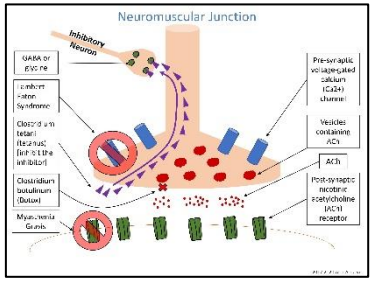
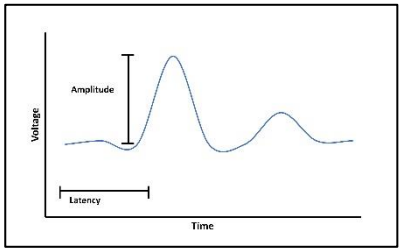
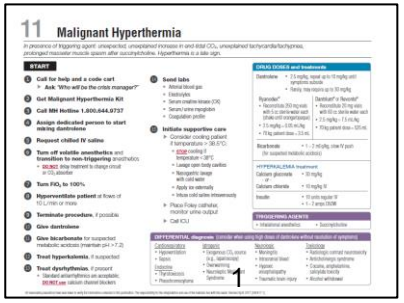



# Data-Driven Didactics Review Session:
# Lifelong Learning in Anesthesia

Alexander Arriaga, MD, MPH, ScD
@AlexArriagaMD
datadrivendidactics.org

| Parameter | Geriatric |
|---|---|
| Functional Residual Capacity | ↑ |
| Minute Ventilation | ↔ |
| Tidal Volume | ↓ |
| Respiratory Rate | ↑ |
| Closing Capacity | ↑ |
| Tracheal Compliance | ↔ |
| Airway Resistance | ↑ |



# Disclosures

**Funded Research within the Past 12 months:**

Grant from the Anesthesia Patient Safety Foundation (APSF) and the Foundation for Anesthesia Education and Research (FAER).

Strategic Advisor for the BWH Center for Diversity and Inclusion and recipient of their Minority Faculty Career Development Award.

**Professional Society Membership/Leadership:**

Editor on the Patient Safety Editorial Board for the American Society of Anesthesiologists, and a Question Author/Editor for the American Board of Anesthesiology, both of which provide a stipend for work that is otherwise done in a volunteer capacity.

This talk represents the views of the presenter and not necessarily the supporting agencies.

The presenter does not believe that any of these represent a conflict of interest.

# Goal and Objectives

**Overall Goal**:

- To provide, at a key moment, a data-driven and lifelong-learning style anesthesia review.

**Objectives**:

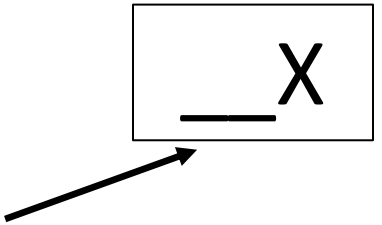
By the end of this session, participants should be able to:

- State anesthesia implications regarding selected high-yield anesthesia topics to guide further learning.
- Apply high-yield, evidence-based anesthesia knowledge towards lifelong learning in anesthesia.

# Public Knowledge on the In-Training Examination (ITE)

- Covers both basic and advanced topics
- ABA Content Outline
- ITE Blueprint
- ITE Gaps in Knowledge ABA reports
- OpenAnesthesia.org: ITE Keywords, previously asked topics from 2008-2021

# Format for this session and slides




- Will review topics, by category. Weighted priority given to key topics.
  - *Numbers on upper right-hand corner signify that the slide addresses topics asked "X" number of times on in-training exams, based on publicly available data, "intended to help plan continuing medical education," "help…identify specific strengths and weaknesses," and/or "assist and support you in the design of your educational program."*[1]
- ***After years of experience reviewing (1) how to create a PowerPoint slide & (2) literature on methods of learning (including active learning): these slides are methodically created to prioritize the stated objective: a data-driven and lifelong-learning style anesthesia review.***
  - Attempts have been made to use no smaller than size 16pt font and provide open-space, with the stated objective taking priority.
- This review attempts to help learners that range from those who struggle with lifelong learning, to those who are already experts.
- Residents who have not done certain specialty rotations have generally enjoyed the "review" of something new.
- Feel free to ask questions.
- No recording; please do not distribute beyond your residency class.

1. American Board of Anesthesiology In-training reports, program summary keywords, and Gaps in Knowledge reports. The keywords are provided to programs nationwide and publicly available at www.openanesthesia.org. Gaps in Knowledge reports are also provided to programs nationwide and/or publicly available at www.theaba.org. For example: https://www.theaba.org/pdfs/ITE_Gaps_Knowledge_Report.pdf. Accessed Sept 24, 2020. The design of this educational program was informed by these keywords.

# References include

- Anesthesia and Uncommon Dz, Miller's Anesthesia, Barash's Clinical Anesthesia, Chestnut's Obstetric Anesthesia, Cote and Lerman's A Practice of Anesthesia for Infants and Children, and other Textbooks.
- Public knowledge on the ITE (mentioned in prior slide).
- OpenAnesthesia.
- Numerous articles/manuscripts, UptoDate, Epocrates & other resources.

*Attempts have been made to cite and squeeze references into individual slides, understanding that this makes slides crowded. Expanded citations/references for a given slide can be provided on request.*

*Views my own. All reasonable precautions have been taken to verify the information contained in this lecture. The responsibility for the interpretation and use of the information lies with the reader.*

# Neuro & Neuromuscular

References for image “Key Ions Involved in Neuromuscular Transmission”: Miller’s Anesthesia, 9th Ed, Ch 35 // Pollard’s Cell Biology, 3rd Ed, Ch 17 // JIvory96, CC BY-SA 4.0, via Wikimedia Commons (https://commons.wikimedia.org/wiki/File:Ca2%2B_sparks.jpg) // https://en.wikipedia.org/wiki/File:NMJ_Signalling_1.jpg CC BY-SA 3.0 // https://open.oregonstate.education/aandp/chapter/10-3-muscle-fiber-excitation-contraction-and-relaxation/ CC BY-SA 4.0 // Litman RS et al. Anesthesiology 2018; PMID 28902673 // Roderick et al. PMID: 12781146.

# Neuro: Electroconvulsive Therapy (ECT)

17X

- Sympathetic swings: initial parasympathetic response and bradycardia (followed by a sympathetic surge). Some pre-treat with glycopyrrolate/atropine (also reduces secretions).
- Caution in patients with risks from hemodynamic swings: e.g., pheochromocytoma, severe coronary disease, sensitivity to increased ICP (ECT briefly increases cerebral blood flow).
- Common agents use to decrease ECT hemodynamic response: labetalol, esmolol, calcium channel blockers (Barash 8th Ed, Ch 33). Diltiazem may reduce seizure duration. Dexmedetomidine and remifentanil also studied as adjuncts.
- Paralysis: succinylcholine popular. Rocuronium/sugammadex being explored but dosing not well established (Miller 9th Ed, Ch 28).

| Induction Agent | Effect on Seizure Duration |
|---|---|
| **Methohexital** | No change |
| **Etomidate** | Increases |
| Ketamine | Increases |
| Propofol | Decreases |

| Adjunct | Effect on Seizure Duration |
|---|---|
| Midazolam | Decreases |
| Lidocaine | Decreases |
| Dexmedetomidine | No change |
| Remifentanil | No change vs increased |

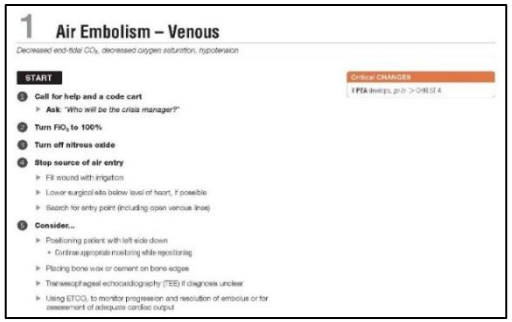
* **Methohexital** (1 to 1.5 mg/kg) has less effect on seizures than other induction agents and has been a traditional "gold standard."

Refs: Barash 8th Ed Ch 33 // Miller 9th Ed, Ch 28// Kadiyala et al 2018; PMID: 29870425 // Deiner et al 2009; PMID: 19359878 // Stripp et al 2018; PMID: 28462732 // Soehle et al 2018; PMID: 29994943 // Tess A et al. Medical consultation for electroconvulsive therapy. UpToDate (June11'19) // Wajima et al 2001; PMID: 11323371 // Wajima et al 2002; PMID: 12500511.

# Air/Fat/Amniotic Fluid Embolism

13X

- Most sensitive test to detect venous air embolism: TEE (0.02mL/kg air)
  - Most sensitive noninvasive test: precordial Doppler (0.05 mL/kg air)
- High risk for venous air embolism: posterior fossa procedure; sitting position craniotomy.
- Fat embolism buzzwords: orthopedic trauma patient (such as long bone/pelvic fracture); hypoxemia, hypotension, tachycardia, tachypnea/respiratory alkalosis, thrombocytopenia; petechial rash.
- Amniotic fluid embolism buzzwords: labor & delivery patient; hypotension, hypoxemia, tachycardia, dyspnea, loss of consciousness, generalized bleeding/coagulopathy/ disseminated intravascular coagulation (DIC).
- Treatment for Air Embolism: Handout


1 Air Embolism – Venous

Decreased end-tidal $CO_2$, decreased oxygen saturation, hypotension

START

1. Call for help and a code cart
   - Ask: *"Who will be the crisis manager?"*
2. Turn $FiO_2$ to 100%
3. Turn off nitrous oxide
4. Stop source of air entry
   - Fill wound with irrigation
   - Lower surgical site below level of heart, if possible
   - Search for entry point (including open venous lines)
5. Consider...
   - Positioning patient with left side down
     - Continue appropriate monitoring while repositioning
   - Placing bone wax or cement on bone edges
   - Transesophageal echocardiography (TEE) if diagnosis unclear
   - Using ETCO$_2$ to monitor progression and resolution of embolus or for assessment of adequate cardiac output

Critical CHANGES

If PEA develops, go to >CHECK 4

Miller 9th Ed, Ch 57 and 64. // Mirski et al 2007; PMID: 17197859 // Chestnut's Obstetric Anesthesia 6th Ed, Ch 38. //Ariadne Labs Operating Room Crisis Checklists. See https://www.ariadnelabs.org/ for latest version. With permission via Creative Commons BY-NC-SA ( https://creativecommons.org/licenses/by-nc-sa/4.0/). Right figure: From Miller 9th Ed, Ch 57 (Fig 57-11). BP , Blood pressure; CO , cardiac output; CVP , central venous pressure; ECG , electrocardiogram; ET-CO 2 , end-tidal carbon dioxide; PAP , pulmonary artery pressure; Stetho , esophageal stethoscope; T-echo , transesophageal echo. Accessed via ClinicalKey.

# 1 Air Embolism – Venous

*Decreased end-tidal $CO_2$, decreased oxygen saturation, hypotension*

**START**

1. **Call for help and a code cart**
   - **Ask**: *"Who will be the crisis manager?"*
2. **Turn $FiO_2$ to 100%**
3. **Turn off nitrous oxide**
4. **Stop source of air entry**
   - Fill wound with irrigation
   - Lower surgical site below level of heart, if possible
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5. **Consider...**
   - Positioning patient with left side down
     - Continue appropriate monitoring while repositioning
   - Placing bone wax or cement on bone edges
   - Transesophageal echocardiography (TEE) if diagnosis unclear
   - Using $ETCO_2$ to monitor progression and resolution of embolus or for assessment of adequate cardiac output

**Critical CHANGES**

If **PEA** develops, *go to* ▷ CHKLST 4

- Also: Consider if Epinephrine needed. From anaphylaxis checklist:

**DRUG DOSES and treatments**

| | |
|---|---|
| Epinephrine: | BOLUS: 10 – 100 mcg, repeat as necessary |
| | INFUSION: 1 – 10 mcg/min |

# Complications of Subarachnoid Hemorrhage (SAH)

20X

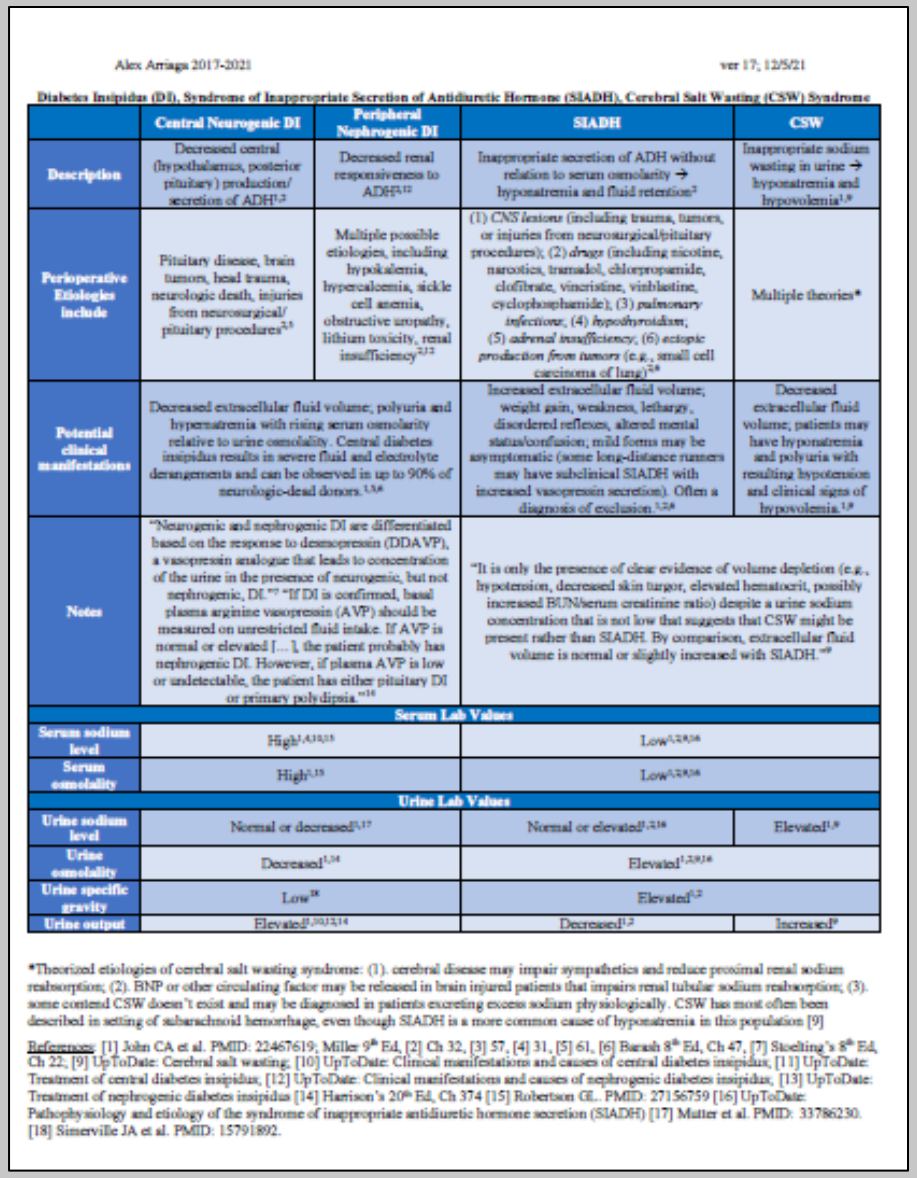
- ECG changes that can occur after SAH: profound "canyon" T wave inversions, nonspecific T-wave abnormalities, QT prolongation, ST-segment depression, and U-waves. "There is typically no relationship between the ECG changes and echocardiographic myocardial dysfunction. ECG abnormalities [alone] do not herald evolving or impending cardiac disease." [Miller 9th Ed, Ch 57]
  - Echocardiography sometimes independently done (SAH can cause a catecholamine mediated myocardial "stunning" injury).
- Neurogenic Pulmonary edema: increased ICP can activate sympathetics → catecholamine surge → increased pulmonary capillary pressure → destruction of capillary/alveolar walls → leakage of fluid.
- Peak occurrence of cerebral vasospasm: 3 days – 2 weeks after SAH; peak at 7 days → some consider SAH surgery early (0-3 days) or late (>10 days).
  - Triple H therapy: hypervolemia, hypertension, hemodilution (controversial).
  - Calcium channel blockers: may mitigate vasospasm (nicardipine) or complications from vasospasm (nimodipine).
- Syndrome of inappropriate secretion of antidiuretic hormone (SIADH), Diabetes Insipidus (DI) and Cerebral Salt Wasting Syndrome (CSW): see handout.

| Hunt-Hess Classification for Intracranial Aneurysm/SAH Severity by Clinical Symptoms | |
|---|---|
| Grade | Clinical Symptoms |
| 1 | Asymptomatic (or minimal headache/nuchal rigidity) |
| 2 | Moderate/severe headache, nuchal rigidity; no neuro deficit except cranial nerve palsy |
| 3 | Confusion, drowsiness, mild focal neuro deficit |
| 4 | Stupor, hemiparesis (moderate/severe), early decerebrate rigidity |
| 5 | Deep coma, decerebrate rigidity, moribund |
| If severe comorbidities and severe vasospasm on imaging, use next highest grade. | |



Miller 9th Ed., Ch 57. // Cottrell/Patel 6th Ed, Ch 23 // Hunt WE, Hess RM. J Neurosurg 1968. PMID: 5635959.

# Syndrome of Inappropriate antidiuretic hormone (SIADH) vs Diabetes Insipidus (DI) vs Cerebral Salt Wasting Syndrome (CSW)



Alex Arriaga 2017-2021 ver 17; 12/5/21

**Diabetes Insipidus (DI), Syndrome of Inappropriate Secretion of Antidiuretic Hormone (SIADH), Cerebral Salt Wasting (CSW) Syndrome**

| | Central Neurogenic DI | Peripheral Nephrogenic DI | SIADH | CSW |
|---|---|---|---|---|
| **Description** | Decreased central (hypothalamus, posterior pituitary) production/ secretion of ADH[1,2] | Decreased renal responsiveness to ADH[5,12] | Inappropriate secretion of ADH without relation to serum osmolarity → hyponatremia and fluid retention[2] | Inappropriate sodium wasting in urine → hyponatremia and hypovolemia[1,9] |
| **Perioperative Etiologies include** | Pituitary disease, brain tumors, head trauma, neurologic death, injuries from neurosurgical/ pituitary procedures[2,5] | Multiple possible etiologies, including hypokalemia, hypercalcemia, sickle cell anemia, obstructive uropathy, lithium toxicity, renal insufficiency[2,12] | (1) *CNS lesions* (including trauma, tumors, or injuries from neurosurgical/pituitary procedures); (2) *drugs* (including nicotine, narcotics, tramadol, chlorpropamide, clofibrate, vincristine, vinblastine, cyclophosphamide); (3) *pulmonary infections*; (4) *hypothyroidism*; (5) *adrenal insufficiency*; (6) *ectopic production from tumors* (e.g., small cell carcinoma of lung)[2,6] | Multiple theories* |
| **Potential clinical manifestations** | Decreased extracellular fluid volume; polyuria and hypernatremia with rising serum osmolarity relative to urine osmolality. Central diabetes insipidus results in severe fluid and electrolyte derangements and can be observed in up to 90% of neurologic-dead donors.[1,3,6] | | Increased extracellular fluid volume; weight gain, weakness, lethargy, disordered reflexes, altered mental status/confusion; mild forms may be asymptomatic (some long-distance runners may have subclinical SIADH with increased vasopressin secretion). Often a diagnosis of exclusion.[1,2,6] | Decreased extracellular fluid volume; patients may have hyponatremia and polyuria with resulting hypotension and clinical signs of hypovolemia.[1,9] |
| **Notes** | "Neurogenic and nephrogenic DI are differentiated based on the response to desmopressin (DDAVP), a vasopressin analogue that leads to concentration of the urine in the presence of neurogenic, but not nephrogenic, DI." "If DI is confirmed, basal plasma arginine vasopressin (AVP) should be measured on unrestricted fluid intake. If AVP is normal or elevated [...], the patient probably has nephrogenic DI. However, if plasma AVP is low or undetectable, the patient has either pituitary DI or primary polydipsia."[16] | | "It is only the presence of clear evidence of volume depletion (e.g., hypotension, decreased skin turgor, elevated hematocrit, possibly increased BUN/serum creatinine ratio) despite a urine sodium concentration that is not low that suggests that CSW might be present rather than SIADH. By comparison, extracellular fluid volume is normal or slightly increased with SIADH."[9] | |
| **Serum Lab Values** | | | | |
| **Serum sodium level** | High[1,4,10,15] | | Low[1,2,9,16] | |
| **Serum osmolality** | High[1,15] | | Low[1,2,9,16] | |
| **Urine Lab Values** | | | | |
| **Urine sodium level** | Normal or decreased[1,17] | | Normal or elevated[1,2,16] | Elevated[1,9] |
| **Urine osmolality** | Decreased[1,14] | | Elevated[1,2,9,16] | |
| **Urine specific gravity** | Low[18] | | Elevated[1,2] | |
| **Urine output** | Elevated[1,10,13,14] | | Decreased[1,2] | Increased[9] |

*Theorized etiologies of cerebral salt wasting syndrome: (1). cerebral disease may impair sympathetics and reduce proximal renal sodium reabsorption; (2). BNP or other circulating factor may be released in brain injured patients that impairs renal tubular sodium reabsorption; (3). some contend CSW doesn't exist and may be diagnosed in patients excreting excess sodium physiologically. CSW has most often been described in setting of subarachnoid hemorrhage, even though SIADH is a more common cause of hyponatremia in this population [9]

References: [1] John CA et al. PMID: 22467619; Miller 9th Ed, [2] Ch 32, [3] 57, [4] 31, [5] 61, [6] Barash 8th Ed, Ch 47, [7] Stoelting's 8th Ed, Ch 22, [9] UpToDate: Cerebral salt wasting; [10] UpToDate: Clinical manifestations and causes of central diabetes insipidus; [11] UpToDate: Treatment of central diabetes insipidus; [12] UpToDate: Clinical manifestations and causes of nephrogenic diabetes insipidus; [13] UpToDate: Treatment of nephrogenic diabetes insipidus [14] Harrison's 20th Ed, Ch 374 [15] Robertson GL. PMID: 27156759 [16] UpToDate: Pathophysiology and etiology of the syndrome of inappropriate antidiuretic hormone secretion (SIADH) [17] Mutter et al. PMID: 33786230. [18] Simerville JA et al. PMID: 15791892.

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| **Urine output** | Elevated[1,10,12,14] | | Decreased[1,2] | Increased[9] |

# Glasgow Coma Scale

6X

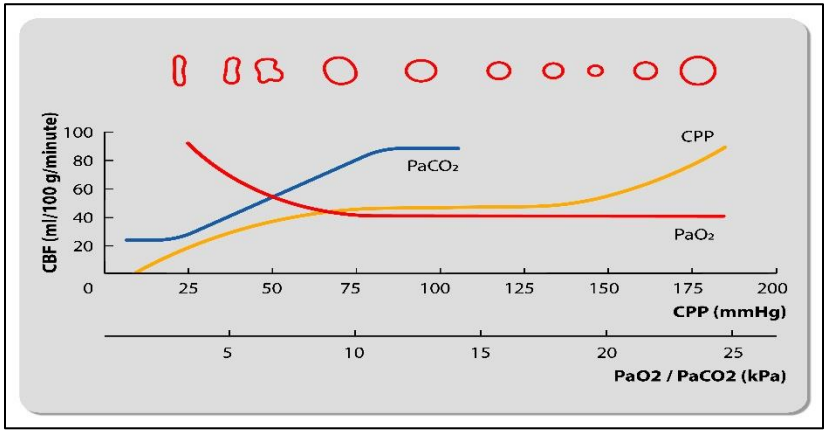
| Eye-Opening Response | Verbal Response | Motor Response |
|---|---|---|
| 4= Spontaneous | 5= Oriented (name, place, date) | 6= Follows commands |
| 3= To sound | 4= Confused | 5= Localizes pain |
| 2= To pressure | 3= Words (inappropriate speech) | 4= Normal flexion |
| 1= None | 2= Sounds (incomprehensible moans/groans) | 3= Abnormal Flexion to pain (decorticate posturing – slow movements, arms across chest, rotation of forearms, clenching of thumbs, extension of legs) |
| | 1=None | 2= Extension to pain (decerebrate posturing) |
| | | 1= None |
| **"NT" is used for a given category if it is non-testable (for example: E4, VNT, M5)** | | |

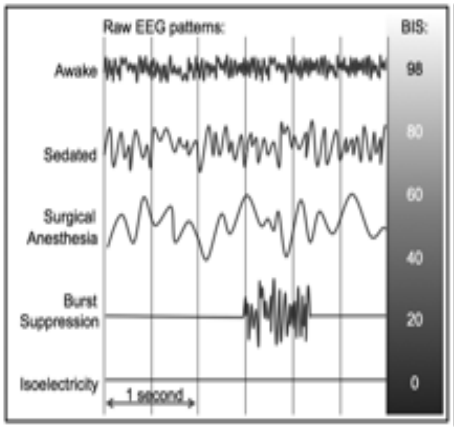
- Less than 8, intubate: "Advanced Trauma Life Support Guidelines suggest that head injured patients should be intubated if their Glasgow coma scale is less than 8."
- Video demonstration available at: www.glasgowcomascale.org (https://youtu.be/v6qpEQxJQO4)

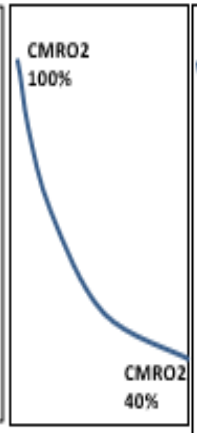
Wilson MH, Habig K, Wright C, et al. Pre-hospital emergency medicine. The Lancet 2015, 386: 2526-34. // https://www.glasgowcomascale.org/downloads/GCS-Assessment-Aid-English.pdf?v=3 Accessed Jan 2, 2021. // Galvagno et al. Advanced Trauma Life Support ® Update 2019: Management and applications for adults and special populations. Anesthsiol Clin 2019; 37: 13-32.

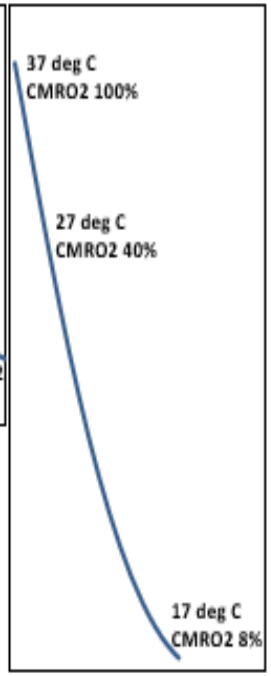
# Factors affecting Cerebral Blood Flow (CBF)

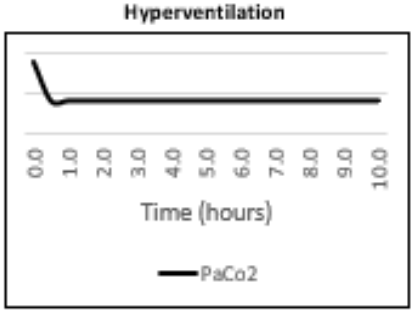
16X

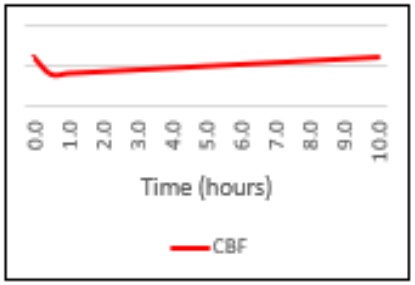


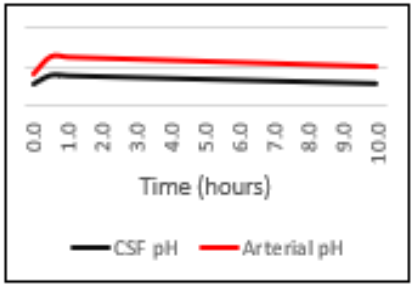




| Anesthetics, CBF, and CMR | | | |
|---|---|---|---|
| | Agent | CBF | CMR |
| Intravenous | Midazolam | ↓ | ↔ |
| | Fentanyl | ↓ | ↓ |
| | Propofol | ↓ | ↓ |
| | Dexmedetomidine | ↓ | ↓ |
| | Remifentanil | * | ↔ |
| | Sufentanil | ↓ | ↓ |
| | Morphine | ↓ | ↓ |
| Inhalational | Sevoflurane | ↑ | ↓ |
| | Isoflurane | ↑ | ↓ |
| | Desflurane | ↑ | ↓ |
| | Halothane | ↑ | ↓ |
| | N2O | ↑ | ↑ |

**Cerebral Perfusion Pressure (CPP)**:
CPP = MAP – ICP (or MAP – CVP , if CVP > ICP)

**Cerebral Blood Flow (CBF)**:
CBF = CPP/CVR

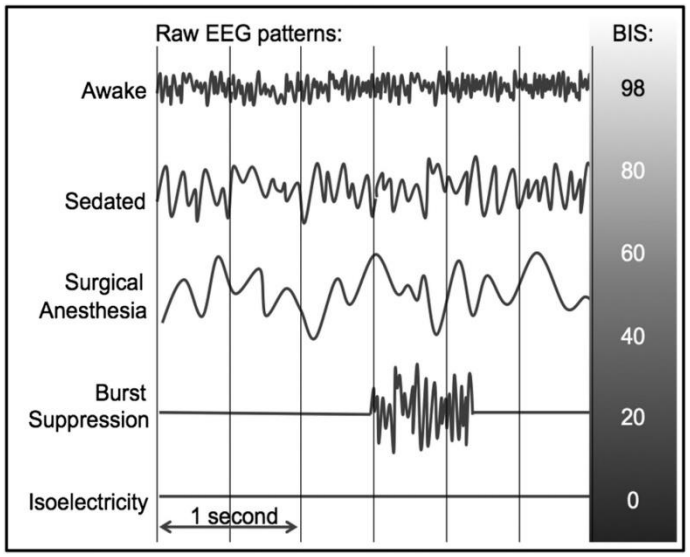
**Factors influencing cerebral blood flow include:**
PaO2, PaCO2, cerebral metabolic rate, mean arterial pressure (cerebral perfusion pressure), vasopressors, blood viscosity, and neurogenic pathways.

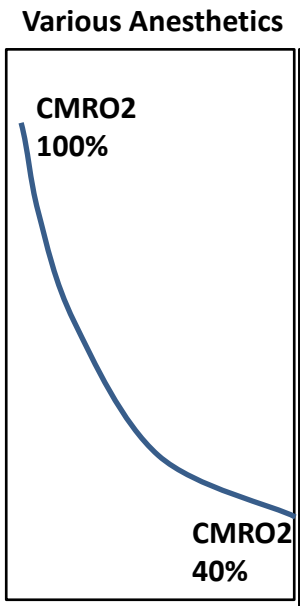
Miller 9th Ed: Ch 11, 57 // Barash 8th Ed, Ch 37 // Cole et al. PMID: 18091252 // Albrecht et al. PMID: 3109079 // EEG image: Wildes et al. PMID: 27311914 Creative Commons CC-BY-NC 4.0. // Autoregulation image: 2044990829, used via license from Shutterstock// Meng et al. PMID 25401418 // Gelb et al. PMID 18227320

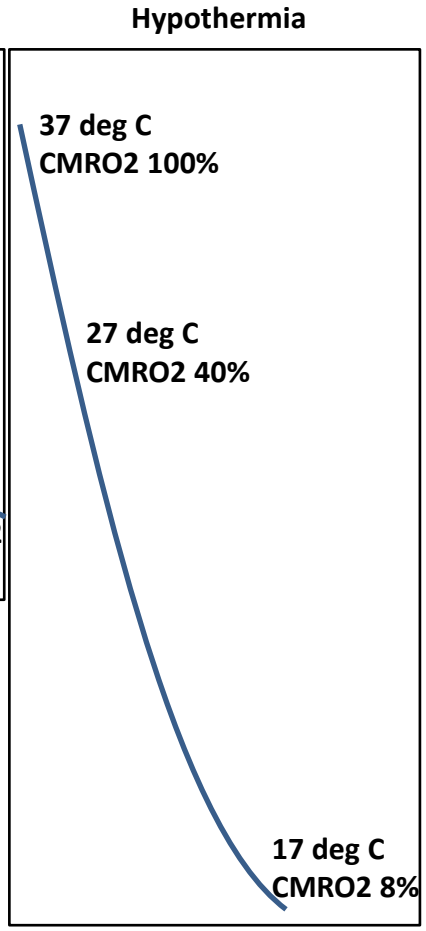
# Factors affecting Cerebral Blood Flow (CBF)

Miller, 9th Ed, Ch 11:

*Neurovascular (flow-metabolism) coupling*: Increased neuronal activity → increased local brain metabolism → "this increase in cerebral metabolic rate (CMR) is associated with a proportional change in CBF."




Anesthetics:

- "When the complete suppression of EEG is achieved, the cerebral metabolic rate of oxygen (CMRO2) is similar irrespective of the anesthetic agent used to achieve EEG suppression."

Temperature:

- "The CMR decreases by 6-7% per degree Celsius of temperature reduction….In contrast to anesthetic drugs, temperature reduction beyond that at which EEG suppression first occurs *does* produce a further decrease in the CMR."



Miller 9th Ed: Ch 11 // EEG image: Wildes et al. PMID: 27311914 Creative Commons CC-BY-NC 4.0.

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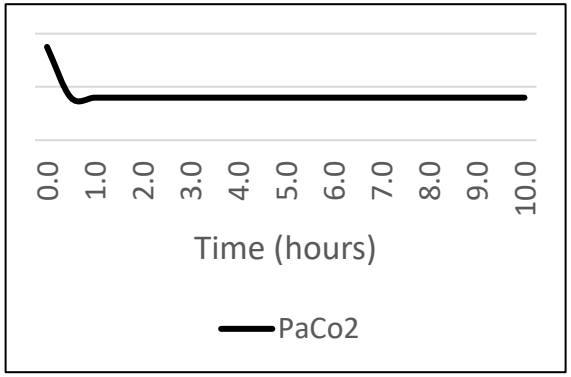
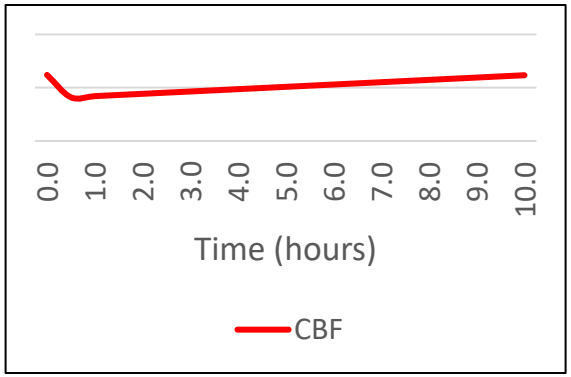
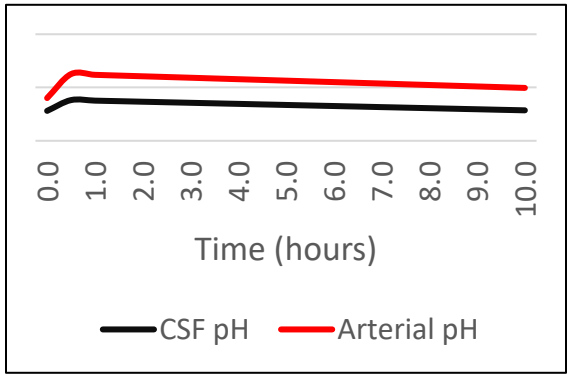
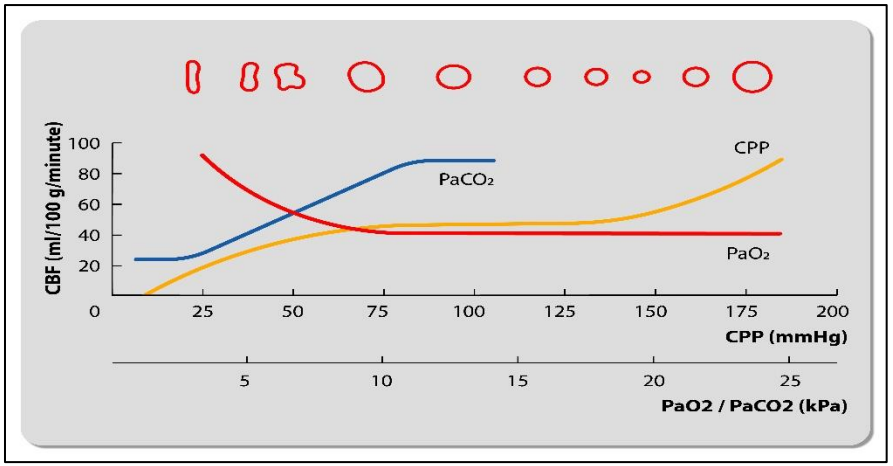
**Hyperventilation**




Miller, 9th Ed, Ch 11:

- "CBF varies directly with PaCO2 in the range of 25 to 70mm Hg."
- "Changes in PaO2 from 60 to more than 300 mm Hg have little influence on CBF. Less than a PaO2 of 60 mm Hg rapidly increases CBF." "The relationship between hemoglobin saturation and CBF is inversely linear."
- "The CBF changes in response to alterations in PaCO2 rapidly occur, but they are not sustained. Despite the maintenance of an increased arterial pH [from hyperventilation], CBF returns toward normal over a period of 6 to 8 hours because the pH of cerebrospinal fluid (CSF) gradually returns to normal levels as a result of extrusion of bicarbonate."
- "In contrast to *respiratory* acidosis, acute systemic *metabolic* acidosis has little immediate effect on CBF because the blood brain barrier (BBB) excludes H+ from the perivascular space."
- "The cerebrovascular responsiveness to PaCO2 is influenced significantly by blood pressure."



Miller 9th Ed: Ch 11, 57 // Albrecht et al. PMID: 3109079. // Autoregulation image: 2044990829, used via license from Shutterstock. // Meng et al. PMID 25401418 // Gelb et al. PMID 18227320

# Factors affecting Cerebral Blood Flow (CBF)

Miller, 9thEd, Ch 11:

- "The net effect of volatile anesthetics on CBF is…a balance between a reduction in CBF caused by CMR suppression and an augmentation of CBF caused by the direct cerebral vasodilation."

- ***Remifentanil**: "Sedative doses of remifentanil alone can cause minor increases in CBF. With larger doses of with the concomitant administration of anesthetic adjuvants, CBF is either unaltered or modestly reduced."

- ****Nitrous Oxide**: "When N2O is administered alone, very substantial increases in CBF and ICP can occur.
  - These substantial increases are somewhat attenuated when nitrous oxide is given with a volatile anesthetic.
  - "[W]hen N2O is administered in combination with intravenous drugs, including barbiturates, benzodiazepines, narcotics, and propofol, [the] cerebral vasodilating effect [from nitrous oxide] is [more] attenuated or even completely inhibited."

| Anesthetics, CBF, and CMR | | | |
|---|---|---|---|
| | Agent | CBF | CMR |
| Intravenous | Midazolam | ↓ | ↔ |
| | Fentanyl | ↓ | ↓ |
| | Propofol | ↓ | ↓ |
| | Dexmedetomidine | ↓ | ↓ |
| | Remifentanil | * | ↔ |
| | Sufentanil | ↓ | ↓ |
| | Morphine | ↓ | ↓ |
| Inhalational | Sevoflurane | ↑ | ↓ |
| | Isoflurane | ↑ | ↓ |
| | Desflurane | ↑ | ↓ |
| | Halothane | ↑ | ↓ |
| | N2O** | ↑ | ↑ |



Miller 9th Ed: Ch 11, 57 // Barash 8th Ed, Ch 37 // Cole et al. PMID: 18091252

# Factors affecting Cerebral Blood Flow (CBF) - Misc

Miller, 9th Ed, Ch 11:

- **Viscosity**: "…viscosity is not a target of manipulation [for CBF] in patients at risk as a result of cerebral ischemia, with the possible exception of those with hematocrit values higher than 55%.."
- **Neurogenic regulation of cerebral blood flow (i.e. innervation from sympathetics)**: "The nature and influence of such pathways in humans are not known, and their manipulation for the purposes of clinical management remains to be systematically investigated."
- **Vasodilators**: "Most drugs used to induce hypotension, including sodium nitroprusside, nitroglycerin, hydralazine, adenosine, and calcium channel blockers, also cause cerebral vasodilation. As a result, CBF either increases or is maintained at pre-hypotensive levels."
- **Pressors**: "When basal pressure is within the normal autoregulation range, an increase in systemic pressure does not significantly affect CBF because the normal autoregulatory response to a rising MAP entails cerebral vasoconstriction…"
- **Age**: "…both CBF and CMRO2 decrease by 15-20% at the age of 80 years."
- **Succinylcholine:** "Although succinylcholine *can* produce increases in ICP [~5mmHg in the lightly anesthetized…], it can still be used for a rapid-sequence induction…[there should be] proper attention to…CO2 tension, arterial blood pressure,…depth of anesthesia and…defasciculation…."

**Cerebral Perfusion Pressure (CPP)**:
CPP = MAP – ICP  (or MAP – CVP , if CVP > ICP)

**Cerebral Blood Flow (CBF)**:
CBF = CPP/CVR

*MAP: Mean Arterial Pressure; ICP: Intracranial Pressure; CVP: central venous pressure ; CVR: cerebrovascular resistance*

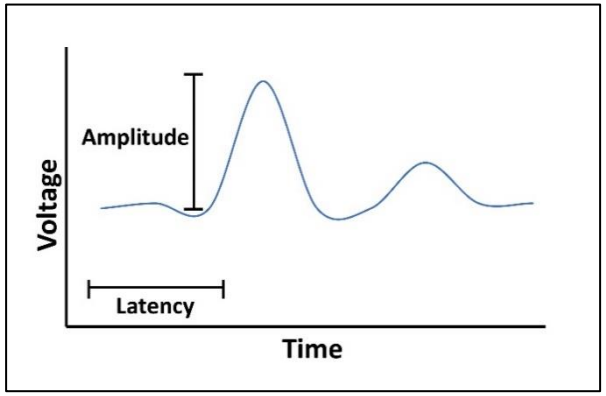
Ref: Barash 8th Ed, Ch 37.

# Factors affecting SSEP's

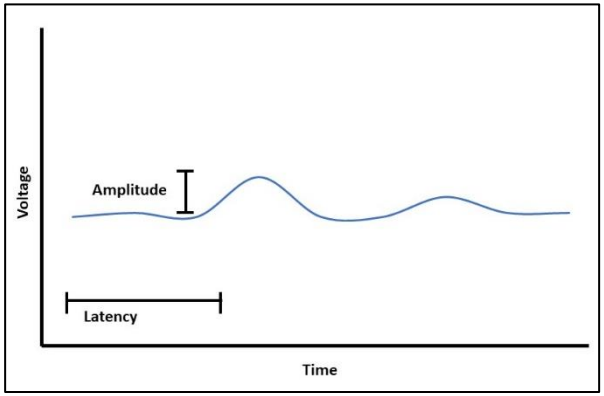
13X

- Latency: time from application of stimulus to onset or peak of the response. (Miller 9th Ed, Ch 39)
- Amplitude: voltage of the recorded response. (Miller 9th Ed, Ch 39)
- Concerning signal change: "The commonly used definitions…include a decrease in the amplitude by 50% or an increase in the latency by 10%." (Barash 8th Ed, Ch 37)
- General factors affecting SSEP's: "Intraoperative changes in evoked responses, such as decreased amplitude, increased latency, or complete loss of the waveform, may result from **surgical trespass**, such as retractor placement or ischemia. They may also reflect systemic changes, such as changes in the **anesthetic drug administration, temperature…**, or **hypoperfusion**." (Miller 9th Ed, Ch 39)
- Anesthetic techniques affecting SSEP's: **Volatile anesthetics** cause decrease in amplitude and increase in latency in nearly linear/dose-dependent fashion. Robust signals have been obtained up to 0.5 MAC. N2O has more depressant effect on signal amplitude than latency. (Barash 8th Ed, Ch37)
- High-Yield Recommended Reading: Barash, 8th Ed, Ch 37, p. 1011 (Evoked Potentials & Anesthesia).
- Handout: PediCrisis Checklist for Loss of Evoked Potentials

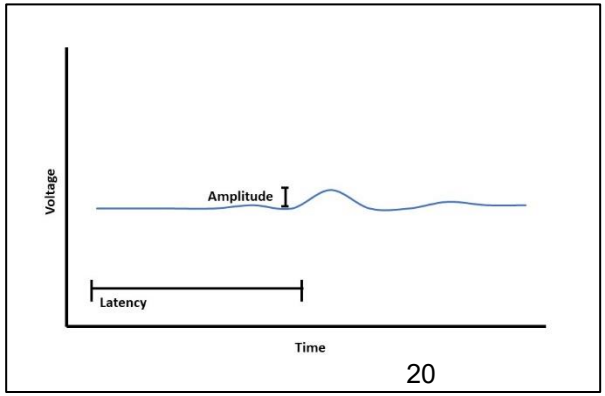
**SSEP Basic Waveform**




**N2O depresses amplitude more than increased latency**




**Volatiles decrease amplitude and increase latency**



# Neuromonitoring Reference Handout



**Popular Evoked Potential Monitoring Modalities & Anesthetic Techniques (Barash 8th Ed/Ch 37/p.1011)**:

(1) **Somatosensory evoked potentials (SSEPs)**: "are elicited in a cyclical, repetitive manner from a peripheral nerve (e.g. median, ulnar, posterior tibial) and usually measured at the level of the subcortex (e.g. upper cervical spine) and cortex (scalp)."[1]

a. Common surgical procedures where SSEP's are used: "…**spine surgery**, especially when posterolateral sensory elements are at risk of ischemia from surgical distraction.[35] They may also be useful during **neurovascular brain surgery** to ensure sufficient perfusion to the somatosensory cortex during procedures that may put this cortex at risk, such as cerebral aneurysm clipping.[36] Lower extremity SSEPs tend to correlate with the integrity of cortex supplied by the ACA whereas upper extremity SSEPs tend to correlate with the cortex supplied by the MCA distribution."[1]

b. Effect of anesthetic techniques: "With regard to cortical SSEPs, **potent volatile anesthetics and nitrous oxide have the greatest inhibitory effect** causing a decrease in amplitude and an increase in wave latency. These drugs may limit the acquisition of robust SSEP signals, **doing so in a nearly linear dose-dependent fashion**. **Robust signals can, however, usually be obtained in neurologically intact patients with up to 0.5 MAC of inhaled agent**.[47] In neurologically impaired patients, such as those with peripheral neuropathy, total intravenous anesthesia (TIVA) might be required and is commonly performed with a hypnotic (e.g., propofol) and an opioid infusion. **Nitrous oxide has more of a depressant effect on signal amplitude rather than latency**. Intravenous anesthetics such as propofol tend to have a very limited effect on SSEPs, unless administered in very high doses. Likewise, opioids tend to have a very minimal effect on SSEPs, except with bolus administration, which may decrease amplitudes transiently. Etomidate and ketamine are exceptions in that they actually can increase cortical amplitudes at clinical doses and have been used to enhance SSEP waveforms. Muscle relaxants are generally beneficial for SSEP monitoring as they eliminate myogenic interference. Lastly, it is important to note that these anesthetic effects are much less prominent **with regard to subcortical, cervical, and peripheral signal acquisition, as these areas are much more resistant to the inhibitory effects of anesthesia**."[1]

c. Concerning signal change: "The commonly used definitions of 'significant changes' to the SSEP waveform include a decrease in the amplitude by 50% or an increase in the latency by 10%."[1]

(2) **Motor evoked potentials (MEPs)**: "are produced at the level of the cortex by direct stimulation of the cerebral cortex or by indirect stimulation of the scalp. MEP signals are usually measured as compound muscle action potentials (CMAPs) at the muscular level."[1]

a. Common surgical procedures where MEP's are used: "…**spine surgery**, especially when anterior elements are at risk, and during **intracranial surgery** during procedures where the motor cortex or descending motor pathway are at risk for injury or ischemia."[1]

b. Effect from anesthetic techniques: "MEPs elicited from the scalp are exquisitely sensitive to the effects of anesthesia. **Potent volatile anesthetics are greatly inhibitory to the acquisition of MEPs**, though doses of 0.5 MAC can still be used. Above this concentration, a nonlinear and greatly accelerated suppression of MEP amplitudes occurs. As with SSEPs, **nitrous oxide depresses MEP amplitudes**. Intravenous anesthetics are generally conducive to MEP acquisition, except at very high doses. As such, TIVA is commonly employed when MEPs are being monitored. Like SSEPs, **ketamine and etomidate may improve MEP amplitudes and lower the electrical threshold required to obtain a response**.[48,49] **Muscle relaxants must be given very judiciously or avoided** completely so as not to abolish the MEP response or prohibitively increase its variability, rendering it difficult to follow over time. [50]"[1]

c. Concerning signal change: "Although there is no formal definition of "significant changes" that warrant concern for altered neural pathway function, a decrease in amplitude of 50% is considered "significant" as is a need to increase the stimulation intensity required to maintain a reproducible signal. Latency of MEPs has much less of a role in defining a worrisome change than with SSEPs.[39]"[1]



Neuromonitoring Reference Handout

(3) **Electromyography (EMG)**: "a monitoring modality that is used to continually assess the integrity of distinct peripheral or cranial nerves or nerve roots. Spontaneous neural electrical activity can be monitored or, in stimulated EMG, electrical current can be induced in a nerve and then that signal can be detected as a means to monitor nerve integrity or identify a nerve.[40] EMG is sensitive to both mechanical and thermal injury. EMG, unlike SSEPs and MEPs, is not a monitor of ischemia. Needle electrodes are placed in a muscle known to be innervated by a particular nerve root, and if that nerve root is disturbed, EMG activity is recorded from that muscle."[1]

a. Common surgical procedures where EMG's are used: "EMG can be monitored in muscles innervated by spinal nerves during spine surgery or in muscles innervated by cranial nerves during various intracranial procedures that may put cranial nerves at risk, such as during acoustic neuroma resection. In addition, a surgeon may use stimulated EMG to identify cranial nerves during surgery.[41] 'Triggered EMG,' as is commonly performed with pedicle screw testing during spine surgery, relies on direct stimulation of the screws being placed within the bony pedicle. If there is disruption of the bony pedicle, and hence contact or near-contact between the screw and neural elements, the amount of current necessary to stimulate the corresponding nerve root will be much less than if the pedicle were intact.[42]"[1]

b. Effect from anesthetic technique: "**Muscle relaxants can impair or, with deep neuromuscular blockade, abolish, EMG signals**. Inhaled and intravenous anesthetics have very little effect on the acquisition of spontaneous or 'triggered' EMG. Hence, it is wise to avoid muscle relaxation or reverse the effects of muscle relaxants prior to pedicle screw testing or cranial nerve identification."[1]

(4) **Brainstem auditory evoked potentials (BAEPs)**: "are used to assess the integrity of the auditory canal, tympanic membrane, hair cells, spiral ganglion, vestibulocochlear nerve (cranial nerve VIII), cochlear nuclei, superior olivary complex, lateral lemniscus, inferior colliculus, and medial geniculate thalamic nuclei. A device that produces auditory stimuli (i.e., clicking sounds) is placed in the external auditory canal and responses are recorded from the scalp."[1]

a. Common surgical procedures where BAEPs are used: "BAEPs are often performed during surgery at or near the brainstem such as microvascular decompression of cranial nerves V or VII or for acoustic neuroma resection."[1]

b. Effect from anesthetic technique: "**BAEPs are extremely robust with little effect from any anesthetic regimen**.… Small increases in latency can be seen with deep inhalational or intravenous anesthesia. Notably, cold irrigation fluids at the brainstem will also cause some increases in interwave latencies."[1]

(5) **Visual evoked potentials (VEPs)**: "are used to assess the integrity of the visual pathway, including the eye, optic nerve, optic chiasm, and visual cortex in the occipital lobe. A bright stimulus is applied to the eyes using special goggles or contact lenses, and responses are recorded from scalp electrodes."[1]

a. Common surgical procedures where VEP's are used: "VEPs may be useful during surgery at or near the optic chiasm or the occipital cortex."[1]

b. "**VEPs are exquisitely sensitive to almost any anesthetic regimen and the difficulty in the ability to obtain and interpret the signals make them very infrequently used**.[46]… Inhalational-based anesthetics, with and without nitrous oxide, are more inhibitory to VEPs than TIVA techniques in general. One proposed anesthetic technique for facilitating VEP monitoring might involve an opioid-based TIVA with muscle relaxants and BIS monitoring, although other techniques may be used"[1]

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# Loss of Evoked Potentials

Management of signal changes during spine surgery





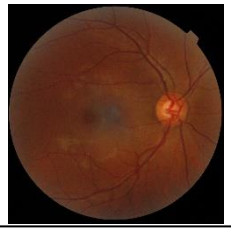
- Notify all members of health care team. Call a "time out"
- Loss of evoked potentials (EP) requires definitive steps to re-establish perfusion/remove mechanical cause; MEP loss for > 40 min may increase possibility of long term injury
  - Assure the presence of attending surgeon, attending anesthesiologist, senior neurologist or neurophysiologist, and experienced nurse
  - Each service: review situation, report on management and corrective actions taken
    - Surgeon: rule out mechanical causes for loss/change including traction weights
    - EP technologist: rule out technical causes for loss/change
    - Anesthesiologist: assure no neuromuscular blockade is present; reverse NMB if necessary
- Check patient positioning (neck, upper and lower extremities)
- Review the anesthetic and consider improving spinal cord perfusion by modifying:
  - Mean arterial pressure: MAP > 65 mmHg using ePHEDrine 0.1 mg/kg IV (MAX 10 mg/dose) and/or phenylephrine 0.3-1 MICROgrams/kg IV (MAX 100 MICROgrams/dose), with repeated doses as needed
  - Hemoglobin: if anemic, transfuse RBC to improve oxygen delivery
  - pH and $PaCO_2$: ensure normocarbia or slight hypercarbia (↑ I/E ratio, ↓ PEEP)
  - Temperature: ensure normothermia
  - Check for "unintended" drugs given (e.g. neuromuscular blocker)
  - Decrease depth of anesthetic and ensure $N_2O$ is under 50%
- Discuss feasibility of a useful wake-up test:
  - Patient is appropriate candidate if capable of following verbal commands
- Consider high-dose steroid if no improvement:
  - MethylPREDNISolone 30 mg/kg IV over one hour, then 5.4 mg/kg/hour IV for 23 hours

# Autonomic Hyperreflexia; Postoperative Vision Loss

16X

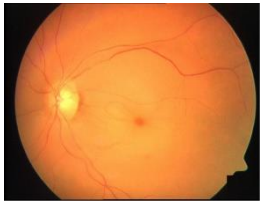
Autonomic dysreflexia/hyperreflexia:

- Patient population: Weeks/months after spinal cord injury at T7 or above.
- Abnormal response: profound hypertension (with headache, sweating, flushing, bradycardia, arrythmias) after stimulus (e.g. surgical; distended bladder) below level of injury.
- Pathophysiology: disruption of descending inhibitory tracts (w/intact sympathetic reflex arcs).
- Treatment: Ideally prevention (consider regional/general anesthesia even if procedure to insensate location). Spinal may be preferred over epidural for denser block and avoidance of sacral sparing. Consider risk/benefit of mild/moderate sedation for minor procedures. Succinylcholine may cause hyperkalemia.



