failure

Hetastarch (HES) Synthetic 154 Coagulopathy and renal dysfunction risk-avoid in colloid sepsis, AKI; largely fallen out of favor

PRBCs Blood product-Transfuse at Hgb <7 g/dL (liberal in cardiac, symptomatic, elderly); 1 unit raises Hgb ~1 g/dL

FFP Blood product-For coagulopathy + active bleeding (INR >1.5); 10-15 mL/kg; does NOT correct factor deficiencies rapidly without active bleeding

Platelets Blood product-Transfuse at <50,000 for surgery; <100,000 for neurosurgery/eye; <10,000 for prophylaxis; 1 unit raises by ~5,000-10,000/mm3

Massive Transfusion Protocol (MTP)-1:1:1 Ratio

- Goal: replace blood with blood-PRBC: FFP: Platelets in 1:1:1 ratio
- Trigger: hemorrhagic shock, anticipated ongoing massive blood loss (>10 units PRBC in 24h)
- Add cryoprecipitate for fibrinogen <150 mg/dL (or <200 in obstetric hemorrhage)
- Tranexamic acid (TXA) 1 g IV within 3 hours of traumatic hemorrhage-significantly reduces mortality.
- Monitor with TEG/ROTEM for goal-directed transfusion strategy

Supine Baseline; FRC decreases vs. Aortocaval compression in pregnancy (tilt 15 degrees left) standing

Trendelenburg Increased VR, CO, ICP, airway Cerebral edema, brachial plexus stretch, endotracheal pressure; diaphragm cephalad tube migration caudad

Reverse Decreased VR; improved surgical Hypotension; VAE risk in awake patient Trendelenburg access upper abdomen

Lithotomy Venous stasis; increased VR Peroneal nerve palsy (most common), DVT, when legs raised; leg compartment syndrome if >4h, femoral nerve injury compartment syndrome risk

Lateral Dependent lung compression; Axillary roll required (NOT in axilla-brachial plexus!); decubitus HPV shifts ventilation upward 'down lung' atelectasis

Prone Improved oxygenation; ETT dislodgement on turning, corneal abrasion, increased airway pressure; facial pressure injuries, VAE, repositioning injury edema

Sitting/Beach Best surgical access Venous air embolism (VAE), paradoxical air embolism if Chair shoulder/posterior fossa; VAE PFO, cerebral hypoperfusion risk highest

- WHO analgesic ladder: Step 1 (non-opioids: NSAIDs, acetaminophen) -> Step 2 (mild opioids: codeine, tramadol) -> Step 3 (strong opioids: morphine, oxycodone) + adjuvants at each step.
- Nociceptive pain: Somatic (sharp, well-localized) or visceral (dull, poorly localized); responds to opioids + NSAIDs.
- Neuropathic pain: Burning, shooting, allodynia; responds to gabapentinoids, TCAs, SNRIs, membrane stabilizers.
- Central sensitization / wind-up: NMDA-mediated; ketamine, magnesium, and methadone target this mechanism.
- Multimodal analgesia: Acetaminophen + NSAID + regional/neuraxial + gabapentinoid + opioid as rescue-reduces opioid consumption and side effects.

- ERAS protocols: preoperative carbohydrate loading, minimizing fasting, multimodal analgesia, early mobilization, fluid optimization, minimizing opioids.

Laryngospasm High-pitched stridor, Jaw thrust, 100% O2, CPAP; succinylcholine 0.1-0.5 paradoxical chest mg/kg if complete (full dose 1-1.5 mg/kg if no IV access movement, SpO2 drop IM)

Negative pressure Post-extubation pink frothy CPAP/BiPAP, diuresis; occurs after forceful inspiration pulm edema (NPPE) sputum, low SpO2 against closed glottis (laryngospasm)

Residual NMB Weak grip, head lift <5 sec, Verify TOF >0.9 before extubation; sugammadex or paradoxical breathing, neostigmine