Normal Exam

Optic Disc Edema



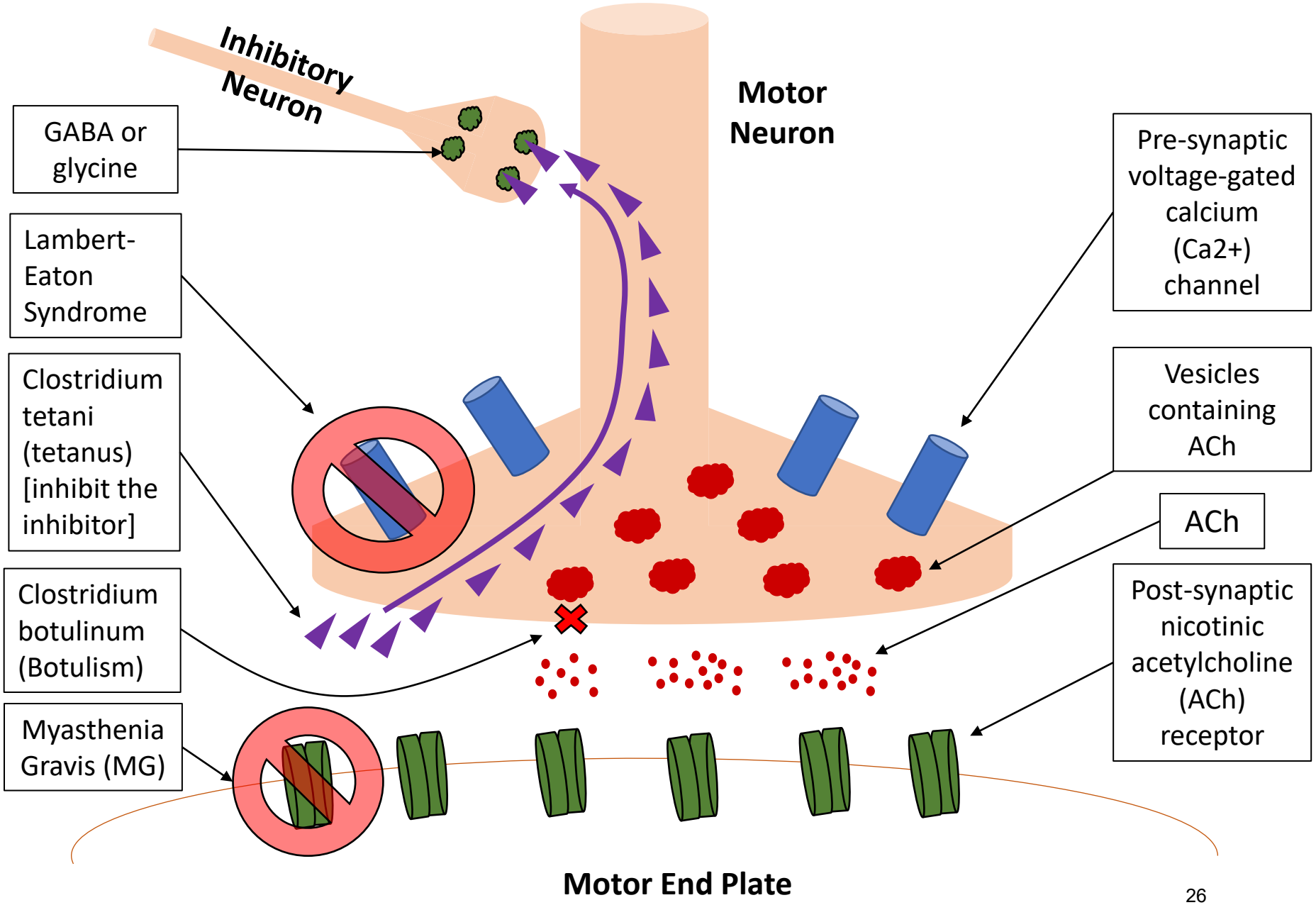
CRAO

Perioperative Visual Loss (POVL): Anterior vs. Posterior ischemic optic neuropathy (ION) vs. Central Retinal Artery Occlusion (AION vs. PION vs. CRAO) vs. Acute Angle Glaucoma :

- Ophthalmic artery is a branch of the internal carotid artery. ION & CRAO cause painless vision loss.
- Buzzwords: *AION*: cardiac surgery, optic disc edema. *PION*: prone spine surgery, high blood loss, normal funduscopic exam. *CRAO*: external eye compression, retrobulbar hemorrhage from nerve block or head/neck surgery, decreased arterial flow (hypotension; thromboembolic event); impaired venous drainage; "cherry red macula."
- Acute angle glaucoma: PAINFUL and red globe, blurry vision, headache, nausea.
- Risk Factors for ION after prone spine surgery: (1) obesity; (2) anesthesia duration; (3) estimated blood loss; (4) lower % colloid for nonblood replacement; (5) male sex; (6) Wilson frame use. (PMID: 22185873)
- Risk Factors for ION after cardiac surgery: (1) carotid artery stenosis; (2) stroke; (3) diabetic retinopathy (decreased risk in uncomplicated DM2); (4) macular degeneration; (5) glaucoma; (6) cataract. Female sex associated w/decreased risk. (PMID: 28244936).
  - High-Yield NEJM video on ION and POVL: https://youtu.be/zxPKDyFBNUE
  - QR Code: Appdx#1 of Practice Advisory Periop Visual Loss/Spine Surgery

Barash 8th Ed, Ch 37 // CRAO Image: Achim Fieß, et al, CC BY 2.0 via Wikimedia Commons https://upload.wikimedia.org/wikipedia/commons/f/f6/Cherry_Red_Spot_Fiess.jpg // Miller 9th Ed Ch 34 // Optic disc edema: ICEH, via Creative Commons license CC BY-NC 2.0 https://www.flickr.com/photos/communityeyehealth/7603596252 // Normal eye exam: Ske., CC BY-SA 3.0 via Wikimedia Commons (https://upload.wikimedia.org/wikipedia/commons/7/7f/Retinography.jpg) // PMID: 26083207; 22185873; 28244936.

# "Image/Buzzwords Co-slides": Myasthenia Gravis, Lambert-Eaton, Botulism, Tetanus



# "Image/Buzzwords Co-slides": Myasthenia Gravis, Lambert-Eaton, Botulism, Tetanus

24X

- Myasthenia Gravis (MG): autoantibodies against post-synaptic nicotinic acetylcholine receptors. **Resistant to succinylcholine** (decreased functional receptors)**; sensitive to nondepolarizers** (or unpredictable effect; sugammadex increasingly considered for reversal). Predictors for post-operative ventilation include:

| Myasthenic History | Pulmonary History |
|---|---|
| Disease duration > 6 years | Other significant pulmonary disease |
| Bulbar (speech/swallow) symptoms preop | Vital capacity less than 2.9L |
| History of myasthenic crisis | |
| Pyridostigmine dose > 750mg/day | |

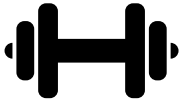
- Lambert-Eaton Myasthenic Syndrome: autoantibodies against presynaptic voltage-gated calcium channels. **Sensitive to succinylcholine AND sensitive to nondepolarizers**.
  - Often a paraneoplastic syndrome: small cell lung cancer is a common underlying malignancy.
  - Unlike MG: (1) more likely to have proximal limb weakness than respiratory, ocular, or bulbar; (2) strength increased with repeated effort; (3) autonomic dysfunction more likely.
- Clostridium botulinum (botulism) and Clostridium tetani (tetanus)
  - Botulinum toxin: neurotoxin prevents acetylcholine vesicle release from presynaptic membrane
    - Pain management: via muscle relaxation and reduction in spasticity
  - Tetanus: retrograde transport of toxin → preferentially affects inhibitory neurons → rigidity/spasms

Miller 9th Ed, Ch 35. // UptoDate: Anesthesia for the patient with myasthenia gravis (May 20, 2019). // Miller's Basics of Anesthesia, 7th Ed, Ch 43 // Berkowitz 2018; PMID: 30273248. // Patil et al 2016; PMID: 26879873.

# Anticholinesterase/Organophosphate (OP) poisoning (for example: certain insecticides, nerve agents)

21X

**Cholinergic Crisis:**



- Muscarinic Signs: DUMBBELS (Diarrhea, Urination, Miosis [pupil constriction], Bronchorrhea/Bronchospasm, Bradycardia, Emesis, Lacrimation, Salivation/Sweating). If crosses blood/brain barrier: seizures, confusion.
- Nicotinic Signs (mostly skeletal/somatic): fasciculations followed by weakness/paralysis.
  - Overdose of a nicotinic anticholinesterase (such as neostigmine) can cause a "cholinergic crisis" (Neostigmine dose for moderate to shallow neuromuscular blockade: 30-70 micrograms/kg).
- *Cholinergic crisis (e.g., too much pyridostigmine) vs. Myasthenic crisis (i.e., autoimmune destruction of post-synaptic acetylcholine receptors): pure myasthenic crisis lacks muscarinic signs.*

- Emergency Pharmacological treatment:
  - Atropine: anticholinergic; titrate to dried secretions/pupillary dilatation/HR>80bpm.
  - Benzodiazepines: OP's can cause seizures.
  - Pralidoxime: reactivates cholinesterase by binding to OP; atropine must also be administered (pralidoxime does not significantly relieve respiratory depression or muscarinic anticholinesterase effects).[1]

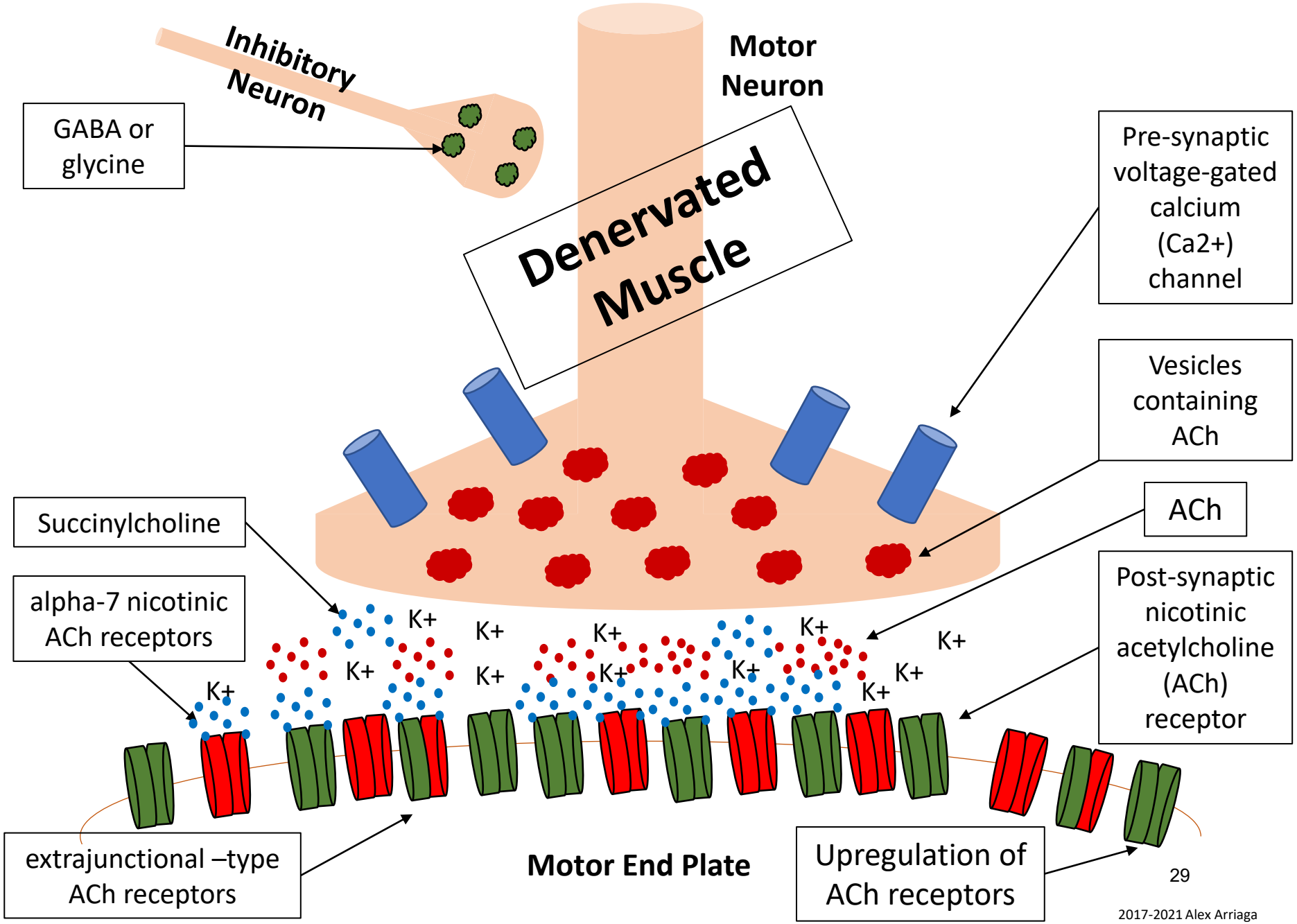
**Combo autoinjectors are sometimes used**

**Prevention/prophylaxis of OP poisoning:** "Pyridostigmine is an appropriate medication for *prophylaxis* against possible nerve agent exposure, whereas atropine and pralidoxime chloride would be appropriate for treatment after exposure" (2019 ITE Gaps in Knowledge Report).

- Pyridostigmine does not cross blood-brain barrier; it forms a reversible complex with cholinesterase that protects from irreversible inhibition by OP's.[1]

UpToDate: Myasthenic crisis (5/15/20). // 1. Pralidoxime & Pyridostigmine – Epocrates & ClinicalKey Drug Monograph // Miller 8th Ed, Ch 83 & Miller 9th Ed Ch 68. // Barash 8th Ed Ch 59. // ITE Gaps in Knowledge Report. Available at www.theaba.org.

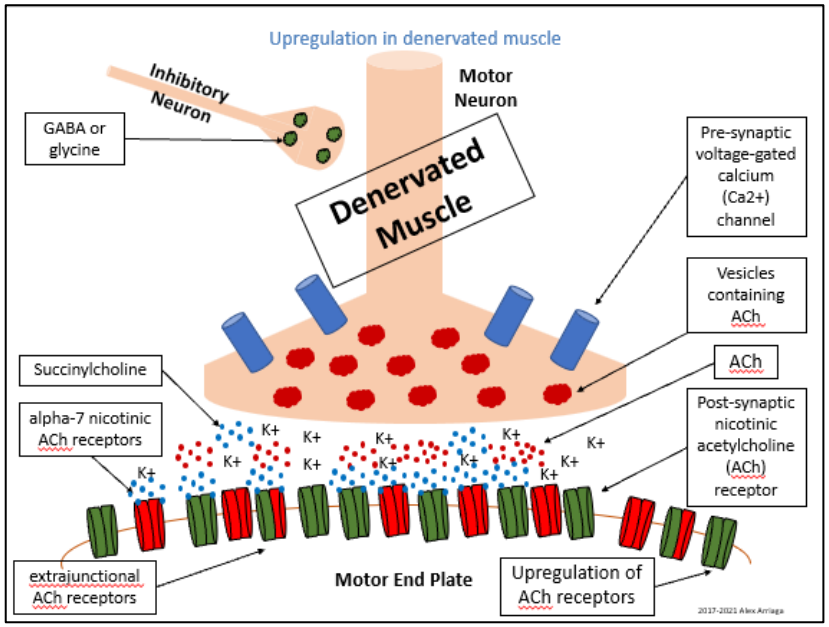
# Upregulation in denervated muscle



# Succinylcholine & Related Topics

32X

## Succinylcholine and Denervated Muscle




**Recommended high-yield reading**:

1. Martyn JAJ. Succinylcholine-induced hyperthermia in acquired pathologic states: etiologic factors and molecular mechanisms. Anesthesiology 2006; 104: 158-69.
2. Miller 9th Ed, Ch 27, pages 794-799 (Pharmacology of Succinylcholine)

Patients particularly susceptible to hyperkalemia from succinylcholine (normal serum potassium increase from Sux: 0.5mEq/dL):

1. CNS & upper motor neuron lesions (e.g. stroke, tumors/masses), especially if weakness.
2. Demyelinating diseases (MS, Guillain-Barre Syndrome).
3. Many muscular disorders (muscular dystrophy [confounded with risk of MH-like syndrome], myotonic dystrophy).
4. Severe burns or crush injuries (starting 24 hours after the injury and PEAKS 7-10 days after the injury).
5. Prolonged immobility or neuromuscular blockade.
6. Severe metabolic acidosis and hypovolemia.

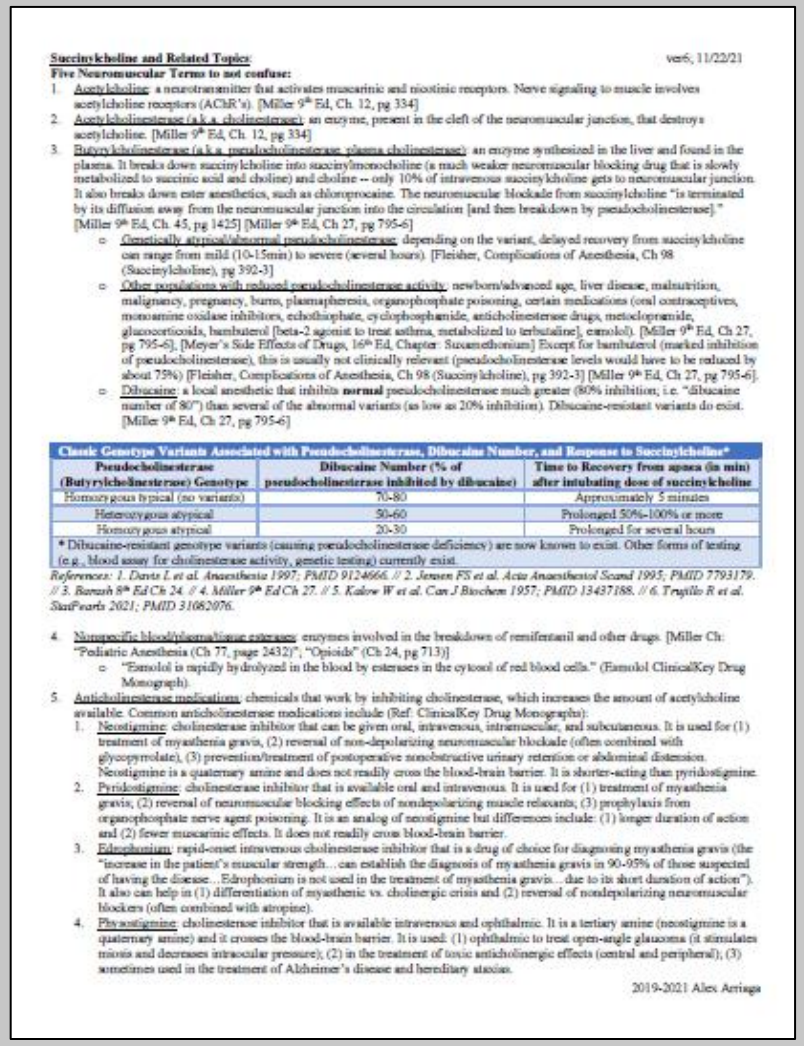
*Upregulation of neuromuscular junction (NMJ) and extrajunctional cholinergic receptors is thought to be the etiology (muscular dystrophy etiology may be rhabdomyolysis).*

Handout: Succinylcholine & Related Topics



Martyn JAJ et al. Neuromuscular physiology and pharmacology. In Miller's Anesthesia, 9th Ed, Ch 12 // Miller 9th Ed, Ch 27

# Handout: Succinylcholine & Related Topics



**Succinylcholine and Related Topics:** ver6, 11/22/21

**Five Neuromuscular Terms to not confuse:**

1. Acetylcholine: a neurotransmitter that activates muscarinic and nicotinic receptors. Nerve signaling to muscle involves acetylcholine receptors (AChR's). [Miller 9th Ed, Ch. 12, pg 334]
2. Acetylcholinesterase (a.k.a. cholinesterase): an enzyme, present in the cleft of the neuromuscular junction, that destroys acetylcholine. [Miller 9th Ed, Ch. 12, pg 334]
3. Butyrylcholinesterase (a.k.a. pseudocholinesterase, plasma cholinesterase): an enzyme synthesized in the liver and found in the plasma. It breaks down succinylcholine into succinylmonocholine (a much weaker neuromuscular blocking drug that is slowly metabolized to succinic acid and choline) and choline -- only 10% of intravenous succinylcholine gets to neuromuscular junction. It also breaks down ester anesthetics, such as chloroprocaine. The neuromuscular blockade from succinylcholine "is terminated by its diffusion away from the neuromuscular junction into the circulation [and then breakdown by pseudocholinesterase]." [Miller 9th Ed, Ch. 45, pg 1425] [Miller 9th Ed, Ch 27, pg 795-6]
   - Genetically atypical/abnormal pseudocholinesterase: depending on the variant, delayed recovery from succinylcholine can range from mild (10-15min) to severe (several hours). [Fleisher, Complications of Anesthesia, Ch 98 (Succinylcholine), pg 392-3]
   - Other populations with reduced pseudocholinesterase activity: newborn/advanced age, liver disease, malnutrition, malignancy, pregnancy, burns, plasmapheresis, organophosphate poisoning, certain medications (oral contraceptives, monoamine oxidase inhibitors, echothiophate, cyclophosphamide, anticholinesterase drugs, metoclopramide, glucocorticoids, bambuterol [beta-2 agonist to treat asthma, metabolized to terbutaline], esmolol). [Miller 9th Ed, Ch 27, pg 795-6], [Meyer's Side Effects of Drugs, 16th Ed, Chapter: Succamethonium] Except for bambuterol (marked inhibition of pseudocholinesterase), this is usually not clinically relevant (pseudocholinesterase levels would have to be reduced by about 75%) [Fleisher, Complications of Anesthesia, Ch 98 (Succinylcholine), pg 392-3] [Miller 9th Ed, Ch 27, pg 795-6].
   - Dibucaine: a local anesthetic that inhibits **normal** pseudocholinesterase much greater (80% inhibition; i.e. "dibucaine number of 80") than several of the abnormal variants (as low as 20% inhibition). Dibucaine-resistant variants do exist. [Miller 9th Ed, Ch 27, pg 795-6]

**Classic Genotype Variants Associated with Pseudocholinesterase, Dibucaine Number, and Response to Succinylcholine***

| Pseudocholinesterase (Butyrylcholinesterase) Genotype | Dibucaine Number (% of pseudocholinesterase inhibited by dibucaine) | Time to Recovery from apnea (in min) after intubating dose of succinylcholine |
|---|---|---|
| Homozygous typical (no variants) | 70-80 | Approximately 5 minutes |
| Heterozygous atypical | 50-60 | Prolonged 50%-100% or more |
| Homozygous atypical | 20-30 | Prolonged for several hours |

* Dibucaine-resistant genotype variants (causing pseudocholinesterase deficiency) are now known to exist. Other forms of testing (e.g., blood assay for cholinesterase activity, genetic testing) currently exist.

*References: 1. Davis L et al. Anaesthesia 1997; PMID 9124666. // 2. Jensen FS et al. Acta Anaesthesiol Scand 1995; PMID 7793179. // 3. Barash 8th Ed Ch 24. // 4. Miller 9th Ed Ch 27. // 5. Kalow W et al. Can J Biochem 1957; PMID 13437188. // 6. Trujillo R et al. StatPearls 2021; PMID 31082076.*

4. Nonspecific blood/plasma/tissue esterases: enzymes involved in the breakdown of remifentanil and other drugs. [Miller Ch: "Pediatric Anesthesia (Ch 77, page 2432)", "Opioids" (Ch 24, pg 713)]
   - "Esmolol is rapidly hydrolyzed in the blood by esterases in the cytosol of red blood cells." (Esmolol ClinicalKey Drug Monograph).
5. Anticholinesterase medications: chemicals that work by inhibiting cholinesterase, which increases the amount of acetylcholine available. Common anticholinesterase medications include (Ref: ClinicalKey Drug Monographs):
   1. Neostigmine: cholinesterase inhibitor that can be given oral, intravenous, intramuscular, and subcutaneous. It is used for (1) treatment of myasthenia gravis, (2) reversal of non-depolarizing neuromuscular blockade (often combined with glycopyrrolate), (3) prevention/treatment of postoperative non-obstructive urinary retention or abdominal distension. Neostigmine is a quaternary amine and does not readily cross the blood-brain barrier. It is shorter-acting than pyridostigmine.
   2. Pyridostigmine: cholinesterase inhibitor that is available oral and intravenous. It is used for (1) treatment of myasthenia gravis; (2) reversal of neuromuscular blocking effects of nondepolarizing muscle relaxants; (3) prophylaxis from organophosphate nerve agent poisoning. It is an analog of neostigmine but differences include: (1) longer duration of action and (2) fewer muscarinic effects. It does not readily cross blood-brain barrier.
   3. Edrophonium: rapid-onset intravenous cholinesterase inhibitor that is a drug of choice for diagnosing myasthenia gravis (the "increase in the patient's muscular strength…can establish the diagnosis of myasthenia gravis in 90-95% of those suspected of having the disease…Edrophonium is not used in the treatment of myasthenia gravis…due to its short duration of action"). It also can help in (1) differentiation of myasthenic vs. cholinergic crisis and (2) reversal of nondepolarizing neuromuscular blockers (often combined with atropine).
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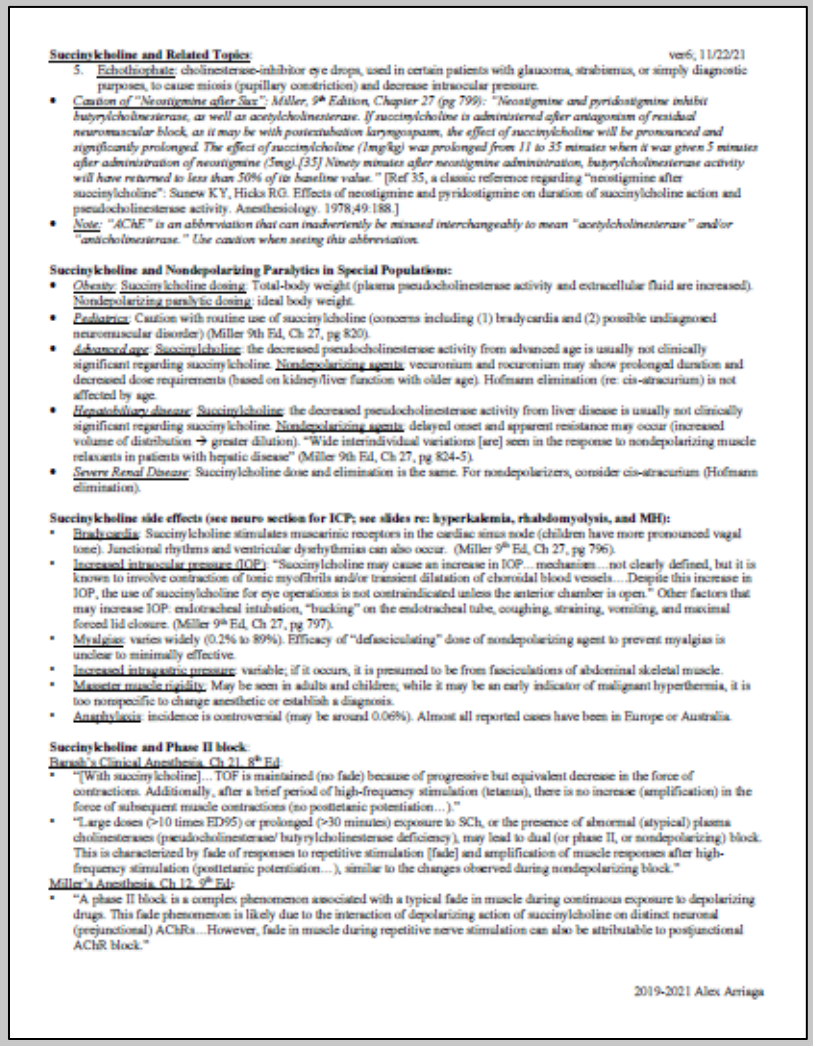

**Succinylcholine and Related Topics:** ver6, 11/22/21

5. Echothiophate: cholinesterase-inhibitor eye drops, used in certain patients with glaucoma, strabismus, or simply diagnostic purposes, to cause miosis (pupillary constriction) and decrease intraocular pressure.

- Caution of "Neostigmine after Sux": *Miller, 9th Edition, Chapter 27 (pg 799): "Neostigmine and pyridostigmine inhibit butyrylcholinesterase, as well as acetylcholinesterase. If succinylcholine is administered after antagonism of residual neuromuscular block, as it may be with postextubation laryngospasm, the effect of succinylcholine will be pronounced and significantly prolonged. The effect of succinylcholine (1mg/kg) was prolonged from 11 to 35 minutes when it was given 5 minutes after administration of neostigmine (5mg). [35] Ninety minutes after neostigmine administration, butyrylcholinesterase activity will have returned to less than 50% of its baseline value."* [Ref 35, a classic reference regarding "neostigmine after succinylcholine": Sunew KY, Hicks RG. Effects of neostigmine and pyridostigmine on duration of succinylcholine action and pseudocholinesterase activity. Anesthesiology. 1978;49:188.]
- *Note: "AChE" is an abbreviation that can inadvertently be misused interchangeably to mean "acetylcholinesterase" and/or "anticholinesterase." Use caution when seeing this abbreviation.*

**Succinylcholine and Nondepolarizing Paralytics in Special Populations:**

- *Obesity*: Succinylcholine dosing: Total-body weight (plasma pseudocholinesterase activity and extracellular fluid are increased). Nondepolarizing paralytic dosing: ideal body weight.
- *Pediatrics*: Caution with routine use of succinylcholine (concerns including (1) bradycardia and (2) possible undiagnosed neuromuscular disorder) (Miller 9th Ed, Ch 27, pg 820).
- *Advanced age*: Succinylcholine: the decreased pseudocholinesterase activity from advanced age is usually not clinically significant regarding succinylcholine. Nondepolarizing agents: vecuronium and rocuronium may show prolonged duration and decreased dose requirements (based on kidney/liver function with older age). Hofmann elimination (re: cis-atracurium) is not affected by age.
- *Hepatobiliary disease*: Succinylcholine: the decreased pseudocholinesterase activity from liver disease is usually not clinically significant regarding succinylcholine. Nondepolarizing agents: delayed onset and apparent resistance may occur (increased volume of distribution → greater dilution). "Wide interindividual variations [are] seen in the response to nondepolarizing muscle relaxants in patients with hepatic disease" (Miller 9th Ed, Ch 27, pg 824-5).
- *Severe Renal Disease*: Succinylcholine dose and elimination is the same. For nondepolarizers, consider cis-atracurium (Hofmann elimination).

**Succinylcholine side effects (see neuro section for ICP; see slides re: hyperkalemia, rhabdomyolysis, and MH):**

- Bradycardia: Succinylcholine stimulates muscarinic receptors in the cardiac sinus node (children have more pronounced vagal tone). Junctional rhythms and ventricular dysrhythmias can also occur. (Miller 9th Ed, Ch 27, pg 796).
- Increased intraocular pressure (IOP): "Succinylcholine may cause an increase in IOP…mechanism…not clearly defined, but it is known to involve contraction of tonic myofibrils and/or transient dilatation of choroidal blood vessels…Despite this increase in IOP, the use of succinylcholine for eye operations is not contraindicated unless the anterior chamber is open." Other factors that may increase IOP: endotracheal intubation, "bucking" on the endotracheal tube, coughing, straining, vomiting, and maximal forced lid closure. (Miller 9th Ed, Ch 27, pg 797).
- Myalgias: varies widely (0.2% to 89%). Efficacy of "defasciculating" dose of nondepolarizing agent to prevent myalgias is unclear to minimally effective.
- Increased intragastric pressure: variable; if it occurs, it is presumed to be from fasciculations of abdominal skeletal muscle.
- Masseter muscle rigidity: May be seen in adults and children; while it may be an early indicator of malignant hyperthermia, it is too nonspecific to change anesthetic or establish a diagnosis.
- Anaphylaxis: incidence is controversial (may be around 0.06%). Almost all reported cases have been in Europe or Australia.

**Succinylcholine and Phase II block:**

Barash's Clinical Anesthesia, Ch 21, 8th Ed:

- "[With succinylcholine]…TOF is maintained (no fade) because of progressive but equivalent decrease in the force of contractions. Additionally, after a brief period of high-frequency stimulation (tetanus), there is no increase (amplification) in the force of subsequent muscle contractions (no posttetanic potentiation…)."
- "Large doses (>10 times ED95) or prolonged (>30 minutes) exposure to SCh, or the presence of abnormal (atypical) plasma cholinesterases (pseudocholinesterase/ butyrylcholinesterase deficiency), may lead to dual (or phase II, or nondepolarizing) block. This is characterized by fade of responses to repetitive stimulation [fade] and amplification of muscle responses after high-frequency stimulation (posttetanic potentiation…), similar to the changes observed during nondepolarizing block."

Miller's Anesthesia, Ch 12, 9th Ed:

- "A phase II block is a complex phenomenon associated with a typical fade in muscle during continuous exposure to depolarizing drugs. This fade phenomenon is likely due to the interaction of depolarizing action of succinylcholine on distinct neuronal (prejunctional) AChRs…However, fade in muscle during repetitive nerve stimulation can also be attributable to postjunctional AChR block."

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Rapidly differentiating the terms acetylcholine, acetylcholinesterase, pseudocholinesterase, nonspecific blood/plasma/tissue esterases, and anticholinesterases should be fluent anesthesiology vocabulary.

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**Succinylcholine side effects (see neuro section for ICP; see slides re: hyperkalemia, rhabdomyolysis, and MH):**

- Bradycardia: Succinylcholine stimulates muscarinic receptors in the cardiac sinus node (children have more pronounced vagal tone). Junctional rhythms and ventricular dysrhythmias can also occur. (Miller 9th Ed, Ch 27, pg 796).
- Increased intraocular pressure (IOP): "Succinylcholine may cause an increase in IOP…mechanism…not clearly defined, but it is known to involve contraction of tonic myofibrils and/or transient dilatation of choroidal blood vessels….Despite this increase in IOP, the use of succinylcholine for eye operations is not contraindicated unless the anterior chamber is open." Other factors that may increase IOP: endotracheal intubation, "bucking" on the endotracheal tube, coughing, straining, vomiting, and maximal forced lid closure. (Miller 9th Ed, Ch 27, pg 797).
- Myalgias: varies widely (0.2% to 89%). Efficacy of "defasciculating" dose of nondepolarizing agent to prevent myalgias is unclear to minimally effective.
- Increased intragastric pressure: variable; if it occurs, it is presumed to be from fasciculations of abdominal skeletal muscle.
- Masseter muscle rigidity: May be seen in adults and children; while it may be an early indicator of malignant hyperthermia, it is too nonspecific to change anesthetic or establish a diagnosis.
- Anaphylaxis: incidence is controversial (may be around 0.06%). Almost all reported cases have been in Europe or Australia.

**Succinylcholine and Phase II block**:

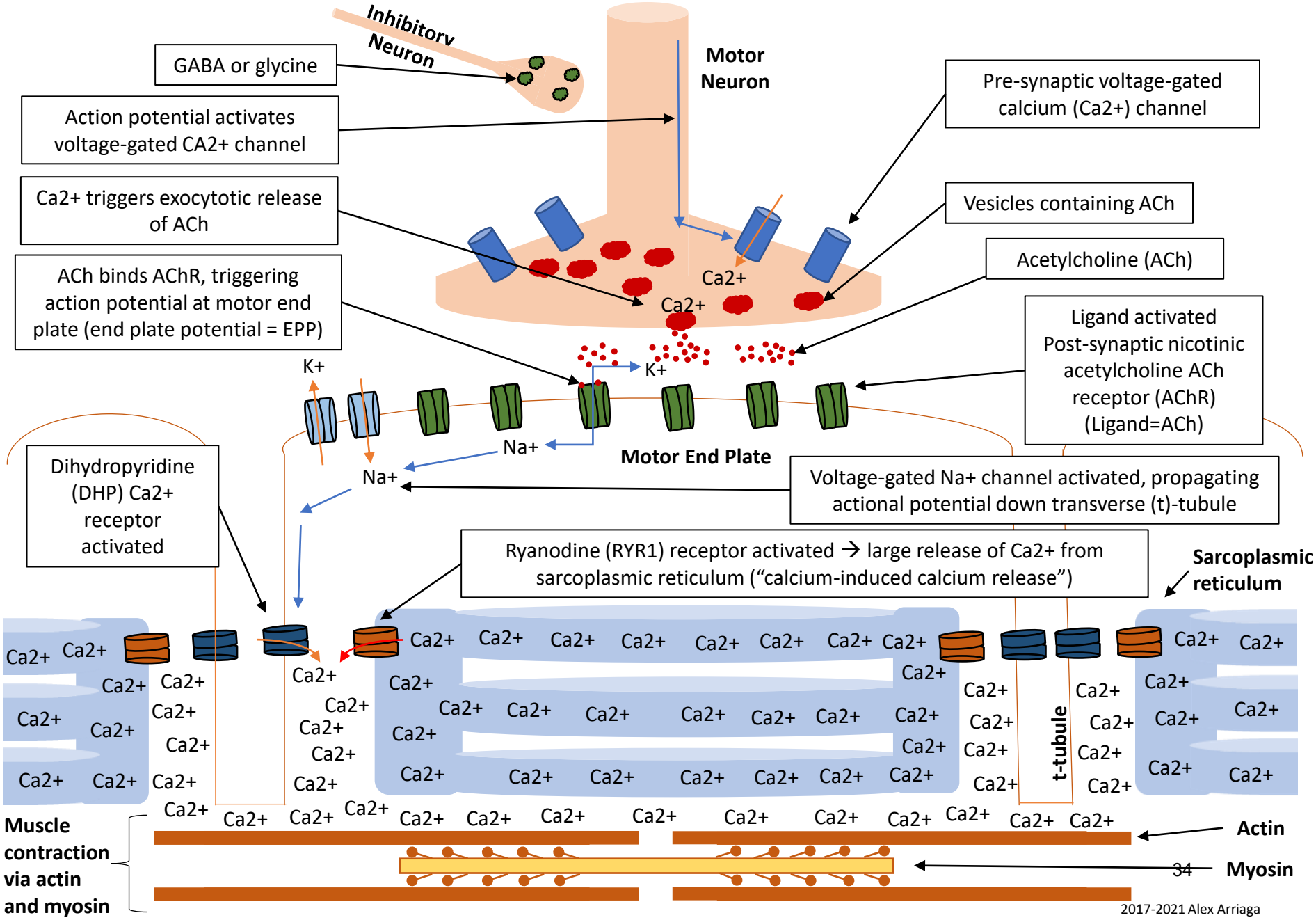
Barash's Clinical Anesthesia, Ch 21, 8th Ed:

- "[With succinylcholine]…TOF is maintained (no fade) because of progressive but equivalent decrease in the force of contractions. Additionally, after a brief period of high-frequency stimulation (tetanus), there is no increase (amplification) in the force of subsequent muscle contractions (no posttetanic potentiation…)."
- "Large doses (>10 times ED95) or prolonged (>30 minutes) exposure to SCh, or the presence of abnormal (atypical) plasma cholinesterases (pseudocholinesterase/ butyrylcholinesterase deficiency), may lead to dual (or phase II, or nondepolarizing) block. This is characterized by fade of responses to repetitive stimulation [fade] and amplification of muscle responses after high-frequency stimulation (posttetanic potentiation…), similar to the changes observed during nondepolarizing block."

Miller's Anesthesia, Ch 12, 9th Ed**:**

- "A phase II block is a complex phenomenon associated with a typical fade in muscle during continuous exposure to depolarizing drugs. This fade phenomenon is likely due to the interaction of depolarizing action of succinylcholine on distinct neuronal (prejunctional) AChRs…However, fade in muscle during repetitive nerve stimulation can also be attributable to postjunctional AChR block."

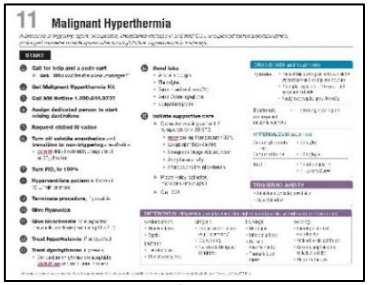
# Key Ions Involved in Neuromuscular Transmission



# Malignant Hyperthermia

15X

- Mechanism: abnormal RYR1 gene (most common) →abnormal ryanodine receptor → significant release of calcium from sarcoplasmic reticulum after triggering agent → uncontrolled muscle contractions → lactic acidosis → muscle breakdown causes hyperkalemia.
- Triggering agents: Volatile anesthetics (e.g., sevoflurane, desflurane, isoflurane), succinylcholine.
- ABG: mixed metabolic and respiratory acidosis (increased lactic acid; inability to hyperventilate enough to release CO2).
- MH vs thyroid storm: Thyroid storm patient may have hyperthyroidism history. Thyroid storm is usually not associated with rigidity, elevated CK, or lactic acidosis. Hypokalemia (not hyperkalemia) is common in thyroid storm. ABG can be helpful.
- Known associated conditions include: Central/Multimini Core disease (Core Myopathies), King-Denborough syndrome (see Litman article for more).
- Testing options: (1) Muscle biopsy contracture studies (halothane, caffeine); (2) genetic testing.
- Dantrolene mechanism: complex; reduces pathologic concentrations of calcium. Can cause muscle weakness. *Avoid calcium channel blockers in treatment of MH*.
- Handout: MH Crisis Checklist.
- QR Code: Litman RS et al. Anesthesiology 2018. PMID 28902673.




References: Barash et al. Clinical Anesthesia, 8th Ed, Ch 24 // Miller 9th Ed, Ch 35 // Cote et al. A Practice of Anesthesia for Infants and Children. 6th Ed, Ch 41. // Openanesthesia: MH vs thyroid storm (available at https://www.openanesthesia.org/mh_vs-_thyroid_storm/) // Litman RS et al. Anesthesiology 2018; PMID 28902673 // Figure: Ariadne Labs Operating Room Crisis Checklists. See www.ariadnelabs.org for latest version. With permission via Creative Commons BY-NC-SA ( https://creativecommons.org/licenses/by-nc-sa/4.0/).

# 11 Malignant Hyperthermia

*In presence of triggering agent: unexpected, unexplained increase in end-tidal $CO_2$, unexplained tachycardia/tachypnea, prolonged masseter muscle spasm after succinylcholine. Hyperthermia is a late sign.*

**START**

1. **Call for help and a code cart**
   - ▶ **Ask**: *"Who will be the crisis manager?"*
2. **Get Malignant Hyperthermia Kit**
3. **Call MH Hotline 1.800.644.9737**
4. **Assign dedicated person to start mixing dantrolene**
5. **Request chilled IV saline**
6. **Turn off volatile anesthetics** and **transition to non-triggering** anesthetics
   - DO NOT delay treatment to change circuit or $CO_2$ absorber
7. **Turn $FiO_2$ to 100%**
8. **Hyperventilate patient** at flows of 10 L/min or more
9. **Terminate procedure**, if possible
10. **Give dantrolene**
11. **Give bicarbonate** for suspected metabolic acidosis (maintain pH >7.2)
12. **Treat hyperkalemia**, if suspected
13. **Treat dysrhythmias**, if present
    - Standard antiarrhythmics are acceptable; DO NOT use calcium channel blockers
14. **Send labs**
    - Arterial blood gas
    - Electrolytes
    - Serum creatine kinase (CK)
    - Serum/urine myoglobin
    - Coagulation profile
15. **Initiate supportive care**
    - ▶ Consider cooling patient if temperature > 38.5°C:
      - STOP cooling if temperature < 38°C
      - Lavage open body cavities
      - Nasogastric lavage with cold water
      - Apply ice externally
      - Infuse cold saline intravenously
    - ▶ Place Foley catheter, monitor urine output
    - ▶ Call ICU

## DRUG DOSES and treatments

**Dantrolene**
- 2.5 mg/kg, repeat up to 10 mg/kg until symptoms subside
- Rarely, may require up to 30 mg/kg

| Ryanodex® | Dantrium® or Revonto® |
|---|---|
| • Reconstitute 250 mg vials with 5 cc sterile water each (shake until orange/opaque) | • Reconstitute 20 mg vials with 60 cc sterile water each |
| • 2.5 mg/kg = 0.05 mL/kg | • 2.5 mg/kg = 7.5 mL/kg |
| • 70 kg patient dose = 3.5 mL | • 70 kg patient dose = 525 mL |

**Bicarbonate** • 1 – 2 mEq/kg, slow IV push
(for suspected metabolic acidosis)

### HYPERKALEMIA treatment

**Calcium gluconate** • 30 mg/kg
*- or -*
**Calcium chloride** • 10 mg/kg IV

**Insulin**
- 10 units regular IV
- 1 – 2 amps D50W

## TRIGGERING AGENTS

- Inhalational anesthetics
- Succinylcholine

## DIFFERENTIAL diagnosis (consider when using high doses of dantrolene without resolution of symptoms)

**Cardiorespiratory**
- Hypoventilation
- Sepsis

**Endocrine**
- Thyrotoxicosis
- Pheochromocytoma

**Iatrogenic**
- Exogenous $CO_2$ source (e.g., laparoscopy)
- Overwarming
- Neuroleptic Malignant Syndrome

**Neurologic**
- Meningitis
- Intracranial bleed
- Hypoxic encephalopathy
- Traumatic brain injury

**Toxicology**
- Radiologic contrast neurotoxicity
- Anticholinergic syndrome
- Cocaine, amphetamine, salicylate toxicity
- Alcohol withdrawal

# Multiple Sclerosis; Muscular/Myotonic Dystrophy

12X

Multiple Sclerosis (MS): autoantibodies against myelin in the Central Nervous System (CNS).

- Some avoid spinal anesthesia if MS exacerbation: demyelination may render the spinal cord more susceptible to local anesthetics. Epidurals have been used successfully.
- Avoid hyperthermia: as little as 1 deg Celsius can affect demyelinated nerve conduction → exacerbation.
- Consider avoiding succinylcholine, particularly if exacerbation: risk of hyperkalemia.

Muscular Dystrophy: X-lined recessive mutations of the gene for dystrophin.

- Duchenne (more severe) and Becker (milder) are the most common.
- Increased risk of cardiomyopathy, conduction, and/or other cardiac disease: consider preop EKG/Echo.
- Avoid succinylcholine: risk of rhabdomyolysis, hyperkalemia, MH-like syndrome.
  - Increased sensitivity to nondepolarizing muscle relaxants (consider sugammadex).
- Some avoid volatile anesthetics: rare risk of MH-like event [Miller 9th Ed Ch 35].

Myotonic dystrophy:

- Prolonged muscle contraction (myotonia) & progressive muscle weakness/wasting.
- Factors increasing periop pulmonary risk: weakness, chronic aspiration, impaired cough reflex.
- Increased risk of cardiac disease (similar considerations as muscular dystrophy)
- Avoid Succinylcholine, Neostigmine, hypothermia/shivering: may cause exaggerated contracture (also, see muscular dystrophy succinylcholine considerations). Consider rocuronium/sugammadex.
- "There is no case report in the literature linking myotonic dystrophy to MH." [Miller/9th Ed/Ch 35]



Miller 9th Ed, Ch 35. // Stoelting's Anesthesia and Co-existing Disease, 7th Ed, Ch 13. // Litman RS et al. Anesthesiology 2018; PMID 28902673.

# Periodic Paralyses; Mitochondrial Myopathies

9X

Periodic Paralyses: weakness, often with changes in serum K+

- Hyperkalemic variant: can be precipitated after potassium-rich meal, fasting, strenuous exercise followed by rest, stress, cold, glucocorticoids, pregnancy.
  - Often admitted preop for dextrose-containing IV solutions while NPO
  - Avoid succinylcholine, neostigmine, potassium, sudden temperature changes, hypoglycemia: can increase serum K+.
  - Be prepared to treat hyperkalemia (insulin, glucose, calcium, etc).
- Hypokalemic variant: can be precipitated by carbohydrate or salt-rich meal, exercise, stress, pregnancy, menstruation, hypothermia. Avoid solutions with high glucose or sodium content. (Miller 9th Ed, Ch 35)

Mitochondrial Myopathies:

- Wide variety of molecular defects from mutations in mitochondrial or nuclear DNA.
- May involve brain, nerves, and muscle, or be subclinical.
- "All inhalational anesthetics and propofol depress mitochondrial function at several levels…ventricular dysrhythmias have been reported after a small dose of bupivacaine"
- "…[while] any anesthesia technique might be used in children with mitochondrial myopathies…*all* children with mitochondrial myopathies must be monitored closely when administering any type of anesthetic." (Cote, 6th Ed, Ch 24)



Miller 9th Ed, Ch 35. // Cote, 6th Ed, Ch 24.

# Miscellaneous Neuromuscular

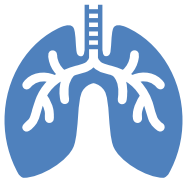
18X

- **<u>Drugs that Prolong Neuromuscular Blockade</u>**: Volatile anesthetics (desflurane > sevoflurane > isoflurane), Local Anesthetics, Procainamide, Calcium-Channel-Blockers, Furosemide, Magnesium, Lithium, Dantrolene, Tamoxifen, and some antibiotics (Metronidazole, Aminoglycosides, Linocasamides [Clindamycin], Polymyxins, Tetracyclines). Also: more than one nondepolarizing neuromuscular blocker at the same time (e.g., rocuronium/cis-atracurium).
  - *Long-term anticonvulsants can cause accelerated recovery from neuromuscular blockade.*
  - "The cephalosporins and penicillins have not been reported to potentiate neuromuscular blockade. […] mannitol appears to have no effect on a nondepolarizing neuromuscular blockade." [Miller 9th Ed, Ch 27]
  - <u>High-Yield Reading</u>: Miller 9th Ed, Ch 27, pgs 817-820.

<table>
<tr><th colspan="5">Causes of Delayed Emergence: "Don't Miss The Criteria for Extubation"</th></tr>
<tr><th>Drugs</th><th>Metabolic</th><th>Temperature</th><th>CVA</th><th>Extra</th></tr>
<tr><td>Residual anesthetic agents (including reversible opioids and benzodiazepine), residual neuromuscular blockade</td><td>Hypoglycemia</td><td rowspan="4">Hypothermia</td><td rowspan="4">Cerebrovascular accident (CVA)/transient ischemic attack (TIA)</td><td>Pseudocholinesterase deficiency</td></tr>
<tr><td rowspan="3">Drugs that prolong neuromuscular blockade (see above)</td><td>Hypercarbia/ acidosis</td><td>Myasthenia Syndromes</td></tr>
<tr><td>Hypocalcemia</td><td rowspan="2">Other disease processes, including neuromuscular disease</td></tr>
<tr><td>Hypermagnesemia</td></tr>
</table>



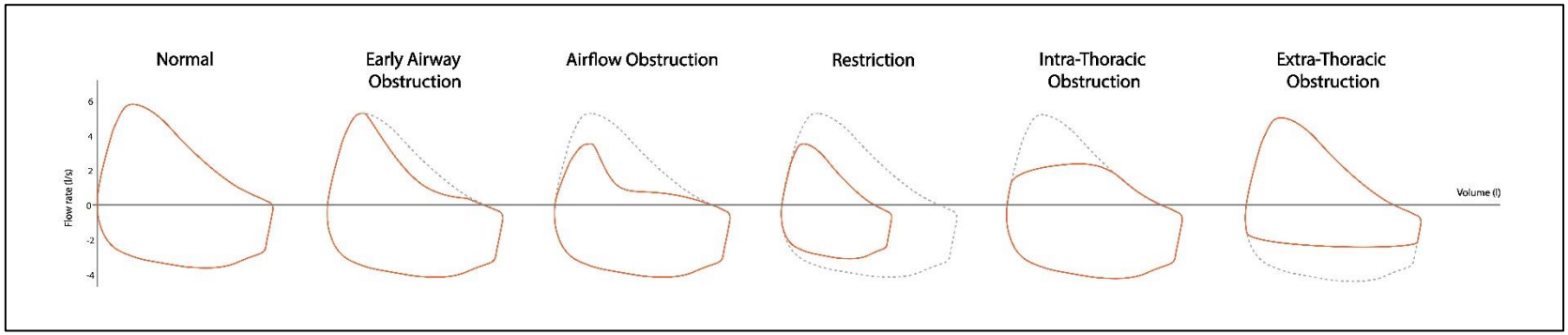
Miller 9th Ed, Ch 27 and 80. // Naguib et al. PMID: 7669466



# Thoracic & Pulmonary

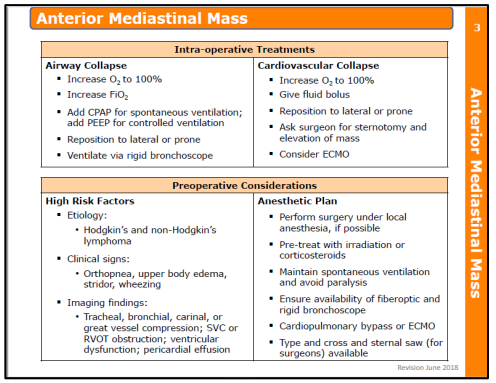
# Thoracic/Pulmonary

## Flow-Volume Loops:




**What is the flow-volume loop for an anterior mediastinal mass?**

- There are several different causes of tumors involving the mediastinum (e.g., thymoma, teratoma, thyroid tumor, lymphoma)
- While Flow-Volume loops may be used in work-up assessing location and dynamic extent of airway obstruction: "Flow-volume loops, specifically the exacerbation of a variable intrathoracic obstructive pattern (expiratory plateau) when supine, are unreliable for predicting which patients will have intraoperative airway collapse." (Miller 9th Ed, Ch 31, 53)
- **History/physical and imaging are essential** (see preoperative considerations of Handout: PediCrisis Checklist for Anterior Mediastinal Mass).



**Anterior Mediastinal Mass**

**Intra-operative Treatments**

| Airway Collapse | Cardiovascular Collapse |
|---|---|
| ▪ Increase $O_2$ to 100%<br>▪ Increase $FiO_2$<br>▪ Add CPAP for spontaneous ventilation; add PEEP for controlled ventilation<br>▪ Reposition to lateral or prone<br>▪ Ventilate via rigid bronchoscope | ▪ Increase $O_2$ to 100%<br>▪ Give fluid bolus<br>▪ Reposition to lateral or prone<br>▪ Ask surgeon for sternotomy and elevation of mass<br>▪ Consider ECMO |

**Preoperative Considerations**

| High Risk Factors | Anesthetic Plan |
|---|---|
| ▪ Etiology:<br>  ▪ Hodgkin's and non-Hodgkin's lymphoma<br>▪ Clinical signs:<br>  ▪ Orthopnea, upper body edema, stridor, wheezing<br>▪ Imaging findings:<br>  ▪ Tracheal, bronchial, carinal, or great vessel compression; SVC or RVOT obstruction; ventricular dysfunction; pericardial effusion | ▪ Perform surgery under local anesthesia, if possible<br>▪ Pre-treat with irradiation or corticosteroids<br>▪ Maintain spontaneous ventilation and avoid paralysis<br>▪ Ensure availability of fiberoptic and rigid bronchoscope<br>▪ Cardiopulmonary bypass or ECMO<br>▪ Type and cross and sternal saw (for surgeons) available |

Revision June 2018

Anterior Mediastinal Mass

# Anterior Mediastinal Mass



## Intra-operative Treatments

### Airway Collapse

- Increase $O_2$ to 100%
- Increase $FiO_2$
- Add CPAP for spontaneous ventilation; add PEEP for controlled ventilation
- Reposition to lateral or prone
- Ventilate via rigid bronchoscope

### Cardiovascular Collapse

- Increase $O_2$ to 100%
- Give fluid bolus
- Reposition to lateral or prone
- Ask surgeon for sternotomy and elevation of mass
- Consider ECMO

## Preoperative Considerations

### High Risk Factors

- Etiology:
  - Hodgkin's and non-Hodgkin's lymphoma
- Clinical signs:
  - Orthopnea, upper body edema, stridor, wheezing
- Imaging findings:
  - Tracheal, bronchial, carinal, or great vessel compression; SVC or RVOT obstruction; ventricular dysfunction; pericardial effusion

### Anesthetic Plan

- Perform surgery under local anesthesia, if possible
- Pre-treat with irradiation or corticosteroids
- Maintain spontaneous ventilation and avoid paralysis
- Ensure availability of fiberoptic and rigid bronchoscope
- Cardiopulmonary bypass or ECMO
- Type and cross and sternal saw (for surgeons) available

Revision June 2018

# Thoracic/Pulmonary

11X

**ARDS vs. TRALI vs. TACO**

| | ARDS[1] | TRALI[2] | TACO[2] |
|---|---|---|---|
| **Timing** | Acute onset or worsening respiratory symptoms (within one week of insult) | Acute onset (within 6 hrs of stopping transfusion) and no evidence of acute lung injury before transfusion | Acute onset (within 12 hrs of stopping transfusion – must have cardiac and ≥ 1 radiographic/clinical/oxygenation criteria) |
| **Imaging** | Bilat CXR/CT opacities not explained by pleural effusions, lobar collapse, lung collapse, pulmonary nodules | Radiographic evidence of bilateral infiltrates | Radiographic and/or clinical evidence of acute or worsening pulmonary edema*** |
| **Cardiac** | Not fully explained by cardiac failure or fluid overload* | No evidence of left atrial hypertension (i.e., circulatory overload) | • Elevated BNP or NT-pro BNP<br>• CV changes**** not explained by other medical condition<br>• Evidence of fluid overload |
| **Oxygenation** | Moderate to severe impaired oxygenation, even with PEEP ≥ 5cmH2O** | Hypoxemia defined by ≥ 1 of the following: (1) P/F ≤ 300mmHg; (2) SpO2 < 90% (room air); (3) other clinical evidence | Evidence of acute or worsening respiratory distress***** |

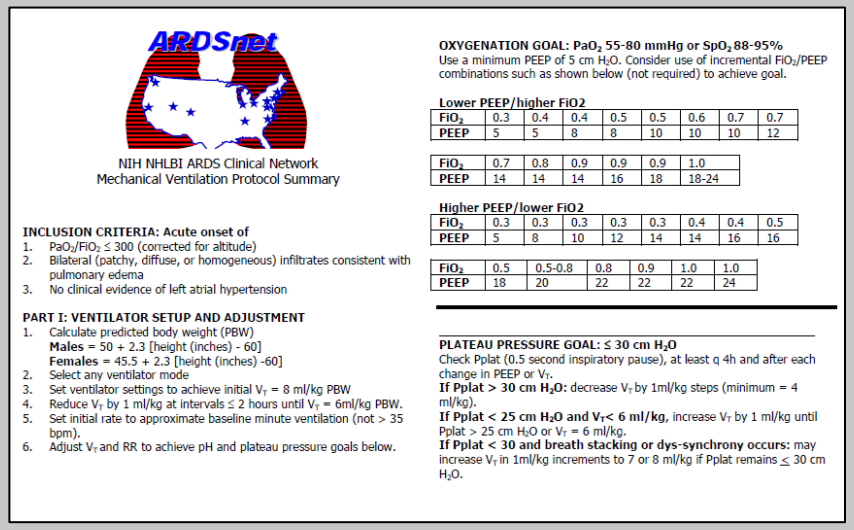
- ARDS Handout: ARDS Clinical Network (ARDSnet) Mechanical Ventilation Protocol Summary[3]
  - 2021 Lancet Review Article: Fundamental initial ICU care elements for ARDS pts include "lung protective ventilation strategy: goal tidal volume ≤ 6 mL/kg, plateau pressure ≤ 30 cm H2O, PEEP relative to FiO2 set according to ARDS Network grids or local practice, generally PEEP ≥ 5 cm H2O."[4]
  - Prone ventilation: Proposed advantages include (1) improved oxygenation; (2) improved ventilation/perfusion matching; (3) less overdistension (non-dependent lung regions); (4) less cyclical opening and closing (dependent lung regions). Sometimes used for severe or moderate-to-severe ARDS.[5] During COVID-19 pandemic, there was use "in awake non-intubated patients with acute hypoxaemic respiratory failure."[4] As with any prone positioning, ETT migration into mainstem bronchus or ETT kinking are possibilities (consider in differential if hypoxemia after prone positoning).[6]
- TRALI/TACO Treatment Considerations: Stop transfusion, alert blood bank, supportive care, consider ARDS treatment principles (TRALI), consider fluid mobilization/diuresis or treatment similar to cardiogenic pulmonary edema from other causes (TACO).

ATS/ESICM/SCCM Guidelines for ARDS Mechanical Ventilation:

*if no ARDS risk factors present, echo or other assessment should be done to exclude hydrostatic pulmonary edema. **(Mild: PaO2/FiO2 [P/F] 201-300mmHg; Moderate: P/F 101-200mmHg; Severe: P/F <100mmHg). *** crackles on lung auscultation, orthopnea, cough, a third heart sound and pinkish frothy sputum in severe cases. **** Elevated central venous pressure, evidence of left heart failure including tachycardia, hypertension, widened pulse pressure, jugular venous distension, enlarged cardiac silhouette and/or peripheral edema. ***** dyspnea, tachypnea, cyanosis and decreased oxygen saturation values in the absence of other specific causes.

References on next slide

# Handout: ARDSnet Mechanical Ventilation Protocol Summary



NIH NHLBI ARDS Clinical Network
Mechanical Ventilation Protocol Summary

**INCLUSION CRITERIA: Acute onset of**
1. $PaO_2/FiO_2 \leq 300$ (corrected for altitude)
2. Bilateral (patchy, diffuse, or homogeneous) infiltrates consistent with pulmonary edema
3. No clinical evidence of left atrial hypertension

**PART I: VENTILATOR SETUP AND ADJUSTMENT**
1. Calculate predicted body weight (PBW)
   **Males** = 50 + 2.3 [height (inches) - 60]
   **Females** = 45.5 + 2.3 [height (inches) -60]
2. Select any ventilator mode
3. Set ventilator settings to achieve initial $V_T$ = 8 ml/kg PBW
4. Reduce $V_T$ by 1 ml/kg at intervals ≤ 2 hours until $V_T$ = 6ml/kg PBW.
5. Set initial rate to approximate baseline minute ventilation (not > 35 bpm).
6. Adjust $V_T$ and RR to achieve pH and plateau pressure goals below.

**OXYGENATION GOAL: $PaO_2$ 55-80 mmHg or $SpO_2$ 88-95%**
Use a minimum PEEP of 5 cm $H_2O$. Consider use of incremental $FiO_2$/PEEP combinations such as shown below (not required) to achieve goal.

**Lower PEEP/higher FiO2**

| $FiO_2$ | 0.3 | 0.4 | 0.4 | 0.5 | 0.5 | 0.6 | 0.7 | 0.7 |
|---|---|---|---|---|---|---|---|---|
| PEEP | 5 | 5 | 8 | 8 | 10 | 10 | 10 | 12 |

| $FiO_2$ | 0.7 | 0.8 | 0.9 | 0.9 | 0.9 | 1.0 |
|---|---|---|---|---|---|---|
| PEEP | 14 | 14 | 14 | 16 | 18 | 18-24 |

**Higher PEEP/lower FiO2**

| $FiO_2$ | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.4 | 0.4 | 0.5 |
|---|---|---|---|---|---|---|---|---|
| PEEP | 5 | 8 | 10 | 12 | 14 | 14 | 16 | 16 |

| $FiO_2$ | 0.5 | 0.5-0.8 | 0.8 | 0.9 | 1.0 | 1.0 |
|---|---|---|---|---|---|---|
| PEEP | 18 | 20 | 22 | 22 | 22 | 24 |

**PLATEAU PRESSURE GOAL: ≤ 30 cm $H_2O$**
Check Pplat (0.5 second inspiratory pause), at least q 4h and after each change in PEEP or $V_T$.
**If Pplat > 30 cm $H_2O$:** decrease $V_T$ by 1ml/kg steps (minimum = 4 ml/kg).
**If Pplat < 25 cm $H_2O$ and $V_T$< 6 ml/kg**, increase $V_T$ by 1 ml/kg until Pplat > 25 cm $H_2O$ or $V_T$ = 6 ml/kg.
**If Pplat < 30 and breath stacking or dys-synchrony occurs:** may increase $V_T$ in 1ml/kg increments to 7 or 8 ml/kg if Pplat remains ≤ 30 cm $H_2O$.

**pH GOAL: 7.30-7.45**
**Acidosis Management: (pH < 7.30)**
**If pH 7.15-7.30:** Increase RR until pH > 7.30 or $PaCO_2$ < 25 (Maximum set RR = 35).

**If pH < 7.15:** Increase RR to 35.
If pH remains < 7.15, $V_T$ may be increased in 1 ml/kg steps until pH > 7.15 (Pplat target of 30 may be exceeded).
May give $NaHCO_3$
**Alkalosis Management: (pH > 7.45)** Decrease vent rate if possible.

**I: E RATIO GOAL:** Recommend that duration of inspiration be ≤ duration of expiration.

**PART II: WEANING**
**A. Conduct a SPONTANEOUS BREATHING TRIAL daily when:**
1. $FiO_2 \leq 0.40$ and PEEP ≤ 8 OR $FiO_2 \leq 0.50$ and PEEP ≤ 5.
2. PEEP and $FiO_2$ ≤ values of previous day.
3. Patient has acceptable spontaneous breathing efforts. (May decrease vent rate by 50% for 5 minutes to detect effort.)
4. Systolic BP ≥ 90 mmHg without vasopressor support.
5. No neuromuscular blocking agents or blockade.

**B. SPONTANEOUS BREATHING TRIAL (SBT):**
**If all above criteria are met and subject has been in the study for at least 12 hours, initiate a trial of UP TO 120 minutes of spontaneous breathing with FiO2 ≤ 0.5 and PEEP ≤ 5:**
1. Place on T-piece, trach collar, or CPAP ≤ 5 cm $H_2O$ with PS ≤ 5
2. Assess for tolerance as below for up to two hours.
   a. $SpO_2 \geq 90$: and/or $PaO_2 \geq 60$ mmHg
   b. Spontaneous $V_T \geq 4$ ml/kg PBW
   c. RR ≤ 35/min
   d. pH ≥ 7.3
   e. No respiratory distress (distress= 2 or more)
      - HR > 120% of baseline
      - Marked accessory muscle use
      - Abdominal paradox
      - Diaphoresis
      - Marked dyspnea
3. If tolerated for at least 30 minutes, consider extubation.
4. If not tolerated resume pre-weaning settings.

Definition of UNASSISTED BREATHING
**(Different from the spontaneous breathing criteria as PS is not allowed)**

1. Extubated with face mask, nasal prong oxygen, or room air, OR
2. T-tube breathing, OR
3. Tracheostomy mask breathing, OR
4. CPAP less than or equal to 5 cm $H_20$ **without pressure support or IMV assistance.**


References from previous slide:

1. ARDS Definition Task Force. ARDS: The Berlin Definition. JAMA 2012. PMID: 22797452
2. CDC National Health Safety Network Biovigilance Protocol. Available at http://www.cdc.gov/nhsn.
3. NIH NHLBI ARDS Clinical Network. Mechanical Ventilation Protocol Summary. Available at http://www.ardsnet.org/tools.shtml.
4. **Meyer et al. Acute respiratory distress syndrome. Lancet 2021; 398: 622-37. PMID: 33894835**
5. **Guérin et al. Prone position in ARDS patients: why, when, how and for whom. Intensive Care Med 2020; 46: 2385-96. PMID: 33169218.**
6. Guérin et al. Prone positioning in severe acute respiratory distress syndrome (PROSEVA study). NEJM 2013. PMID 23688302
7. Miller 9th Ed, Ch 49
8. Goldberg et al. State of the art management of transfusion-related acute lung injury (TRALI). Curr Pharm Des 2012; PMID 22621274.
9. UpToDate articles:
   1. ARDS: Clinical features, diagnosis, and complications in adults.
   2. Prone ventilation for adult patients with ARDS.
   3. Transfusion-related acute lung injury (TRALI).
   4. Transfusion associated circulatory overload (TACO).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**OXYGENATION GOAL: $PaO_2$ 55-80 mmHg or $SpO_2$ 88-95%**

Use a minimum PEEP of 5 cm $H_2O$. Consider use of incremental $FiO_2$/PEEP combinations such as shown below (not required) to achieve goal.

**Lower PEEP/higher FiO2**

| **$FiO_2$** | 0.3 | 0.4 | 0.4 | 0.5 | 0.5 | 0.6 | 0.7 | 0.7 |
|---|---|---|---|---|---|---|---|---|
| **PEEP** | 5 | 5 | 8 | 8 | 10 | 10 | 10 | 12 |

| **$FiO_2$** | 0.7 | 0.8 | 0.9 | 0.9 | 0.9 | 1.0 |
|---|---|---|---|---|---|---|
| **PEEP** | 14 | 14 | 14 | 16 | 18 | 18-24 |

**Higher PEEP/lower FiO2**

| **$FiO_2$** | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.4 | 0.4 | 0.5 |
|---|---|---|---|---|---|---|---|---|
| **PEEP** | 5 | 8 | 10 | 12 | 14 | 14 | 16 | 16 |

| **$FiO_2$** | 0.5 | 0.5-0.8 | 0.8 | 0.9 | 1.0 | 1.0 |
|---|---|---|---|---|---|---|
| **PEEP** | 18 | 20 | 22 | 22 | 22 | 24 |

**PLATEAU PRESSURE GOAL: $\leq$ 30 cm $H_2O$**

Check Pplat (0.5 second inspiratory pause), at least q 4h and after each change in PEEP or $V_T$.

**If Pplat > 30 cm $H_2O$:** decrease $V_T$ by 1ml/kg steps (minimum = 4 ml/kg).

**If Pplat < 25 cm $H_2O$ and $V_T$< 6 ml/kg**, increase $V_T$ by 1 ml/kg until Pplat > 25 cm $H_2O$ or $V_T$ = 6 ml/kg.

**If Pplat < 30 and breath stacking or dys-synchrony occurs:** may increase $V_T$ in 1ml/kg increments to 7 or 8 ml/kg if Pplat remains $\leq$ 30 cm $H_2O$.

**pH GOAL: 7.30-7.45**

**Acidosis Management: (pH < 7.30)**

**If pH 7.15-7.30:** Increase RR until pH > 7.30 or $PaCO_2$ < 25 (Maximum set RR = 35).

.

**If pH < 7.15:** Increase RR to 35.

If pH remains < 7.15, $V_T$ may be increased in 1 ml/kg steps until pH > 7.15 (Pplat target of 30 may be exceeded).

May give $NaHCO_3$

**Alkalosis Management: (pH > 7.45)** Decrease vent rate if possible.

---

**I: E RATIO GOAL**: Recommend that duration of inspiration be ≤ duration of expiration.

**PART II: WEANING**

**A. Conduct a SPONTANEOUS BREATHING TRIAL daily when:**

1. $FiO_2 \leq 0.40$ and PEEP ≤ 8 OR $FiO_2 \leq 0.50$ and PEEP ≤ 5.
2. PEEP and $FiO_2 \leq$ values of previous day.
3. Patient has acceptable spontaneous breathing efforts. (May decrease vent rate by 50% for 5 minutes to detect effort.)
4. Systolic BP ≥ 90 mmHg without vasopressor support.
5. No neuromuscular blocking agents or blockade.

**B. SPONTANEOUS BREATHING TRIAL (SBT):**

**If all above criteria are met and subject has been in the study for at least 12 hours, initiate a trial of UP TO 120 minutes of spontaneous breathing with FiO2 ≤ 0.5 and PEEP ≤ 5:**

1. Place on T-piece, trach collar, or CPAP ≤ 5 cm $H_2O$ with PS ≤ 5
2. Assess for tolerance as below for up to two hours.
   a. $SpO_2 \geq 90$: and/or $PaO_2 \geq 60$ mmHg
   b. Spontaneous $V_T \geq 4$ ml/kg PBW
   c. RR ≤ 35/min
   d. pH ≥ 7.3
   e. No respiratory distress (distress= 2 or more)
      - HR > 120% of baseline
      - Marked accessory muscle use
      - Abdominal paradox
      - Diaphoresis
      - Marked dyspnea
3. If tolerated for at least 30 minutes, consider extubation.
4. If not tolerated resume pre-weaning settings.

Definition of UNASSISTED BREATHING

**(Different from the spontaneous breathing criteria as PS is not allowed)**

1. Extubated with face mask, nasal prong oxygen, or room air, OR
2. T-tube breathing, OR
3. Tracheostomy mask breathing, OR
4. CPAP less than or equal to 5 cm $H_20$ **without pressure support or IMV assistance.**

# Thoracic/Pulmonary

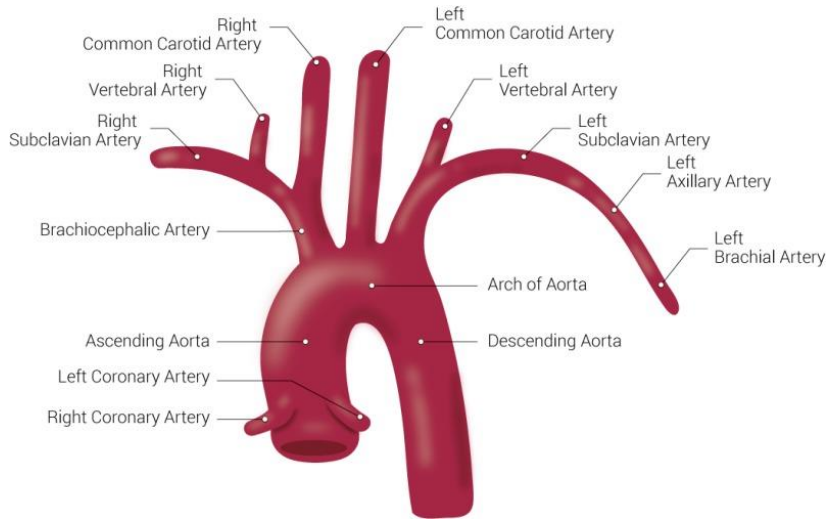
19X

One Lung Ventilation topics:

- Bronchial blockers: **Pros**: can be used with single-lumen ETT if challenging airway; can placed to achieve selective lobar collapse; **Cons**: failure to achieve desired lung separation could occur from abnormal anatomy, lack of seal, or other malpositions (most dangerous: balloon could move and lodge above carina → total airway obstruction); could get caught in staple line if miscommunication.
- Key Bronch landmarks for Left Double Lumen Tube (DLT) placement: *Bronch passed via tracheal lumen*: (1) edge of endobronchial cuff around entrance of left mainstem bronchus; (2) view of right upper lobe bronchus and three orifices (apical, anterior, posterior). *Bronch passed via endobronchial lumen*: (3) visualization of bronchial bifurcation at end of left mainstem bronchus (left upper and left lower bronchi). // Slinger bronch simulator: http://www.thoracic-anesthesia.com/?page_id=2
- Hypoxemia during one-lung ventilation:

| Less Disruptive | More Involved |
|---|---|
| FiO2 100% | Return to two-lung ventilation |
| Recheck positioning via bronch | CPAP to nondependent (operative) lung |
| Suction for mucus plugs | Ligate/Clamp ipsilateral pulm artery (i.e. during pneumonectomy) |
| PEEP to dependent (ventilated) lung | Urgent cardiopulmonary bypass |

Mediastinoscopy and vascular compression: place pulseOx on Right finger to look for innominate artery (aka brachiocephalic artery) compression; Left BP cuff for systemic BP.

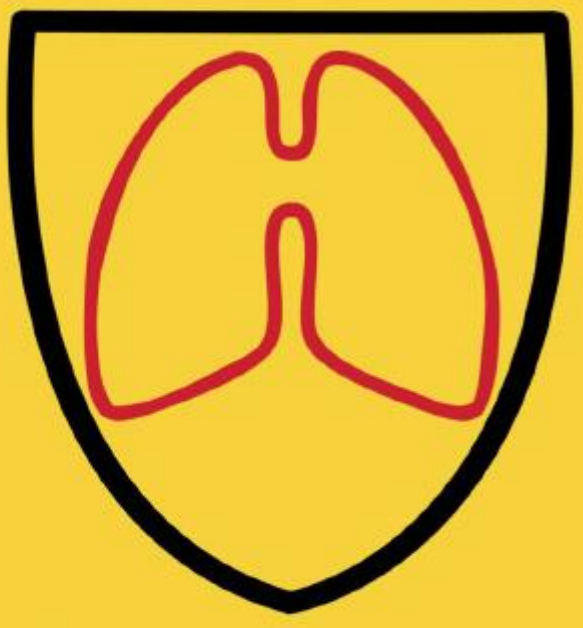





Miller 9th Ed, Ch 53 // Image: Palmer B. StatPearls Creative Commons CC-BY-4.0 https://www.ncbi.nlm.nih.gov/books/NBK499911/figure/article-17736.image.f1/

# THORACIC CRISIS MANUAL

From The Canadian Thoracic Taskforce







UNIVERSITY OF CALGARY

v1.0

All reasonable precautions have been taken to verify the information in this publication. The responsibility for the interpretation and use of the materials lies with the reader. Revised August, 2021.

# 1 Hypoxemia During One-Lung Ventilation

$SpO_2$ < 90% or $PaO_2$ < 60 mmHg despite 100% $FiO_2$

**START**

1. Increase to 100% $FiO_2$
2. Confirm position of lung isolation device
3. Recruit the ventilated lung
4. Optimize PEEP to the ventilated lung
5. Suction secretions from ventilated lung
6. Consider bronchodilator therapy to ventilated lung
7. Decrease volatile anesthetic or consider TIVA
8. Ensure normal cardiac output
9. Ensure adequate hemoglobin level
10. Notify surgeon of severe or refractory hypoxemia:
    - Call for help
    - $O_2$ insufflation/CPAP/HFJV to nonventilated lung
    - Resume two-lung ventilation
    - Consider pulmonary artery clamp to nonventilated lung
    - Consider inhaled nitric oxide (10-40 ppm)
    - Consider ECMO/CPB

**RISK FACTORS**

Right-sided surgery
Prior contralateral lung resection
Supine position
Normal $FEV_1$
Low $PaO_2$ on two-lung ventilation
**High** A-a gradient for $CO_2$

**OXYGENATION TECHNIQUES**

$V_T$ 4-6 ml/kg IBW
I:E ratio 1:2 (routine)
- 1:1-1:2 (restrictive deficit)
- 1:4-1:6 (obstructive deficit)

Ventilated Lung:
- Recruitment maneuver
- PEEP 3-10 cm $H_2O$

Nonventilated Lung:
- CPAP 5-10 cm $H_2O$
- $O_2$ insufflation 2-3 L/min

HFJV: 100-200 RR, DP 15-30 psi, I:E 1:1-1:2

**HYPOXEMIA & RIGID BRONCHOSCOPY**

- Manual ventilation via bronchoscope
- Reposition bronchoscope above carina
- Suction secretions
- Retrieve tumor fragments
- Achieve pulmonary hemostasis
- Consider and manage pneumothorax

# Thoracic/Pulmonary

23X

Carbon monoxide (CO) poisoning/carboxyhemoglobinemia: SpO2 falsely elevated relative to SaO2. Methemoglobinemia: SpO2 falsely approaches 85%. → Use Multiwavelength pulse oximeter ("Pulse CO-Oximeter" is Masimo trademark).

- Both increase oxyhemoglobin affinity for O2 → both cause left shift of oxyhemoglobin dissociation curve.
- p50: The PO2 at which hemoglobin if 50% saturated with oxygen.

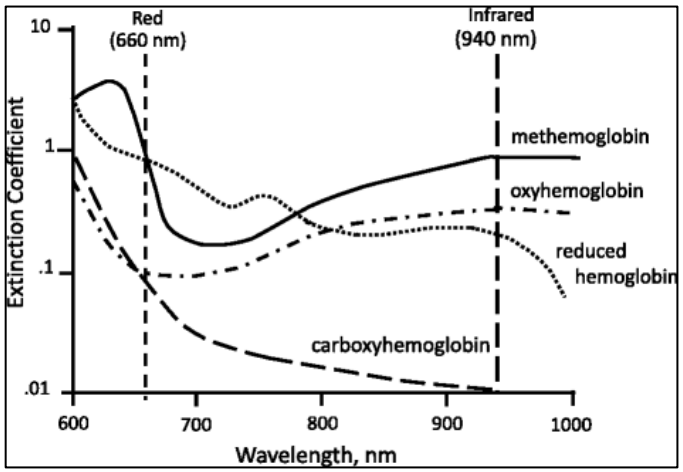
| COHb level | Comments/Symptoms (COHb = Carboxyhemoglobin) |
|---|---|
| ≤10% | Smokers |
| 15-20% | Headaches, dizziness, confusion |
| >20% | Progression of symptoms: Nausea/vomiting, seizures, myocardial ischemia, organ dysfunction, coma, imminent death (>60-80%) |
| >25% | Hyperbaric oxygen therapy discussed/considered |

Smoking cessation: Optimal time: 8 weeks preop. Some say "increased sputum/reactive airways" in short term after cessation. Many recommend immediate cessation preop regardless. Cessation drops carboxyhemoglobin → oxyhemoglobin dissociation curve shifts back to the right.

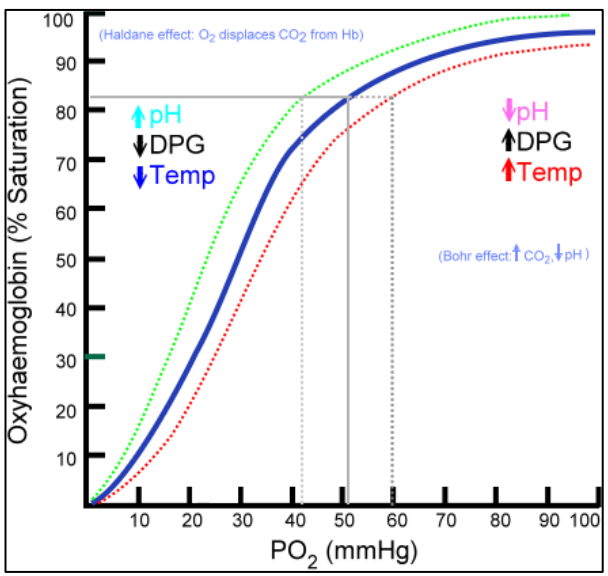
- ASA Statement on Smoking Cessation: "surgery may represent a teachable moment for…smoking cessation…patients should abstain from smoking…both **before** and after surgery."

*Kahn Academy video on Haldane and Bohr effect (Dr. Rishi Desai)*: https://youtu.be/dHi9ctwDUnc

**Pulse oximeter typically uses 660 & 940nm**




**Oxyhemoglobin Dissociation Curve**





UptoDate. Strategies to reduce pulmonary complications in adults. // OpenAnesthesia CO Poisoning. // Extinction coefficients image: Jubran A. PMID 26179876. Creative Commons CC-BY-4.0 // Miller Basics 7th Ed, Ch 5. // Miller 9th Ed, Ch 13, 75 // Dissociation Curve: Ratznium/Aaronsharpe. Wikimedia Commons public domain. https://commons.wikimedia.org/wiki/File:Oxyhaemoglobin_dissociation_curve.png // https://www.masimo.com/company/news/news-media/2005/ Accessed 12/18/19 // Barash 8th Ed, Ch 53 // Ferri's Clinical Advisor 2022: Carbon Monoxide Poisoning // ASA Statement on Smoking Cessation.

# Hyperbaric Oxygen Therapy (HBOT)

10X

Common criteria for HBOT **in acute carbon monoxide (CO) poisoning:**[1]

- Neurologic impairment (including loss of consciousness, altered mental status, dizziness).
- Myocardial ischemia, arrhythmias, heart failure.
- HbCO higher than 25%
- Pregnant patient with signs of fetal distress.

HBOT Seizure: Can occur from oxygen toxicity to CNS. Tx: Decrease FiO2 to room air (21%). Benzodiazepine +/- anticonvulsants. Supportive care. Don't decompress chamber while pt convulsing (airway closure from seizure & failure to exhale could lead to pulmonary barotrauma & arterial gas embolism). Seizure hx doesn't increase risk (risk increases w/increasing pO2 and exposure time). Seizures rarely recur with further HBOT Tx.

HBOT, MAC, and N2O: "Because of its high MAC value (1.04), general anesthesia with N2O can usually only be obtained in a hyperbaric environment….The anesthetic state was associated with tachypnea, tachycardia, increases in systemic blood pressure, mydriasis, diaphoresis,…clonus,…A stable level of physiologic activity was difficult to maintain."[3]

| Undersea & Hyperbaric Medical Society Hyperbaric Oxygen Therapy Indications[2] |
|---|
| Air or Gas Embolism |
| Arterial Insufficiencies (e.g., central retinal artery occlusion, selected problem wounds) |
| Carbon Monoxide Poisoning |
| Clostridial Myonecrosis (Gas Gangrene) |
| Compromised Grafts and Flaps |
| Acute Traumatic Ischemia (e.g., crush injury) |
| Decompression Sickness |
| Delayed Radiation Injuries |
| Sudden Sensorineural Hearing Loss |
| Intracranial Abscess |
| Necrotizing Soft Tissue Infection |
| Refractory Osteomyelitis |
| Severe Anemia |
| Thermal Burns |

1. Miller 9th Ed Ch 75. // 2. https://www.uhms.org/resources/hbo-indications.html (14th Ed) // 3. Russel GB. Hyperbaric nitrous oxide as a sole anesthetic agent in humans. Anesth Analg 1990; 70:289-95 // UpToDate: Hyperbaric Oxygen Therapy.

# Cardiac & Hematology

# Cardiac & Hematology

40X+
(incl protamine reaction table and TEE resources)

- Bradycardia in patient with Heart Transplant: Transplanted heart may have total autonomic denervation. "Vagal maneuver" (stimulation of carotid sinus) may not work. Use **"ENIGmatic" drugs**: **E**pinephrine, **N**orepinephrine, **I**soproterenol, **G**lucagon.
- Heparin resistance attempting to go on bypass:
  - Most common cause: antithrombin III (AT3) deficiency → Tx: recombinant AT3 or FFP.
  - If patient has significant heparin induced thrombocytopenia/thrombosis (HITT) and needs cardiopulmonary bypass: consider direct thrombin inhibitor (e.g., bivalrudin).
- Contraindications to Intra-aortic balloon pump (IABP): severe aortic insufficiency; severe peripheral vascular disease.
- Handouts: [1] Cognitive Aid for Heparin Resistance, [2] Protamine Reaction (Zenati et al), and [3] Cardiac Tamponade (Society for Pediatric Anesthesia); [4] Left-sided Valvular lesions & HCM; [5] Selected online free TEE education video lectures.

American Society of Echocardiography (ASE) 2013 Guidelines for comprehensive TEE (includes 28 suggested views):

ASE and Society for Cardiovascular Anesthesiologists (SCA) 2013 Consensus Statement for Basic TEE (includes 11 views of basic TEE and typical distribution of RCA, LAD and LCx):

Classic 1999 ASE/SCE TEE article:

STS/SCA/AmSECT Guidelines for Anticoagulation during Cardiopulm Bypass:

# 5. Heparin Resistance

Initiate for High (>400 u/kg) Heparin Management System (HMS) Recommended Dose

## ACTIONS

1. PERFUSIONIST report suspicion of Heparin Resistance
   - Based upon HMS recommended dose – Threshold 400 u/kg
2. Administer HMS recommended bolus of heparin, check ACT
3. If **LOW**, administer additional **5 000 – 10 000 u** of heparin, check ACT
4. *Was patient on IV/SQ heparin preoperatively?* If **YES** proceed to **STEP 7**
5. IF **NO**, administer bolus of heparin to cumulative maximum 50 000 units, repeat ACT
6. If ACT remains unsatisfactory, proceed to **STEP 8**
7. **Assume** Antithrombin (AT) III Deficiency
   1. Administer 500 u Antithrombin III (AT III)
      - Ensure an additional dose is available after administration
      - Alternatively, administer 2 u Fresh Frozen Plasma or Cryo
   2. Repeat ACT
   3. If ACT low, administer additional 500 u AT III, repeat ACT
8. Consider
   1. Lower ACT target and perform OPCAB and administer a fixed heparin dose regimen
9. Start CPB when target ACT achieved or option from **Step 7** selected

## DRUG DOSES

| | |
|---|---|
| Heparin: | 300 u/kg |
| Antithrombin III: | 500-1000 IU IV |
| Bivalirudin: | 0.75 mg/kg IV *bolus* |
| | 1.75 mg/kg/hr IV *infusion* |
| | **Target:** ACT > 300 |

## PHARMACY

(XXX) XXX-XXXX

OR xXXXXX

## Heparin Allergy

**Utilize Bivalirudin**

From VA Boston Cardiac Surgery Crisis Checklists. With permission from Dr. M. Zenati and thanks to Yule S, Dias R, et al.

# Protamine Reactions

| | Type I | Type II | Type III |
|---|---|---|---|
| Clinical Presentation | • Mild hypotension<br>• Normal airway pressures | • Moderate/severe hypotension<br>• Anaphylactoid symptoms (e.g., bronchospasm, increased airway pressures) | • Severe hypotension<br>• Pulmonary hypertension/elevated pulmonary artery pressures<br>• Right heart failure |
| Pathophysiology (hypotheses) | • May be allergic (IgE) or nonallergic (IgG/complement) | | • Heparin/protamine complex that lodge into pulmonary vasculature and release mediators. |
| Risk factors | • Previous protamine exposure (including protamine Hagedorn insulin), fish allergy, vasectomy, pre-existing hemodynamic instability/decreased LV function | | |
| Treatment | • Volume resuscitation<br>• Vasopressor support<br>• Lower protamine infusion rate | • Escalate vasopressor support (e.g., epinephrine, norepinephrine, calcium chloride)<br>• Optimize intravenous/arterial access<br>• Consider:<br>  • Albuterol<br>  • Milrinone<br>  • Reheparinization/cardiopulomary bypass | |

Miller's Anesthesia, 9th Ed, Ch 54; Barash 8th Ed, Ch 39

# 3. Protamine Reaction

## ACTIONS

1. First witness alerts READER of "**Protamine Reaction Emergency**"
   - A. *Reader press&hold Vocera button and announce:*
     *" Protamine Reaction Emergency"*
   - A. *Start crisis timer*
2. DISCONTINUE Protamine and Propofol
3. Volume Resuscitation: 1L Crystalloid
4. Open cardiac massage **by expert (avoid graft damage)**
5. Vasopressor or Inotropic Therapy (see drug doses at right)
6. If hypotension *refractory* to treatment modalities:
   - A. Consider administration of **methylene blue**
   - B. Repeat heparin (300 u/kg) and cannulation
   - C. **Re-start pump if severe refractory hypotension lasting >5 min**

## Signs and Symptoms of Protamine Reaction

Severe hypotension refractory to high-dose vasopressors

(MAP <50 mmHg)

Low systemic vascular resistance (<800 dyne/s/cm$^{-5}$)

Central venous pressure < 5 mmHg

Capillary Wedge Pressure < 10 mmHg

Normal to Elevated Cardiac Index (> 2.5L/min/m$^2$)

## Drug Doses

| | |
|---|---|
| Ephedrine: | 5-25 mg bolus IV q5min |
| Epinephrine: | 1-10 mcg/min *IV infusion* |
| | 10-100 mcg IV *bolus* prn |
| **Methylene Blue:** | 1-2 mg/kg IV |
| Norepinephrine: | 2-10 mcg/min *IV infusion* |
| Phenylephrine: | 100-500 mcg bolus IV q5min |
| Methylprednisolone: | 30 mg/kg IV over 30 min |
| Nebulized Albuterol: | 1.25-5mg q4h |

## Guidelines for Protamine Administration

**Dose:** 1-1.3 mg/100 IU heparin

Prior to infusion, ready vasoactive therapy

Give slowly over 5-10 minutes

Pause infusion if hypotension develops

From VA Boston Cardiac Surgery Crisis Checklists. With permission from Dr. M. Zenati and thanks to Yule S, Dias R, et al.

# Tamponade, Cardiac

**Tamponade physiology occurs when increased pericardial pressure impairs diastolic filling**



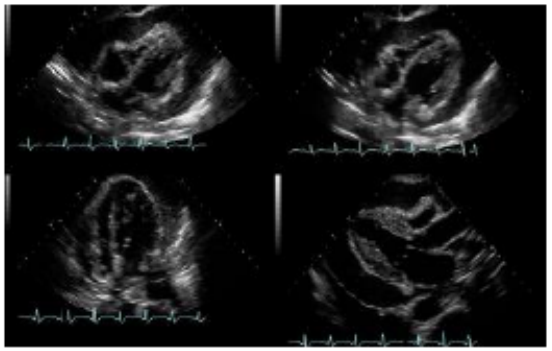


## Signs & Symptoms

- Beck's Triad: muffled heart tones, distended neck veins, decreased systolic blood pressure
- Pulsus Paradoxus: cyclic inspiratory decrease in systolic BP of more than 10mmHg
- Electrical Alternans: cyclic alteration in magnitude of p waves, QRS complex & t-waves
- Typical presentation of acute tamponade = sudden hypotension, tachycardia & tachypnea; patient may be unable to lie flat

## Diagnosis

- Echocardiography/ultrasound: diastolic compression or collapse of RA/RV, leftward displacement of ventricular septum, exaggerated increase in RV size with reciprocal decrease in LV size during inspiration



## Treatment - **imaging is key in deciding treatment**

- Pericardiocentesis awake/local for large effusions prior to GA
- Surgical for postoperative tamponade (cause is often local collections of clotted blood)

## Anesthetic Considerations

- Progressive decrease in SV with an increased CVP → systemic hypotension → cardiogenic shock
- Goals: maintain sympathetic tone and CO via ↑ HR and contractility/fluid bolus prn
  - Induction: Ketamine (1-2 mg/kg IV), muscle relaxant
  - If CV collapse: EPINEPHrine 0.05-0.1 MICROgrams/kg IV bolus or infusion (0.01-0.1 MICROgrams/kg/min)
  - Access: Large bore PIV; arterial line ideal but should not delay treatment in hemodynamically unstable patient
  - Avoid: cardiac depression, vasodilation, ↓ HR; ↑ airway pressure (will ↓ venous return) so may need small tidal volumes or hand ventilation

## Differential Diagnosis

- CHF, PE
- If pulsus paradoxus: respiratory distress, airway obstruction, COPD, PE, RV infarction

First Published Nov 2018

# Handout: Left-sided Valvular lesions & HCM

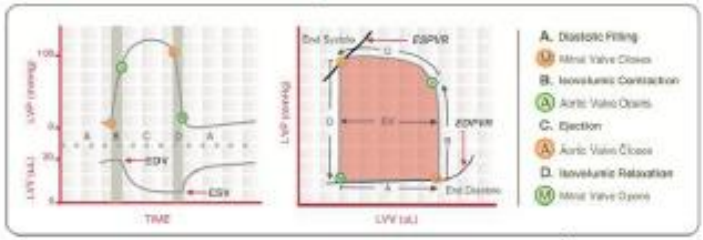
**Anesthetic/Hemodynamic Goals for Left-sided Valvular lesions and Hypertrophic Cardiomyopathy:**

Hemodynamic Goals

| Lesion | Preload | Systemic Vascular Resistance | Heart Rate | Contractility |
|---|---|---|---|---|
| *Aortic Stenosis (AS)* | ↑ | ↑ | ↓ | → |
| *Mitral Stenosis (MS)* | ↑ | → or ↑ | ↓ | → |
| *Mitral Regurgitation (MR)* | ↑ | ↓ | ↑ | → |
| *Aortic Insufficiency (AI)* | ↓ | ↓ | ↑ | → |
| *Hypertrophic Cardiomyopathy (HCM)* | ↑ | ↑ | ↓ | ↓ |

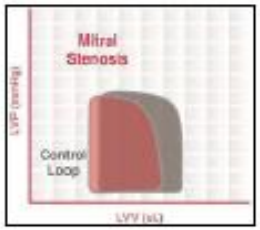
- Pts with AS and HCM are particularly dependent on "atrial kick" (sinus rhythm) → i.e. Afib is particularly detrimental. Systolic Anterior Motion: if HCM is severe, the anterior mitral valve leaflet or chordal structures can be pulled into the left ventricular outflow tract (LVOT) → LVOT obstruction and possible MR.

Standard Left Ventricular Pressure-Volume Loop:

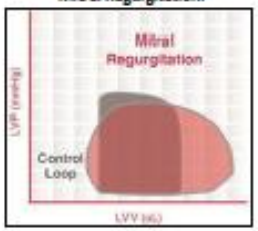



Pressure-Volume Loops for Left Ventricular Valvular Lesions:

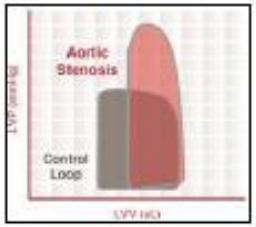
Mitral Stenosis:



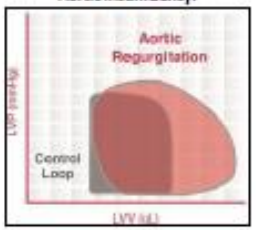

Mitral Regurgitation:




Aortic Stenosis:




Aortic Insufficiency:




References: 1. Essential Clinical Anesthesia. Cambridge University Press, 2011.
2. Pressure-Volume Loop.
https://commons.wikimedia.org/wiki/File:Cardiac_Pressure_Volume_Loop.jpg
With permission via Creative Commons CC BY-SA 3.0, Andyhenson, via Wikimedia Commons.
3. Aortic Regurgitation, Mitral Regurgitation, Mitral Stenosis, Aortic Stenosis.
https://commons.wikimedia.org/wiki/File:Aortic_regurgitation.jpg
https://commons.wikimedia.org/wiki/File:Mitral_stenosis.jpg
https://commons.wikimedia.org/wiki/File:Mitral_regurgitation.jpg
https://commons.wikimedia.org/wiki/File:Aortic_stenosis.jpg
With permission via Creative Commons CC BY 3.0, BlaiseAlleyne, via Wikimedia Commons.
4. Miller 9th Ed, Ch 54 (Anesthesia for Cardiac Surgical Procedures).