PONV Nausea, vomiting postop Apfel score: female, nonsmoker, PONV/motion sickness hx, opioids; prophylaxis: ondansetron, dexamethasone, scopolamine patch; TIVA reduces PONV vs. volatile

Emergence agitation Combative, disoriented, Rule out pain, hypoxia, urinary retention, residual thrashing immediately paralytics; propofol 0.5-1 mg/kg, physostigmine 0.5-2 postop mg, dexmedetomidine

Shivering Muscle tremors, increased Meperidine 25 mg IV most effective; warming; clonidine, O2 consumption dexmedetomidine (400-500%)

PART VII – SURGICAL PROCEDURES AND SPECIAL POPULATIONS

Procedure-specific anesthesia and care of pediatric, obstetric, geriatric, obese, and other special populations.

This domain tests your ability to apply anesthetic principles to specific surgical settings and vulnerable patient populations. Special populations-pediatric, obstetric, geriatric, and obese patients-are especially high-yield.

Cardiac (CABG, valve) CPB management: heparin 300-400 units/kg, ACT >400 sec; myocardial protection with cardioplegia; protamine reversal post-bypass; TEE essential; weaning from bypass: rhythm, temperature, volume

TAVR/Minimally GA or MAC/sedation; TEE mandatory; rapid pacing for deployment; hemodynamic invasive cardiac management during valve deployment; paravalvular leak assessment post-deployment

Neurosurgery ICP management: head up 15-30 degrees, avoid N2O, hyperventilate to PCO2 35 (not <30), (craniotomy) mannitol 0.25-1 g/kg, dexamethasone; avoid ketamine; avoid hypotension (CPP goal); TIVA preferred for neuromonitoring

Carotid endarterectomy GA vs. regional (cervical plexus block); maintain cerebral perfusion during (CEA) cross-clamp; shunting decision; NIRS monitoring for cerebral ischemia; hypertension common post-clamp removal

Thoracic (lung One-lung ventilation (OLV): DLT or bronchial blocker; HPV blunts V/Q mismatch; resection) lung isolation verification with FOB; TV 4-6 mL/kg IBW during OLV; treat refractory hypoxia: CPAP nondependent, PEEP dependent, partial PPV, re-expand lung

Abdominal/Laparoscopi Pneumoperitoneum (CO2): increased PaCO2, ICP, airway pressure; decreased FRC; c Trendelenburg worsens effects; watch for subcutaneous emphysema and CO2 embolism

Orthopedic (TJR, spine) Fat embolism with IM reaming; tourniquet deflation: hypotension, metabolic acidosis, reperfusion; DVT prophylaxis; cement reaction; regional preferred to reduce blood loss

Ophthalmologic Oculocardiac reflex (OCR): bradycardia with traction on EOM; treat with IV atropine, release traction; IOP: ketamine controversial; avoid succinylcholine in open globe; LMA often sufficient

Robotic/laparoscopic Steep Trendelenburg + pneumoperitoneum; facial edema; ETT migration; airway prostatectomy edema post-extubation; monitor for subcutaneous emphysema

- Highest risk: sitting/beach chair craniotomy, posterior fossa, hepatic resection, spine surgery.
- Signs: mill-wheel murmur (esophageal stethoscope), decreased ETCO2, increased ETN2, hypotension, dysrhythmias.
- TEE is most sensitive monitor; Doppler is most practical
- Treatment: flood field with saline, occlude wound, Durant maneuver (left lateral decubitus + Trendelenburg), aspiration through CVP catheter at RA, 100% O2, D/C N2O, CPR if arrest.
- Physiology: Higher HR, lower BP, higher O2 consumption (6-8 mL/kg/min vs. 3 mL/kg/min adults); rapid desaturation; VTdead space/VT ratio same as adult (~0.33)
- Inhalation induction: Sevoflurane with 70% N2O + 30% O2; MAC higher in infants (sevoflurane MAC 3.3% in neonates); higher cardiac output = faster equilibration.
- ETT sizing (uncuffed): (Age/4) + 4 = tube size; cuffed tubes now preferred in all ages.
- ETT depth (cm at lip): Weight (kg) + 10, OR age/2 + 12
- Fluid management: Maintenance: 4/2/1 rule (4 mL/kg/h for first 10 kg; 2 mL/kg/h for next 10 kg; 1 mL/kg/h for each kg >20)
- Hypoglycemia risk: Check glucose in premature, small for gestational age, diabetic mothers, neonates; supplement with D5 or D10 if needed.
- Laryngospasm: 0.87% incidence in children vs. 0.08% adults; most common anesthesia complication in peds; risk with URI, young age, inexperienced provider.