Hemodynamic Goals

| Lesion | Preload | Systemic Vascular Resistance | Heart Rate | Contractility |
|---|---|---|---|---|
| *Aortic Stenosis (AS)* | ↑ | ↑ | ↓ | → |
| *Mitral Stenosis (MS)* | ↑ | → or ↑ | ↓ | → |
| *Mitral Regurgitation (MR)* | ↑ | ↓ | ↑ | → |
| *Aortic Insufficiency (AI)* | ↓ | ↓ | ↑ | → |
| *Hypertrophic Cardiomyopathy (HCM)* | ↑ | ↑ | ↓ | ↓ |

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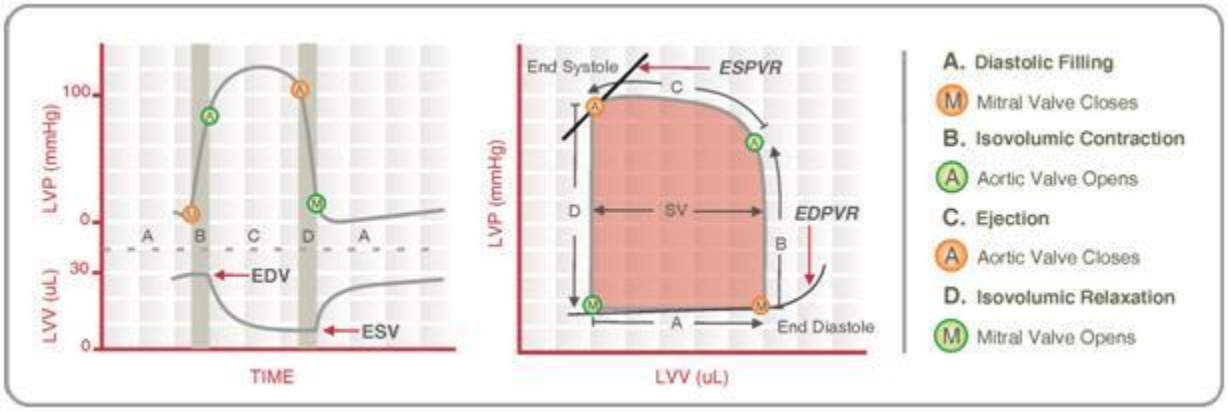
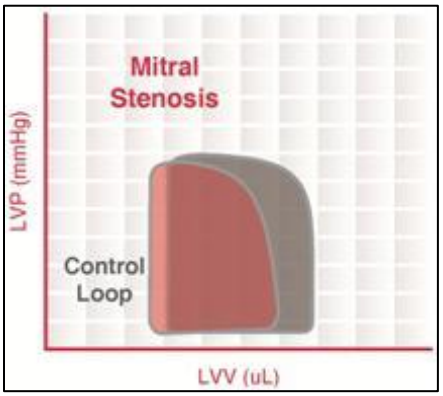
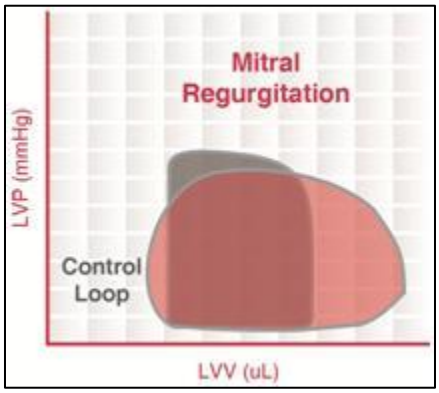



**Pressure-Volume Loops for Left Ventricular Valvular Lesions:**

**Mitral Stenosis:**




**Mitral Regurgitation:**

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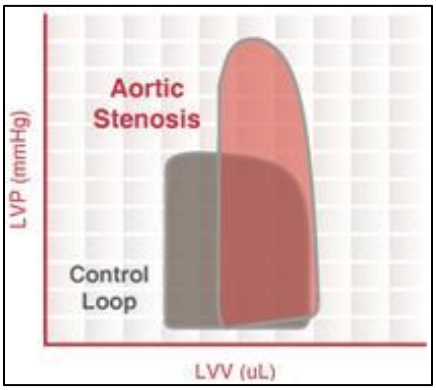
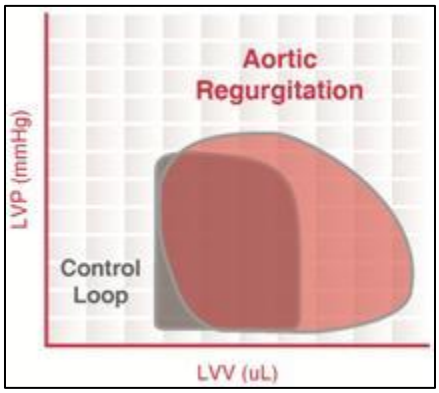



**Aortic Insufficiency:**




References: 1. Essential Clinical Anesthesia. Cambridge University Press. 2011.
2. Pressure-Volume Loop. https://commons.wikimedia.org/wiki/File:Cardiac_Pressure_Volume_Loop.jpg. With permission via Creative Commons CC BY-SA 3.0, Andyhenton, via Wikimedia Commons.
3. Aortic Regurgitation, Mitral Regurgitation, Mitral Stenosis, Aortic Stenosis. https://commons.wikimedia.org/wiki/File:Aortic_regurgitation.jpg, https://commons.wikimedia.org/wiki/File:Mitral_stenosis.jpg, https://commons.wikimedia.org/wiki/File:Mitral_regurgitation.jpg, https://commons.wikimedia.org/wiki/File:Aortic_stenosis.jpg. With permission via Creative Commons CC BY 3.0, BitzBlitz, via Wikimedia Commons.
4. Miller 9th Ed, Ch 54 (Anesthesia for Cardiac Surgical Procedures).

# Selected Free Online Anesthesia Education Videos Containing TEE Content

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2. [Uploaded Jan 21, 2018]: Schell R. University of Kentucky Cardiac Keyword Review Part 1 of 3, 2 of 3, and 3 of 3. Part 1 Available at https://youtu.be/VbS8dAe3Qek. Part 2 available at https://youtu.be/tfUPKix9vPI. Part 3 available at https://youtu.be/ToQc279bjkw. Accessed 12/17/19.
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   - ***The first 5min23sec of part 1 has an intro and "one-liners" on the keywords and Gaps-in-Knowledge from both 2017 and 2016.** Part 1 reviews the following topics: (1) Cardiac Anatomy; (2) Cardiac Physiology; and (3) Preoperative Cardiac Evaluation. Part 2 reviews the following topics: (4) Monitoring; (5) Heart Failure Physiology; and (6) Electrolytes, Dysrhythmias, Pacemakers. Part 3 reviews the following topics: (7) Physiologic changes special conditions; Aging, Obesity; (8) Cardiac Pathology: Valves, congenital, other; (9) Cardiopulmonary bypass; (10) Inotropes, vasopressors, vasodilators.*
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**OpenAnesthesia:**

- Course in Basic TEE (https://www.openanesthesia.org/course-in-basic-tee/)
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# Cardiac: Adult Advanced Life Support ("ACLS")

25X

- 2020 AHA ACLS Algorithms largely unchanged for cardiac arrest, tachycardia, and bradycardia
  - 2018 American Heart Association (AHA) ACLS Updated statement: "**Amiodarone or lidocaine** may be considered for VF/pVT that is unresponsive to defibrillation."[1]
  - *Of note: avoid lidocaine if cardiac arrest may be from Local Anesthetic Systemic Toxicity (LAST)!*[2]
- Epinephrine 1mg IV in adults for cardiac arrest: The alpha-adrenergic effects (vasoconstriction, increased aortic diastolic pressure) can increase coronary and cerebral perfusion pressure (Miller 9thEd/Ch86). Epinephrine also **decreases the cellular refractory period and stabilizes VF**.[3] Epinephrine also bronchodilates and **inhibits release of histamine from mast cells** (helpful in anaphylaxis). *Ongoing controversy surrounding increased myocardial work from 1mg epinephrine.*
  - Update to "Anesthesia ACLS" (Anes Analg):[4] recommends titrating Epi 100-1,000 mcg IV.
  - ASRA:Cardiac Arrest & Local Anes Syst Toxicity:[2] advise smaller Epi doses:"start with ≤ 1 mcg/kg."
- Handouts: (1) Crisis Checklists: Unstable Bradycardia, Cardiac Arrest (Asystole/PEA & VF/VT), Unstable Tachycardia, and Anaphylaxis (special circumstances of ACLS); (2) Stanford Emergency Manual entry: SVT – Stable and Unstable
  - Most common cause of periop anaphylaxis (Barash 8th Ed/Ch 9 & ref[5] below):
    - Globally: neuromuscular blockers > antibiotics, latex
    - U.S. (sparse data): antibiotics are perhaps > neuromuscular blockers

2020 AHA Neonatal Resuscitation Algorithm:

1. Panchal AR, Berg KM, Kudenchuk PJ, et al. 2018 American Heart Association focused update on advanced cardiovascular life support use of antiarrhythmic drugs during and immediately after cardiac arrest: an update to the American Heart Association guidelines for cardiopulmonary resuscitation and emergency cardiovascular care [published online November 5, 2018]. Circulation. // 2. Neal et al. Reg Anes Pain Med 2020; PMID: 33148630. // 3. Tovar OH et al. Epinephrine facilitates cardiac fibrillation by shortening action potential refractoriness. J Mol Cell Cardiol 1997; 29:1447-1455.//4. Moitra et al. Anes Analg 2018; PMID: 30044297. // 5. Dewatcher et al. Perioperative anaphylaxis: what should be known? Curr Allergy Asthma Rep 2015; 15: 21 // Barash 8th Ed, Ch9.

# 3 Bradycardia – Unstable

*HR < 50 bpm with hypotension, acutely altered mental status, shock, ischemic chest discomfort, or acute heart failure*

**START**

1. **Call for help and a code cart**
   - **Ask**: *"Who will be the crisis manager?"*
2. **Turn $FiO_2$ to 100%**
   - Verify oxygenation/ventilation adequate
3. **Give atropine**
4. **Stop surgical stimulation** (if laparoscopy, desufflate)
5. **If atropine ineffective**:
   - Start epinephrine or dopamine infusion

   *– or –*
   - Start transcutaneous pacing
6. **Consider**...
   - Turning off volatile anesthetics if patient remains unstable
   - Calling for expert consultation (e.g., Cardiologist)
   - Assessing for drug induced causes (e.g., beta blockers, calcium channel blockers, digoxin)
   - Calling for cardiology consultation if myocardial infarction suspected (e.g., ECG changes)

**DRUG DOSES and treatments**

| | |
|---|---|
| Atropine: | 0.5 mg IV, may repeat up to 3 mg total |
| Epinephrine: | 2 – 10 mcg/min IV |
| *–or–* Dopamine: | 2 – 20 mcg/kg/min IV |

OVERDOSE treatments

**Beta-blocker**: Glucagon: 2 – 4 mg IV push

**Calcium channel blocker**: Calcium chloride: 1 g IV

**Digoxin**: Digoxin Immune FAB; consult pharmacy for patient-specific dosing

**TRANSCUTANEOUS PACING instructions**

1. Place pacing electrodes front and back
2. Connect 3-lead ECG from pacing defibrillator to the patient
3. Turn monitor/defibrillator to PACER mode
4. Set PACER RATE (ppm) to 80/minute
   (adjust based on clinical response once pacing is established)
5. Start at 60 mA of PACER OUTPUT and increase until electrical capture
   (pacer spikes aligned with QRS complex)
6. Set final milliamperes 10 mA above initial capture level
7. Confirm effective capture
   - Electrically: assess ECG tracing
   - Mechanically: palpate femoral pulse (carotid pulse unreliable)

**Critical CHANGES**

If **PEA** develops, *go to* ▷ CHKLST 4

**During RESUSCITATION**

| | |
|---|---|
| Airway: | Assess and secure |
| Circulation: | • Confirm adequate IV or IO access<br>• Consider IV fluids wide open |

# 4 Cardiac Arrest – Asystole / PEA


*Non-shockable pulseless cardiac arrest*

**START**

1. **Call for help and a code cart**
   - **Ask**: *"Who will be the crisis manager?"*
   - **Say**: *"The top priority is high-quality CPR"*
2. **Put backboard under patient, supine position**
3. **Turn $FiO_2$ to 100%, turn off volatile anesthetics**
4. **Start CPR and assessment cycle...**
   - **Perform CPR**
     - "Hard and fast" about 100–120 compressions/min to depth of 2–2.3 inches
     - Ensure full chest recoil with minimal interruptions
     - 10 breaths/minute, do not overventilate
   - **Give epinephrine**
     - Repeat epinephrine every 3–5 minutes
   - **Assess every 2 minutes**
     - Change CPR compression provider
     - Check $ETCO_2$
       If: < 10 mm Hg, evaluate CPR technique
       If: Sudden increase to > 40 mm Hg, may indicate return of spontaneous circulation
     - Check rhythm; if rhythm organized check pulse
       If: Asystole / PEA continues:
       – Resume CPR and assessment cycle (restart Step 4)
       – Read aloud Hs & Ts (see list in right column)
       If: VF / VT
       – Resume CPR
       – *go to* ▷ CHKLST 5

## DRUG DOSES and treatments

Epinephrine: 1 mg IV, repeat every 3–5 mins.

### TOXIN treatment

Local anesthetic:
- Intralipid 1.5 mL/kg IV bolus
- Repeat 1–2 times for persistent asystole
- Start infusion 0.25–0.5 mL/kg/min for 30–60 minutes for refractory hypotension

Beta-blocker: Glucagon 2–4 mg IV push

Calcium channel blocker: Calcium chloride 1 g IV

### HYPERKALEMIA treatment

| | |
|---|---|
| 1. Calcium gluconate *- or -* Calcium chloride | • 30 mg/kg IV<br>• 10 mg/kg IV |
| 2. Insulin | • 10 units regular IV with 1–2 amps D50W as needed |
| 3. Sodium bicarbonate if pH <7.2 | • 1–2 mEq/kg slow IV push |

## Hs & Ts

- Hydrogen ion (acidosis)
- Hyperkalemia
- Hypothermia
- Hypovolemia
- Hypoxia
- Tamponade (cardiac)
- Tension pneumothorax
- Thrombosis (coronary/pulmonary)
- Toxin (local anesthetic, beta blocker, calcium channel blocker)

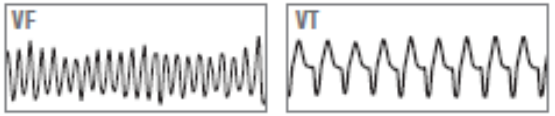
## During CPR

Airway: Bag-mask sufficient (if ventilation adequate)

Circulation:
- Confirm adequate IV or IO access
- Consider IV fluids wide open

Assign roles: Chest compressions, Airway, Vascular access, Documentation, Code cart, Time keeping

# 5 Cardiac Arrest – VF/VT




*Shockable pulseless cardiac arrest*

**START**

1. **Call for help and a code cart**
   - **Ask**: *"Who will be the crisis manager?"*
   - **Say**: *"Shock patient as soon defibrillator arrives"*
2. **Put backboard under patient, supine position**
3. **Turn $FiO_2$ to 100%, turn off volatile anesthetics**
4. **Start CPR — defibrillation — assessment cycle**
   - **Perform CPR**
     - "Hard and fast" about 100–120 compressions/min to depth of 2–2.3 inches
     - Ensure full chest recoil with minimal interruptions
     - 10 breaths/minute, do not overventilate
   - **Defibrillate**
     - Shock at highest setting
     - Resume CPR immediately after shock
   - **Give epinephrine**
     - Repeat epinephrine every 3–5 minutes
   - **Consider giving antiarrhythmics for refractory VF/VT** (amiodarone preferred, if available)
   - **Assess every 2 minutes**
     - Change CPR compression provider
     - Check $ETCO_2$
       If: < 10 mm Hg, evaluate CPR technique
       If: Sudden increase to > 40 mm Hg, may indicate return of spontaneous circulation
     - Treat reversible causes, consider reading aloud Hs & Ts (see list in right column)
     - Check rhythm; if rhythm organized check pulse
       If: VF/VT continues: Resume CPR–defibrillation–assessment cycle (restart Step 4)
       If: Asystole/PEA: *go to* ▷ CHKLST 4

**DRUG DOSES and treatments**

Epinephrine: 1 mg IV, repeat every 3–5 mins.

ANTIARRHYTHMICS

Amiodarone:
- 1st dose: 300 mg/IV/IO
- 2nd dose: 150 mg/IV/IO

Magnesium: 1 to 2 g IV/IO for Torsades de Pointes

**DEFIBRILLATOR instructions**

1. Place electrodes on chest.
2. Turn defibrillator ON, set to DEFIB mode, and increase ENERGY LEVEL...
   - Biphasic: Follow manufacturer recommendation; if unknown use highest setting
   - Monophasic: 360J
3. Deliver shock: press CHARGE then press SHOCK.

**Hs & Ts**

- Hydrogen ion (acidosis)
- Hyperkalemia
- Hypothermia
- Hypovolemia
- Hypoxia
- Tamponade (cardiac)
- Tension pneumothorax
- Thrombosis (coronary/pulmonary)
- Toxin (local anesthetic, beta blocker, calcium channel blocker)

**During CPR**

Airway: Bag-mask sufficient (if ventilation adequate)

Circulation:
- Confirm adequate IV or IO access
- Consider IV fluids wide open

Assign roles: Chest compressions, Airway, Vascular access, Documentation, Code cart, Time keeping

# 12 Tachycardia – Unstable

*Persistent tachycardia with hypotension, ischemic chest pain, altered mental status or shock*

**START**

1. **Call for help and a code cart**
   - **Ask**: *"Who will be the crisis manager?"*
2. **Turn $FiO_2$ to 100%** and **turn down volatile anesthetics**
3. **Analyze rhythm**
   - If wide complex, irregular: treat as VF, *go to* ▷ CHKLST 5
   - Otherwise: prepare for cardioversion
4. **Prepare for immediate synchronized cardioversion**
   1. Sedate all conscious patients unless deteriorating rapidly
   2. Turn monitor/defibrillator ON, set to defibrillator mode
   3. Place electrodes on chest
   4. Engage synchronization mode
   5. Look for mark/spike on the R-wave indicating synchronization mode
   6. Adjust if necessary until SYNC markers seen with each R-wave
5. **Cardiovert at appropriate energy level**
   1. Determine appropriate energy level using Biphasic Cardioversion table at right; begin with lowest energy level and progress as needed
   2. Select energy level
   3. Press charge button
   4. Press and hold shock button
   5. Check monitor; if tachycardia persists, increase energy level
   6. Engage synchronization mode after delivery of each shock
6. **Consider expert consultation**

**BIPHASIC CARDIOVERSION energy levels**

| CONDITION | ENERGY LEVEL (progression) |
|---|---|
| Narrow complex, regular | 50 J → 100 J → 150 J → 200 J |
| Narrow complex, irregular | 120 J → 150 J → 200 J |
| Wide complex, regular | 100 J → 150 J → 200 J |
| Wide complex, irregular | Treat as VF: *go to* ▷ CHKLST 5 |

**Critical CHANGES**

If **cardioversion needed and impossible to synchronize shock**, use high-energy unsynchronized shocks

*Defibrillation doses:*

Biphasic: Follow manufacturer recommendation; if unknown use highest setting

Monophasic: 360J

If **cardiac arrest**, go to:

▷ CHKLST 5 Cardiac Arrest – VF/VT

▷ CHKLST 4 Cardiac Arrest – Asystole/PEA

**During RESUSCITATION**

Airway: Assess and secure

Circulation:
- Confirm adequate IV or IO access
- Consider IV fluids wide open

# SVT - Unstable and Stable

**Non-compensatory tachycardia and Pulse present**
**Often rate >150 or sudden onset**

TREATMENT

| Task | Actions |
|---|---|
| **Crisis Resources** | • Inform team • Identify leader<br>• Call a code • Call for code cart |
| **Pulse Check** | • **If no pulse: start CPR and**<br>**See Asystole/PEA #1** |
| **Airway** | • **100% $O_2$ 10 - 15 L/min**<br>• Confirm adequate ventilation and oxygenation |
| **Defib Pads** | • Place defibrillator pads for possible cardioversion |
| **Determine if UNSTABLE** | • **Unstable if ANY of the following:**<br>• SBP < 75 mmHg<br>• Sudden SBP decrease below patient's baseline<br>• Acute ischemia or chest pain<br>• Acute congestive heart failure<br>• Acutely altered mental status<br>• If stable: go to next page<br>• **If unstable: continue below** |

**UNSTABLE SVT:**

| | |
|---|---|
| **Immediate Synchronized Cardioversion** | • If patient not anesthetized: consider sedation<br>• Cardiovert with settings depending on QRS complex (narrow or wide) and rhythm (regular or irregular)<br>• Narrow complex and regular: **Sync 50 - 100 J biphasic**<br>• Narrow complex and irregular: **Sync 120 - 200 J biphasic**<br>• Wide complex and regular: **Sync 100 J biphasic**<br>• Wide complex and irregular: **Unsync 200 J biphasic** |
| **Refractory SVT** | • If still unstable:<br>• Repeat synchronized shock with increased joules<br>• Consider amiodarone 150 mg IV over 10 min |

STABLE SVT ON NEXT PAGE »





TREATMENT

**STABLE SVT:**

| | |
|---|---|
| **Vagal Maneuvers** | • Consider vagal maneuver before medications |
| **Determine SVT Type** | • Identify complex: narrow or wide<br>• Identify rhythm: regular or irregular<br>• Treat based on SVT type using medication doses provided below |

| Narrow and regular | Wide and regular |
|---|---|
| • Adenosine<br>• If not converted: rate control with beta blocker or calcium channel blocker | • If SVT with aberrancy: adenosine<br>• If VT or uncertain VT: give amiodarone. May add procainamide or sotalol |
| **Narrow and irregular** | **Wide and irregular** |
| • Rate control with beta blocker or calcium channel blocker<br>• Consider amiodarone | • This is likely polymorphic VT<br>• Consider magnesium for torsades<br>• Consult Cardiology STAT |

| | |
|---|---|
| **Meds** | • **Adenosine*** push 6 mg IV, flush, and watch monitor to identify SVT type (watch for asystole). May follow with 12 mg IV<br>• **Beta blocker:**<br>**Esmolol*** 0.5 mg/kg IV over 1 minute. May repeat after 1 minute. Then infusion of 50 - 300 mcg/kg/min.<br>**Metoprolol*** 1 - 2.5 mg IV push. May repeat or double after 3 - 5 minutes<br>• **Calcium channel blocker:**<br>**Diltiazem*** 10 - 20 mg IV over 2 minutes. May repeat after 5 minutes. Then infusion of 5 - 10 mg/hr<br>• **Amiodarone** 150 mg IV **SLOWLY** over 10 minutes to avoid cardiovascular collapse. May repeat once. Then infusion of 1 mg/min<br>• **Procainamide*** 20 - 50 mg/min IV (max 17 mg/kg) until arrhythmia suppressed. Then infusion of 1 - 4 mg/min<br>• **Sotalol*** 100 mg IV over 5 min<br>**Use with caution if asthma, avoid if WPW/CHF* |
| **ECG** | • Obtain 12-lead ECG or print rhythm strip |
| **Labs** | • Consider arterial line placement, ABG, and electrolytes |
| **Expert Consult** | • Consider STAT Cardiology consult for rhythm diagnosis, treatment, and disposition |

END

Stanford Anesthesia Cognitive Aid Program,* Emergency Manual: Cognitive aids for perioperative crises, Version 4, 2021. See http://emergencymanual.stanford.edu for latest version. Creative Commons BY-NC-ND (https://creativecommons.org/licenses/by-nc-nd/4.0/legalcode).
*Goldhaber-Fiebert SN, Austin N, Sultan E, Burian BK, Burden A, Howard SK, Gaba DM, Harrison TK.

# 2 Anaphylaxis

*Hypotension, bronchospasm, high peak-airway pressures, decrease or lack of breath sounds, tachycardia, urticaria*

**START**

1. **Call for help and a code cart**
   - **Ask**: *"Who will be the crisis manager?"*
2. **Give epinephrine bolus** (may be repeated)
3. **Open IV fluids and/or give fluid bolus**
4. **Remove potential causative agents**
5. **Turn $FiO_2$ to 100%**
6. **Establish/secure airway**
7. **Consider**...
   - Turning off volatile anesthetics if patient remains unstable
   - Vasopressin for patients with continued hypotension despite repeated doses of epinephrine
   - Epinephrine infusion for patients who initially respond to bolus doses of epinephrine but experience continued symptoms
   - Diphenhydramine
   - H2 blockers
   - Hydrocortisone
   - Tryptase level: Check within first hour, repeat at 4 hr and at 18–24 hrs post reaction
   - Terminate procedure

**DRUG DOSES and treatments**

| | |
|---|---|
| Epinephrine: | BOLUS: 10–100 mcg, repeat as necessary (dilute 1 mg in 250 mL = 4 mcg/mL)<br>INFUSION: 1–10 mcg/min |
| Vasopressin: | 1–2 units IV |
| Diphenhydramine: | 25–50 mg IV |
| H2 blockers: | Ranitidine: 50 mg IV<br>Cimetidine: 300 mg IV |
| Hydrocortisone: | 100 mg IV |

**Common CAUSATIVE AGENTS**

- Neuromuscular blocking agents
- Antibiotics
- Latex products
- IV contrast

**Critical CHANGES**

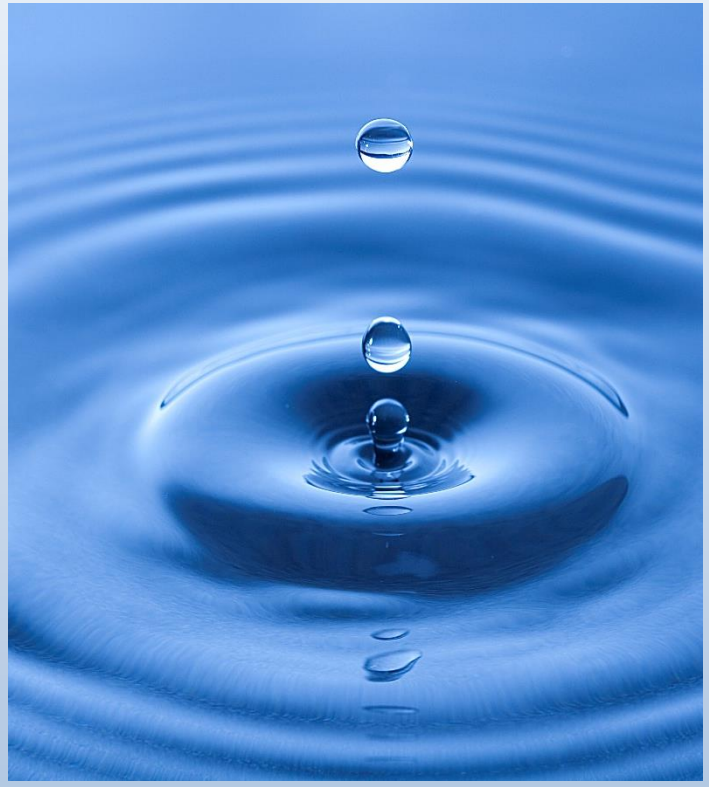
If **cardiac arrest**, *go to*:

▷ CHKLST 4 Cardiac Arrest – Asystole/PEA
▷ CHKLST 5 Cardiac Arrest – VF/VT

# Real-Time Debriefing after the Critical Event

**Potential elements for debriefing just after a perioperative event include (but are not limited to)**:

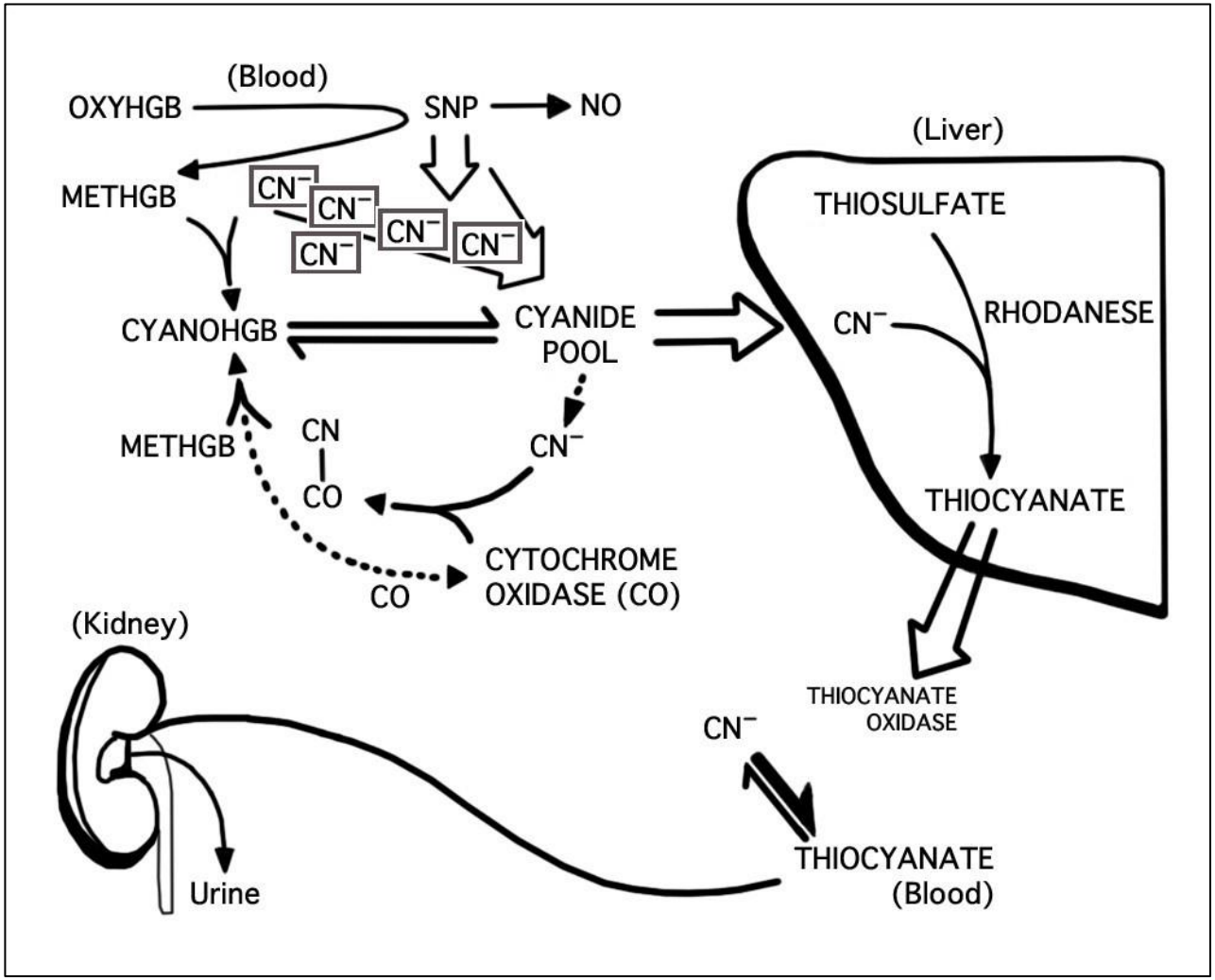
1. **W**elfare check:
- Assessing if team members are ok to continue providing care
2. **A**cute/Short-term corrections:
- Matters to be addressed before next case?
- Clinical/patient care needs?
3. **T**eam Reactions and Reflection:
- Summarize case and listen to team member reactions
- Plus/Delta: Matters that went well and matters that could be improved
4. **E**ducation:
- Lessons learned from the event and the debriefing
5. **R**esource Awareness and longer-term needs:
- Improve awareness of local peer-support and employee assistance resources
- Assess if any follow-up needed (e.g. safety/QI report)



*While a drop of water may seem small in time and space, it can have a substantial ripple effect.*

Chen YK, Arriaga AF. Crisis checklists in emergency medicine: another step forward for cognitive aids. BMJ Qual Saf 2021.  Image: Restivo D. Water Drop impact on water surface. Available at https://commons.wikimedia.org/wiki/File:Water_drop_impact_on_a_water-surface_-_(5).jpg. Accessed Feb 13, 2021. With permission via Creative Commons CC BY-SA 2.0 License (https://creativecommons.org/licenses/by-sa/2.0/legalcode).

# “Image/Buzzwords Co-slides”: Sodium Nitroprusside, Cyanide, Methemoglobinemia




CN-: cyanide ions; CO: cytochrome oxidase; CYANOHGB: cyanomethemoglobin; METHGB: methemoglobin; NO: nitric oxide; OXYHGB: oxyhemoglobin; SNP: sodium nitroprusside

# "Image/Buzzwords Co-slides": Sodium Nitroprusside, Cyanide, Methemoglobinemia

13X

- Sodium Nitroprusside and Pathogenesis of Cyanide Toxicity (see figure):

1. OXYHGB donates electron to SNP to generate NO and 5 CN- . OXYHGB becomes METHGB, which can bind one cyanide ion to become CYANOHGB (a nontoxic compound).
2. If other CN- cannot be cleared, they bind to the ferric ion of mitochondrial cytochrome oxidase & block oxygen utilization in oxidative phosphorylation → anaerobic metabolism.
    - Diagnosis of cyanide toxicity: **profound metabolic acidosis, cherry-red color** blood (as opposed to methemoglobinemia, which is chocolate brown), **mixed venous blood with INCREASED oxygen levels** (less oxygen taken up by cells).
    - Treatment of cyanide toxicity: (1) Sodium thiosulfate: increases metabolism of CN- to thiocyanate (cleared by kidneys). Pts w/impaired renal function are at risk for thiocyanate toxicity (tinnitus, visual disturbances, delirium, seizures); (2) Nitrates (e.g. amyl nitrate, sodium nitrite) via their ability to produce METHGB; (3) Hydroxocobalamin(parenteral preparation of Vitamin B12): chelates CN- and inactivates it.

- Methemoglobinemia:
    - Notable causative drugs include: nitroprusside, nitrates, nitroglycerin, metoclopramide, cocaine and several local anesthetics – particularly benzocaine (in theory, also lidocaine & prilocaine, which are the components of EMLA cream).
    - METHGB prevents O2 binding to HGB & OXYHGB develops increased affinity for O2 → **left-shift of oxygen-hemoglobin dissociation curve, cyanosis, SpO2 inaccurately 85%** (need multiwavelength pulse oximeter ("Pulse CO-Oximeter" is Masimo trademark).
    - Treatment: Methylene blue (**UNLESS** patient has glucose-6-phosphate dehydrogenase [G6PD] deficiency – these patients can get hemolysis and worsened condition from methylene blue) +/- ascorbic acid (aka Vitamin C, which is ok to use in pts with G6PD deficiency).

Nemergut ME, et al. Blood Conservation and Transfusion Medicine. In Smith's Anesthesia for Infants and Children, 2017. // Saeui et al. Biochemical issues in emergency medicine: diagnostic and therapeutic considerations of selected toxic presentations. Am J Em Med 2012; 30: 213-235. // Friederich JA et al. Sodium nitroprusside: twenty years and counting. Anesth Analg 1995; 81: 152-62. // Hammer et al. PMID 23631460

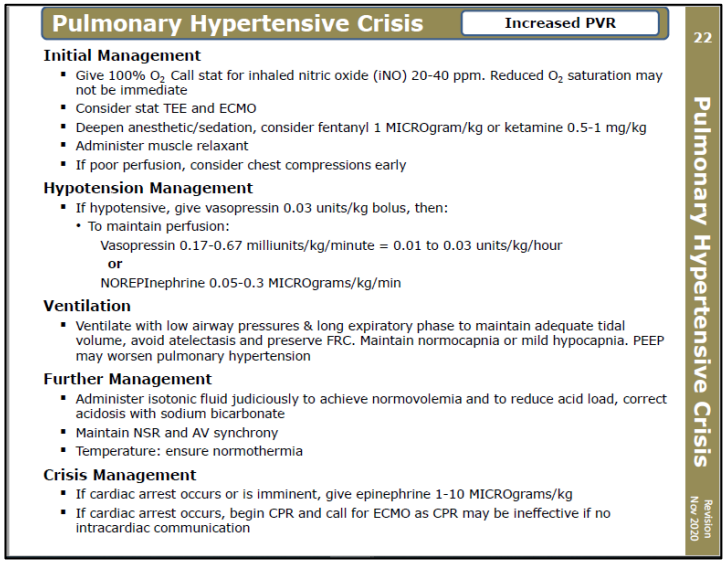
# Nitric Oxide

5X

- Formed by endothelial cells or given via inhalation. **Inhaled** nitric oxide produces **selective pulmonary vasodilation** (smooth muscle relaxation from cGMP pathways).

- Indications:
  - Pulmonary hypertension
  - Persistent pulmonary hypertension of newborn
  - ARDS
  - Neonatal respiratory distress syndrome,
  - Altitude sickness
  - Chronic lung disease
  - Sickle cell disease (mechanism unclear, may cause peripheral vasodilation in these patients).

Handout: Pulmonary Hypertensive Crisis Checklist (Soc Ped Anes)



**Pulmonary Hypertensive Crisis** — Increased PVR

**Initial Management**
- Give 100% $O_2$. Call stat for inhaled nitric oxide (iNO) 20-40 ppm. Reduced $O_2$ saturation may not be immediate
- Consider stat TEE and ECMO
- Deepen anesthetic/sedation, consider fentanyl 1 MICROgram/kg or ketamine 0.5-1 mg/kg
- Administer muscle relaxant
- If poor perfusion, consider chest compressions early

**Hypotension Management**
- If hypotensive, give vasopressin 0.03 units/kg bolus, then:
  - To maintain perfusion:
    Vasopressin 0.17-0.67 milliunits/kg/minute = 0.01 to 0.03 units/kg/hour
    **or**
    NOREPInephrine 0.05-0.3 MICROgrams/kg/min

**Ventilation**
- Ventilate with low airway pressures & long expiratory phase to maintain adequate tidal volume, avoid atelectasis and preserve FRC. Maintain normocapnia or mild hypocapnia. PEEP may worsen pulmonary hypertension

**Further Management**
- Administer isotonic fluid judiciously to achieve normovolemia and to reduce acid load, correct acidosis with sodium bicarbonate
- Maintain NSR and AV synchrony
- Temperature: ensure normothermia

**Crisis Management**
- If cardiac arrest occurs or is imminent, give epinephrine 1-10 MICROgrams/kg
- If cardiac arrest occurs, begin CPR and call for ECMO as CPR may be ineffective if no intracardiac communication

22 Pulmonary Hypertensive Crisis Revision Nov 2020

- Half-life: a few seconds. It should be slowly weaned and not abruptly discontinued.

- End products of metabolism: methemoglobin and nitrate.



Pulmonary Hypertensive Crisis Checklist. Society for Pediatric Anesthesia. // Nitric Oxide ClinicalKey Drug Monograph. Accessed 12/18/19.

# Pulmonary Hypertensive Crisis

**Increased PVR**





Revision Nov 2020

## Initial Management

- Give 100% $O_2$ Call stat for inhaled nitric oxide (iNO) 20-40 ppm. Reduced $O_2$ saturation may not be immediate
- Consider stat TEE and ECMO
- Deepen anesthetic/sedation, consider fentanyl 1 MICROgram/kg or ketamine 0.5-1 mg/kg
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- If poor perfusion, consider chest compressions early

## Hypotension Management

- If hypotensive, give vasopressin 0.03 units/kg bolus, then:
  - To maintain perfusion:

    Vasopressin 0.17-0.67 milliunits/kg/minute = 0.01 to 0.03 units/kg/hour

    **or**

    NOREPInephrine 0.05-0.3 MICROgrams/kg/min

## Ventilation

- Ventilate with low airway pressures & long expiratory phase to maintain adequate tidal volume, avoid atelectasis and preserve FRC. Maintain normocapnia or mild hypocapnia. PEEP may worsen pulmonary hypertension

## Further Management

- Administer isotonic fluid judiciously to achieve normovolemia and to reduce acid load, correct acidosis with sodium bicarbonate
- Maintain NSR and AV synchrony
- Temperature: ensure normothermia

## Crisis Management

- If cardiac arrest occurs or is imminent, give epinephrine 1-10 MICROgrams/kg
- If cardiac arrest occurs, begin CPR and call for ECMO as CPR may be ineffective if no intracardiac communication

# Pulmonary Hypertensive Crisis

Mean PAP > Mean SAP





**Recognition:** Acute ↓ O2 sat, ↓ SBP, ↓EtCO2, ↑ CVP, ↑Airway pressures

**Mechanism:** Abrupt pulmonary vasoconstriction with resultant RV failure, ↓CO, and ↓ BP

**Management**

- Administer 100% oxygen
- Call for nitric oxide (iNO) ASAP
- Hyperventilation and alkalinization
- Support cardiac output
  - ✓ Adequate preload
  - ✓ Inotropes: dopamine, dobutamine, epinephrine
- Utilize pulmonary vasodilators
- Attenuate noxious stimuli: deepen anesthetic/sedation, administer narcotic
- Maintain NSR and AV synchrony
- Consider ECMO activation

**Diagnostic studies**

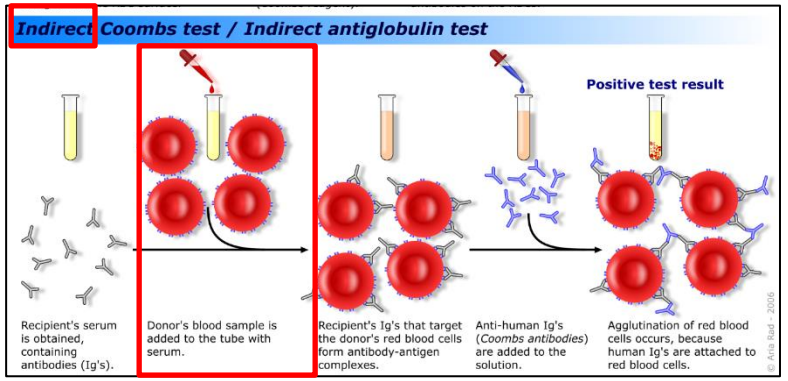
- ECG: New ST segment changes
- Echo: RVSP > ½ systemic, worsening TR, ↑ RV dilatation or dysfunction, systolic septal flattening

| Pulm Vasodilator Class & Mechanism | Drug and Dosing |
|---|---|
| **Nitric Oxide pathway:** | |
| **▪INHALED NO (iNO)** Activates cGMP dependent signaling pathways. ↑ intracellular Ca uptake and smooth muscle relaxation | • iNO 10-40ppm |
| **▪Phosphodiesterase Inhibitors** ↓ PDE 3,5 effect thereby ↑ing intracellular cGMP levels | • Milrinone IV 0.25-0.75mcg/kg/min |
| **Prostacyclin analogs** ↑prostacyclin effect mediating pulmonary vasodilation, smooth muscle relaxation and inhibiting platelet aggregation. | • Epoprostenol IV 1-2ng/kg/min (maintenance) or 40ng/kg/min INHALED<br>• Iloprost 2.5-5mcg INHALED |

# Transfusions

16X

Antibody Screen vs. Crossmatch (both can be done via indirect Coombs test): **Antibody screen:** Recipient's serum mixed with commercially supplied RBCs [known to contain common antigens]. **Crossmatch**: Recipient's serum mixed with Donor RBCs.

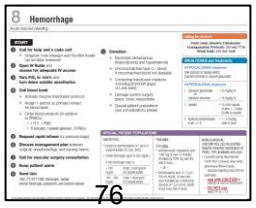



Washed, Leukoreduced, Irradiated Blood Products:

- IgA deficiency and transfusion: Pt with anti-IgA antibodies and donor has IgA antigen → severe, often rapid, allergic reaction can occur.
  - Alternative option: **Washed** RBCs "so that all traces of donor IgA have been removed or with blood that lacks the IgA protein." [Miller 9th Ed/Ch 49]
- **Leukoreduced** blood products lower risk of: febrile reaction; HLA alloimmunization, CMV, transmission of variant Creutzfeld-Jakob disease, and leukocyte-induced immunomodulation. Many institutions implement "universal leukoreduction." [Miller 9th Ed/Ch 49]
- **Irradiated** cellular products (RBC, platelets, granulocytes – FFP and cryoprecipitate are noncellular and no not need irradiation): Prevents proliferation of donor T-lymphocytes (can cause graft-versus-host disease). Indications include critically ill children, marrow cell transplant recipients, and other select indications. [Miller 9th Ed/Ch 49]

Citrate Intoxication & Transfusion: Citrate binds (chelates) calcium and can cause **hypocalcemia** (hypotension, narrow pulse pressure, arrhythmias, confusion, tetany) and coagulopathy (calcium is co-factor in coagulation cascade). **Patients at increased risk**: liver disease/liver transplant status, as well as pediatric patients (reduced citrate metabolism). [Miller 9th Ed/Ch 47,49,60 & Barash 8th Ed Ch 53]

Handout:
Hemorrhage
Crisis Checklist





Upper Figure: Coombs test schematic. Available at https://en.wikipedia.org/wiki/Coombs_test. Available by GNU Free Documentation License & Creative Commons Attribution-Share Alike 3.0 Unported license.

# 8 Hemorrhage

*Acute massive bleeding*

**START**

1. **Call for help and a code cart**
   - **Ask**: *"Who will be the crisis manager?"*
2. **Open IV fluids** and **assess for adequate IV access**
3. **Turn $FiO_2$ to 100%** and **turn down volatile anesthetics**
4. **Call blood bank**
   - Activate massive transfusion protocol
   - Assign 1 person as primary contact for blood bank
   - Order blood products (in addition to PRBCs)
     - 1 FFP : 1 PRBC
     - If indicated, 6 units of platelets
5. **Request rapid infuser** (or pressure bags)
6. **Discuss management plan** between surgical, anesthesiology, and nursing teams
7. **Call for surgery consultation**
8. **Keep patient warm**
9. **Send labs**
   CBC, PT/PTT/INR, fibrinogen, lactate, arterial blood gas, potassium, and ionized calcium
10. **Consider...**
    - Electrolyte disturbances (hypocalcemia and hyperkalemia)
    - Uncrossmatched type O-neg blood if crossmatched blood not available
    - Damage control surgery (pack, close, resuscitate)
    - Special patient populations (see considerations below)

## DRUG DOSES and treatments

**HYPOCALCEMIA treatment**

Give calcium to replace deficit (calcium chloride or calcium gluconate)

**HYPERKALEMIA treatment**

| | |
|---|---|
| 1. Calcium gluconate<br>*- or -*<br>Calcium chloride | • 30 mg/kg IV<br><br>• 10 mg/kg IV |
| 2. Insulin | • 10 units regular IV with 1–2 amps D50W as needed |
| 3. Sodium bicarbonate if pH < 7.2 | • 1–2 mEq/kg slow IV push |

## SPECIAL PATIENT POPULATIONS

**OBSTETRIC:**

- Empirical administration of 1 pool of cryoprecipitate (10 cryo units)
- Check fibrinogen (goal is 200 mg/dL)

| | |
|---|---|
| < 100 mg/dL | Order 2 more pools of cryoprecipitate |
| 100 – 200 mg/dL | Order 1 more pool of cryoprecipitate |

**TRAUMA:**

Give either...

- Antifibrinolytic tranexamic acid: 1000 mg IV over 10 minutes followed by 1000 mg over the next 8 hours

*– or –*

- Aminocaproic acid: 4–5 g in 250 mL NS/RL IV over first hour followed by a continuing infusion of 1 g in 50 mL NS/RL IV per hour over 8 hours

**NON-SURGICAL UNCONTROLLED BLEEDING despite massive transfusion of PRBC, FFP, platelets and cryo:**

- Consider giving Recombinant Factor VIIa: 40 mcg/kg IV
  - Surgical bleeding must first be controlled
  - **use with CAUTION** in patients at risk for thrombosis
  - **DO NOT use** when PH is < 7.2

# Transfusions (cont'd)

9X

#1 cause of Transfusion-Associated Fatality (2015-2019/FDA): **Transfusion Associated Circulatory Overload (TACO) (34%);** #2: Transfusion related acute lung injury (TRALI) and possible TRALI (24%); #3: microbial contamination (14%); #4: hemolytic transfusion reaction (HTR) due to non-ABO incompatibilities (13%); #5: HTRs due to ABO incompatibilities (7%); #5: anaphylaxis reactions (7%); #7: hypotensive reactions (1%) . Latest FDA Stats: https://www.fda.gov/media/147628/download

Contents of cryoprecipitate: "Fibrinogen (about 15 g/L), fibronectin, vWF, FVIII, and FXIII." [Barash 8th Ed]

Indications for FFP (Miller 9th Ed, Ch 49; based on ASA Practice Guidelines for Blood Management; ):

1. "…correction of coagulopathy when [INR > 2], in the absence of heparin.
2. …correction of coagulopathy due to coagulation deficiencies in patients transfused with more than one blood volume (approximately 70 mL/kg) when coagulation studies cannot be easily or quickly obtained.
3. Replacement of known coagulation factor deficiencies with associated bleeding, disseminated intravascular coagulation (DIC), or both, when specific components are not available.
4. Reversal of warfarin anticoagulation when severe bleeding is present and prothrombin complex concentrations are not available."

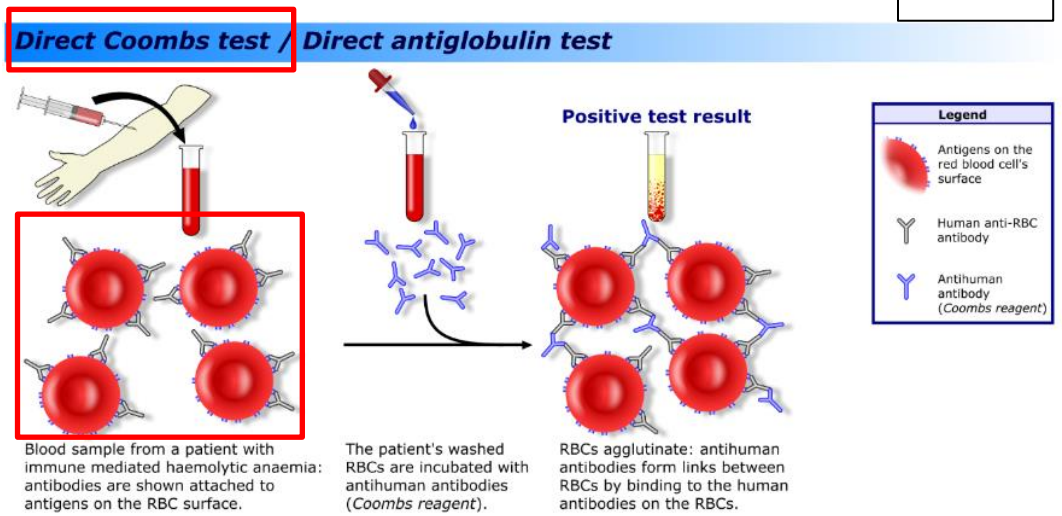
❖ Barash 8th Ed also adds: "Heparin resistance secondary to antithrombin deficiency when antithrombin concentrate is not available" and "treatment of hereditary angioedema when C1-esterase inhibitor is not available."

Suggested Criteria for Preop Transfusion of Non-RBC Blood Products (ASA 2015 Practice Guidelines for Blood Management):

# Transfusion Reactions

11X

- Mild febrile vs hemolytic reaction: "A **direct antiglobulin test** readily differentiates a hemolytic reaction from a febrile reaction because this test rules out the attachment of an RBC antibody to transfused donor RBCs…No clear consensus exists on whether the transfusion should be terminated when a febrile reaction occurs." [Miller 9th Ed, Ch49]




- Hemolytic transfusion reaction lab findings: low serum haptoglobin (hemolysis → hemoglobinemia → hemoglobin binds to haptoglobin), elevated indirect bilirubin and lactate dehydrogenase, hemoglobinuria, positive direct Coombs test, possible DIC.
- Delayed hemolytic transfusion reaction: May present 2-21 days after the transfusion (decreased hematocrit, jaundice, hemoglobinuria, and/or impaired renal function).

**Transfusion Reactions** — Reactions may occur with any type of blood product

26

**For All Reactions:**

- Stop transfusion
- Disconnect donor product and IV tubing
- Infuse normal saline through clean tubing
- Examine blood product ID; determine correct pt
- Send product to Blood Bank
- Determine the type of reaction:

| | Hemolytic | Non-Hemolytic | Anaphylactic |
|---|---|---|---|
| Signs | Hemoglobinemia, hemoglobinuria, DIC, ↓ BP, ↑ HR, bronchospasm | ↓ BP, bronchospasm, pulmonary edema, fever, rash | Erythema, urticaria, angioedema, bronchospasm, tachycardia, shock |
| Treatment | ▪ Furosemide 1-2 mg/kg IV (MAX 40 mg)<br>▪ Mannitol 0.25-1 g/kg<br>▪ Support BP to maintain renal perfusion<br>▪ Maintain urine output at least 1-2 mL/kg/hour<br>▪ Prepare for cardiovascular instability<br>▪ Send blood and urine sample to laboratory | ▪ Treat fever<br>▪ Treat pulmonary edema<br>▪ Observe for signs of hemolysis | ▪ Support airway and circulation as necessary<br>▪ EPINEPHrine 1-10 MICROgrams/kg IV<br>▪ DiphenhydrAMINE 1 mg/kg IV (MAX 50 mg)<br>▪ MethylPREDNISolone 2 mg/kg IV (MAX 60 mg)<br>▪ Maintain intravascular volume |

Revision June 2020

Transfusion Reactions

Society for Pediatric Anesthesia Critical Event Checklists. Revision Packet Nov 2020. Latest update available at http://www.pedsanesthesia.org // Miller 9th Ed, Ch 49 // Hematology: Basic Principles and Practice 7th Ed, Ch 110. // Rad A. Coombs test schematic. https://en.wikipedia.org/wiki/Coombs_test. Available by GNU Free Documentation License & Creative Commons Attribution-Share Alike 3.0 Unported license. // https://www.ncbi.nlm.nih.gov/books/NBK448158/

# von Willebrand disease (vWD)

2X

Von Willebrand factor (vWF): **synthesized in the endothelium and platelet**; vWF circulates as a complex with Factor VIII and acts as a ligand for platelet adhesion via the GPIb receptor. Disease can be quantitative or qualitative.

Desmopressin (DDAVP): analog of antidiuretic hormone/ vasopressin; stimulates release of vWF, factor 8, and plasminogen activator (no clinically significant tPA-like fibrinolysis). Typical IV dose: 0.3 mcg/kg over 30-60min. Intranasal spray also exists.

**** Avoid DDAVP in type 2B**: DDAVP in pts with type 2B → increased abnormal vWF → thrombocytopenia.

<table>
<tr><th>Type</th><th>Quantitative/Qualitative</th><th>Description</th><th>Notes on Treatment</th></tr>
<tr><td>1</td><td>Quantitative vVF defect</td><td>Most common (80% of cases)</td><td>Periop DDAVP often used</td></tr>
<tr><td>2A</td><td rowspan="4">Qualitative defect; patient may also have a quantitative component</td><td rowspan="2">Defect in platelet adhesion (2A also has deficiency of vWF multimers)</td><td rowspan="2">Factor 8 and/or vWF preparation may be needed</td></tr>
<tr><td>2M</td></tr>
<tr><td>2N</td><td>Decreased vWF affinity for Factor 8</td><td>Factor 8 often needed (vWF may not suffice)</td></tr>
<tr><td>2B</td><td>Increased platelet binding affinity**</td><td rowspan="2">Often treated with (1) Factor 8 plus vWF or (2) cryoprecipitate</td></tr>
<tr><td>3</td><td>Quantitative (almost complete absence of vWF)</td><td>vWF levels may be undectectable</td></tr>
</table>

Anes Uncomm Dz 6th Ed Ch 11 // Miller 9th Ed Ch 31 // Barash 8th Ed Ch 17// Stoelting 8th Ed Ch 23 // Hematology: Basic Principles and Practice 7th Ed, Ch 138

# Hemophilia; Factor V Leiden; Porphyria

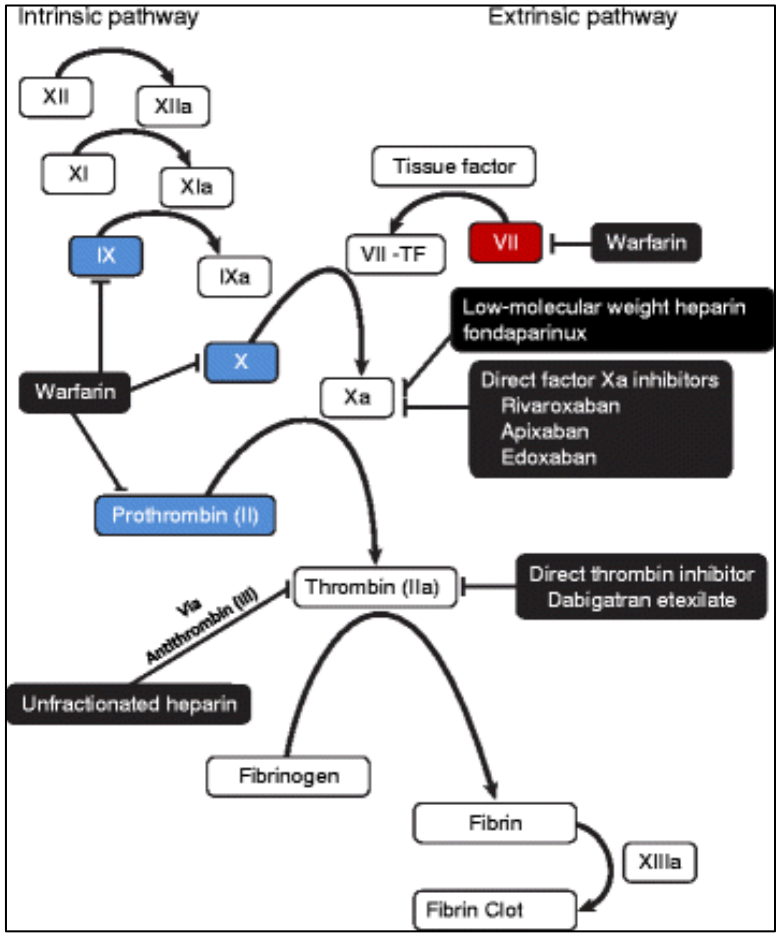
10X
Incl next slide

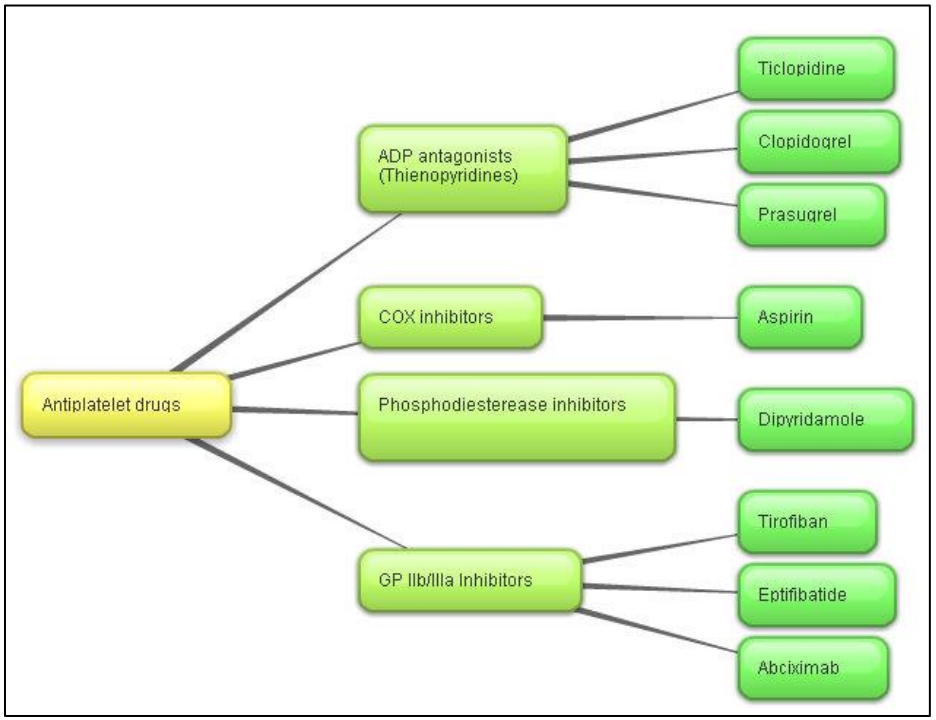
- Hemophilia A: defect in Factor VIII activity; Hemophilia B: deficiency of Factor IX activity.
  - Both X-linked; often present in childhood (spontaneous joint/deep muscle bleeding).
- Hemophilia A/B treatment options include: giving the relevant factor concentrate; giving a blood product with the relevant factor; DDAVP for mild Hemophilia A.
- Patients with Hemophilia from Factor VIII or IX antibodies: "Patients with inhibitors to FVIII or FIX often respond to bypass agents such as rFVIIa or prothrombin complex concentrates (PCCs [contains factors II, VII, IX, X, and proteins C and S])." [Barash Ch 17, 8th Ed]
- Hemophilia and elective procedures: **Involve hematologist** and:
  - Restore level to 40% of normal [Miller 9th Ed, Ch 32 – Concurrent Diseases]
  - For major surgery: restore level to 80%-100% for hemophilia A and 60%-80% for hemophilia B. [Miller 9th Ed, Ch 31 – Preop Eval]
- Factor V Leiden: Mutation to Factor V that makes it insensitive to activated protein C (a natural anticoagulant) → hypercoagulable state. **Treatment:** "Only patients who present with a thrombotic event require anticoagulation." [Anes Uncomm Dx 6th ed]
- Acute Intermittent Porphyria: an inducible porphyria that results from defect in heme synthesis. **Agents that can trigger an attack include** (acute neurological/GI symptoms, hypertension/tachycardia): ketorolac, sulfonamides, barbituates, diazepam, phenytoin, and birth control pills. Ketamine and etomidate have been porphyrogenic in rats.



OpenAnesthesia: Hemophilia: Factor deficiencies. Srivastava A, Brewer AK, Mauser-Bunschoten EP, et al. Guidelines for the management of hemophilia. *Haemophilia*. 2013;19(1):e1– e47.

# Popular Antithrombotic (Anticoagulant/Antiplatelet) Agents




- Fondaparinux:[1] "selectively binds to antithrombin III, potentiating factor Xa neutralization and inhibiting thrombin formation (synthetic selective factor Xa inhibitor)"
- Enoxaparin:[1] "binds to antithrombin III and accelerates activity, inhibiting thrombin and factor Xa (low-molecular weight heparin)."

1. Epocrates // Anticoagulants image: Brown KS et al. PMID 27659071. via Creative Commons CC-BY-4.0 // Antiplatelets image: Vtvu, CC BY-SA 3.0 via Wikimedia Commons (https://commons.wikimedia.org/wiki/File:Antiplatelet_agents_classification.jpg) //

# Self-Directed Deep Dive: Antithrombotics and Antihemorrhagics
# WHO Anatomical Therapeutic Chemical (ATC) Classification System

| V·T·E | Antithrombotics (thrombolytics, anticoagulants and antiplatelet drugs) (B01) | | [hide] |
|---|---|---|---|
| Antiplatelet drugs | Glycoprotein IIb/IIIa inhibitors | | Abciximab · Eptifibatide · Orbofiban · Roxifiban · Sibrafiban[§] · Tirofiban |
| | ADP receptor/$P2Y_{12}$ inhibitors | | Thienopyridines (Clopidogrel · Prasugrel · Ticlopidine) · Nucleotide/nucleoside analogs (Cangrelor · Elinogrel · Ticagrelor) |
| | Prostaglandin analogue (PGI2) | | Beraprost · Iloprost · Prostacyclin · Treprostinil |
| | COX inhibitors | | Acetylsalicylic acid/Aspirin[#] · Aloxiprin · Carbasalate calcium · Indobufen · Triflusal |
| | Thromboxane inhibitors | | Thromboxane synthase inhibitors (Dipyridamole (+ aspirin) · Picotamide · Terbogrel) · Receptor antagonists (Terbogrel · Terutroban[§]) |
| | Phosphodiesterase inhibitors | | Cilostazol · Dipyridamole · Triflusal |
| | Other | | Cloricromen · Ditazole · Vorapaxar |
| Anticoagulants | Vitamin K antagonists (inhibit II, VII, IX, X) | | Coumarins: Acenocoumarol · Coumatetralyl · Dicoumarol · Ethyl biscoumacetate · Phenprocoumon · Warfarin[#] · 1,3-Indandiones: Clorindione · Diphenadione · Phenindione · Other: Tioclomarol |
| | Factor Xa inhibitors (with some II inhibition) | Heparin group/ glycosaminoglycans/ (bind antithrombin) | **Low-molecular-weight heparin** (Bemiparin · Certoparin · Dalteparin · Enoxaparin · Nadroparin · Parnaparin · Reviparin · Tinzaparin) · Oligosaccharides (Fondaparinux · Idraparinux[§]) · Heparinoids (Danaparoid · Dermatan sulfate · Sulodexide) |
| | | Direct Xa inhibitors ("xabans") | Apixaban · Betrixaban · Darexaban[§] · Edoxaban · Otamixaban[§] · Rivaroxaban |
| | Direct thrombin (IIa) inhibitors | | Bivalent: Hirudin (Bivalirudin · Desirudin · Lepirudin[‡]) · Univalent: Argatroban · Dabigatran · Efegatran · Inogatran[§] · Melagatran[‡] · Ximelagatran[‡] |
| | Other | | Antithrombin III · Defibrotide · Nafamostat · Protein C (Drotrecogin alfa[‡]) · Ramatroban · REG1 |
| Thrombolytic drugs/ fibrinolytics | Plasminogen activators: r-tPA (Alteplase[#] · Reteplase · Tenecteplase · Desmoteplase[†]) · UPA (Saruplase · Urokinase) · Anistreplase · Monteplase · Streptokinase[#] · Other serine endopeptidases: Ancrod[‡] · Brinase · Fibrinolysin | | |
| Non-medicinal | Citrate · EDTA · Oxalate | | |

[#]WHO-EM · [‡]Withdrawn from market · Clinical trials: ([†]Phase III · [§]Never to phase III)

| V·T·E | Antihemorrhagics (B02) | | [hide] |
|---|---|---|---|
| Antihemorrhagics (coagulation) | Systemic | Vitamin K | Phytomenadione ($K_1$) · Menadione ($K_3$) |
| | | Coagulation factors | *intrinsic:* IX/Nonacog alfa · VIII/Damoctocog alfa pegol/Efmoroctocog alfa/Moroctocog alfa/Susoctocog alfa/Turoctocog alfa<br>*extrinsic:* VII/Eptacog alfa<br>*common:* X · II/Thrombin · I/Fibrinogen · XIII/Catridecacog<br>*combinations:* Prothrombin complex concentrate (II, VII, IX, X, protein C and S) |
| | | Other systemic | Batroxobin · Carbazochrome · Etamsylate · Fostamatinib · *thrombopoietin receptor agonist* (Romiplostim · Avatrombopag · Eltrombopag · Lusutrombopag) |
| | Local | | Absorbable gelatin sponge · Calcium alginate · Collagen · Epinephrine/adrenalone · Fibrin glue · Oxidized cellulose · Tetragalacturonic acid hydroxymethylester · Thrombin · Hemostatic Powder Spray TC-325 |
| Antifibrinolytics | *amino acids* (Aminocaproic acid · Tranexamic acid · Aminomethylbenzoic acid) · *serpins* (Aprotinin · Alfa1 antitrypsin · C1-inhibitor · Camostat) · unsorted (Ulinastatin) | | |

ASRA Guidelines for Regional Anesthesia in the Patient Receiving Antithrombotic or Thrombolytic therapy



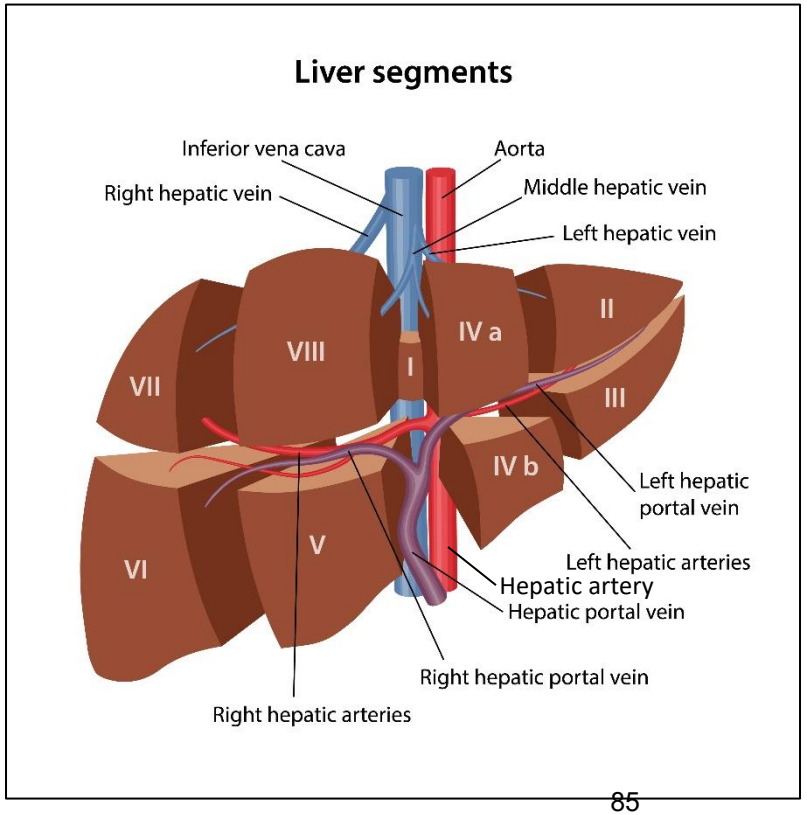
Wikipedia: ATC code B01 (https://en.wikipedia.org/wiki/ATC_code_B01) and B02 (https://en.wikipedia.org/wiki/ATC_code_B02) // WHO Collaborating Centre for Drug Statistics Methodology (https://www.whocc.no/) //

# Liver

# Liver: Anatomy, Physiology, and Hepatic Blood Flow

7X

- Blood Supply: 25% from hepatic artery; 75% from the portal vein. Each provides 50% of oxygen to liver.[1]
  - Hepatic veins drain to inferior vena cava (IVC). Increased central venous pressure (CVP; from positive pressure ventilation, congestive heart failure, excessive intravascular fluids) → increased pressure on hepatic veins → decreased hepatic flow and liver venous congestion.
    - Lower CVP's or higher stroke volume variations (SVV) are sometimes used to limit vascular congestion during hepatic resection.[1]
  - Portal blood flow (PBF) comes from splanchnic circulation and is dependent on cardiac output and mean arterial pressure (MAP).
- Volatile Anesthetics: isoflurane, sevoflurane, and desflurane decrease PBF in a dose-dependent manner via reduction in MAP and cardiac output.
  - *Hepatic Arterial Buffer Response (HABR)*: reduced PBF is matched with increase in hepatic arterial blood flow to maintain total hepatic blood flow (HABR is not preserved with halothane).
- Other Extrinsic factors that can decrease hepatic flow:[2]
  - Pain, hypoxemia, and surgical stress (especially if close to liver) → increased splanchnic vascular resistance → decreased hepatic flow.
  - Nonselective beta-blockers (e.g., propranolol) via decreased cardiac output (beta-1) and splanchnic vasoconstriction (beta-2).



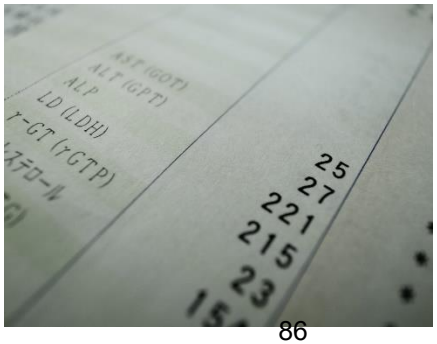



Refs: 1. Miller 9th Ed, Ch 16. // 2. Miller Basics of Anesthesia 7th Ed, Ch 28 // Image: Bolbot O; used under license from Shutterstock.com

# Liver: Physiology, Protein Synthesis, and Labs

7X

- 80-90% of circulating proteins are synthesized in the liver.[1]
  - "The liver is the site of synthesis for all procoagulant and anticoagulant factors, with the exception of tissue thromboplastin (III), calcium (IV), and von Willebrand factor (VIII)."[1]
    - Vitamin-K-dependent coagulation factors/proteins: Factors II, VII, IX, X, and proteins C and S.
- Ratio of AST to ALT: ALT often higher than AST in hepatic injury; AST often higher than ALT in alcoholic liver disease and Wilson disease (genetic disorder causing excess copper accumulation).[1]
- Enterohepatic circulation: 95% of bile acids secreted into the duodenum are reabsorbed via the terminal ileum and returned to the liver.
- Bilirubin excretion: Bilirubin is product of heme catabolism. Hepatocytes convert unconjugated bilirubin into conjugated bilirubin (via bilirubin *glucuronyl transferase enzyme*) and excreted in bile.
  - *Gilbert's syndrome*: mild decreased activity of enzyme → unconjugated hyperbilirubinemia.
  - *Crigler-Najjar syndrome*: severe deficiency of enzyme (neonatal jaundice, brain damage).
  - Conjugated bilirubin is converted to urobilinogen in colon, which is excreted in urine/stool (pale stool and dark urine may be a sign of cholestasis). Some of the urobilinogen is reabsorbed to the liver via the enterohepatic circulation.
- Hemolysis vs. Hepatocellular Injury vs. Cholestasis:
  - Hemolysis associated with unconjugated hyperbilirubinemia;
  - Hepatocellular injury associated with increased AST & ALT (decreased in very advanced disease) and decreased albumin;
  - Cholestasis associated with increased alkaline phosphatase and gamma glutamyl transpeptidase (GGT).

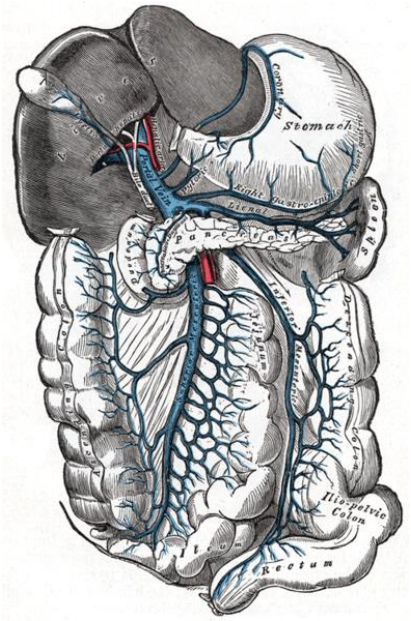





Refs: 1. Miller 9th Ed, Ch 16. // Image: "Result of liver function test" by matsuyuki is licensed with CC BY-SA 2.0. To view a copy of this license, visit https://creativecommons.org/licenses/by-sa/2.0/

# Pathophysiology of End-Stage Liver Disease

- Cirrhosis → fibrosis and destruction of hepatic vasculature → portal hypertension and release of vascular mediators (including nitric oxide) → splanchnic vasodilation, gastroesophageal varices, and portosystemic shunts. Portosystemic shunts can cause hepatic encephalopathy.[1]
  - Cardiovascular complications: Hyperdynamic circulation -- high cardiac output, low arterial blood pressure, low systemic vascular resistance, decreased effective circulating volume (more intravascular volume is sequestered in the splanchnic vascular bed).[1]
- Hepatorenal syndrome (HRS): advanced liver disease and acute kidney injury (AKI) in the absence of any apparent cause and refractory to volume expansion or stopping diuretics (diagnosis of exclusion).
  - *Pathophysiology*: Splanchnic vasodilation from cirrhosis → decrease in effective circulating volume → decrease in arterial blood pressure → activation of sympathetic, renin-angiotensin-aldosterone, and vasopressin systems → reduction in renal perfusion and glomerular filtration.[1]
- Hepatopulmonary syndrome (HPS)[1,2]: portal hypertension → intrapulmonary vascular dilations (IPVD; possibly due to release or failure-to-clear vasoactive mediators, such as nitric oxide) → PaO2 less than 70mmHg or alveolar-arterial oxygen gradient greater than 15mmHg on room air; ventilation-perfusion mismatch. Since IPVD's predominate in the bases of the lungs, some patients get:
  - Platypnea: dyspnea when going from supine to standing.
  - Orthodeoxia: decrease in PaO2 (more than 5% or 4mmHg) when going from supine to standing.
- Portopulmonary hypertension: pulmonary arterial hypertension that is otherwise unexplained in patient with portal hypertension. mPAP greater than 45 is contraindication to liver transplant.[1]






Refs: 1. Miller 9th Ed, Ch 16 & 60. //2. UpToDate: Hepatopulmonary syndrome in adults// Image: Gray H. Anatomy of the Human Body. Portal Vein. Public Domain, via Wikimedia Commons. Available at: https://commons.wikimedia.org/wiki/File:Gray591.png

# Misc End-Stage Liver Disease

6X

- Kinetics of Neuromuscular blocking agents in end-stage liver disease:[1]
  - Vecuronium and Rocuronium (i.e., aminosteroid neuromuscular blocking agents) have a larger volume of distribution in cirrhotic patients → slower rate of onset and longer duration of action.
  - Some use rocuronium instead of cis-atracurium for liver transplant "because the duration of the neuromuscular block appears to be a useful predictor of primary allograft function."

Child-Turcotte Pugh (CTP) and Model for End-Stage Liver Disease (MELD) scores:

- Original MELD: included INR, bilirubin, creatinine. Newer ones add serum sodium (Na-MELD) and age (i-MELD).
- MELD calculators are available online: https://optn.transplant.hrsa.gov/resources/allocation-calculators/meld-calculator/
- Downsides of CTP include the subjectivity of ascites and encephalopathy scoring (and responsiveness to diuretics, lactulose, rifaximin) and ceiling/floor effects due to a min score of 5 and max of 15.
- "Studies comparing…CTP to MELD have yielded conflicting results likely due to small sample sizes and differences in primary outcome measures and surgical procedures…both scores should be used in conjunction with other available patient data when attempting to risk-stratify cirrhotic patients for nonhepatic surgery."

| Child-Turcotte-Pugh Score (Class A: 5-6 points; B: 7-9; C: 10-15) | | Points | | |
|---|---|---|---|---|
| | | 1 | 2 | 3 |
| Some Subjectivity | Encephalopathy grade | None | 1-2 | 3-4 |
| | Ascites | Absent | Slight | Moderate |
| | Bilirubin (mg/dL) | <2 | 2-3 | >3 |
| | Albumin (g/dL) | >3.5 | 2.8-3.5 | <2.8 |
| | International normalized ratio (INR) | <4 | 4-6 | >6 |

Encephalopathy Grades (West Haven Criteria):[1] (1): Trivial lack of awareness; shortened attention span; disordered sleep; (2): Lethargy, behavioral change; asterixis; (3): Somnolence, confusion; gross disorientation; bizarre behavior; (4) Coma



Refs: 1. Miller 9th Ed, Ch 16 & 60. //2. UpToDate: Model for End-Stage Liver Disease (MELD) // Wiesner et al PMID: 11460223 // Pugh et al PMID: 4541913

# Liver Transplantation

7X

Preanhepatic Phase: starts with surgical incision & ends with vascular exclusion and hepatectomy of liver.

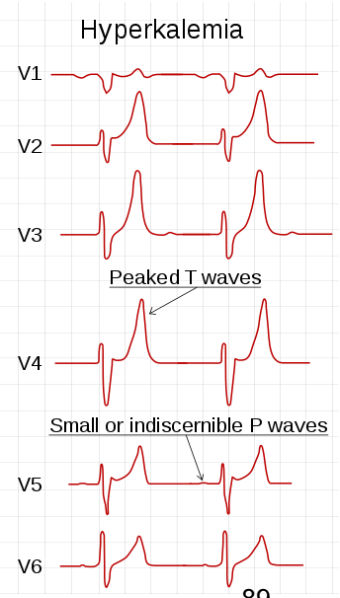
- Hypovolemia can occur from drainage of ascites. Preexisting coagulopathy & portal hypertension can increase bleeding risk. Hyperkalemia may occur from transfusions. Hypokalemia treated cautiously (neohepatic phase associated with hyperkalemia). Patient may have pre-existing hyponatremia.
- *Citrate intoxication* (the liver metabolizes citrate; citrate is present in blood products and can bind calcium → ionized hypocalcemia). Hypomagnesemia can also occur from citrate infusion. *ECG signs of hypocalcemia*: prolonged QT, heart block.[2]

Anhepatic Phase: starts with vascular exclusion of flow to liver and ends with graft reperfusion.

- In absence of venovenous bypass (which carries risk of embolic event), clamping IVC (suprahepatic and infrahepatic) can decrease venous return up to 50%. Venovenous bypass (VVB) or a "piggyback" technique (partial IVC clamping and IVC preservation) can decrease this issue. VVB risks include embolic events.

Neohepatic Phase: begins with reperfusion of the graft liver via portal vein.

- Risk of abrupt hyperkalemia and acidosis (donor liver often preserved in potassium-rich solution; ischemic time can cause acidosis). Calcium chloride and sodium bicarbonate may be initial drugs of choice.
- Associated with increase in preload and decrease in systemic vascular resistance and blood pressure.
- Postreperfusion syndrome (PRS): systemic hypotension and pulmonary hypertension within first 5 minutes of reperfusion.






Refs: 1. Miller 9th Ed, Ch 60. // 2. Miller 9th ed, Ch 47 // Image: hyperkalemia (Mikael Häggström, Public domain, via Wikimedia Commons; available at https://commons.wikimedia.org/wiki/File:ECG_in_hyperkalemia.svg. Accessed May 5, 2021)

# Pediatrics

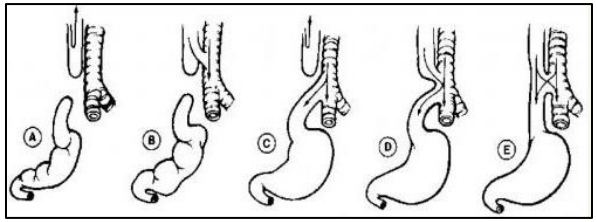
# Pediatrics

14X

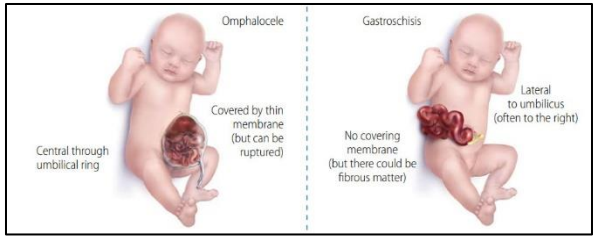
**Tracheo-esophageal fistula (TEF):**[1,2]

- Type C is most common; during repair: ideally, the ETT balloon should be distal to fistula but above carina (sometimes fistula is close to the carina).
- VACTERL (Vertebral, Anal, Cardiac, TE fistula, Renal, Limb) – consider Echo and other preop testing.

**TE Fistula**

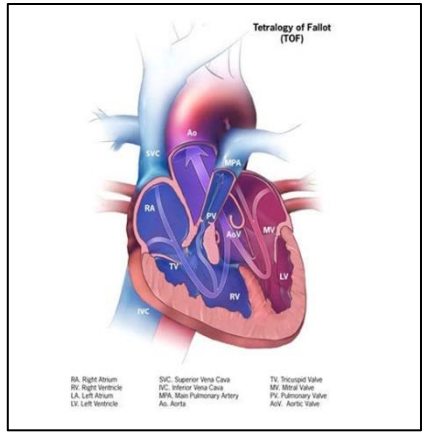



**Omphalocele and Gastroschisis:**[1,2]




- Omphalocele: herniated viscera/intestines emerge from umbilicus (covered by membranous sac) due to failure of gut migration from yolk sac into abdomen. Association w/several abnormalities (e.g., congenital heart disease, exstrophy of bladder, Beckwith-Wiedemann syndrome [macroglossia that can be associated w/airway difficulty, hypoglycemia, visceromegaly, polycythemia]).
- Gastroschisis: herniated viscera/intestines emerge in periumbilical area (exposed to air) from gestational occlusion of omphalomesenteric artery. Gut may be foreshortened & inflamed. Less often associated w/other abnormalities.
- Management: initial: protect viscera, avoid hypothermia. Abdominal closure may increase intraabdominal pressure, increase PEEP, impair venous return, & impair perfusion of liver/kidneys →altered drug metabolism (closure often staged; intrabdominal pressure sometimes monitored).

**Tetralogy of Fallot:**




- Anatomy: Right ventricular outflow tract obstruction (RVOT), ventricular septal defect, overriding aorta, right ventricular hypertrophy.
- **Tet-Spells:** Pathophysiology: transient near occlusion of RVOT, sometimes when infant agitated/upset (possibly from right ventricle/infundibular contractility, peripheral vasodilation, hyperventilation). Tx: reduce the right-to-left shunt: 100% FiO2, phenylephrine, knee-to-chest position (increases SVR), IV fluids. Also: beta-blockers (reduces contractility) & opioids (facilitates sedation & decreased minute ventilation).

1. Cote 6th Ed, Ch 37. // 2. Miller's 9th Ed, Ch 77 // TE Fistula figure: Salik et al. PMID 30570997 Creative Commons CC-BY-4.0. Omphalocele, Gastroschisis and Tetralogy Fallot images: CDC NCBDDD https://www.cdc.gov/ncbddd/birthdefects/omphalocele.html https://www.cdc.gov/ncbddd/birthdefects/surveillancemanual/quick-reference-handbook/gastroschisis.html#fig51 https://www.cdc.gov/ncbddd/birthdefects/surveillancemanual/quick-reference-handbook/tetralogy-of-fallot.html ; public domain; does not constitute endorsement or recommendation by U.S. Government, DHHS, or CDC; available free of charge at CDC website // OpenAnesthesia: Tetralogy of Fallot RX //

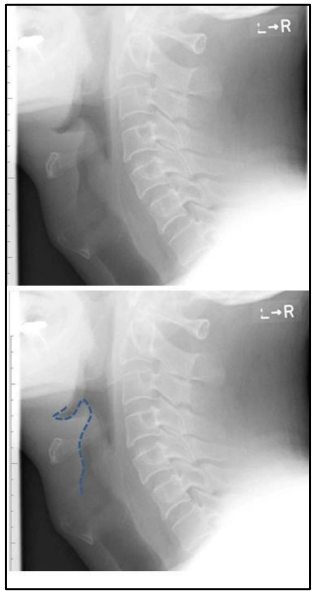
# Pediatrics

12X

Epiglottitis:

- Potentially life-threatening infection of supraglottic structures. Often caused by Haemophilus influenza B or Group A strep. Severe sore throat, stridor, drooling, patient sitting in tripod position. Induction: airway manipulation in O.R. with monitors on and surgeon present; maintain spontaneous ventilation (inhalational induction), avoid paralytics.
- Croup (laryngotracheo-bronchitis) is often less urgent, associated with barking cough, often caused by parainfluenzae virus.

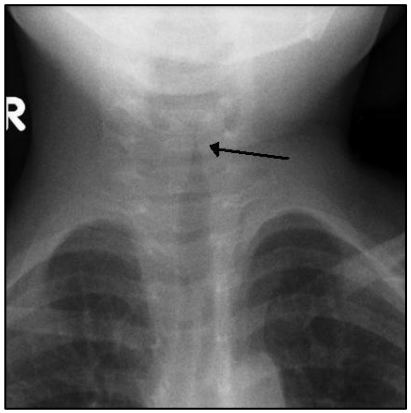
Epiglottitis: "Thumbprint sign"



Adult vs. Pediatric Normal Airway Anatomy:

- Pediatric airway: larynx/glottis higher in neck (closer to C3 than C5 [adults]). Some (controversial) say narrowest point of airway is cricoid cartilage (until age 5), as opposed to glottic opening (adults). Large tongue/occiput and omega-shaped epiglottis.

Croup: "Steeple sign"




Neonatal postoperative apnea:

- Most conservative approach: If under 60-weeks post-conceptual age (PCA): 24-hour observation (at least 12-hours if under 50 wks PCA). Some use caffeine and theophylline as stimulants. Some use pure regional/local anesthesia (i.e., no sedation). Other risk factors: anemia, apnea at home; small-for-gestational-age may be protective.

Grover C. NEJM 2011 PMID 21812674 // Epiglottitis image: https://commons.wikimedia.org/wiki/File:Compare_epiglottis.jpg; CC BY-SA 3.0, via Wikimedia Commons // Lee FE-H. Murray and Nadel's textbook of Emergency Medicine. 2016 // Croup image: https://commons.wikimedia.org/wiki/File:Croup_steeple_sign.jpg, CC BY-SA 3.0, via Wikimedia Commons // OpenAnesthesia: Postoperative apnea: post conceptual age // Miller 9th Ed Ch 77 // Barash 8th Ed Ch 43

# Pediatric ETT Size; Peds Syndromes/Airway

7X

| Peds ETT Size[1,2] | Peds ETT Insertion Distance[1,2] |
|---|---|
| **Uncuffed** ETT for children above age 2 yrs (mm Inner Diameter [ID]): **(Age [in years]/4) + 4** (or 4.5)<br>• Equivalent formula: (Age in yrs + 16)/4<br>• 1-2yrs: 4.0-5.0 ID ETT; 6mo-1yr: 3.5-4.0 ID ETT; Neonate-6mo: 3.0-3.5 ID ETT; 1000-2500g: 3.0 ID ETT; (2.5 if 1000g) | Oral ETT from lips to mid-trachea:<br>• Less than 1,000 g in weight: 6 cm; 1,000 to 3,000 g: 7 to 9 cm; term neonate: 10 cm; infants and children: **10 + age (years) mm**.<br>• Alternatives: [Age (years)/2] + 12 ; [Weight (kg)/5 + 12]; **ID of ETT x 3**. |
| **Cuffed** ETT (mmID): **(Age [in years]/4) + 3** (for children <2 years) or + 3.5 (for those >2 years). | |

| Syndromes Associated with Airway Difficulties Include:[1,2] | |
|---|---|
| Pierre Robin sequence | hypoplastic mandible, pseudomacroglossia, high-arched cleft palate" |
| Treacher Collins syndrome | malar, mandibular hypoplasia and +/- cleft lip, choanal atresia, cervical spine deformity, congenital heart disease, macrostomia or mircostomia |
| Crouzon syndrome | maxillary hypoplasia, inverted V-shaped palate, ocular proptosis, criosynostosis, +/- large tongue |
| Apert syndrome | maxillary hypoplasia, narrow palate, craniosynostosis, flat facies, hypertelorism, +/- cleft palate, congenital heart disease, hydronephrosis, polycystic kidneys, esophageal atresia, syndactyly |
| Down syndrome | small mouth, hypoplastic mandible, protruding tongue, cervical spine subluxation, associated with cardiac disease (ASD, VSD, AV canal defects), hypotonia, duodenal atresia, mental handicap |

High-Yield Recommended Read: Cote 6th Ed Ch14, Table e14.1: Syndromes/Disease Processes Associated with Airway Difficulties



1. Cote's A Practice of Anesthesia for Infants and Children, 6th Ed, Ch 14. // 2. Barash 8th Ed Ch 43

# Pediatrics

31X
Including PONV guidelines

- Pyloric Stenosis: “medical emergency, not surgical emergency”
  - Early metabolic abnormality: hypokalemic, hypochloremic metabolic alkalosis (from vomiting). Reason for paradoxical aciduria: kidneys attempt to maintain pH by excreting HCO3 & conserve sodium at the expense of H+. IV Fluid: Consider D5 ½ NS with 40mmol/L KCL.
- 4-2-1 Rule (hourly IV fluid requirement):
  - 4ml/kg for first 10kg; 2ml/kg for next 10kg; 1mL/kg for every kg after 20kg.
  - “Hypotension is a late sign of hypovolemia.” Other signs to look for: tachycardia, decreased skin turgor/cap refill, decreased urine output.
- Spinal block in infant vs. adults:
  - Infants have less hemodynamic changes from spinal. Dural sac (closer to S3 than S1 [adults]) and spinal cord (closer to L3 than L1 [adults]) extend lower.
- Fetal Hemoglobin: Binds oxygen tighter than adult hemoglobin (left shift of oxyhemoglobin dissociation curve; i.e., P50 is lower than adult).
- Risk Factors for PONV in children (& adults) and management algorithms:

  See 2020 SAMBA/ASER Guidelines:

# Geriatrics

# Geriatrics: Physiologic Changes of Aging

28X

CNS: Increased: (1) sensitivity to anesthesia; (2) risk of postop delirium/cognitive dysfunction [Mill Ch 65]

Cardiac: arterial stiffening/increased afterload; diastolic dysfunction more common; decreased ability of sympathetic and autonomic system to respond to physiologic derangement. [Miller 9th Ed Ch 65]

Pulmonary: **increased closing capacity (point at which small airways close)**, increased work of breathing, decreased respiratory response to hypoxia and hypercarbia, increased risk for aspiration/pneumonia, diaphragm weakens and chest wall thickens. [Miller 9th Ed Ch 65]

Kidney: *"In healthy patients, serum creatinine is unlikely to change significantly between the ages of 40 and 70."* [2019 ITE Gaps in Knowledge] – Older patients may have "normal" serum creatinine levels while also having decreased lean muscle mass.

| Parameter | Geriatric |
|---|---|
| Functional Residual Capacity | ↑ |
| Minute Ventilation | ↔ |
| Tidal Volume | ↓ |
| Respiratory Rate | ↑ |
| Closing Capacity | ↑ |
| Tracheal Compliance | ↔ |
| Airway Resistance | ↑ |

- **Meperidine**: renal excretion of normeperidine (toxic metabolite) decreases with age.[Barash 8Ed/Ch34]
- **Morphine**: Renal insufficiency can lead to accumulation of morphine-6-glucuronide, which has activity at the mu-opioid receptor. [Miller 9th Ed Ch 59]

Muscle Relaxants: Succinylcholine: no change (decreased in pseudocholinesterase usually not clinically significant). Vecuronium/Rocuronium: depends on kidney/liver function. Cis-atracurium: Hofmann elimination usually not affected by age. [Miller 9th Ed, Ch 27]

Changes in MAC: "The minimum alveolar concentration **(MAC) decreases approximately 6% per decade** for most inhalation anesthetics." [Miller 9th Ed Ch 65 & Barash 8Ed/Ch 34]

- **Fentanyl, remifentanil, and sufentanil** are approximately twice as potent in older patients.

# Emergence Excitement/Delirium (Postoperative)

5X

**Emergence Excitement**: "…a transient confusional state that is associated with emergence from general anesthesia." [Miller, 8th Ed, Ch 96]

- **More common in children receiving volatiles** "and is terminated either spontaneously or after an IV dose of Propofol, midazolam, clonidine, dexmedetomidine, ketamine, opioids, or a host of other medications." [Barash 8th Ed/Ch 43 – Peds Anesthesia]

**Delirium (postoperative)**:

- "acute cognitive disruption characterized by inattention, a fluctuating course, and cognitive disturbance." [Miller 9th Ed/Ch 82]
- Often short lived (24hrs) but can extend beyond hospital discharge. [Barash 8th Ed/Ch34]

**Treatment of Postoperative Delirium**:

- Supportive care, search for underlying cause, limit benzodiazepines and drugs with atropinic properties (except glycopyrrolate), consider typical (e.g., haloperidol) and atypical antipsychotics, [Barash 8Ed/Ch 34]

| **Popular perioperative medications with anticholinergic properties that are on the 2019 Beers Criteria® for Potentially Inappropriate Medication (PIM) use in Older Adults (American Geriatrics Society)** |
|---|
| Diphenhydramine |
| Scopolamine |
| Promethazine |
| Hydroxyzine |



Miller 9th Ed, Ch 65. // AGS 2019 Updated Beers Criteria® for Potentially Inappropriate Medication Use in Older Adults. PMID: 30693946.

# Geriatrics: Perioperative Neurocognitive Disorders (PND)

4X

**Perioperative Neurocognitive Disorders (PND):** "an overarching term for cognitive impairment or change, including delirium, identified in the preoperative period." [Miller 9th Ed/Ch 82]

**Risk factors for Postoperative Neurocognitive Disorders (Miller 9th Ed, Ch 82 & Recommended Reads):**

| Most Commonly Cited | Other Potential Factors |
|---|---|
| Age | History of delirium |
| Preexisting cognitive impairment (new term: "Mild/Major Neurocognitive Disorder") | Frailty |
| Debated: surgical procedure type | ASA physical status |
| Widely debated: Type of anesthesia (i.e. regional vs. general; volatile vs. total intravenous general anesthesia -- see below). | Impairment in Activities of Daily Living (ADL's) |
| | Smoking |
| | Polypharmacy, including psychotropic meds |

- Recommended Reading: Miller 9th Edition, Ch 82, Table 82-1 (Recommended new terminology for perioperative cognitive changes). *Interesting reads*: Culley et al 2016 (PMID 27127918). Eckenhoff et al 2020 (PMID: 31834869).

**Regional Anesthesia (RA) vs General Anesthesia (GA) and Perioperative Neurocognitive Disorders:**

- Widely debated. Historically, some RA vs GA studies had patients getting RA with deep sedation.
- PND may be the result of preexisting vulnerabilities & the surgery itself. [Miller 9th Ed/Ch 82]
- Hip Fracture Surgery in Older Adults: NEJM 2021 randomized trial (Neuman et al; PMID: 34623788): "Spinal anesthesia for hip-fracture surgery in older adults was not superior to general anesthesia with respect to survival and recovery of ambulation at 60 days. The incidence of postoperative delirium was similar with the two types of anesthesia."

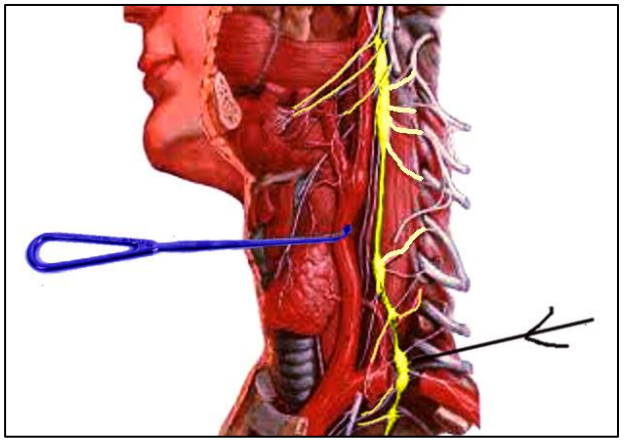
# Pain

# Pain

Complex Regional Pain Syndrome (CRPS):

- **"SAT Exam Injury"**: **S**udomotor symptoms/sympathetic dysfunction, **A**llodynia/hyperalgesia, **T**rauma, **E**xclude other causes, **I**njury (CRPS type II: known nerve injury; if only the other criteria present: CRPS type I). Pain should not just be limited to a single nerve distribution.
- Treatment (adapted from Rho et al*): (1) Physical therapy (& biopsychosocial approach); (2) non-opioid, tricyclic antidepressant, gabapentin, +/- mild opioid analgesics; (3) diagnostic sympathetic block; (4) somatic block (if sympathetic block fails); (5) spinal cord stimulator/ intrathecal medications.

**Stellate Ganglion**



| Stellate Ganglion Block | |
|---|---|
| Indications/Uses | Sympathetically-mediated pain at head/neck/upper extremity (such as CRPS), vascular insufficiency, intractable angina, hyperhidrosis, phantom limb pain, neuropathic pain (such as post-herpetic neuralgia) |
| Stellate ganglion location | Over head of 1st rib at junction of T1 transverse/uncinate process. It is the fusion of the superior thoracic ganglion & inferior cervical ganglion. Block is typically at C6 or C7 level (volume spread). |
| Signs of successful block | Horner's syndrome (miosis [constricted pupil]), ptosis, anhidrosis), nasal congestion, venodilation hand/forearm, increase in temperature of blocked limb $\geq$ 1 deg Celsuis |
| Complications/ other side effects | hoarseness (RLN), dyspnea (phrenic nerve), neuraxial/spinal block, seizures, hematoma, nerve injury, pneumothorax, esophageal perforation |

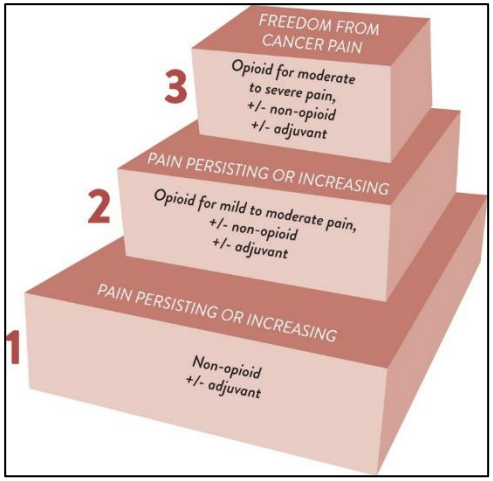
Image: https://www.ncbi.nlm.nih.gov/books/NBK539807/ via Creative Commons CC-BY-4.0. // OpenAnesthesia: Stellate Ganglion Block: effects // * Noted to be adapted from Rho et al, Mayo Clin Proc 2002 // Hyder and Rathmell. Ch 44 of Miller's Basics of Anesthesia, 7th Ed.