Physiologic Changes in Pregnancy

Cardiovascular CO increases 40-50%; HR up Aortocaval compression-tilt to left; supine 15-20 bpm; SVR decreases 20% hypotension syndrome

Respiratory MV increases 50%; FRC Pre-oxygenate for 3-5 min; early desaturation during decreases 20%; O2 consumption intubation up 20%; rapid desaturation

GI Delayed gastric emptying; RSI for all general anesthesia after 12-18 weeks decreased LES tone; increased gestation aspiration risk

Hematologic Dilutional anemia; hypercoagulable Normal Hgb 10-11 g/dL; DVT risk; thrombocytopenia may state; WBC increases complicate neuraxial

CNS MAC decreases ~40%; spinal Reduced anesthetic requirements; dose decreases ~30% progesterone-mediated

- Labor analgesia: Epidural or CSE (combined spinal-epidural); initiate with low-concentration bupivacaine (0.0625-0.125%) + fentanyl; test dose 3 mL 2% lidocaine + epi 1:200,000.
- Cesarean spinal: Hyperbaric bupivacaine 10-12 mg + fentanyl 15-25 mcg + preservative-free morphine 0.1-0.2 mg; target T4 sensory level.
- Spinal hypotension in OB: Phenylephrine first-line (preserves uteroplacental blood flow better than ephedrine); prophylactic phenylephrine infusion recommended.
- Fetal heart rate changes: Late decelerations = uteroplacental insufficiency; variable = cord compression; severe bradycardia = emergency C-section may be needed.
- HELLP syndrome: Hemolysis, Elevated Liver enzymes, Low Platelets; associated with preeclampsia; platelet threshold for epidural debated (most anesthesiologists use >75,000-80,000)
- Amniotic fluid embolism: Sudden cardiovascular collapse + DIC + hypoxia during labor or delivery; treatment supportive; cardiopulmonary resuscitation; highly lethal.
- Postpartum hemorrhage: Oxytocin first-line uterotonic (20-40 units in 1L LR); if refractory: methylergonovine (avoid in HTN), 15-methyl-PGF2alpha (avoid in asthma), misoprostol.

- Pharmacokinetics: Decreased hepatic and renal function -> prolonged drug effect; decreased plasma albumin -> more free drug; increased body fat -> larger Vd for lipophilic drugs.
- Reduced MAC: MAC decreases ~6% per decade after age 40; elderly require less volatile anesthetic.
- Cardiovascular: Decreased cardiac reserve; diastolic dysfunction common; orthostatic hypotension; blunted baroreceptor reflex.
- Respiratory: Increased closing capacity (exceeds FRC at age ~65 supine); decreased hypoxic and hypercapnic ventilatory responses; increased aspiration risk.
- Postoperative cognitive dysfunction (POCD): Risk increases with age, depth of anesthesia, duration, polypharmacy; BIS-guided anesthesia may reduce risk; avoid benzodiazepines in elderly.
- Emergence delirium: Hypoactive or hyperactive; multifactorial; rule out pain, hypoxia, urinary retention, medication effects.
- Airway: Increased Mallampati, short neck, limited mobility, redundant tissue-ALWAYS preoxygenate optimally; ramped position (ear to sternal notch); 25 degrees head-up reduces aspiration risk.
- Dosing: Use IBW for volatile agent MAC; lean body weight (LBW) for most IV drugs; TBW for succinylcholine (due to increased pseudocholinesterase activity)
- Respiratory: Decreased FRC, increased work of breathing; OSA common-screen with STOP-BANG; CPAP/BiPAP pre and postop in OSA patients.
- Bariatric surgery: RSI required (full stomach); LMA Fastrach or video laryngoscope preferred; postop opioid minimization critical in OSA; walking epidural or regional whenever possible.
- STOP-BANG Score >=3 = High OSA risk: Snoring, Tired, Observed apnea, Pressure (HTN),.