# Pain

15X

WHO Cancer Pain Ladder:

- WHO 1986 examples: *Non-opioids*: aspirin, acetaminophen; *weak opioid*: codeine; *strong opioids*: morphine, hydromorphone, methadone, buprenorphine; *adjuvant drug classes:* anticonvulsants, neuroleptics, anxiolytics, antidepressants, corticosteroids.
- WHO 2018 update: "a cancer pain management ladder is useful as a teaching tool and as a general guide to pain management based on pain severity…it cannot replace individualized therapeutic planning…"
- "Step 4": interventional therapy (nerve block, epidural, spinal cord stimulator, etc).




Celiac Plexus Block:

- Celiac plexus is at T12-L1 level. Provides sensory innervation and sympathetic outflow to pancreas, liver, gallbladder, spleen, kidneys, and GI tract from distal stomach to splenic flexure. Commonly considered in management of pancreatic cancer pain.
- Agent: alcohol can be given with small amount of local anesthesia to reduce pain on injection; phenol painless on injection.
- Most common complications: diarrhea, orthostatic hypotension. Rare complications: paraplegia (artery of Adamkiewicz injury), aorta/vena cava puncture, retroperitoneal hemorrhage, visceral organ injury, pneumothorax, local anesthetic systemic toxicity.
- Other blocks: Hypogastric block (many pelvic cancers); Ganglion impar block (perineal/rectal cancers)

1. Cancer pain relief. Geneva: World Health Organization; 1986 http://apps.who.int/iris/bitstream/handle/10665/43944/9241561009_eng.pdf // 2. (including image: WHO guidelines for the pharmacological and radiotherapeutic management of cancer pain in adults and adolescents. Geneva: World Health Organization; 2018. Creative Commons License: CC BY-NC-SA 3.0 IGO https://www.ncbi.nlm.nih.gov/books/NBK537489/ // Miller 9th Ed Ch 51 // Miller Basics 7th Ed Ch 44 //OpenAnesthesia: celiac plexus block: complications // Practical Management of Pain, 5th Ed, Ch 59

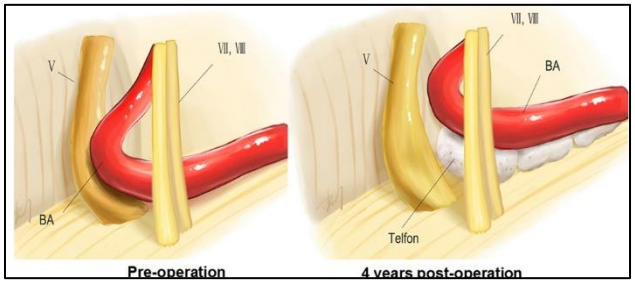
# Pain

17X

Trigeminal neuralgia:

- Most common cause: vascular compression of trigeminal nerve root by blood vessel(s) (often the superior cerebellar artery)
- Most effective/first-line agent: carbamezapine or oxcarbazepine (feared side effect: aplastic anemia).
- Alternative treatment options include: Surgical referral (surgical microvascular decompression a popular consideration), gabapentin, pregabalin, lamotrigine, baclofen.[1,2]

**Microvascular Decompression for Trigeminal Neuralgia**




Post-herpetic neuralgia:

•Can last 7 days pre and 6 months post shingles vesicles.

•Most common dermatomes: thoracic and trigeminal.

•Risk Factors: Severe pain and/or sensory abnormalities during acute herpes zoster; older age.

•Prevention/Treatment: antivirals, tricyclics, serotonin-norepinephrine reuptake inhibitors, gabapentin, lidocaine, sympathetic blockade (e.g., stellate ganglion block). Zoster vaccine (live-attenuated): FDA licensed for pts > 50yrs, recommended for pts > 60 yrs, including those w/previous zoster.

Rib Fracture Pain Management:

- Therapy is focused on minimizing pulmonary complications from the fracture.
- Regional options include epidural, paravertebral block, intercostal block(s)
- Regarding systemic absorption: (Intercostal > Caudal > Lumbar/Thoracic > Peripheral nerve block): intercostal has the highest amount of local anesthesia systemic absorption.

1. Trigeminal Neuralgia (UpToDate). // 2. Cruccu et al NEJM 2020, PMID: 32813951 // Kroger AT. Immunization. In Principles of Infectious Disease, 8th Ed /102
OpenAnesthesia: Trigeminal Neuraglia, Anesthetic Absorption: regional anesthesia techniques, rib fractures // Image: Wang et al. BMC Neurology; Creative Commons CC-BY-4.0 PMID 31481028. // Miller 9th Ed Ch 66

# Obstetrics

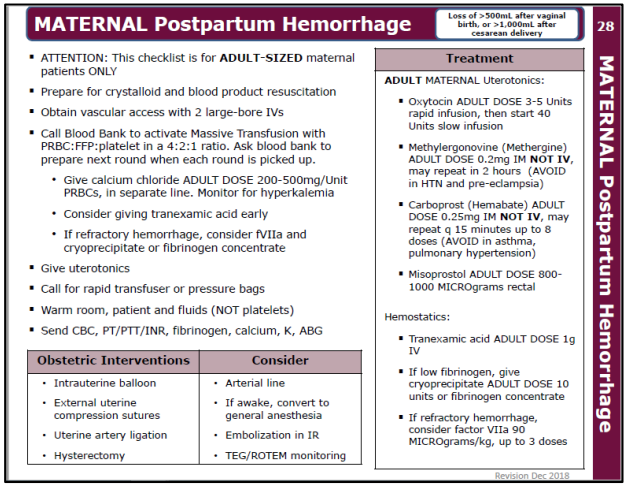
# Obstetrics: Uterotonics, Uterine Relaxants

27X

Uterotonics:

- Oxytocin (aka Pitocin; relaxant effect on vascular smooth muscle; lowers SVR and can cause hypotension & tachycardia)
- Methylergonovine (aka Methergine; increases uterine contraction force/frequency; can cause increase in BP; avoid in patients with hypertension [pre-eclampsia]).
- Carboprost (aka 15-methyl prostaglandin F-2-alpha; aka Hemabate; synthetic prostaglandin; can cause bronchospasm; avoid in patients with asthma).
- Misoprostol (aka Cytotec; prostaglandin; produces uterine contractions).

Handout: Maternal Postpartum Hemorrhage Checklist, Society for Pediatric Anesthesia



**MATERNAL Postpartum Hemorrhage**

Loss of >500mL after vaginal birth, or >1,000mL after cesarean delivery

28

MATERNAL Postpartum Hemorrhage

- ATTENTION: This checklist is for **ADULT-SIZED** maternal patients ONLY
- Prepare for crystalloid and blood product resuscitation
- Obtain vascular access with 2 large-bore IVs
- Call Blood Bank to activate Massive Transfusion with PRBC:FFP:platelet in a 4:2:1 ratio. Ask blood bank to prepare next round when each round is picked up.
  - Give calcium chloride ADULT DOSE 200-500mg/Unit PRBCs, in separate line. Monitor for hyperkalemia
  - Consider giving tranexamic acid early
  - If refractory hemorrhage, consider fVIIa and cryoprecipitate or fibrinogen concentrate
- Give uterotonics
- Call for rapid transfuser or pressure bags
- Warm room, patient and fluids (NOT platelets)
- Send CBC, PT/PTT/INR, fibrinogen, calcium, K, ABG

| Obstetric Interventions | Consider |
|---|---|
| • Intrauterine balloon | • Arterial line |
| • External uterine compression sutures | • If awake, convert to general anesthesia |
| • Uterine artery ligation | • Embolization in IR |
| • Hysterectomy | • TEG/ROTEM monitoring |

**Treatment**

**ADULT** MATERNAL Uterotonics:

- Oxytocin ADULT DOSE 3-5 Units rapid infusion, then start 40 Units slow infusion
- Methylergonovine (Methergine) ADULT DOSE 0.2mg **IM NOT IV**, may repeat in 2 hours (AVOID in HTN and pre-eclampsia)
- Carboprost (Hemabate) ADULT DOSE 0.25mg **IM NOT IV**, may repeat q 15 minutes up to 8 doses (AVOID in asthma, pulmonary hypertension)
- Misoprostol ADULT DOSE 800-1000 MICROgrams rectal

Hemostatics:

- Tranexamic acid ADULT DOSE 1g IV
- If low fibrinogen, give cryoprecipitate ADULT DOSE 10 units or fibrinogen concentrate
- If refractory hemorrhage, consider factor VIIa 90 MICROgrams/kg, up to 3 doses

Revision Dec 2018

Uterine Relaxants:

Nitroglycerin and volatile anesthetics most popular.

Beta-agonists (terbutaline) and magnesium sometimes used.



Chestnut OB Anesthesia, 6th Ed, Ch 37 // Epocrates drug reference for selected agents.

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Loss of >500mL after vaginal birth, or >1,000mL after cesarean delivery





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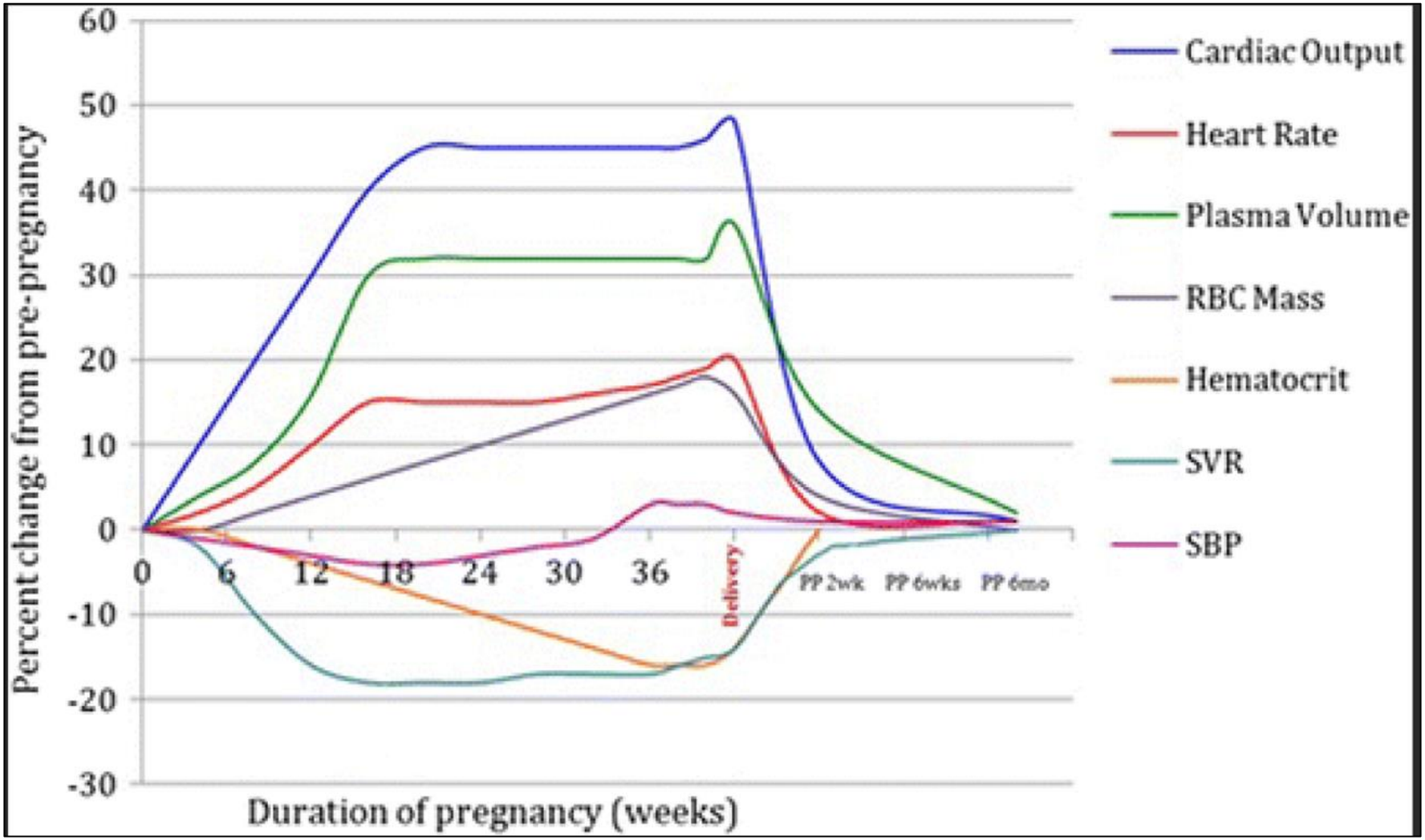
Revision Dec 2018

# Physiologic Changes of Pregnancy

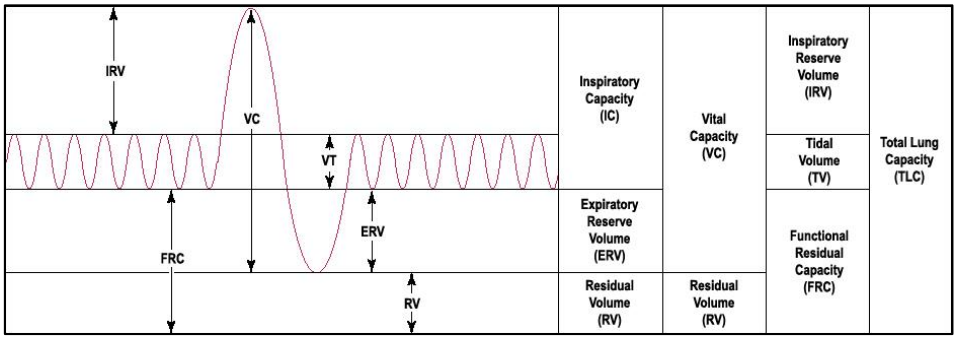
## Hemodynamic Changes and Time Course

32X

(incl next slides on physiologic changes of pregnancy)



# Physiologic Respiratory Changes Throughout Life




| Parameter | Term Neonate | Term Gestation | Obesity | Geriatric |
|---|---|---|---|---|
| Functional Residual Capacity | ↓/↔[1,2,4] | ↓ (-20%)**[5] | ↓**[3] | ↑[11] |
| Minute Ventilation | ↑[1] | ↑ (+45%)*****[5] | ↓/↔[7,9] | ↔[12] |
| Tidal Volume | ↔ [1,4] | ↑ (+45%)*****[5] | ↓[7] | ↓[12] |
| Respiratory Rate | ↑[1] | ↑[7] | ↑/↔[7] | ↑[12] |
| Closing Capacity | ↑[1,2] | ↔***[5] | ↔***[9] | ↑******[10,13] |
| Tracheal Compliance | ↑****[4] | ↔ | ↔ | ↔ |
| Airway Resistance | ↑[4] | *[5,7] | ↑[8,9] | ↑[12] |
| **Common causes of decreased FRC**: PANGOS (Pregnancy, Ascites, Neonate, General Anesthesia, Obesity, Supine Position)<br>**Common causes of increased closing capacity**: ACLS (Advanced age, Chronic bronchitis, LV failure, Smoking/Surgery) | | | | |

* Pulmonary resistance decreases; upper airway changes can lead to increased airflow resistance/snoring; if pregnancy and obesity, airway resistance may increase from reduction of lung volumes.

** Decrease in FRC is accompanied by a decrease in expiratory reserve volume. In both pregnancy and obesity, this is related to mass effect (i.e., compression of lung parenchyma)

*** Closing capacity may not change, but reduced FRC relative to normal closing capacity may cause increased airway closure

**** May be due to cartilaginous immaturity; dynamic collapse with inspiration/expiration may be more likely

***** Results from hormonal changes (progesterone is respiratory stimulant) and increase in CO2 production at rest

****** Increased chest wall rigidity and decreased respiratory muscle strength can lead to increased closing capacity (the point at which small airway collapse).

1. Miller Basics 7th Ed Ch 34 // 2. Cote 6th Ed Ch 13 // 3. Miller 9th Ed Ch 13 // 4. Cote 6th Ed Ch 2 // 5. Chestnut 6th Ed Ch 2 // 6. Anesth Uncomm Dz 6th Ed Ch 6 // 7. Chestnut 6th Ed Ch 49 // 8. Stoelting 7th Ed Ch 19 // 9. Nunn & Lamb's Applied Respiratory Physiology, 9th Ed Ch 15 // 10. Miller 9th Ed Ch 65 // 11. Barash 8th Ed Ch 34 // 12. Brocklehurst's Textbook of Geriatric Medicine and Gerontology //13. PMID 14557122 // with acknowledgement to Joseph Mintz, MD

# Other Physiologic Changes of Pregnancy

| Renal Changes and Time Course | | |
|---|---|---|
| **Parameter** | **Change** | **Notes** |
| GFR | Increase | Increased 50% by 3rd month of pregnancy; remains elevated until 3 months postpartum.[1] |
| Renal Blood Flow | Increase | Rises 60%-80% by mid-pregnancy; it is 50% greater than nonpregnant values in 3rd trimester.[1] |
| Creatinine Clearance | Increase | Increases early in pregnancy; reaches max by end of 1st trimester; slight decrease near-term.[2] 2020 ITE Gaps in Knowledge: *"The increase in creatinine clearance that occurs with pregnancy returns to prepregnant levels 8 to 12 weeks postpartum."* |
| BUN | Decrease | Decreases to 8-9 mg/dL by end of 1st trimester; stays there until term.[2] |
| Serum Cr concentration | Decrease | Decreases progressively to 0.5-0.6mg/dL by end of pregnancy.[2] |

| Coagulation System Changes at Term Gestation | |
|---|---|
| Pro-coagulants that increase | Factors I, VII, VIII, IX, X, XII, and von Willebrand factor |
| Anti-coagulants that decrease | Antithrombin III, Protein S |
| Unchanged factors include | Protein C (anti-coagulant); Factor II and Factor V (pro-coagulants) |

| Potential EKG/Echocardiographic Changes | |
|---|---|
| Echocardiography changes | LV hypertrophy; tricuspid, pulmonic, and mitral regurgitation |
| EKG Changes | Increased heart rate; shortened PR and uncorrected QT interval; depressed ST segments and isoelectric low-voltage T waves in left-sided precordial and limb leads |



1. Miller 9th Ed, Ch 62. // 2. Chestnut 6th Ed, Ch 2. // GFR: Glomerular filtration rate; BUN: Blood Urea Nitrogen; Cr: creatinine

# Obstetrics: Misc

13X

- Primary determinant of local anesthetic:
  - Potency: Lipid Solubility (aka "Meyer Overton correlation").
  - Onset: pKa (example: lidocaine has low pKa). *Exception*: 2-Chloroprocaine (pKa is high, but low systemic toxicity, so high concentration used).
  - Duration: Protein binding. *2020 ITE Gaps in Knowledge: "The duration of action of epidural bupivacaine is not greatly affected by the addition of epinephrine."*

- Placental transfer of medications:
  - Drugs that poorly cross the placenta to the Fetus: Heparin, Paralytics, Insulin, Glycopyrrolate.
  - Fetal trapping of lidocaine (concept would also apply to mepivacaine): Fetal pH more acidic than maternal pH, lidocaine is a weak base → lidocaine gets "trapped" on fetal side. Bupivicaine diffuses poorly to placenta because of protein binding. Chloroprocaine poorly transfers to placenta because it is rapidly eliminated on maternal side by plasma cholinesterase.

- Transient Neurologic Symptoms:
  - Buttock/thigh/leg pain w/in 24 hrs, usually after spinal anesthesia, lasting up to 10 days. No bladder/bowel symptoms (as opposed to cauda equina syndrome).
  - "The likelihood of TNS is highest after intrathecal **lidocaine** and **mepivacaine,** and are far less frequent with bupivacaine and other local anesthetics….TNS occur more commonly in patients who are placed in the **lithotomy** position for surgery." [Miller's 9th Ed, Ch 45]



1. Miller 9th Ed, Ch 45. // 2. Chestnut 6th Ed, Ch 13, 33. // Brown et al. PMID: 934571

# Obstetrics: Misc

12X
Incl next slide

- Fetal Heart Rate Decelerations
  - Early: Compression of fetal head, possible reflex vagal response to mild hypoxia (not ominous).
  - Variable: Umbilical cord compression against fetus → decreased umbilical blood flow.
  - Late: Uteroplacental insufficiency
- Maternal hypotension can cause fetal bradycardia: consider treating borderline hypotension in mom if the fetal tracing is nonreassuring.
- Antiphospholipid syndrome: hypercoagulable state that can cause recurrent pregnancy loss.
- Pain dermatomes of labor: First stage: T10-L1; Second stage: S2-S4. Sensory block for a c-section: T4-S4 (afferent nerves innervating abdominal/pelvic organs accompany sympathetic fibers – sympathetic trunk is T5 to L1).
- Non-obstetric surgery during pregnancy (ASA/ACOG joint opinion; updated 2019):
  - Medically necessary surgery should not be delayed regardless of trimester; elective surgery should be postponed until after delivery.
  - Consider corticosteroids if viable premature gestational age; provide
  - Appropriate periop DVT prophylaxis.
  - "fetal monitoring should be individualized and, if used, based on gestational age, type of surgery, and facilities available."
  - Fetal monitoring may apply if: (1) fetus is viable; (2) monitoring physically possible; (3) OB surgery provider available; (4) mom gives appropriate informed consent; (5) surgery can be safely altered/interrupted for emergency delivery.



ASA/ACOG Joint Document on Nonobstetric Surgery During Pregnancy. Available at: https://www.asahq.org/standards-and-guidelines/nonobstetric-surgery-during-pregnancy // Chestnut 6th Ed, Ch 8, 23, 26, 40 //

# Preeclampsia & Imitators

**Diagnostic Criteria for Preeclampsia**

Blood Pressure:

- Systolic blood pressure of 140 mm Hg or more or diastolic blood pressure of 90 mm Hg or more on two occasions at least 4 hours apart after 20 weeks of gestation in a woman with a previously normal blood pressure

**or**

- *Severe feature*: Systolic blood pressure of 160 mm Hg or more, or diastolic blood pressure of 110 mm Hg or more, in patient not already on antihypertensive therapy. (Severe hypertension can be confirmed within a short interval [minutes] to facilitate timely antihypertensive therapy).

**and**

Proteinuria:

- 300 mg or more per 24-hour urine collection (or this amount extrapolated from a timed collection)

**or**

- Protein/creatinine ratio of 0.3 or more

**or**

- Dipstick reading of 2+ (used only if other quantitative methods not available)

**or**

Severe features:

- Thrombocytopenia (platelet count less than 100 x $10^9$/L
- Impaired liver function not accounted for by alternative diagnoses and as indicated by abnormally elevated blood concentrations of liver enzymes (to more than twice the upper limit normal concentrations), or by severe persistent right upper quadrant or epigastric pain unresponsive to medications
- Renal insufficiency (serum creatinine concentration more than 1.1 mg/dL or a doubling of the serum creatinine concentration in the absence of other renal disease)
- Pulmonary edema
- New-onset headache unresponsive to medication and not accounted for by alternative diagnoses
- Visual disturbances

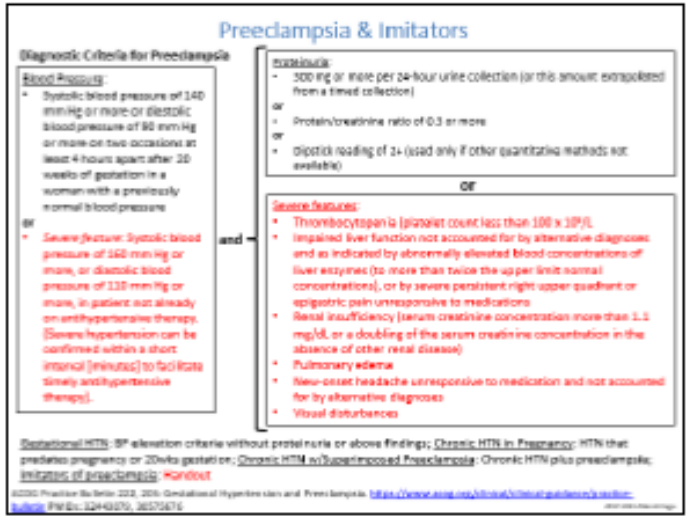
Gestational HTN: BP elevation criteria without proteinuria or above findings; Chronic HTN in Pregnancy: HTN that predates pregnancy or 20wks gestation; Chronic HTN w/Superimposed Preeclampsia: Chronic HTN plus preeclampsia; Imitators of preeclampsia: Handout

ACOG Practice Bulletin 222, 203: Gestational Hypertension and Preeclampsia. https://www.acog.org/clinical/clinical-guidance/practice-bulletin PMIDs: 32443079, 30575676

# Preeclampsia and Imitators

Preeclampsia and Imitators:

**Diagnostic Criteria for Preeclampsia:**




**Excerpts on Imitators of Preeclampsia (from UptoDate article on *Preeclampsia: Clinical features and Diagnosis*):**

- Antiphospholipid syndrome: "hypertension, proteinuria, thrombocytopenia and other signs of end-organ dysfunction can be seen in antiphospholipid syndrome. The absence of laboratory evidence of antiphospholipid antibodies excludes this diagnosis."

- Acute Fatty Liver of Pregnancy (AFLP): "Anorexia, nausea and vomiting are common clinical features of AFLP. Low-grade fever can be present in AFLP, but does **not** occur in preeclampsia/HELLP. AFLP is associated with more serious liver dysfunction. Hypoglycemia and DIC are common features, while unusual in preeclampsia/HELLP. AFLP is also usually associated with more significant renal dysfunction compared to preeclampsia/HELLP."

- TTP or HUS: "Although neurologic abnormalities and acute renal failure are often seen in TTP & HUS, respectively they are not always seen, and these disorders may be indistinguishable from severe preeclampsia/HELLP syndrome. Preeclampsia/HELLP begins to resolve within 48 hours after delivery, while TTP & HUS does not resolve with delivery. Distinguishing among TTP, HUS and related thrombotic microangiopathy syndromes may be challenging."

- Exacerbation of systemic lupus erythematosus (SLE): "Flares of SLE are likely to be associated with hypocomplementemia and increased titers from anti-DNA antibodies, by comparison, complement levels are usually, but not always, normal or increased in preeclampsia. Acute onset, accelerated HTN is more likely to be due to preeclampsia than a lupus flare."

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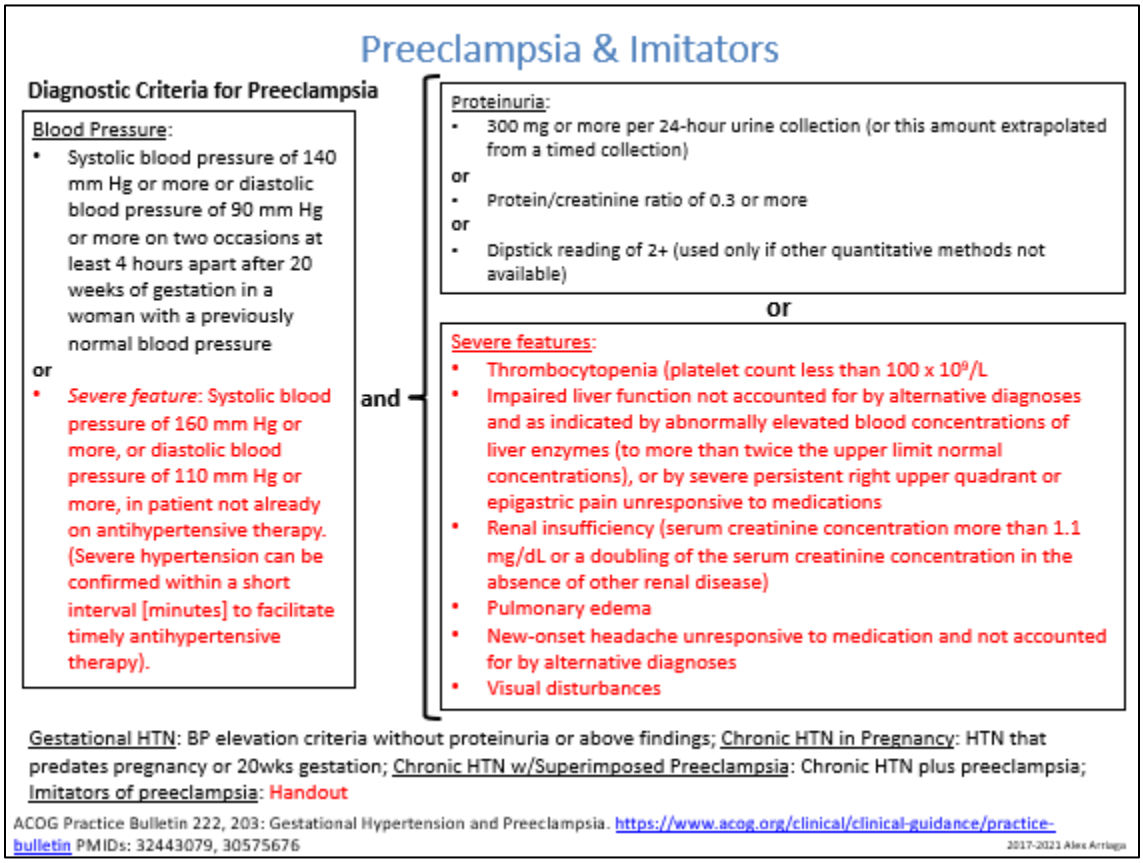


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# Obstetrics: Misc

15X

- Risk factors for Post-Dural Puncture Headache (PDPH): Female sex, younger age, large bore needle, beveled (Quincke) needle, multiple dural punctures, prior PDPH history, pregnancy, vaginal delivery (vs c-section).
  - Pneumocephalus buzzwords: often abrupt onset frontal headache, immediately after dural puncture
- Magnesium toxicity: (Tx: calcium, loop diuretics, supportive care)

| Serum Mg level (mg/dL) | Comments/Signs/Symptoms |
|---|---|
| 1.7-2.4 | Normal range |
| 5-9 | Therapeutic range for seizure prophylaxis in preeclampsia with severe features (side effects may include sedation, weakness, and EKG changes: widened QRS, long PR) |
| ~12 | Loss of deep tendon/patellar reflexes |
| 15-20 | Respiratory arrest |
| 25 | Asystole |

APGAR: **A**ppearance: acrocyanotic (trunk pink, extremities blue)=1; **P**ulse: <100bpm=1; **G**rimace (instead of active cough and sneezing)=1; **A**ctivity: some extremity flexion instead of active movement=1; **R**espiratory effort: irregular, slow, shallow, or gasping=1



Chestnut OB Anesthesia, 6th Ed, Ch 9, 30, 35.

# Regional

# Peripheral Nerve Blocks

50X
incl images & L.A.S.T.

Side Effects/Complications of Interscalene Block:

- **Ipsilateral phrenic nerve block** → diaphragmatic paresis "occurs in 100% of patients undergoing interscalene blockade [at the conventional level (C6) of blockade]…and is associated with a 25% reduction in pulmonary function."
- **Pneumothorax:** "[risk] is small when the needle is correctly placed at the C5 or C6 level because of the distance from the dome of the pleura."
- **Bezold-Jarish reflex**: "**Severe hypotension and bradycardia…**can occur in awake, sitting patients undergoing shoulder surgery under an interscalene block. The cause is presumed to be stimulation of intracardiac mechanoreceptors by decreased venous return, producing an abrupt withdrawal of sympathetic tone and enhanced parasympathetic output. This effect results in bradycardia, hypotension, and syncope."
- "**Epidural and intrathecal injections** can occur with this block…" [Miller Ch 57 8th Ed]
- Other complications: "**intravascular injection with seizures and cardiac arrest**,… **Horner syndrome [miosis/constricted pupil, ptosis, anhidrosis]**, hoarseness, and dysphagia." [Miller Ch 79, 8th Ed]

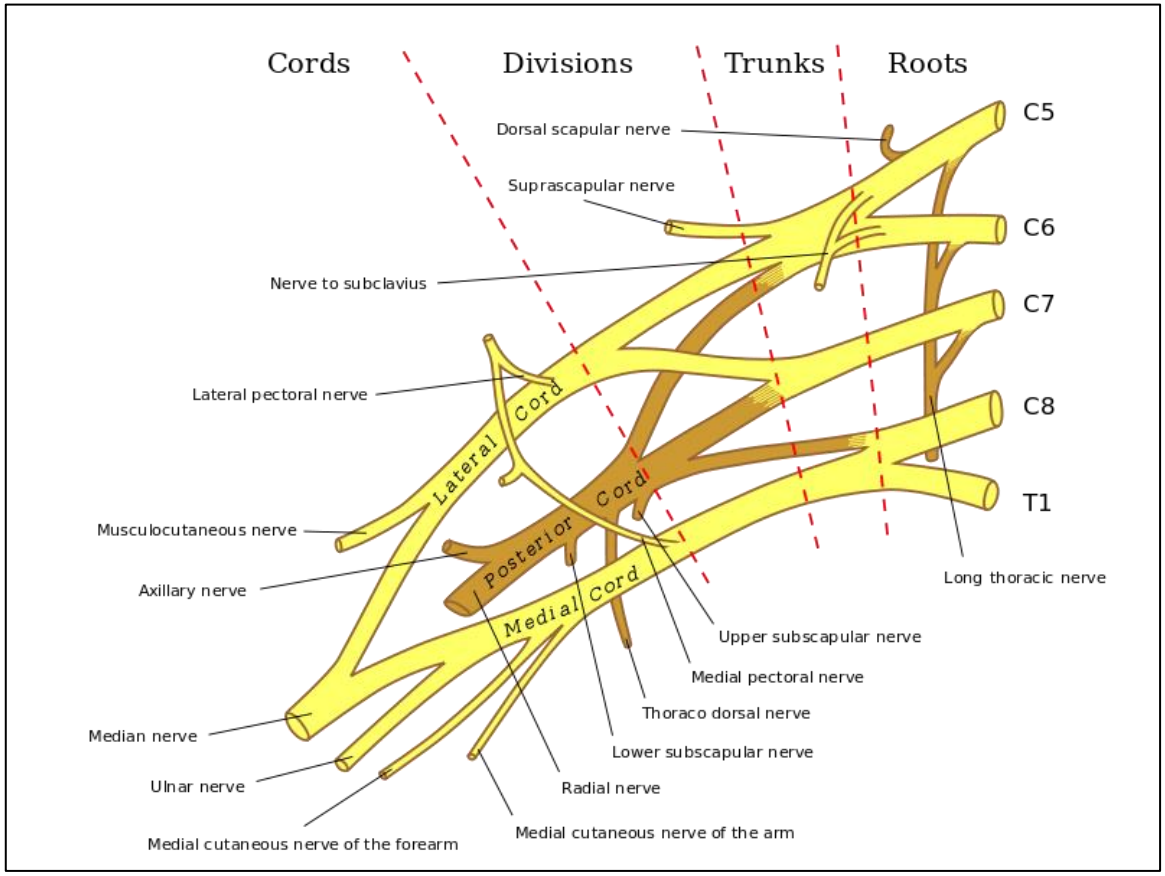
Complications of Axillary nerve Block: Systemic toxicity (especially if transarterial approach and large volume of local anesthetic), nerve injury, hematoma, infection.

Local Anesthetic Systemic Toxicity (L.A.S.T):

- Key medication in treatment: Lipid Emulsion 20%
- Epinephrine smaller doses preferred (≤ 1 mcg/kg)
- Key medications to avoid: beta-blockers, calcium channel blockers, vasopressin, local anesthetics.

**ASRA 2020 Checklist for Local Anesthetic Systemic Toxicity**

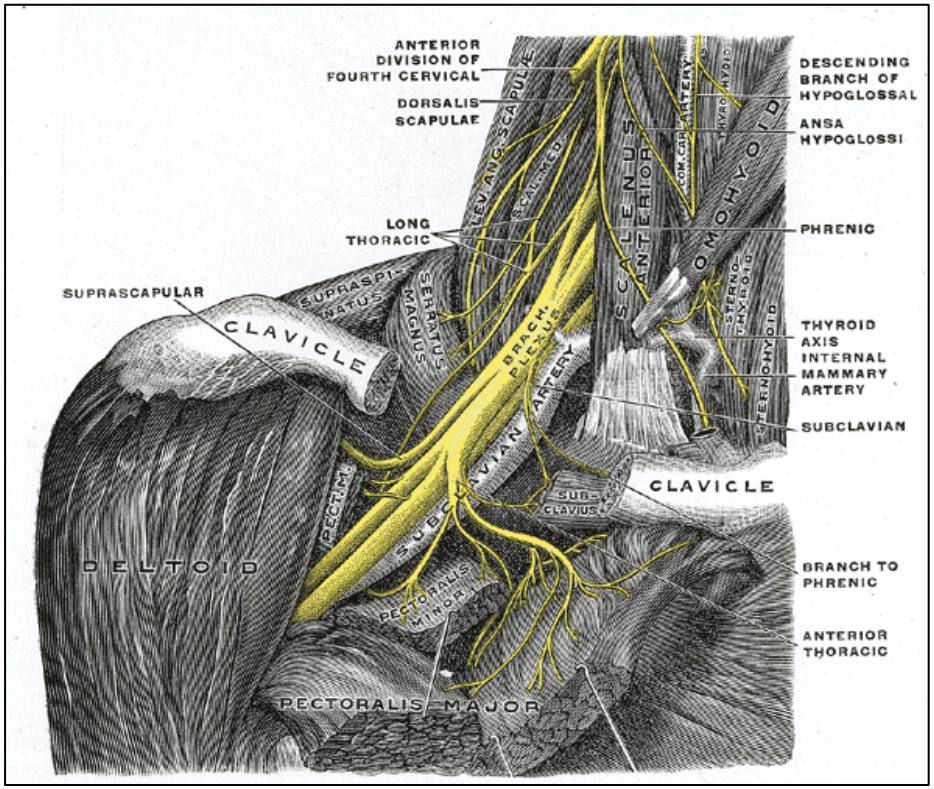
# Brachial Plexus Anatomy



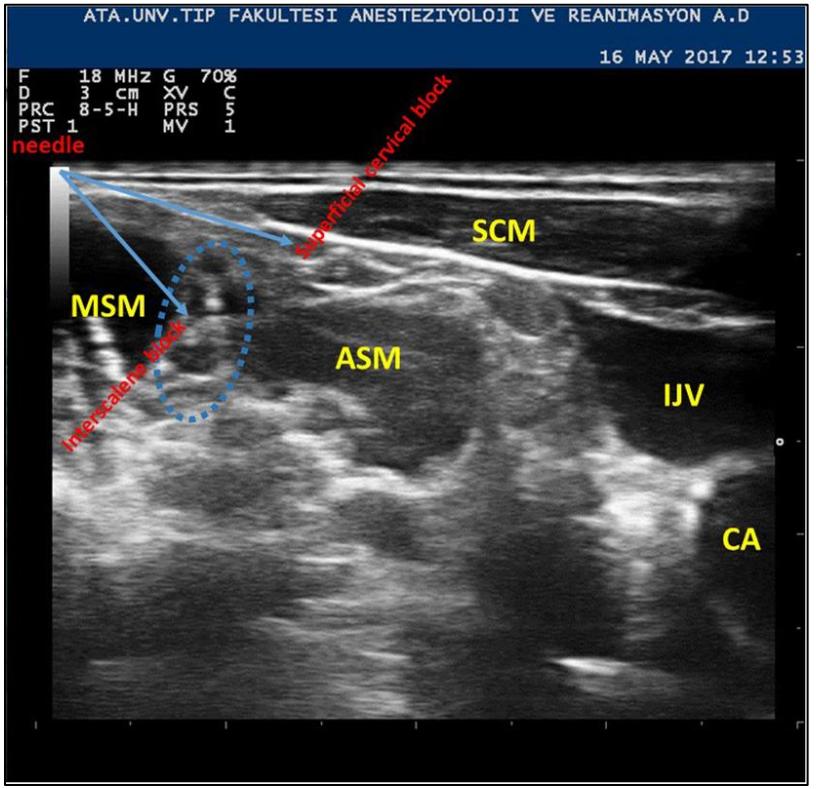

- Interscalene Block: Used for shoulder surgery. "Blockade occurs at the level of the **superior and middle trunks**….blockade of the inferior trunk (C8 through T1) is often incomplete"
- Supraclavicular Block: Used for surgery on elbow, forearm, and hand. "Blockade occurs at the **distal trunk-proximal division level**."
- Axillary Block: "Indications…include surgery to the forearm and hand. Elbow procedures are also performed successfully using the axillary approach….Blockade occurs **at the level of the terminal nerves [branches]**." [Miller Ch 57, 8th Ed] Axillary blocks often supplemented with blocks to musculocutaneous nerve and the intercostobrachial nerve (a branch of T2).

# Interscalene & Superficial Cervical Plexus Block Anatomy

**Anatomy**




**Ultrasound Anatomy**




Interscalene Block:

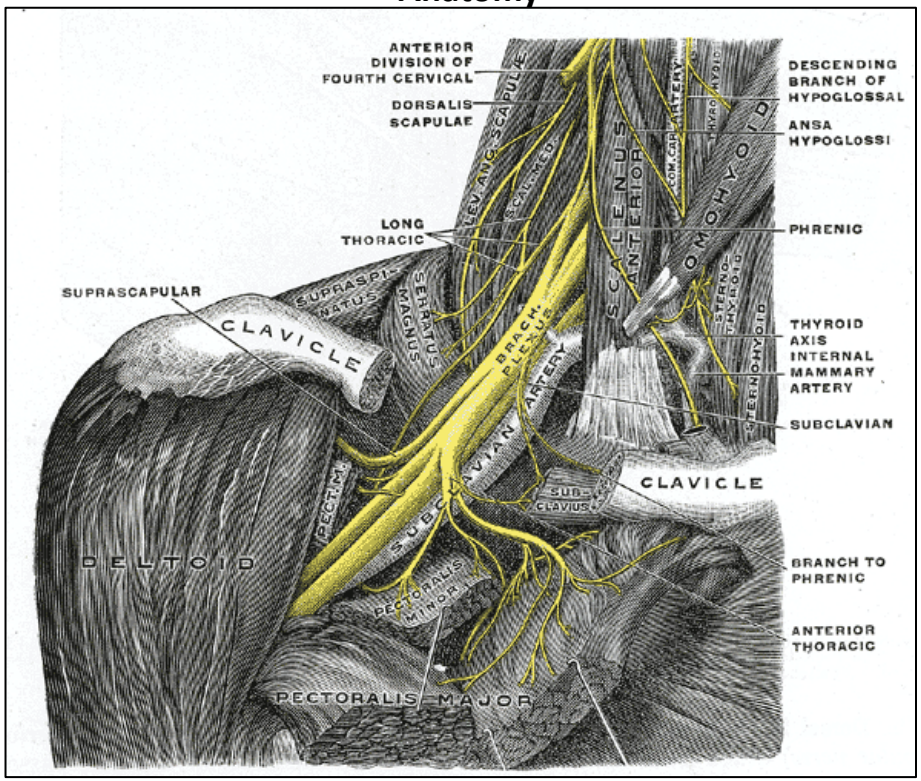
- Often done for shoulder surgery in patients without major pulmonary disease.
- Blockade of inferior trunk (C8, T1 → ulnar nerve) can be incomplete. [Miller 9th Ed, Ch 46]



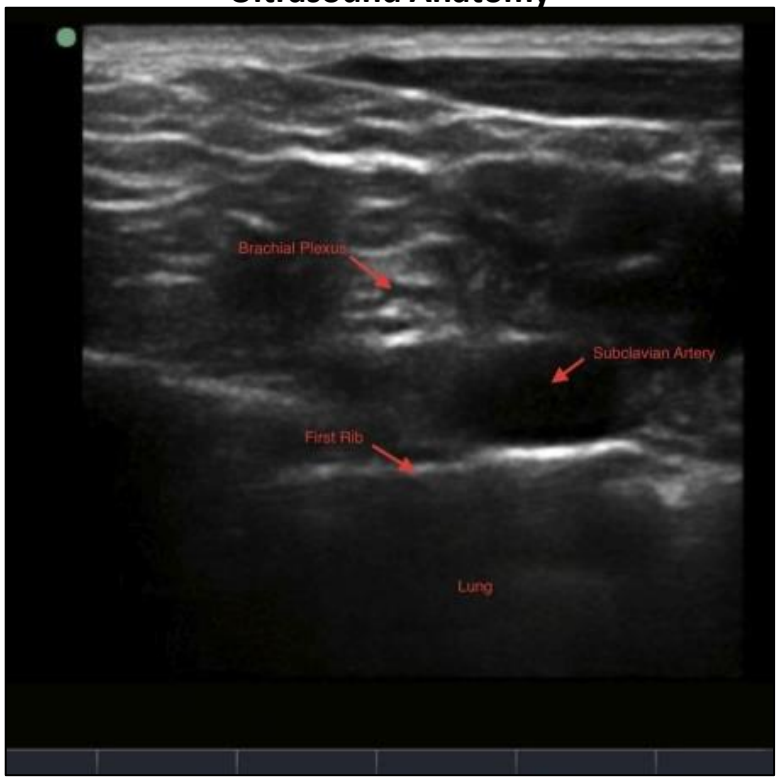
Anatomy image: Henry Vandyke Carter, https://commons.wikimedia.org/wiki/File:Gray808.png, Public domain, via Wikimedia Commons // Ultrasound Image: Kaciroglu et al. Kaciroglu, A. et al. Ultrasound-guided combined interscalene and superficial cervical plexus blocks for anesthesia management during clavicle fracture surgery. Ain-Shams J Anesthesiol 11, 28 (2019). https://doi.org/10.1186/s42077-019-0039-5. Creative Commons CC-BY-4.0.

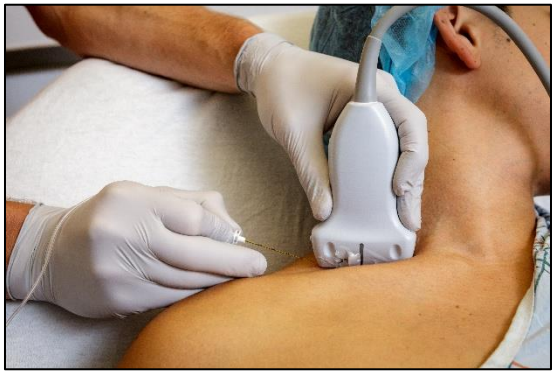
# Supraclavicular Block Anatomy

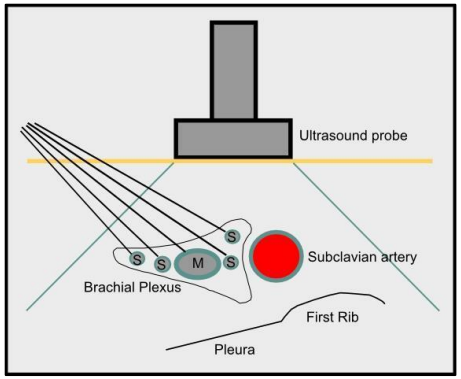
**Anatomy**




**Ultrasound Anatomy**



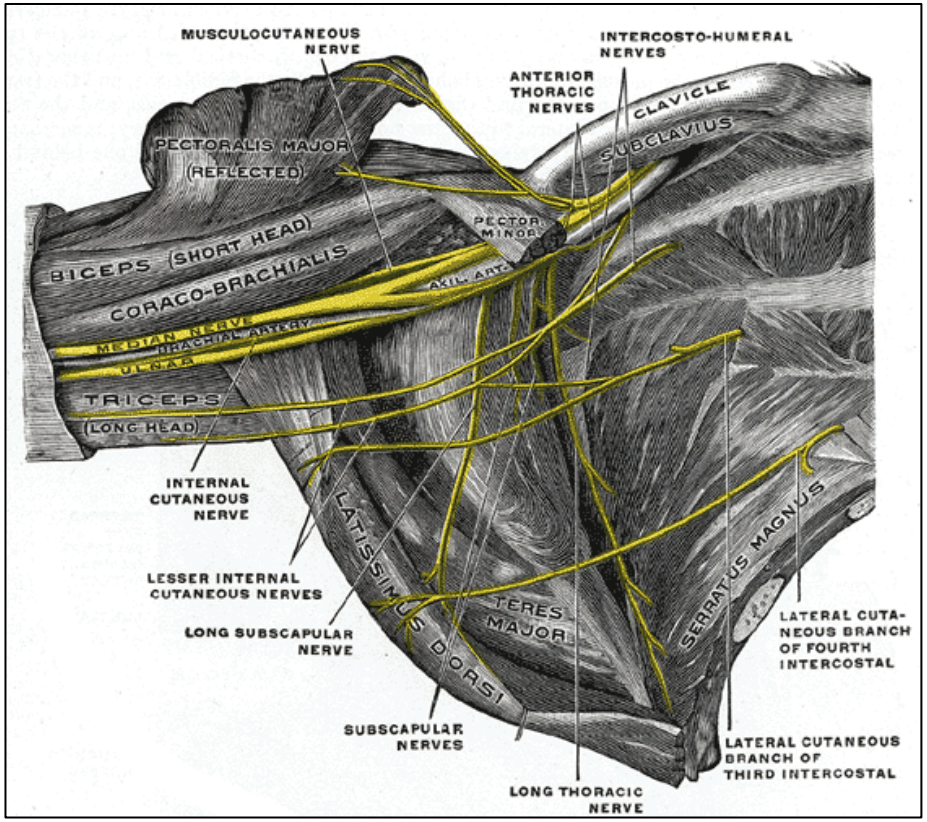






Anatomy image: Henry Vandyke Carter, https://commons.wikimedia.org/wiki/File:Gray808.png, Public domain, via Wikimedia Commons // Illustration: D'Souza et al. PMID: 30085598 Creative Commons CC-BY-4.0 // Photo: 729072025, used via license from Shutterstock.com // Ultrasound image: Change et al. PMID: 29083659. Creative Commons CC-BY-4.0

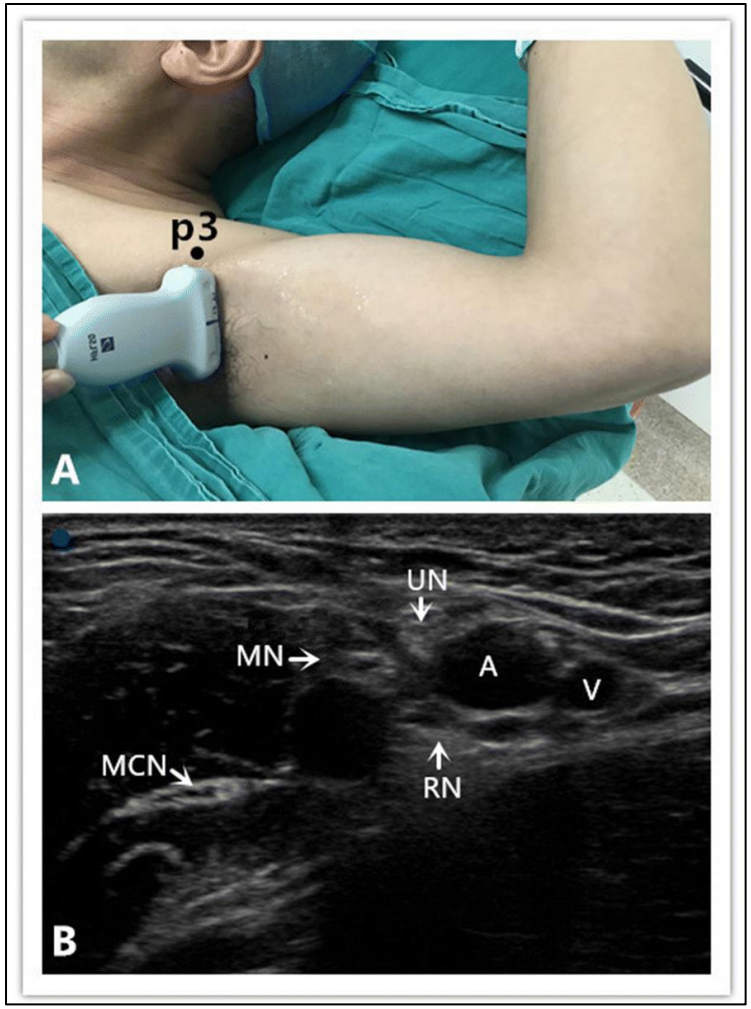
# Axillary/Musculocutaneous Block Anatomy

**Anatomy**



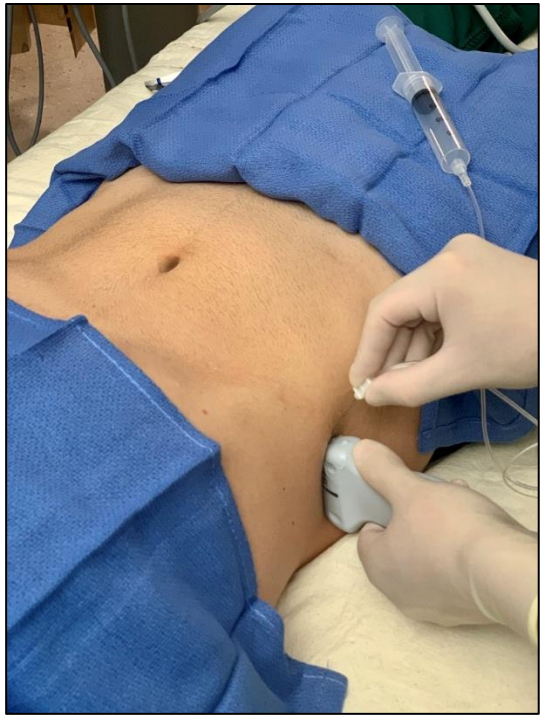

"Although anatomic variations exist, typically, the median nerve is found superior to the artery, the ulnar nerve is inferior, and the radial nerve is posterior and somewhat lateral…**At this level, the musculocutaneous nerve [sensory to lateral forearm] has already left the sheath** and lies with the coracobrachialis muscle."[1]

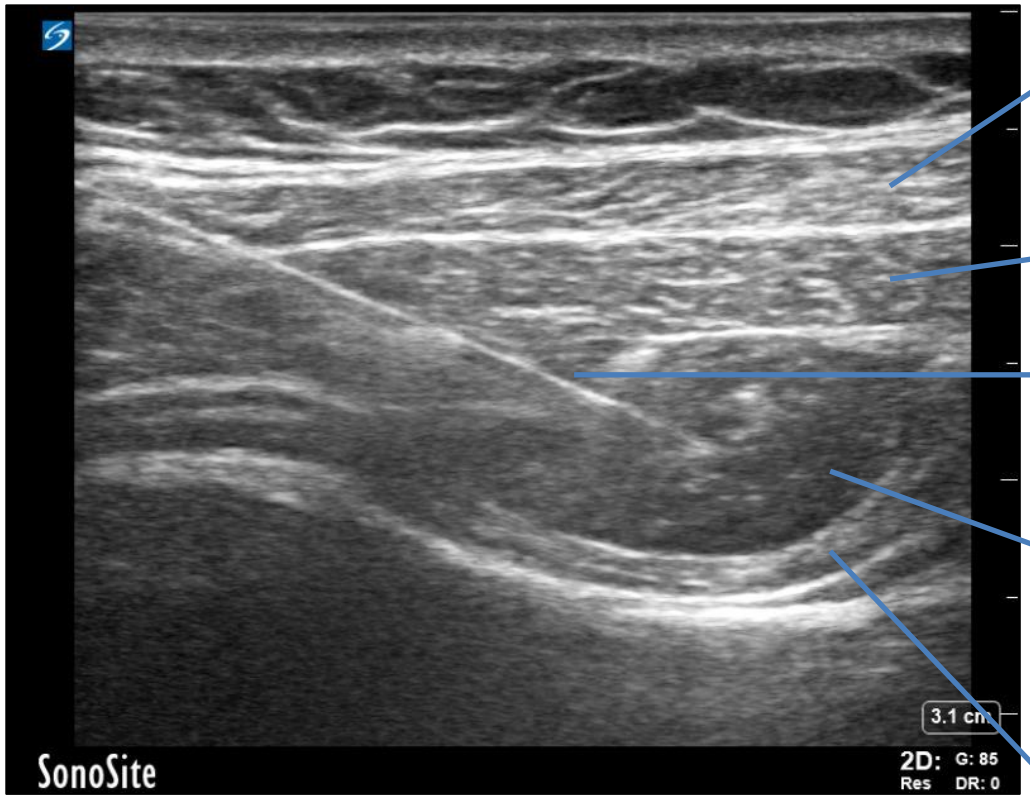
**Ultrasound Anatomy**




MCN: musculocutaneous nerve; MN: median nerve; UN: ulnar nerve; RN: radial nerve; A: axillary artery; V: axillary vein

# TAP Block Anatomy




External oblique (EO) muscle

Internal oblique(IO) muscle

Needle

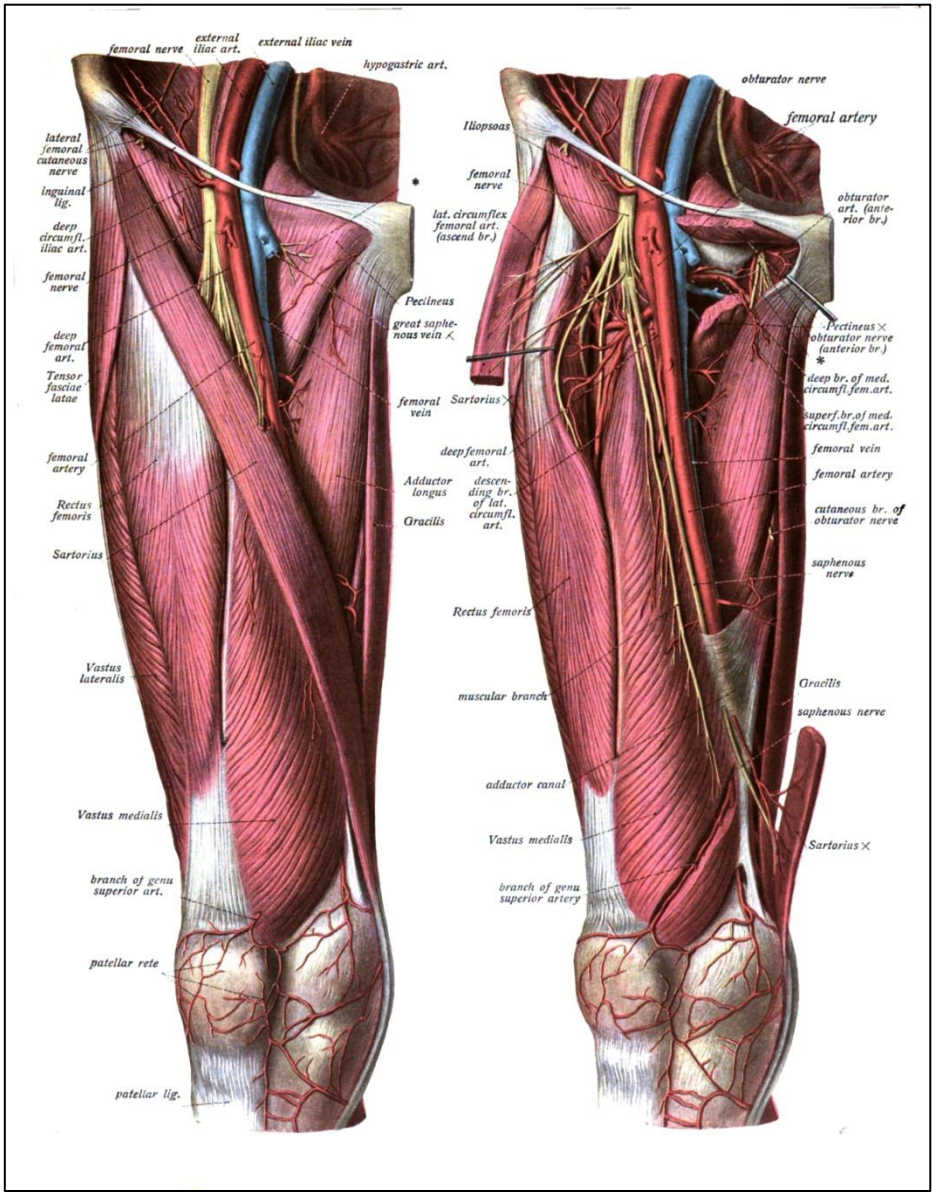
Local anesthetic hydrodissecting plane between the IO and TA.

Transversus abdominis (TA)

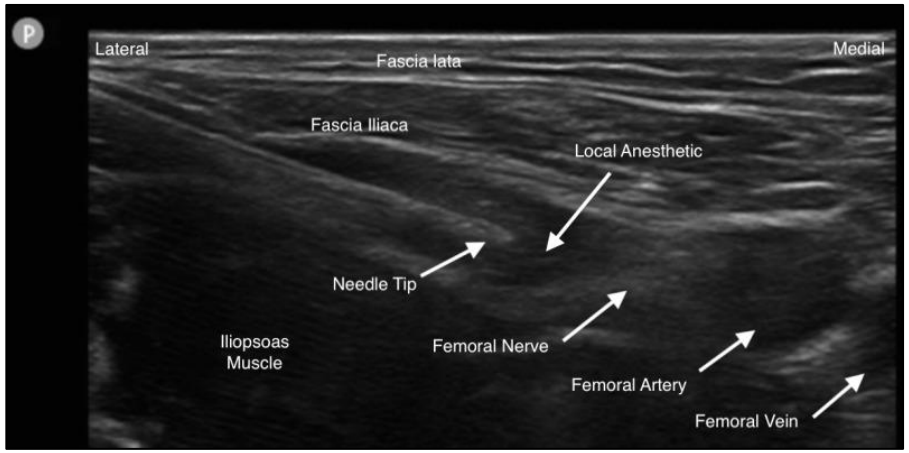
"TAP blocks are indicated for any lower abdominal surgery, including hernia repair, appendectomy, caesarian delivery, abdominal hysterectomy, laparoscopic surgery, renal transplantation, and prostatectomy. Bilateral blocks can be used for midline incisions or laparoscopic procedures. It is reasonable to expect analgesia between T10 and L1 with a single injection." [Miller Ch 57, 8th Ed]

# Femoral Nerve Block Anatomy

**Lower extremity anatomy**



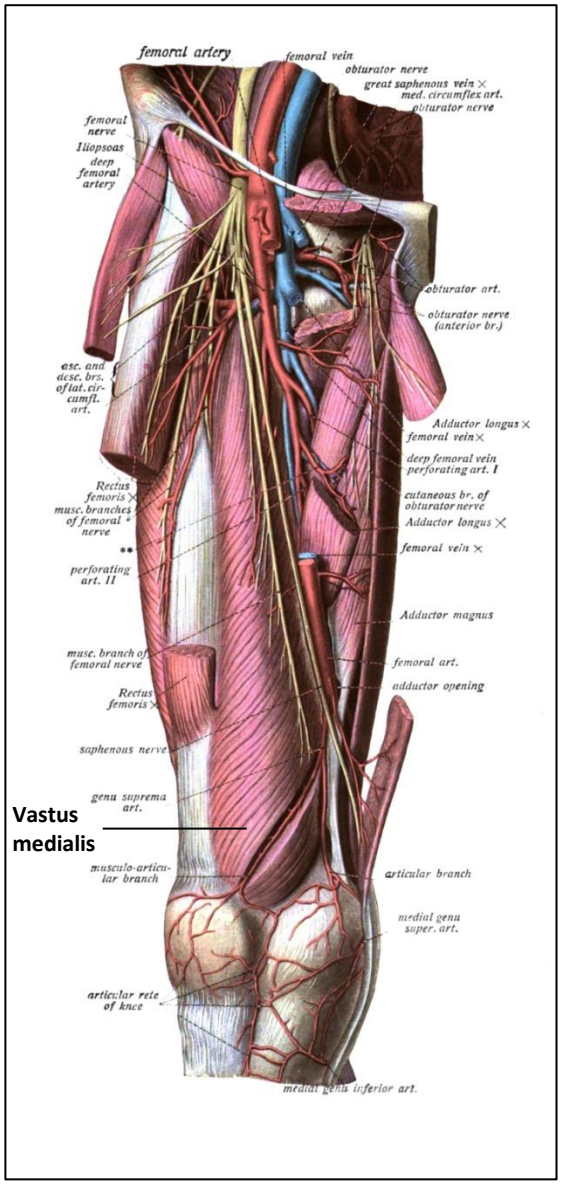

**Ultrasound Anatomy**



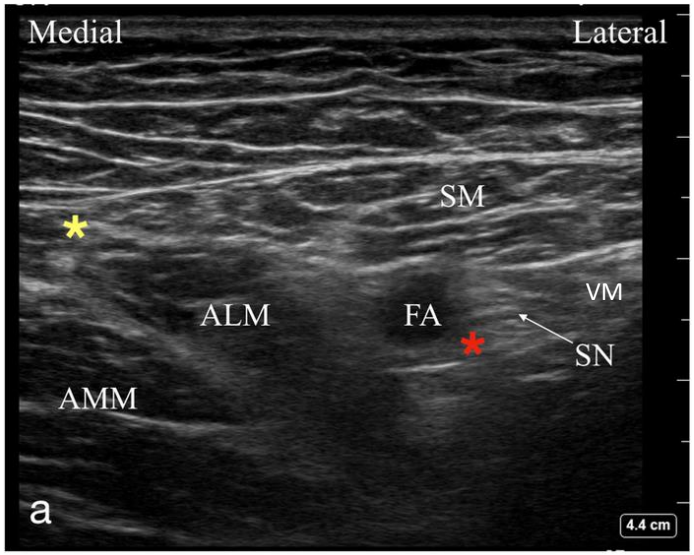

**Femoral Nerve**: Formed from the posterior divisions of L2, L3, and L4. **Motor innervation:** quadriceps, sartorius, and pectineus muscles. "**Sensory branches** include the anterior cutaneous nerve of the thigh, the infrapatellar nerve, and the saphenous nerve. These nerves innervate the anterior thigh, the patella, and the medial leg and foot, respectively."[1,2]

# Adductor Canal Block Anatomy

**More Lower extremity anatomy**

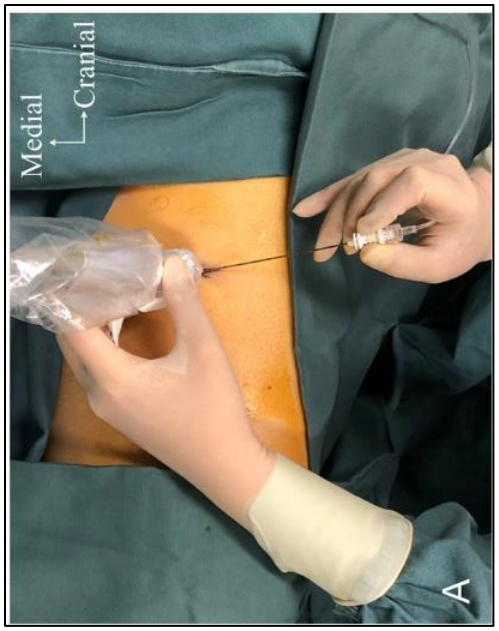



**Ultrasound Anatomy**




AMM: adductor magnus muscle; ALM: adductor longus muscle; SM: sartorius muscle; FA: femoral artery; VM: vastus medialis

**In-plane approach, needle direction lateral to medial**



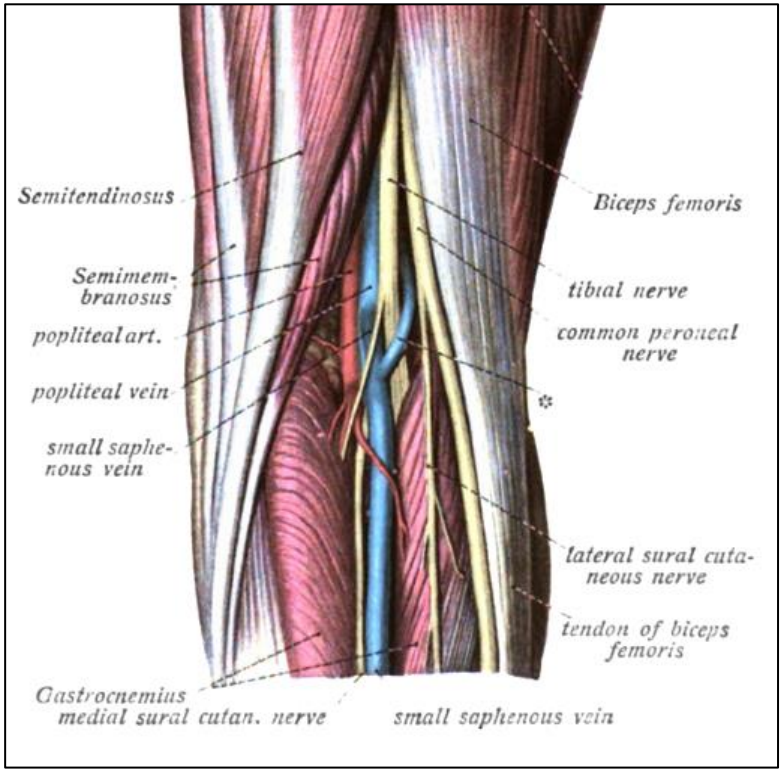

**<u>Saphenous Nerve</u>**: "terminal branch of the posterior division of the femoral nerve…**sensory innervation** to the medial, anteromedial, and posteromedial aspects of the lower extremity from the distal thigh to the medial malleolus."[1]

**<u>Nerve to the Vastus Medialis</u>:** "also a branch of the posterior division of the femoral nerve. It travels lateral to the superficial femoral artery within the adductor canal and sends multiple branches to the vastus medialis and supplies the anteromedial portion of the knee capsule."

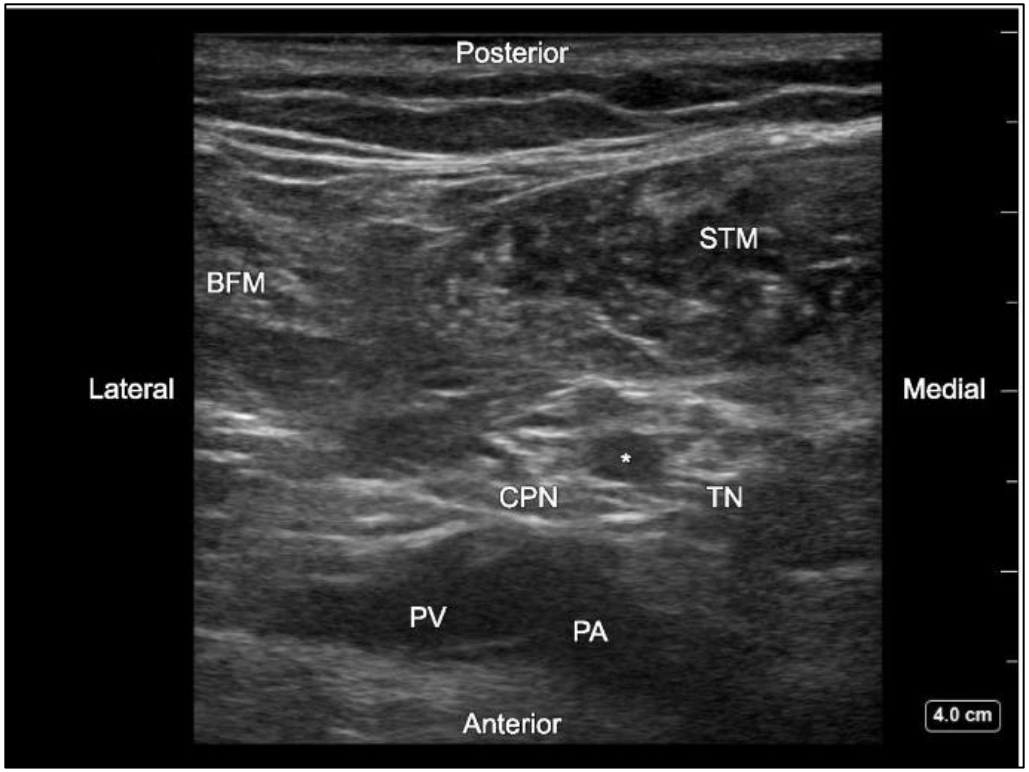
Photo and Ultrasound Image: excerpt adapted from Fei et al. PMID: 33036554; Creative Commons CC-BY-4.0 // More Lower Extremity Anatomy: Adapted from Dr. Johannes Sobotta, Public domain, via Wikimedia Commons https://commons.wikimedia.org/wiki/File:Sobo_1909_575-576.png // 1. Brown's Atlas Reg Anes,Ch 18,5th Ed // Adaptations reflect views of presentation author.

# Popliteal Fossa Block Anatomy

**Anatomy**




**Ultrasound Anatomy**



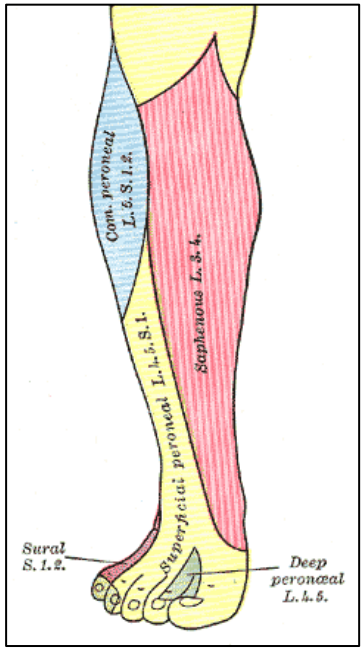

"Near the upper border of the popliteal fossa, the two components of the sciatic nerve separate. The peroneal nerve diverges laterally, and the larger tibial branch descends almost straight down through the fossa. The tibial nerve and popliteal vessels then disappear deep to the converging heads of the gastrocnemius muscle." "This block is chiefly used for foot and ankle surgery. "[1]

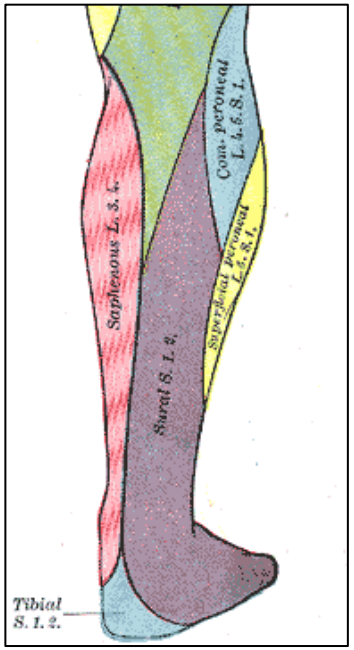
BFM: biceps femoris muscle; STM: semitendinosus muscle; TN: tibial nerve; CPN: common peroneal nerve; PA: popliteal artery; PV: popliteal vein (Note: asterisk depicts an anomalous vessel within the sheath around the TN and the CPN)

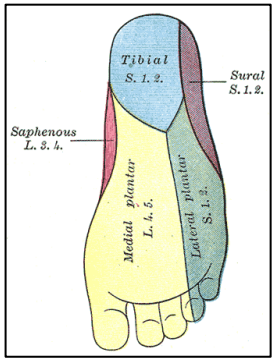
# Ankle Block Anatomy

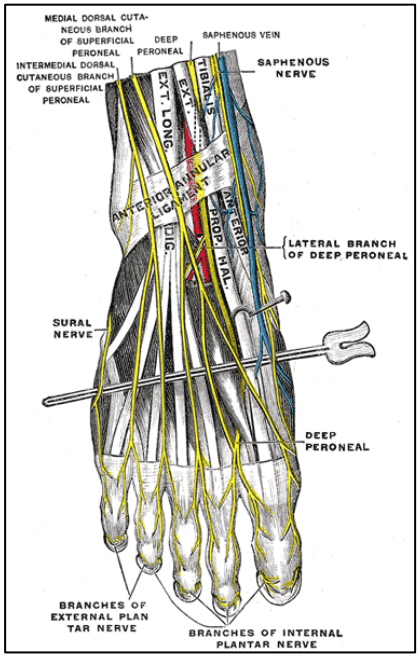
**Dorsal side of foot**

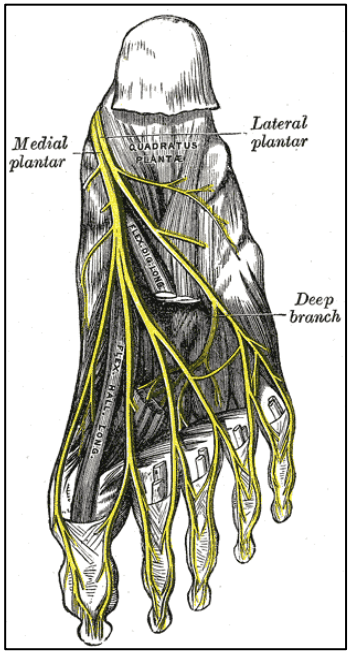
**Plantar side of foot**



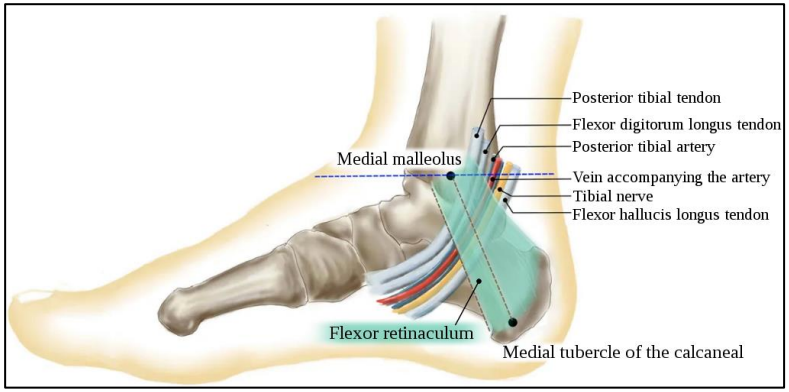




Nerves to block at ankle:

1. Saphenous nerve

<u>Four branches of the sciatic nerve</u>:

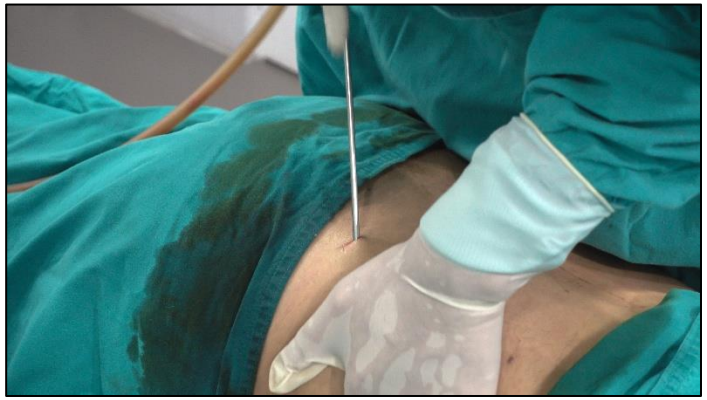
2. Posterior tibial (lateral plantar and medial plantar nerves are branches of posterior tibial nerve)
3. Sural
4. Superficial peroneal
5. Deep peroneal



# Tumescent Anesthesia

11X

- Total Dose of lidocaine: can range from 35-55mg/kg.[1]
- Peak serum level of lidocaine: 12-14 hours after injection, with decline over subsequent 6-14 hours.[1]
  - "35 to 55 mg/kg doses have been used safely because the tumescent technique results in a single compartment clearance similar to that of a sustained-release medication."[1]



- "There have been several cases of cardiac arrest and death during plastic surgery procedures…multiple risk factors…high local anesthetic concentrations and concomitant use of sedatives may have contributed…."[2] "An office liposuction should be limited to 5L of total aspirant….Large volume liposuction should not be performed in conjunction with other procedures."[1]

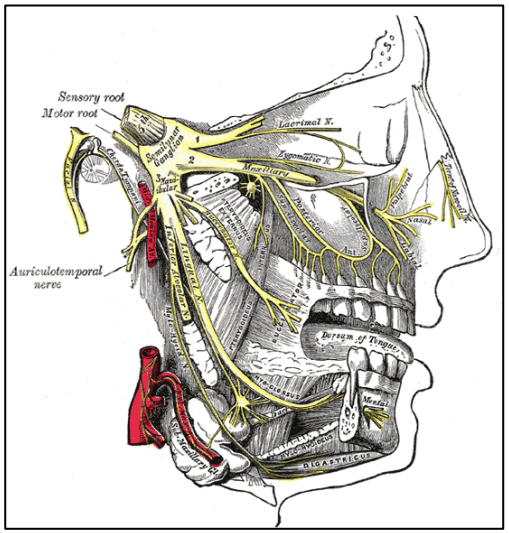
- 2002 survey of the American Society of Dermatologic Surgery: no mortality among 66,570 procedures; serious adverse events more frequent in hospitals and ASC's than in offices (hospitals and ASC's may see sicker pts and remove more fat); morbidity had better correlation with area of body suctioned (more morbidity from abdomen and buttocks than extremities) than facility where procedure took place.[1,3]

1. Barash 8th Ed, Ch 32 // 2. Miller 8th Ed, Ch 36 // 3. Housman TS, et al. The safety of liposuction: results of a national survey. Dermatol Surg 2002; 28: 971-8 // ID: 642254683, used under license from Shutterstock.com

# Anatomy & Airway

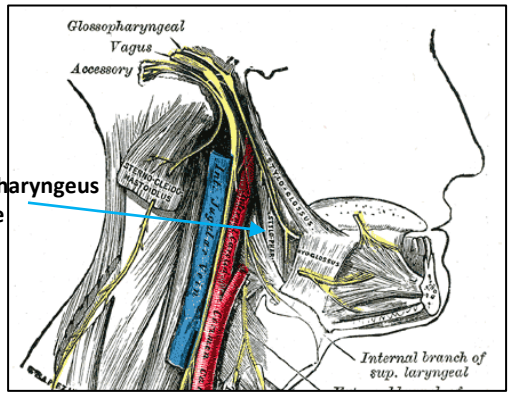
# “Image/Buzzwords Co-slides”: Airway Anatomy and Innervation

## Trigeminal Nerve (CN V)

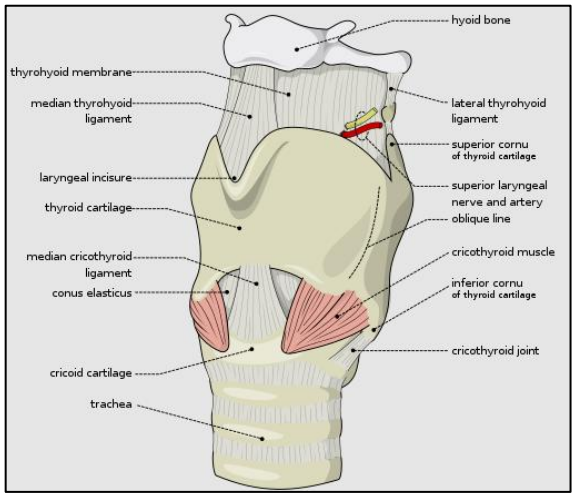



## Glossopharyngeal Nerve (CN IX)

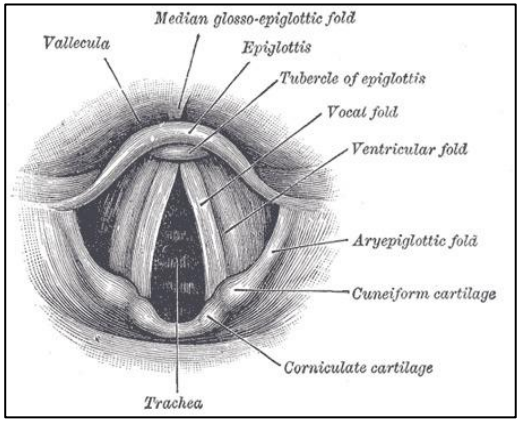
stylopharyngeus muscle




## Cricothyroid muscle



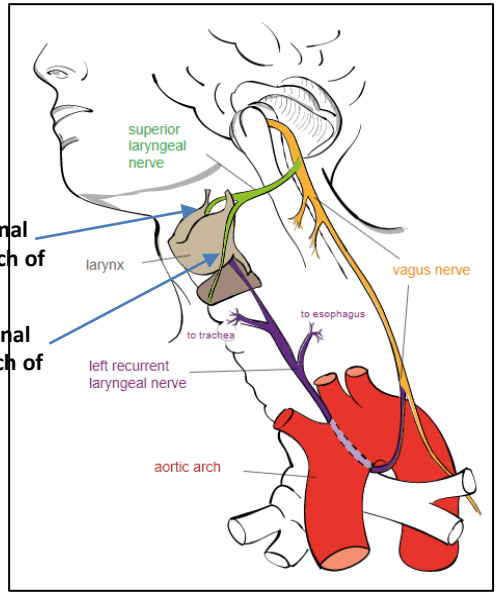

## Laryngoscopic view of larynx




## (Left) Vagus Nerve (CN X)

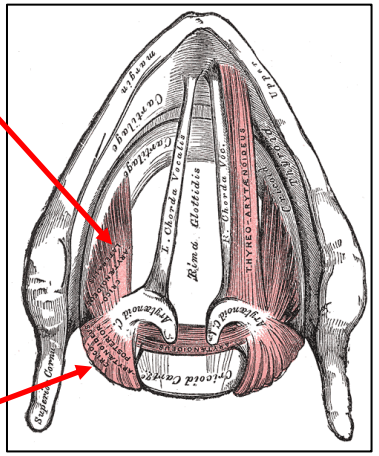
internal branch of SLN

external branch of SLN




## Lateral cricoarytenoid muscle (adductor of vocal fold)

## Posterior cricoarytenoid muscle (abductor of vocal fold)



Trigeminal/Glossopharyngeal nerves, Lateral/Posterior cricoarytenoid muscles:, and laryngoscopic view of larnyx https://commons.wikimedia.org/wiki/File:Gray778.png, https://commons.wikimedia.org/wiki/File:Gray793.png, https://commons.wikimedia.org/wiki/File:Gray960.png, https://commons.wikimedia.org/wiki/File:Gray956.png, Henry Vandyke Carter, Public domain, via Wikimedia Commons // Left Vagus nerve: Jkwchui, https://commons.wikimedia.org/wiki/File:Recurrent_laryngeal_nerve.svg, CC BY-SA 3.0 via Wikimedia Commons // Cricothyroid muscle: Olek Remesz (wiki-pl: Orem, commons: Orem), CC BY-SA 2.5 <https://creativecommons.org/licenses/by-sa/2.5>, via Wikimedia Commons (https://commons.wikimedia.org/wiki/File:Larynx_external_en.svg)

# "Image/Buzzwords Co-slides": Airway Anatomy and Innervation

25X

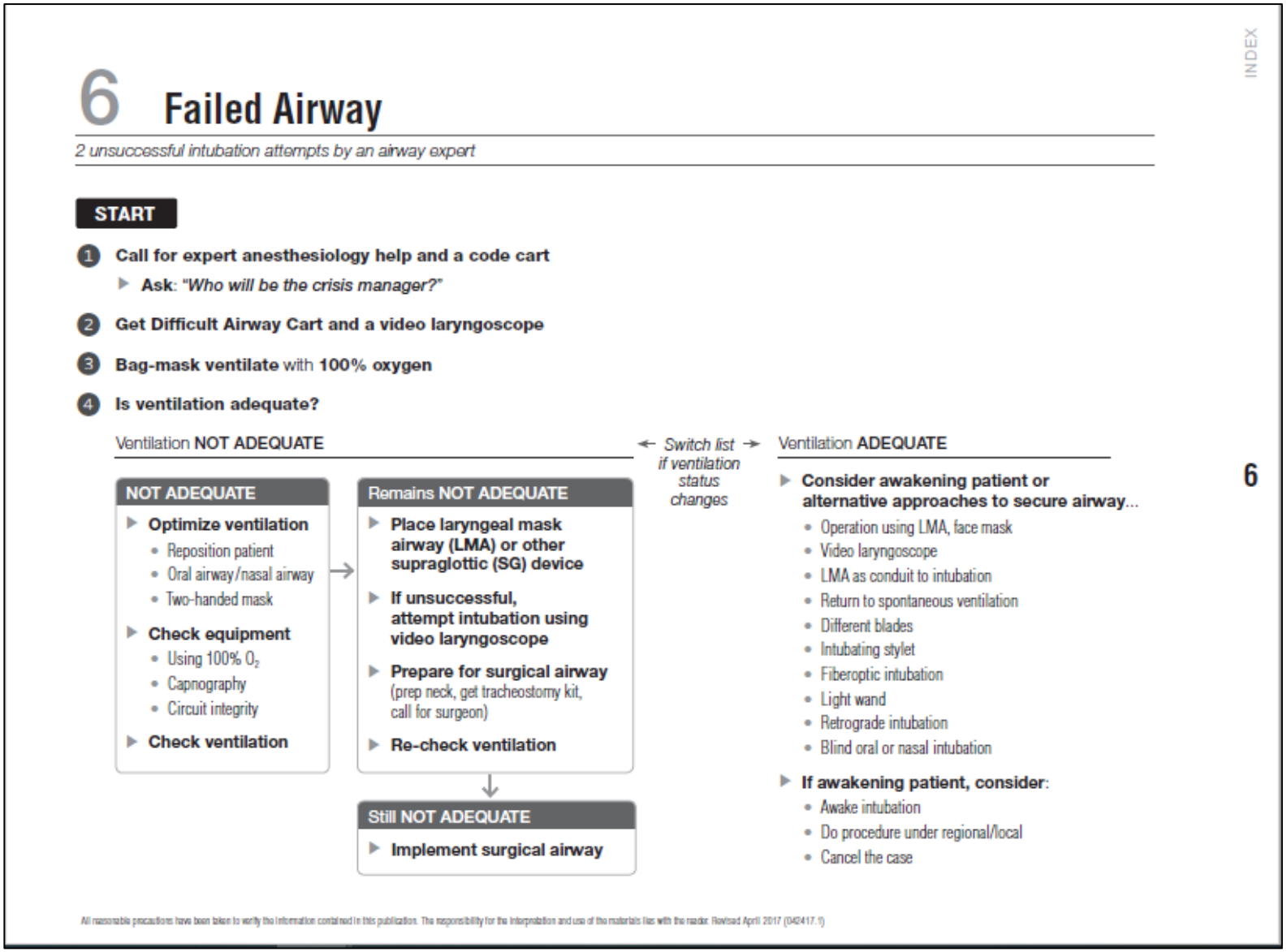
- Trigeminal Nerve (CN V): sensory to nasal mucosa and nasal cavity (V2: maxillary branch).
- Glossopharyngeal nerve (CN IX): sensory to posterior third of tongue, walls of pharynx, and anterior surface of epiglottis.
    - Gag/Pharyngeal Reflex: most sensory from CNIX (some sensory from CNV2 [nasopharynx] and CN X).
        - Motor innervation: Stylopharyngeus muscle innervated by CNIX (elevates larynx and elevates/dilates pharynx to facilitate swallowing food). All *other pharyngeal muscles are innervated by the pharyngeal branch of CN X.*
- Vagus Nerve (CN X):
    - Superior Laryngeal Nerve:
        - Internal Branch: sensory to base of tongue, posterior surface of epiglottis, aryepiglottic folds and arytenoids.
        - External Branch: motor innervation to cricothyroid muscle (voice pitch).
    - Recurrent Laryngeal Nerve: (1) sensory innervation to vocal folds and trachea. (2) motor innervation to all muscles of larynx except cricothyroid muscle.
        - *Unilateral injury*: hoarseness (injured cord in paramedian position); *Bilateral injury*: dyspnea, stridor, partial or complete airway obstruction (bilateral cords in paramedian position).
        - Airway obstruction after thyroid/parathyroid surgery: history/physical to differentiate RLN injury vs hematoma; hypocalcemia not usually a cause until 24-48 hours postop (in these patients, look for muscle spasms and ECG changes).
        - The RLN can be injured during head/neck surgery (e.g., thyroid, parathyroid, cervical spine, carotid endarteractomy), cardiothoracic surgery (e.g., patent ductus arteriosus (PDA) repair [left RLN]), interscalene block, & other procedures.
        - Posterior cricoarytenoid muscle: the only abductor of the larynx (i.e., only muscle to open the true vocal folds). It opposes the action of the lateral cricoarytenoid muscles.



Barash 8th Ed, C28 // Miller 9th Ed Chs 44 & 70 // Cumming's Otolaryngology 7th Ed Ch 53 // KJ Lee's Essential Otolaryngology: Head and Neck Surgery, 12th Ed. Chs 36 & 50 // Jain et al. PMID 31613499

# Difficult Airway

11X, incl next slide



INDEX

## 6 Failed Airway

*2 unsuccessful intubation attempts by an airway expert*

**START**

1. **Call for expert anesthesiology help and a code cart**
   - **Ask**: *"Who will be the crisis manager?"*
2. **Get Difficult Airway Cart and a video laryngoscope**
3. **Bag-mask ventilate** with **100% oxygen**
4. **Is ventilation adequate?**

Ventilation **NOT ADEQUATE** ← *Switch list if ventilation status changes* → Ventilation **ADEQUATE**

**NOT ADEQUATE**
- **Optimize ventilation**
  - Reposition patient
  - Oral airway/nasal airway
  - Two-handed mask
- **Check equipment**
  - Using 100% $O_2$
  - Capnography
  - Circuit integrity
- **Check ventilation**

→

**Remains NOT ADEQUATE**
- **Place laryngeal mask airway (LMA) or other supraglottic (SG) device**
- **If unsuccessful, attempt intubation using video laryngoscope**
- **Prepare for surgical airway** (prep neck, get tracheostomy kit, call for surgeon)
- **Re-check ventilation**

↓

**Still NOT ADEQUATE**
- **Implement surgical airway**

- **Consider awakening patient or alternative approaches to secure airway...**
  - Operation using LMA, face mask
  - Video laryngoscope
  - LMA as conduit to intubation
  - Return to spontaneous ventilation
  - Different blades
  - Intubating stylet
  - Fiberoptic intubation
  - Light wand
  - Retrograde intubation
  - Blind oral or nasal intubation
- **If awakening patient, consider:**
  - Awake intubation
  - Do procedure under regional/local
  - Cancel the case

6

All reasonable precautions have been taken to verify the information contained in this publication. The responsibility for the interpretation and use of the materials lies with the reader. Revised April 2017 (042417.1)

NEJM Cricothyroidotomy video: https://www.nejm.org/doi/full/10.1056/NEJMvcm0706755

(https://youtu.be/Fb_EdieQet8)

# Difficult Airway Predictors

## Predictors of difficult intubation and/or difficult mask ventilation:

**Langeron O, Masso E, Huraux C, et al. Predictors of difficult mask ventilation. Anesthesiology 2000; 92: 1229-36.**

- Multivariate risk factors for difficult mask ventilation: **Beard (Odds Ratio 3.18** [95% Confidence Interval 1.39-7.27; p=0.006]), BMI 26 or greater (OR 2.75 [1.64-4.62; p<0.001]), Lack of teeth (OR 2.28 [1.26-4.10; p=0.006]), Age 55 or greater (OR 2.26 [1.34-3.81; p=0.002]), Snoring history (OR 1.84 [1.09-3.10; p=0.02]).

**Shiga T et al. Predicting difficult intubation in apparently normal patients: A meta-analysis of bedside screening test performance. Anesthesiology 2005; 103: 429-37**.

- "The most useful bedside test for prediction was found to be a **combination of the Mallampati classification and thyromental distance**….combinations of tests add some incremental diagnostic value in comparison to the value of each test alone."

**Kheterpal S et al. Incidence and predictors of difficult and impossible mask ventilation. Anesthesiology 2006; 105: 885-91**.

- "**Limited or severely limited mandibular protrusion**[**p<0.0001**], abnormal neck anatomy [thick/obese: p=0.019], sleep apnea [p=0.036], snoring [p=0.049], and body mass index of 30 kg/m or greater [p=0.053] were independent predictors of grade 3 [inadequate, unstable, or requiring two providers] or 4 [impossible to ventilate] mask ventilation and difficult intubation."

**Kheterpal S et al. Prediction and outcomes of impossible mask ventilation: A review of 50,000 anesthetics. Anesthesiology 2009; 110: 891-7**.

- "**Neck radiation changes** [**Adjusted Hazard Ratio 7.1** (95% Confidence Interval 2.1-24.2; p=0.002)] , male sex [Adjusted HR 3.3 (1.8-6.3; p<0.001)], sleep apnea [Adjusted HR 2.4 (1.3-4.3; p=0.005)], Mallampati III or IV [Adjusted HR 2.0 (1.1-3.4; p=0.014)], and presence of beard [Adjusted HR 1.9 (1.1-3.3; p=0.024)] were identified as independent predictors."

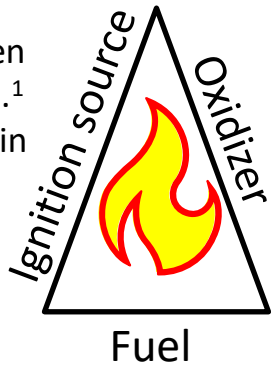
**Kheterpal S et al. Incidence, predictors, and outcomes of difficult mask ventilation combined with difficult laryngoscopy. Anesthesiology 2013; 119: 1360-1369**

- **Risk Index Classification System**: Class I (0-3 risk factors; reference), Class II (4 risk factors; OR 2.56), Class III (5 risk factors; OR 4.18), Class IV (6 risk factors; OR 9.23), Class V (7-11 risk factors; OR 18.4). Risk Factors: Mallampati III or IV (Adjusted Odds Ratio 3.21 [95% CI 2.45-4.22; p<0.001]), Neck radiation changes or neck mass (2.57 [1.18-5.60; p=0.017]), Male sex (2.46 [1.80-3.36; p<0.001]), Limited thyromental distance (2.40 [1.68-3.44; p<0.001]), Presence of teeth (2.38 [1.50-3.79; p<0.001]), Body mass index 30 or more (2.16 [1.58-2.94; p<0.001]), Age 46 or more (1.93 [1.35-2.76; p<0.001]), Presence of beard (1.64 [1.21-2.24; p0.002]), Thick neck (1.53 [1.13-2.07; p=0.006]), Sleep apnea (1.59 [1.12-2.27; p=0.010]), Unstable cervical spine or limited neck extension (1.47 [1.05-2.05; p=0.024]), and Limited or severely limited jaw protrusion (1.47 [1.05-2.05; p=0.028]).

# Airway & Operating Room Fire

12X

- Fire Triad: (1) fuel (e.g., ETT, drapes), (2) oxidizer, (3) ignition source (Miller 9th Ed, Ch 70).
- Silverstein Fire Risk Assessment Tool: One point for each: 1. Surgical site above xiphoid, 2. Open oxygen source (e.g., facemask, nasal cannula), 3. Ignition source (electrocautery, laser, fiberoptic light source).[1] Some add additional point based on prepping agent (e.g., alcohol-based – acetone as well as other skin prep/adhesive agents are flammable).
- ASA 2013 Practice Advisory: (1) Use ETT resistant to laser being used; (2) Fill tracheal cuff with saline and indicator dye (e.g., methylene blue, indocyanine green); (3) Reduce FiO2 to "minimum required to avoid hypoxia (and stop nitrous oxide)." **For Airway/Breathing Circuit Fire**: Remove ETT, stop flow of airway gases, remove flammable/burning materials from airway, pour saline/water into airway.

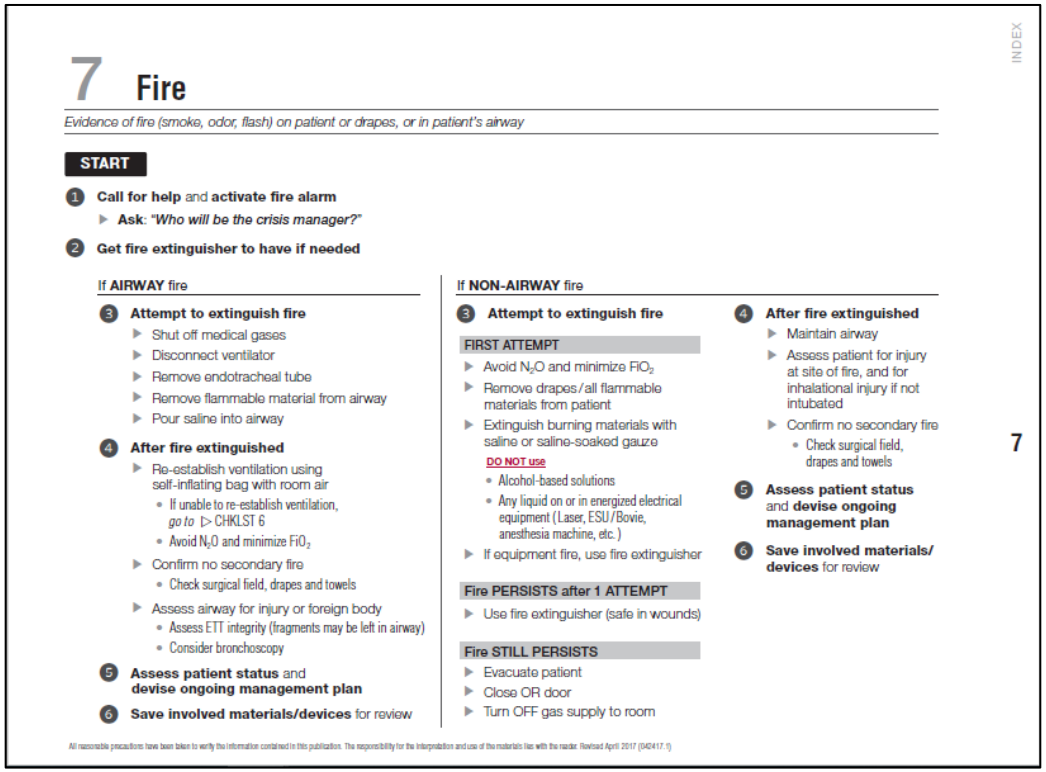



**Potential ETT Options for Airway Laser Surgery**
**** Preoperatively discuss with surgeon, including laser used and ETT preference ****

**CO2 or KTP (potassium titanyl phosphate) lasers:**
- Stainless steel corrugated spiral ETT
- Red rubber ETT wrapped with aluminum or copper foil
- Silicone ETT wrapped in aluminum foil

**Nd/YAG, Argon, and CO2 lasers**:
- Soft/flexible white rubber ETT covered with copper foil.

QR Code: Table from APSF Article on Common Prep Solutions and Their Alcohol Content



INDEX

## 7 Fire

*Evidence of fire (smoke, odor, flash) on patient or drapes, or in patient's airway*

**START**

1. **Call for help** and **activate fire alarm**
   - **Ask**: *"Who will be the crisis manager?"*
2. **Get fire extinguisher to have if needed**

**If AIRWAY fire**

3. **Attempt to extinguish fire**
   - Shut off medical gases
   - Disconnect ventilator
   - Remove endotracheal tube
   - Remove flammable material from airway
   - Pour saline into airway
4. **After fire extinguished**
   - Re-establish ventilation using self-inflating bag with room air
     - If unable to re-establish ventilation, *go to* ▷ CHKLST 6
     - Avoid $N_2O$ and minimize $FiO_2$
   - Confirm no secondary fire
     - Check surgical field, drapes and towels
   - Assess airway for injury or foreign body
     - Assess ETT integrity (fragments may be left in airway)
     - Consider bronchoscopy
5. **Assess patient status** and **devise ongoing management plan**
6. **Save involved materials/devices** for review

**If NON-AIRWAY fire**

3. **Attempt to extinguish fire**

FIRST ATTEMPT
- Avoid $N_2O$ and minimize $FiO_2$
- Remove drapes/all flammable materials from patient
- Extinguish burning materials with saline or saline-soaked gauze

DO NOT use
- Alcohol-based solutions
- Any liquid on or in energized electrical equipment (Laser, ESU/Bovie, anesthesia machine, etc.)