PART VIII – BOARD DAY STRATEGY AND QUICK REFERENCE

- Know your 4 domains and their weights: Basic Sciences 20%, Equipment 20%, General Principles 35%, Surgical/Special 25%.
- The NCE is adaptive-a hard question is a GOOD sign; stay calm and keep going
- For 'select ALL that apply' MCR questions: evaluate each option independently; partial credit is.
- Calculation questions: bring your calculator skills; common calcs are drug doses, blood loss, O2 content, compliance.
- If your exam stops at 100 questions-do NOT assume you failed; most passes occur at minimum question count.
- Pass rate (2025): 90.5% first-time-the odds are strongly in your favor with solid preparation.
- Read AANA practice advisories and standards-ethics/scope of practice questions draw from these documents.

Normal Laboratory Values

PaCO2 35-45 mmHg Respiratory acid-base control

PaO2 80-100 mmHg <60 mmHg = respiratory failure threshold

HCO3-22-26 mEq/L Metabolic acid-base control

SaO2 >95% <90% requires urgent intervention

Na+ 135-145 mEq/L Hyponatremia <130: risk of seizure

K+ 3.5-5.0 mEq/L <3.0 or >6.0 arrhythmia risk

Glucose 70-110 mg/dL Perioperative target 140-180 mg/dL (ICU)

Creatinine 0.6-1.2 mg/dL >1.5 impairs drug clearance

PT/INR 11-13 sec / 0.9-1.1 >1.5 INR: FFP before neuraxial

APTT 25-35 sec >2x normal with heparin therapy

Platelets 150,000-400,000/m <80,000: avoid neuraxial; <50,000: transfuse before surgery m3

Hgb 12-17 g/dL Transfuse threshold typically Hgb <7 g/dL

M Methanol, Metformin Visual symptoms with methanol; lactic acidosis with metformin

U Uremia Renal failure-accumulation of organic acids

P Propylene glycol, Found in some IV medications Paraldehyde

L Lactic acidosis Shock, sepsis, ischemia, cyanide, liver failure

E Ethylene glycol Antifreeze ingestion; calcium oxalate crystals in urine

S Salicylates Aspirin toxicity; mixed respiratory alkalosis + metabolic acidosis

Cardiac Dysrhythmia–Perioperative Management

- SVT: Adenosine 6 mg rapid IV push (12 mg x2 if needed); Valsalva or carotid sinus massage; cardiovert if unstable.
- New A-fib with RVR: Rate control (metoprolol, diltiazem, digoxin); anticoagulation if >48h; cardiovert if hemodynamically unstable.
- PVCs: Benign in isolation; runs of PVCs or R-on-T: amiodarone or lidocaine; correct electrolytes; treat ischemia.
- VT (pulseless): Defibrillate 200J biphasic; amiodarone 300 mg IV; follow ACLS; treat reversible causes (5H/5T)
- VF: Immediate defibrillation; CPR; epinephrine 1 mg q3-5 min; amiodarone after 3rd shock.
- Bradycardia: Atropine 0.5 mg IV (up to 3 mg); glycopyrrolate 0.2 mg; pacing if refractory; epinephrine if profound.
- Torsades de Pointes: Magnesium sulfate 1-2 g IV; correct QT-prolonging drugs, K+, Mg2+; overdrive pacing.

5Hs and 5Ts-Reversible Causes of Cardiac Arrest

- 5 Hs: Hypovolemia, Hypoxia, Hydrogen ion (acidosis), Hypo/Hyperkalemia, Hypothermia.
- 5 Ts: Tension pneumothorax, Tamponade (cardiac), Toxins, Thrombosis (pulmonary),
- Treat all reversible causes simultaneously during CPR
- TEE is invaluable in unexplained intraoperative cardiac arrest-diagnose and treat in real time.

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PART IX – CRISIS ALGORITHMS AND PROFESSIONAL PRACTICE

Essential crisis protocols and professional practice topics for a complete NCE review.

Malignant Hyperthermia (MH)

MH is a rare pharmacogenetic emergency triggered by volatile anesthetics and/or succinylcholine. Survival depends on early recognition and rapid dantrolene.

Recognition

- Early: rising ETCO2, tachycardia, masseter rigidity/trismus, mixed acidosis.
- Later: hyperthermia, generalized rigidity, hyperkalemia, myoglobinuria, arrhythmias, DIC.

Management

- Call for help and MH cart; discontinue triggers; switch to non-triggering anesthetic (TIVA).
- Hyperventilate with 100% oxygen at high fresh-gas flows.
- Dantrolene 2.5 mg/kg IV repeated until controlled (often cumulative >=10 mg/kg).
- Cool if core temperature >39 C; stop cooling near 38 C.
- Treat hyperkalemia and arrhythmias; avoid calcium-channel blockers with dantrolene.
- Send labs (ABG, electrolytes, CK, coagulation, urine); maintain urine output; ICU monitoring for recurrence.
- Stop injection; manage airway; 100% oxygen; benzodiazepines for seizures.
- Lipid emulsion 20%: 1.5 mL/kg lean body weight bolus, then infusion per ASRA checklist; repeat bolus if needed.
- Modify ACLS (smaller epinephrine doses); avoid local anesthetic antiarrhythmics; consider CPB if refractory.

Perioperative Anaphylaxis

- Common triggers: NMBAs, antibiotics, latex, chlorhexidine, colloids/dyes.
- Treat with epinephrine, fluids, oxygen/airway support; adjunct antihistamines/steroids; obtain tryptase when feasible.
- Plan primary and backup strategies before induction; optimize first-pass success.
- Limit attempts; prioritize oxygenation; call for help early.
- Cannot intubate/cannot oxygenate: emergency front-of-neck access without delay.
- Treat difficult extubation as a planned procedure.

High Spinal / Total Spinal

- Support airway/ventilation; treat bradycardia and hypotension aggressively; left uterine displacement in obstetrics.
- Verify backup ventilation, oxygen supply (pipeline and cylinder), leak checks, scavenging, absorbent, valves, ventilator, monitors/alarms, suction, airway equipment, and drug safety organization.
- Perform a full check before the first case daily and an abbreviated check between cases per institutional policy.

Temperature, Awareness, and Transfusion Emergencies

- Prevent hypothermia with active warming; monitor temperature for longer anesthetics.
- Awareness risk rises with light anesthesia, NMBAs, emergencies, TIVA without monitoring, and substance use history.
- Differentiate AHTR, TRALI, TACO, and anaphylactic transfusion reactions quickly; stop the transfusion and support ABCs.

PACU Discharge Concepts

- Use Aldrete or institutional criteria plus pain, PONV, bleeding, and block regression standards.
- Extend monitoring for OSA and other high-risk patients; ensure CPAP availability when indicated.

Professional Practice and Safety Culture

- Informed consent, accurate documentation, controlled-substance security, and closed-loop communication are core professional duties.
- Speak-up culture, fatigue management, and adverse-event reporting improve patient safety and team performance.

Ultrasound Basics for Anesthesia

- High-frequency probes for superficial nerves/vessels; low-frequency for deeper targets.
- Maintain probe-marker orientation, visualize the needle tip, and confirm vascular entry with compression/Doppler as appropriate.

Closing Encouragement

You now have a domain-aligned course spanning basic sciences, equipment, pharmacology, clinical principles, special populations, and crisis care. Practice deliberately, calculate confidently, and rehearse algorithms until they are automatic.

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