- If equipment fire, use fire extinguisher

Fire PERSISTS after 1 ATTEMPT
- Use fire extinguisher (safe in wounds)

Fire STILL PERSISTS
- Evacuate patient
- Close OR door
- Turn OFF gas supply to room

4. **After fire extinguished**
   - Maintain airway
   - Assess patient for injury at site of fire, and for inhalational injury if not intubated
   - Confirm no secondary fire
     - Check surgical field, drapes and towels
5. **Assess patient status** and **devise ongoing management plan**
6. **Save involved materials/devices** for review

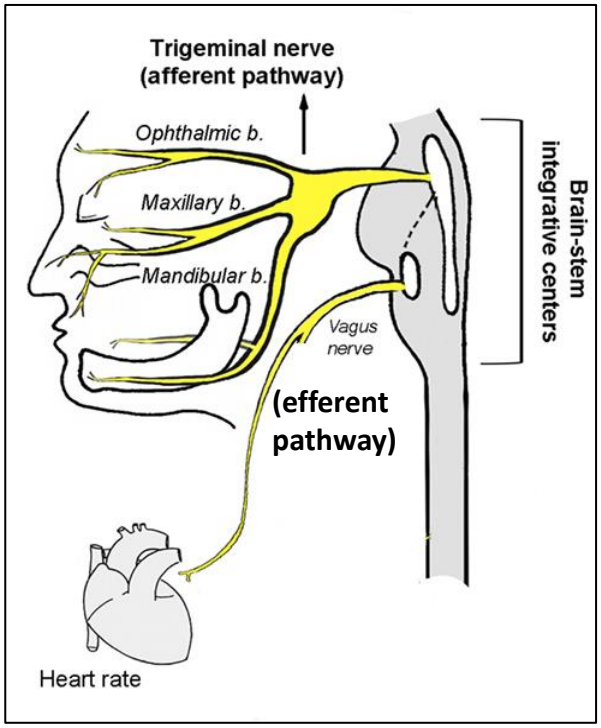
7

All reasonable precautions have been taken to verify the information contained in this publication. The responsibility for the interpretation and use of the materials lies with the reader. Revised April 2017 (042417.1)

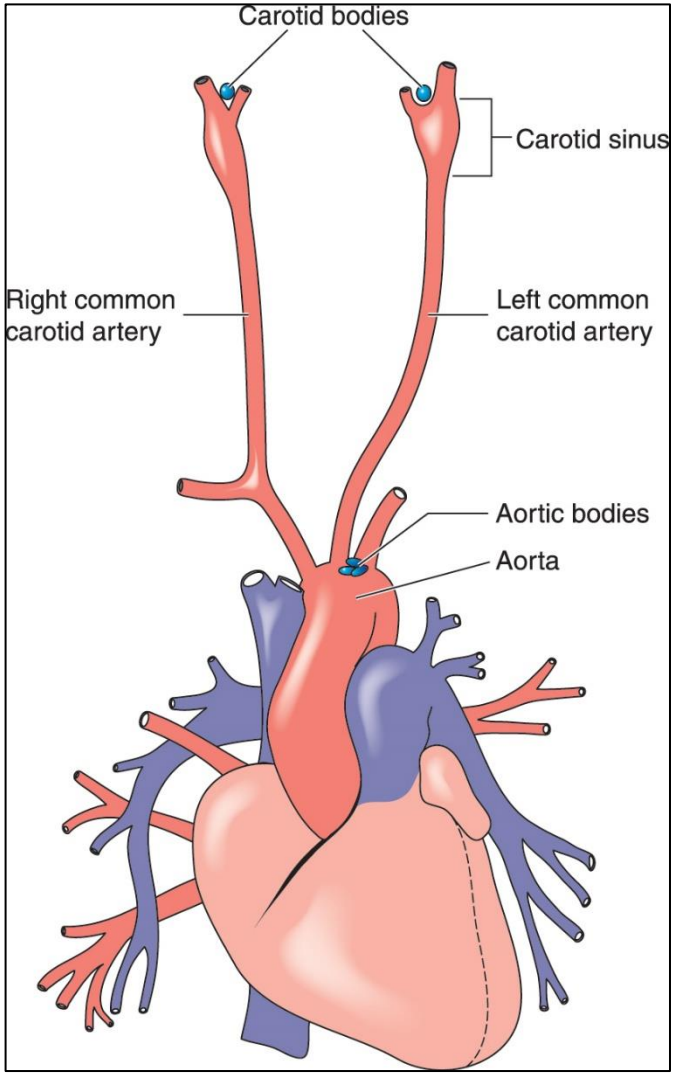
1. Mathias JM. Scoring fire risk for surgical patients. OR manager. 2006 Jan;22(1):19 // Miller 9th Ed, Ch 70. // Airway for Laser Surgery; PMID: 33232076 // Fire Checklist: From Ariadne Labs Operating Room Crisis Checklists. See https://www.ariadnelabs.org/ for latest version. With permission via Creative Commons BY-NC-SA (https://creativecommons.org/licenses/by-nc-sa/4.0/).

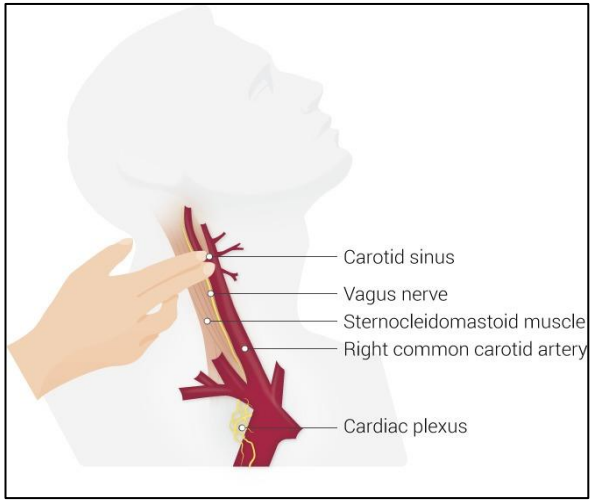
# “Image/Buzzwords Co-slides”:
# Anatomy: Oculocardiac and other Reflexes

## Oculocardiac Reflex




## Carotid Body (peripheral chemoreceptors) and Carotid Sinus (baroreceptors)

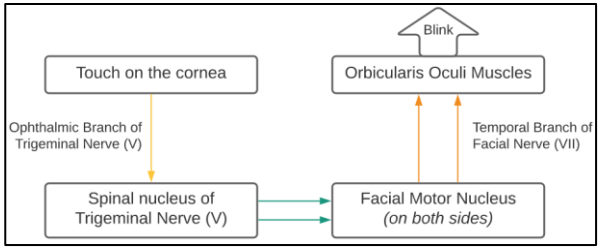



**Khan Academy Videos related to carotid body and carotid sinus (Dr. Rishi Desai):**

1. Peripheral chemoreceptors: https://youtu.be/cJXY3Cywrnc
2. Regulation of blood pressure with baroreceptors: https://youtu.be/ajLgwCygHsc
3. The respiratory center: https://youtu.be/_BFDgTci0ck
4. Central chemoreceptors: https://youtu.be/lVacrVMmJX8

## Corneal Reflex




Oculocardiac Reflex: adapted from Buchholz et al. https://doi.org/10.3389/fneur.2017.00052 Creative Commons CC-BY-4.0. // Carotid body and carotid sinus images: Blamb, used under license from Shutterstock.com. // Carotid sinus massage: Kenny et al. PMID: 30725856 . Creative Commons CC-BY-4.0 // Corneal reflex: Gaurav Sinha, CC BY-SA 4.0, https://commons.wikimedia.org/wiki/File:Corneal_Reflex_Pathway_Flowchart.svg, via Wikimedia Commons

# "Image/Buzzwords Co-slides": Anatomy: Oculocardiac and other Reflexes

20X

Oculocardiac reflex: can be triggered by traction on extraocular muscles or external pressure to globe

- Afferent limb: long and short ciliary nerves -> ciliary ganglion → **ophthalmic branch of trigeminal nerve (cranial nerve V1)** → Gasserian (trigeminal) ganglion → brainstem.
- Efferent limb: Vagus nerve (CN X) → bradycardia, other dysrhythmias
- Intraop Tx: Tell surgeon to remove stimulation; consider atropine and/or glycopyrrolate.

Carotid Body vs. Carotid Sinus:

- Peripheral chemoreceptors in carotid bodies and aortic body: cells respond to mostly to hypoxemia/O2 tension (Some sensitivity to hypercarbia [pH], but mostly hypoxemia driven) -> glossopharyngeal nerve (CN IX) & vagal nerve (CN X) → medulla → change in ventilatory drive.
  - Some sympathetic component, but largely considered a ventilatory response.
  - Carotid endarterectomy patients may be sensitive to respiratory depressant affects of opioids.
- Baroreceptors in walls of carotid sinus and aortic arch: hypertension, vagal maneuver, surgical stimulation, or carotid angioplasty/stent → carotid sinus baroreceptors → CN IX & CNX → medulla → decreased sympathetic tone and parasympathetic activation (bradycardia, decreased cardiac contractility, decreased vascular tone).
  - "Vagal maneuver" can be attempted to stimulate the carotid sinus for a patient in SVT.
  - Some surgeons infiltrate carotid sinus w/local during carotid endarterectomy to blunt reflex.

Bainbridge reflex: increased heart rate when right atrium/great veins stretched by volume.

Cushing reflex: increased ICP → ischemia at medullary vasomotor center → sympathetic activation → hypertension and increased myocardial contractility → reflex bradycardia

Corneal reflex: see diagram on previous slide. May be a component of neuroprognostication after cardiac arrest. Sedation can inhibit this reflex. Different cranial nerves than pupillary light reflex (which involves CN2&3).



Cote's A Practice of Anesthesia for Infants and Children, 6th Ed, Ch 34 // Miller 9th Ed Ch 14 // OpenAnesthesia: corneal reflex: anatomy (Caldwell S and Dabreo E) & carotid body: hypoxic drive // PMID's: 30664547, 31919808

# Perioperative Medicine

# Preoperative Medicine/Assessment

23X

**ACC/AHA Guidelines: Perioperative Cardiac Evaluation for Noncardiac Surgery and Revised Cardiac Risk Index (RCRI)[1]**

**Algorithm:**

| RCRI risk factors: *0-1 factors*: low risk of major adverse cardiac event (MACE); ≥ *2 factors*: elevated risk |
|---|
| High-risk surgery (intrathoracic, intra-abdominal, or suprainguinal vascular) |
| CAD (history of ischemic heart disease) |
| CHF |
| CVA or TIA history |
| Diabetes mellitus requiring insulin |
| Preop serum creatinine ≥ 2mg/dL |

**ACC/AHA Guidelines: Treatment Algorithm for Timing of Elective Noncardiac Surgery in Patients with Coronary Stents:[2]**

Obstructive Sleep Apnea (OSA) Dx (varies):[3] ≥ 5 events per hr (apneic, hypopneic, or respiratory-effort related arousals), each assoc w/O2 desat, & daytime symptoms (unless ≥ 15 events/hr).

STOP-BANG OSA risk factors:[4] Snoring, Tired, Observed apnea, blood Pressure (HTN), BMI>35, Age>50, Neck circumference>40cm, Gender = male.

**AHA/ACC Guidelines: Infective endocarditis (IE) preprocedure antibiotic prophylaxis:[5]**

"Prophylaxis against IE is reasonable before dental procedures that involve manipulation of gingival tissue, manipulation of the periapical region of teeth, or perforation of the oral mucosa in patients with the following:

1. Prosthetic cardiac valves, including transcatheter implanted prostheses and homografts.
2. Prosthetic material used for cardiac valve repair, such as annuloplasty rings and chords.
3. Previous IE.
4. Unrepaired cyanotic congenital heart disease or repaired congenital heart disease, with residual shunts or valvular regurgitation at the site of or adjacent to the site of a prosthetic patch or prosthetic device.
5. Cardiac transplant with valve regurgitation due to a structurally abnormal valve."

"There is no evidence for IE prophylaxis in gastrointestinal procedures or genitourinary procedures, absent known active infection."



1. Fleisher LA et al 2014 PMID 25085961 // 2. Fleisher LA et al 2016 PMID 27026020 // 3. Kapur et al 2017 PMID 28162150 // 4. Chung et al 2012 PMID 22401881 // 5. Nishimura et al 2017 PMID 28298458.

# Cardiac Implantable Electronic Devices

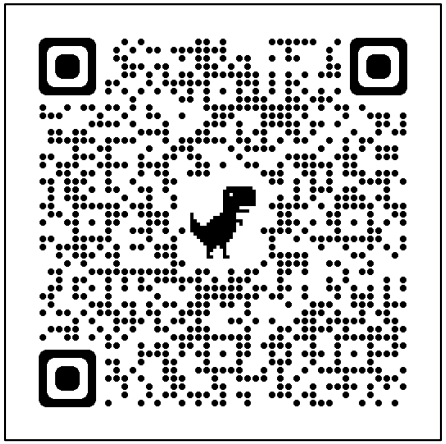
7X

Generic Pacemaker codes:*

| Position I (Paced Chamber) | Position II (Sensed Chamber) | Position III Response to Sensing | Position IV Programmability | Position V Multisite Pacing |
|---|---|---|---|---|
| A= Atrium<br>V= Ventricle<br>O = None<br>D=Dual (A&V) | A= Atrium<br>V= Ventricle<br>O = None<br>D=Dual (A&V) | I= Inhibited<br>T= Triggered<br>O=None<br>D=Dual (I&T) | R= Rate modulation<br>O=None | A= Atrium<br>V= Ventricle<br>O = None<br>D=Dual (A&V) |

- Common items to look for in interrogation report: (1) Interrogation date; (2) manufacturer; (3) type of device (e.g., pacemaker, ICD); (4) device settings; (5) pacemaker dependence // underlying rhythm; (6) battery life.
- Interrogation note timing: "For patients with a **pacemaker**, they should have an interrogation report within the last **12 months**; patients with an **ICD** or CRT should have a report within the previous **6 months**." (Miller 9th Ed, Ch 38 [citing ACCF/AHA/HRS guidelines]).
    - ASA 2020 Practice Advisory: consultants and ASA members agree that "a cardiac implantable electronic device should be interrogated within 3 to 6 months before a procedure."
- If the device is in close proximity to surgical field (e.g., some thoracic surgical procedures), the team may also consider whether a sterile magnet could be available for placement over the device as needed.

**Summary Recommendations form ASA Practice Advisory on Cardiac Implantable Electronic Device Management**



* Generic codes from the North American Society of Pacing and Electrophysiology (NASPE) and the British Pacing and Electrophysiology group (BPEG): References: Miller 9th Ed Ch 38 // ASA Practice Advisory for the Perioperative Management of Patients with Cardiac Implantable Electronic Devices.

# ASA Physical Status, NPO Guidelines, Monitoring Standards, Sedation Continuum

28X

**ASA Physical Status Classification System**

**ASA Standards for Basic Anesthesia Monitoring**

**ASA Continuum of Depth of Sedation**

**ASA Physical Status Examples were updated December 2020:**

- **Now with dedicated categories for pediatric and obstetric examples**

**Summary Recommendations from ASA Guidelines for preop fasting and use of pharmacological agents to reduce aspiration risk**

2020 BASIC Exam Gaps in Knowledge: *"The ASA Standards for Basic Anesthesia Monitoring require audible alarm alerts only for certain monitoring parameters."*

From ASA Standards:

- "When the **pulse oximeter** is utilized, the **variable pitch pulse tone and the low threshold alarm** shall be audible to the anesthesiologist or the anesthesia care team personnel."
- "When **capnography or capnometry** is utilized, the **end tidal CO2 alarm** shall be audible to the anesthesiologist or the anesthesia care team personnel."
- "When **ventilation is controlled by a mechanical ventilator**, there shall be in continuous use a **device that is capable of detecting disconnection of components of the breathing system**. The device must give an audible signal when its alarm threshold is exceeded."

URL for ongoing updates to ASA Guidelines, Statements and related documents: https://www.asahq.org/standards-and-guidelines

# Miscellaneous

# Homeopathic Meds and Herbals

- Echinacea (activates cell-mediated immunity): decreased effectiveness of immunosuppresants.
- Ephedra (increases HR/BP/sympathetics): tachycardia, hypertension (risk of MI, stroke); life-threatening interaction with MAO inhibitors.
- Garlic, Ginger, Ginkgo (inhibits platelet aggregation): increased bleeding
- Ginseng (inhibits platelet aggregation and can cause hypoglycemia): increased bleeding, altered mental status.
- Kava (anxiolytic): may change MAC requirements
- Saw Palmetto (inhibits cyclooxygenase): increased bleeding
- St John's Wort (inhibits neurotransmitter uptake): induces cytochrome P450 enzymes
- Valerian (sedative): may change MAC requirements

*"The use of ginseng and garlic as herbal supplements does not represent a contraindication to spinal anesthesia."* [2019 ITE Gaps in Knowledge]



Wang CZ, Yuan CS, Moss J. Anesthetic Implications of Complementary and Alternative Medications. In Miller's Anesthesia, 8th Ed

# High-Yield Formulas: M5 Board Review URL

**Public URL for M5 Board Review Equations (via Google search)**:

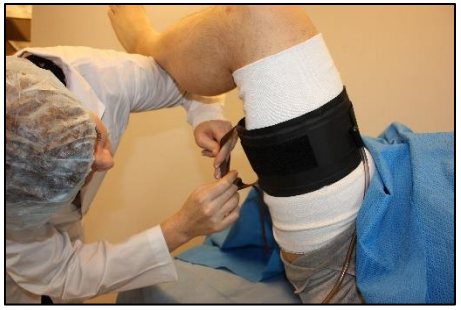
https://m5boardreview.com/wp-content/uploads/M5_equations.pdf

## Exceptionally High Yield:

1. Allowable blood loss; Estimated blood volume
2. Volume/Pressure Oxygen-availability from E-cylinder gas tank.
3. Poiseuille's law for IV flow rate.
4. Systemic vascular resistance and cardiac output formula.
5. Arterial content of oxygen including understanding of contribution from hemoglobin saturation and PaO2; Oxygen delivery
6. Alveolar gas equation.

# Tourniquet Management for Orthopedic Surgery (i.e. not Bier Blocks)

10X



- Tourniquet usually inflated 100mmHg over patient's systolic BP for thigh (50mmHg for the arm) for up to 2 hours.[1]

- Complications after deflation:[2]
  1. Bleeding
  2. Nerve injury/ischemia, especially after extended inflation (greater than 2 hours – deflating tourniquet for 30 minutes may reduce risk);
  3. Pain (may manifest as increased BP/heart rate; thought to be from firing of C-fibers)
  4. Hypotension (from release of acidic metabolites from ischemic limb).
  5. "Transient systemic metabolic acidosis, increased arterial CO2 levels, and decreased systolic BP can be expected with tourniquet deflation and are generally well tolerated in healthy patients."[1]

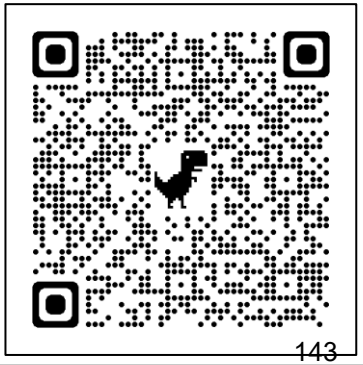
1. Barash 8th Ed, Ch 51. // 2. Miller's Basics of Anesthesia, 7th Ed, Ch 32 // Image: By Wikiwcetl - Own work, CC BY-SA 4.0, https://commons.wikimedia.org/w/index.php?curid=63113472

# MRI Safety

15X

- MRI Compatibility of supplies/implants: "Certain metals such as nickel and cobalt are dangerous because they are magnetic, whereas other metals such as aluminum, titanium, copper, and silver do not pose a missile danger." [Miller/Basics Ch 38]
- Thermal burns: Monitoring lines should not form a loop or cross. Tattoos/cosmetics are not contraindicated but may contain iron or other metals that can cause heat/burns/image artifact (consider cold compress). MRI pulse oximeters should not physically connect patient to monitoring equipment (to prevent "**Antenna effect**," where wires of certain lengths can interact with RF coil pulses to generate heat).
- MRI artifact to monitors: "The radiofrequency pulse from an MRI can cause a pressure transducer to generate artifactual spikes. This can lead to erroneously high arterial blood pressure readings that could mislead the anesthesia provider. Visual inspection of the waveform allows rapid detection of this artifact." [Miller/Basics Ch 38] Also, ECG interpretation may be limited. [ASA Pract Advis 2015]
- MRI and resuscitation: "Immediately remove patient from zone IV while initiating CPR, if indicated." [ASA Pract Advis 2015]
- Gadolinium and acute or severe renal insufficiency: can cause nephrogenic systemic fibrosis.
- Other: MRI generates high-level acoustic noise. A quench can both displace oxygen in Zone IV and generate high-pressure from escaping gases and trap those inside.

**MRI Zone Definitions and Summary Recommendations from ASA MRI Practice Advisory**



143

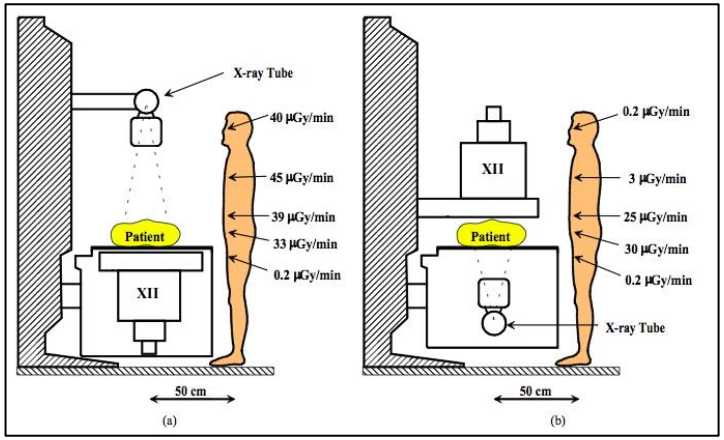
Image: Sung et al. Full-thickness burn on finger due to pulse oximetry during magnetic resonance imaging in a conscious patient. Arch Plas Surg 2016; 43: 612-3

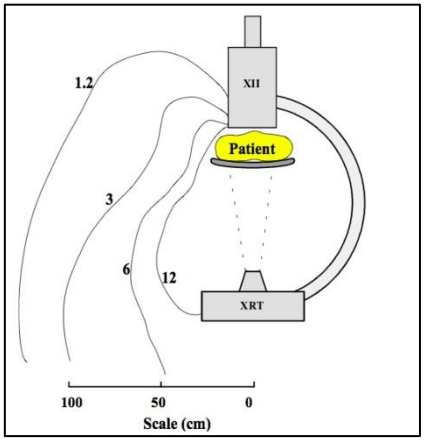
# Radiology/Radiation (cont'd)

14X

- Contrast-induced nephropathy: "increase in serum creatinine of 0.5 mg/dL or a 25% increase from the baseline within 48 to 72 hours after iodinated contrast medium administration." Risk factors: CRI (increases risk 20X), hx renal dz, prior renal surgery, proteinuria, DM, HTN, gout, nephrotoxic drugs (NSAIDS, aminoglycosides, diuretics). Prevention options: hydration, maintain urine output, sodium bicarb infusion.[1]
  - Metformin and Contrast Dye: contrast-induced nephropathy can lead to metformin retention and lactic acidosis. Evidence is mixed; may be more relevant in patients with pre-existing abnormal renal function.[2]
- Occupational eye injury from lasers or radiation: Hazards include direct exposure and reflected/scattered radiation. Occupational x-ray exposure to eye can cause cataracts. "[Laser] injuries include corneal and retinal burns, destruction of the macula or optic nerve, and cataract formation."[3]
  - "[C]lear plastic lenses block the far-infrared (10,600 nm) radiation from carbon dioxide lasers but provide no protection against the near-infrared (1064nm) radiation emitted by Nd:YAG lasers."[3]
  - "For KTP and argon lasers, all OR personnel require protective amber-colored eyeglasses"[4]
  - OSHA: "Opaque goggles are to be worn if in the direct x-ray field."[5] Different forms of lead glasses with side shields/goggles exist.

- Radiation exposure and distance: Radiation exposure is inversely proportional to the square of the distance from the source. "Six feet of air provides protection the equivalent of 9 inches of concrete or 2.5mm of lead."[3]




Left image: Occupational skin absorbed dose near fluoroscopic equipment without protective equipment (a) over-couch; (b) under-couch X-ray tube. Right image: Isodose curves (in microGy/min) for mobile C-arm.


1. Barash 8th Ed Ch 33. // 2. Iodinated contrast media chapter in Meyler's Side Effects of Drugs, 16th Ed // 3. Miller 9th Ed, Ch 88. // 4. Hagberg & Benumof's Airway Management 4th Ed Ch 39. // 5. OSHA: https://www.osha.gov/otm/section-6-health-care-facilities/chapter-1 // Left Image: By Kieranmaher - Own work, Public Domain, https://commons.wikimedia.org/wiki/File:OverUnderCouchDoses.jpg // Goggles: By Han-Kwang, CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=8424277 Right Image: By Kieranmaher - Own work, Public Domain, https://commons.wikimedia.org/wiki/File:CArmDoseProfiles.jpg //PMID: 21285864, 29729877

# Substance Abuse/ Anesthesiologist

12X

- Risk Factors for substance use disorder (SUD): "No study has clearly identified individual factors, and those often cited are not specific to the practice of anesthesiology. Risk factors for SUDs may be biologic, psychological, or occupational." [Miller 9th Ed, Ch 88]
- Signs/manifestations of SUD within anesthesia practice include [see also Miller 9th Ed, Ch 88 & Barash 8th Ed, Ch 3]: increasing quantities of narcotics dispensed, behavioral changes, recurrent documentation errors or sloppy charting, unexplained absences, being difficult to locate when on-call, unusual willingness for activities that could mask drug diversion while alone. Physical and other signs may include those of use or withdrawal (pinpoint pupils, tremors/diaphoresis, alcohol odor on breath, weight loss), long sleeves hiding needle marks, witnessed use, sudden death from use.
- Most common drugs misused by anesthesia personnel:
  - JAMA 2013 study on substance use disorder among anesthesiology residents, 1975-2009 (PMID: 24302092): "The most common substance category was intravenous opioids [fentanyl with highest frequency], followed by alcohol, marijuana or cocaine, anesthetics/hypnotics, and oral opioids."
  - Miller 9th Ed Ch 88: "The most common substance misused by anesthesia personnel has traditionally been opioids…Over the past several years there has been an increase in the abuse of other drugs, including propofol, ketamine, and remifentanil, as well as volatile anesthetics."
  - Barash 8th Ed Ch 3: "Initial reports indicated the popularity of meperidine, diazepam, and barbiturates, then synthetic opioids and inhalational agents, and more recently propofol."
- High Relapse rates among anesthesia providers: different studies cited in Miller 9th Ed, Ch 88 include: 16% , 25%, 29%, and 40.6%. "Relapse…highest in physicians who become addicted to potent narcotics early in their career."
- Death Rate: "…more than twice as high in anesthesiologists as internists." "The death rate for anesthesiologists with substance use disorders is 9% to 15%." [Mill 9thEd/Ch88]
- Treatment Lessons from Physician Health Programs [Miller 9th Ed, Ch 88]: (1) zero-tolerance policies; (2) individualized evaluation/treatment; (3) frequent random drug testing; (4) leverage medical boards, hospitals, and medical groups to deter relapse, (5) clear definition of "relapse" with meaningful consequences; (6) 12-step programs such as Alcoholics/Narcotics Anonymous.
- Naltrexone may reduce relapse.

# Statistics and Mathematics



**Excellent Review Article:**
Guller U, Delong E. Interpreting statistics in medical literature: a *vade mecum* for surgeons. J Am Coll Surg 2004; 198: 441-458. PMID 14992748.



Vade mecum: "a handbook or guide that is kept constantly at hand for consultation." - Oxford English Dictionary

# Types of Data: Interval Data

| Data Type | Examples |
|---|---|
| Continuous Interval (some refer to as “interval” or “continuous”) | Age, Temperature |
| Discrete Interval (limited to integer values only) | Parity, Number of first-start cases. |

- Continuous and discrete data are both examples of ***interval data*** (variables with equal distance between successive intervals).

- Common terms associated with continuous variables:
  - Mean: (sum of all observed values)/(number of observed values)
  - Median: middle value (or average of middle value and the one after it if even number of observations)
  - Mode: most frequently occurring value
  - Standard deviation (SD): refers to a formula that measures the variability/scatter of the distribution of the data. **SD can still be high with large sample size** if the data is highly scattered.
  - Standard error of the mean (SEM): approximated by (SD)/√n , where n represents the sample size. **SEM gets smaller with increasing sample size** and gives a more precise estimate of the population mean you are sampling from.



Rosner B. Fundamentals of Biostatistics, 8th Ed, pg 167-70. // Guller U et al. J Am Coll Surg 2004; 198: 441-58.

# The Normal Distribution

The normal distribution for a random continuous variable refers to a mathematical formula where the distribution of the variable follows a symmetric bell-shaped curve around an average μ ("mu") with changes in slope around a standard deviation σ ("sigma").

In a normal distribution, the mean, median, and mode are equal.

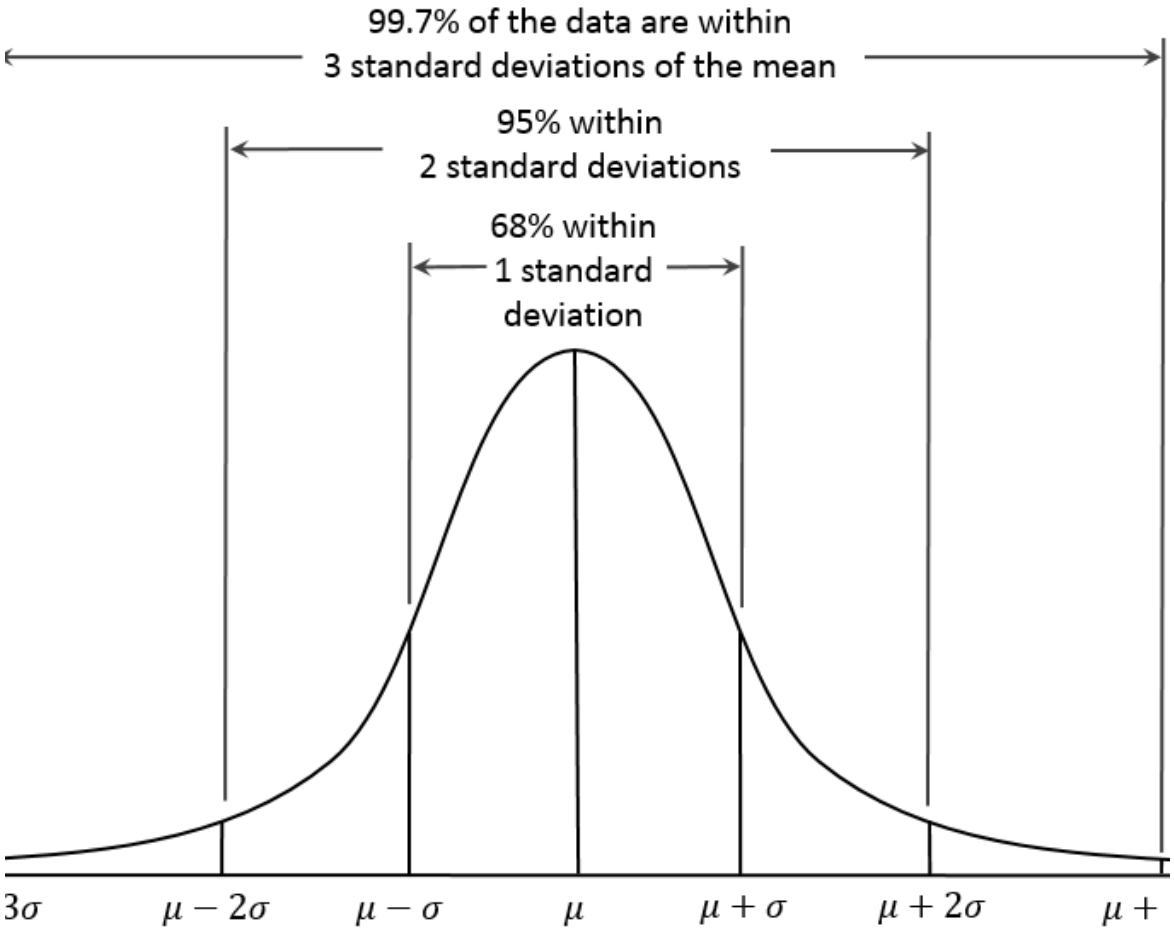



Figure: Empirical rule based on the normal distribution, by Dan Kernler. https://commons.wikimedia.org/wiki/File:Empirical_Rule.PNG. Creative Commons CC BY-SA 4.0 License. April 28, 2020. Rosner B. Fundamentals of Biostatistics, 8th Ed, pg 171-173.

# Why is the Normal Distribution Important in Statistics?

- Continuous variables that are ***normally distributed*** can be tested with popular parametric statistical tests.
- ***Parametric Statistical Tests*** require the variable being tested to be assumed to follow a known distribution with known *parameters*.
  - For example: a continuous variable with a mean and standard deviation that follows a normal distribution.
- ***Nonparametric Statistical Tests*** don't require these assumptions and usually involve ranking/ordering the observations and making comparisons. They may have less statistical power.

**Popular Parametric Statistical Tests for Normally Distributed Continuous Variables**

**T-test & its variations**

- Paired t-test
- Unpaired t-test
  - Equal variances unpaired t-test
  - Unpaired t-test for unequal variances

**Analysis of Variance (ANOVA) & its variations**

- One-way ANOVA
  - Comparison of more than two means against one outcome variable of primary interest.
- One-way Analysis of Covariance (ANCOVA)
  - One-way ANOVA while controlling for confounders/covariates.
- Two-way ANOVA/ANCOVA
- Multivariate analysis of variance (MANOVA)

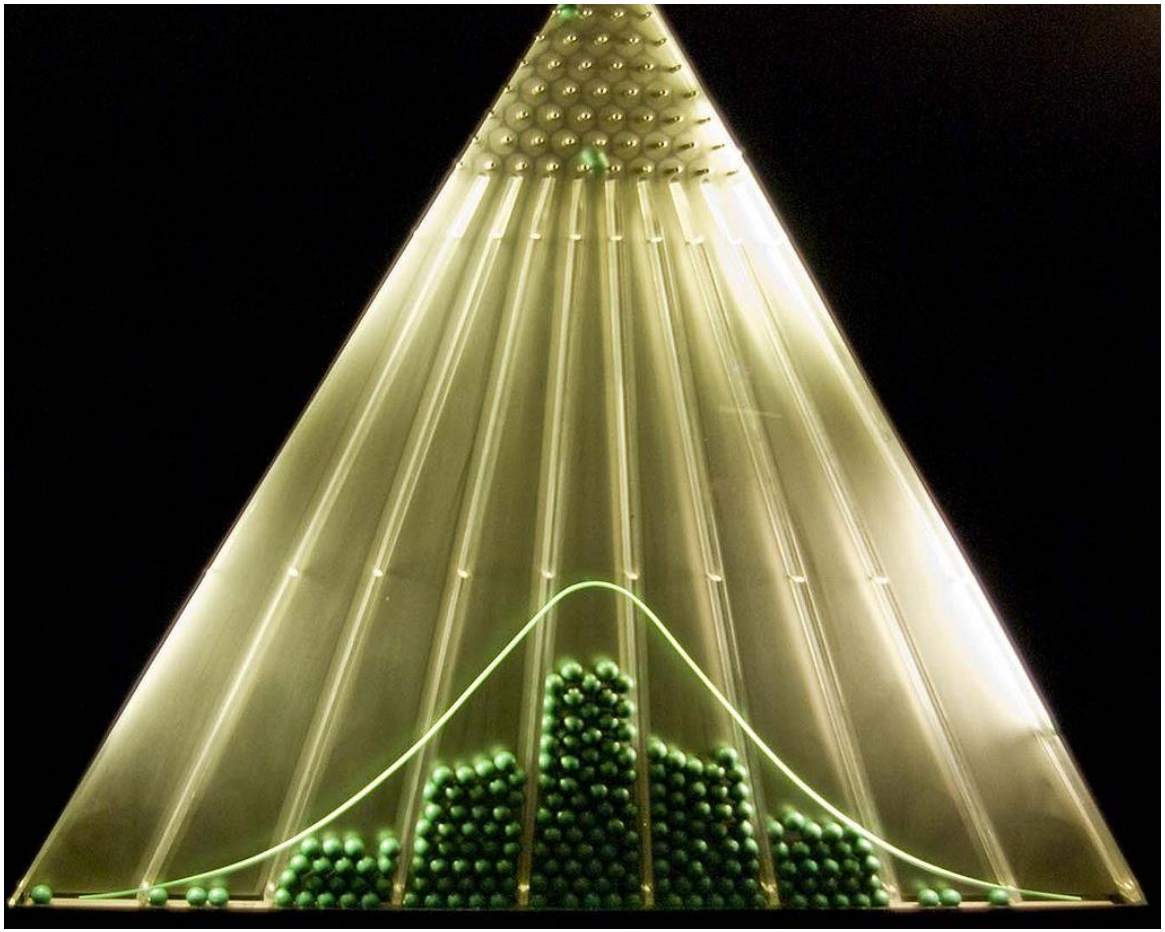


Rosner B. Fundamentals of Biostatistics, 8th Ed, pg 119, 338, 364.

# The Central Limit Theorem

According to the **central limit theorem**, a continuous variable with any random distribution approaches a normal distribution if the sample size is sufficiently large.

In this image, a binomial distribution (at each peg, the ball can drop to the left or right) approaches a normal distribution with a large enough sample size.



Top: Galton Box (demonstrates normal distribution) by Antoine Taveneaux. Creative Commons CC BY-SA 3.0 License. April 28, 2020. https://commons.wikimedia.org/wiki/File:Planche_de_Galton.jpg. April 28, 2020. // Rosner B. Fundamentals of Biostatistics, 8th Ed, pg 119.

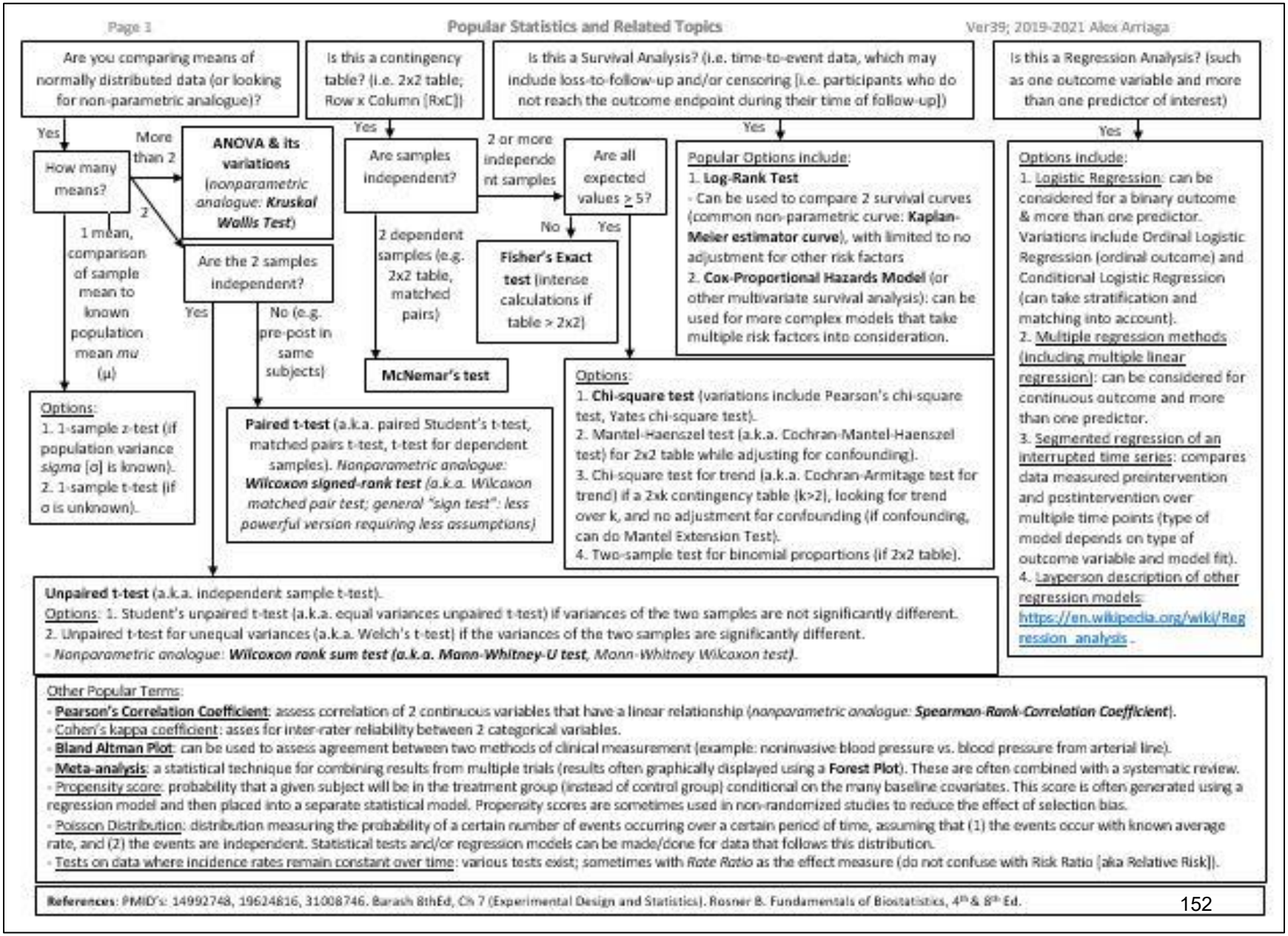
# Types of Data: Binary and Categorical Data

| Data Type | Examples |
|---|---|
| Binary | Dead/Alive; Pregnant/Not-Pregnant; Chip falling to the left or right on a Plinko board |
| Categorical | |
| --- Ordinal Categorical | ASA-1, ASA-1E, ASA-2, ASA-2E, ASA-3, ASA-3E, ASA-4, ASA-4E |
| --- Nominal Categorical | Red, Blue, Green, Purple, Yellow |

- Many statistical tests comparing binary or categorical variables to each other can be expressed using **contingency tables** placed in a Row x Column [RxC] format (such as a 2x2 table).
- Table to the right bottom: Example of contingency table with unpaired data (i.e., those getting antibiotics are different patients from those not getting it; the sample of patients who received pre-incision antibiotics are independent of patients who did not receive pre-incision antibiotics ).

| | | Postoperative Surgical Site Infection | |
|---|---|---|---|
| | | Yes | No |
| Pre-incision antibiotics | Yes | a | b |
| | No | c | d |

# High-Yield Mathematics/Statistics Handout (1 of 4)



# High-Yield Mathematics/Statistics Handout (2 of 4)



**Selected Example Studies of Popular Statistical Tests:**

| Statistical Test | Reference & Title of Example Study | Summary Relevant to the Statistical Test |
|---|---|---|
| 1-sample t-test | Agarwal et al. A longitudinal survey of adult spine and peripheral nerve case entries during neurosurgery residency training. J Neurosurg Spine 2018; 29: 442-7. | Analysis of ACGME case logs for national sample of graduating neurosurgical residents (n=877) compared to ACGME minimum requirements (which was taken as a proxy for the population mean). Among other results, the authors found a national average of 125.7 lumbar discectomies compared to the ACGME required minimum of 25 (one-sample t-test p<0.0001). |
| Unpaired t-test | Min et al. Randomized trial comparing early and late administration of rocuronium before and after checking mask ventilation in patients with normal airways. Anes Analg 2019; 129: 380-6. | Randomized trial of 114 patients with normal airways receiving IV rocuronium either before ("early"; n=58) or after ("late"; n=56) checking mask ventilation. The average mask expiratory tidal volume after apnea was larger in the early (552mL) rocuronium group than the late (393mL) group: "mean difference, 160mL/breath; 95% CI, 98-221 mL/breath; p<0.001, unpaired t test." |
| One-way ANOVA | Christiansen et al. Volume of ropivacaine 0.2% and common peroneal nerve block duration: a randomized, double-blind cohort trial in healthy volunteers. Anaesthesia 2018; 73: 1361-1367. | Randomized trial of 60 volunteers allocated to receive one of five volumes of ropivacaine 0.2% (2.5, 5, 10, 15, or 20mL) for ultrasound-guided block of the common peroneal nerve. Differences of mean duration of sensory block (in hours) between the five groups were assessed via the one-way ANOVA test. Mean sensory block durations were 9.2h (2.5mL), 12.5h (5mL), 15.5h (10mL), 17.3h (15mL), and 17.3h (20mL); one-way ANOVA p<0.0001. |
| Fisher's Exact Test | Ferschl et al. A comparison of spinal anesthesia versus monitored anesthesia care with local anesthesia in minimally invasive fetal surgery. Anesth Analg 2020; 130: 409-15. | Retrospective observational study of anesthetic characteristics of 136 pregnant patients undergoing minimally invasive fetal surgery under spinal anesthesia (n=56) or monitored anesthesia care (n=80) over 6 years (2011-2016). One of the findings: the authors observed that remifentanil was given in 0/56 spinal anesthesia patients and 5/80 monitored anesthesia care patients (Fisher's Exact test p=0.08). |
| McNemar's Test | Ramsingh et al. Auscultation versus point-of-care ultrasound to determine endotracheal versus bronchial intubation: A diagnostic accuracy study. Anesthesiology 2016; 124: 1012-20. | Randomized study of 42 patients allocated to have their ETT intentionally placed via fiberoptic guidance into one of the mainstem bronchi or trachea. A blinded anesthesiologist assessed location of the ETT by auscultation. Each assessment was matched to a second blinded anesthesiologist who assessed the ETT location of the same patient via an ultrasound exam of the pulmonary tree and lung expansion. The four matched combinations were as follows: (1) Auscultation correct and ultrasound correct: 26/42; (2) Auscultation correct and ultrasound incorrect: 0/42; (3) Ultrasound correct and auscultation incorrect: 14/42; (4) Ultrasound incorrect and auscultation incorrect: 2/42. McNemar's test p<0.0001. |
| Conditional Logistic Regression | Clifford et al. Risk factors and clinical outcomes associated with perioperative transfusion-associated circulatory overload. Anesthesiology 2017; 126: 409-18. | Case-control study of 163 adults undergoing noncardiac surgery who developed perioperative transfusion-associated circulatory overload (matched to 726 transfused controls who did not develop respiratory complications). A conditional logistic regression multivariable model revealed the following predictors of the binary outcome of transfusion-associated circulatory overload: emergency surgery (p<0.001), chronic kidney disease (p=0.007), left ventricular dysfunction (p=0.028), previous beta-adrenergic receptor antagonist use (p=0.027), blood product type (p=0.011), and increasing intraoperative fluid administration (p<0.001). |
| Kaplan Meier estimator curve and Log-rank test. | Sharpe et al. Intrathecal morphine versus intrathecal hydromorphone for analgesia after cesarean delivery: A randomized trial. Anesthesiology 2020; epub ahead of print. | Randomized trial of 138 parturients undergoing scheduled cesarean delivery allocated to receive intrathecal morphine (150 micrograms) or intrathecal hydromorphone (75 micrograms) as part of a spinal anesthetic. Median time to first request for postoperative opioid was displayed using a Kaplan Meier estimator curve with data censored at 24 hours for patients who did not request opioids by 24 hours postop. The median time to first opioid request was 5.4 hours for hydromorphone and 12.1 hours for morphine (log-rank test p=0.2). |

# High-Yield Mathematics/Statistics Handout (3 of 4)



**Odds Ratio, Risk Ratio, Absolute Risk Reduction, Number Needed to Treat:**

**Reference Terms:** Risk: "the probability that an event will occur within a stated period of time."[1] Some refer to this probability using the letter "p." Odds = a numerical expression of relative probabilities. Formula: p/1-p, or risk/(1-risk). Example: for **10:1** odds, p=**10**/11, and 1-p= **1**/11.

Classic 2 x 2 table:

| | | Outcome: Yes | Outcome: No |
|---|---|---|---|
| **Exposed** | Yes | a | b |
| | No | c | d |

Note that a,b,c, and d are arranged as if you were reading left → right, then up → down.

- Risk of the exposed group experiencing the outcome: a/(a+b). Risk of the unexposed group experiencing the outcome: c/(c+d)
- **Risk Ratio (i.e. relative risk)** = [a/(a+b)]/[c/(c+d)]. Reporting a risk ratio in words: The risk of developing the outcome for exposed subjects is XX times that of unexposed subjects.
- Absolute risk reduction (ARR): [a/(a+b)] – [c/(c+d)]. In words: ARR: proportion of patients who didn't have the outcome due to lack of exposure.
- Number needed to treat: 1/(ARR). In words: Number of subjects who need to be treated (or have the exposure removed) in order to prevent one case from occurring.
- **Odds ratio**: [(a/b)]/[(c/d)]. This formula can be derived by taking the ratio of odds in the exposed versus unexposed, where odds = risk/(1-risk). In words: The odds of the outcome in the exposed group are XX times that of the unexposed group.
- **Note**: Odds ratio is approximately the same as the risk ratio for a rare outcome (i.e. if risk is very low, the term "1-risk" approaches zero). Conversely, the odds ratio can substantially differ from the risk ratio when the outcome is common.[1,2]

**Type I Error, Type II Error, Power, and Sample Size:**

| | | Reality/Truth: No difference exists | Reality/Truth: A true difference exists |
|---|---|---|---|
| **Study Finding** | Statistically significant result (null hypothesis rejected) | Type I error (a.k.a. alpha error) | Correct |
| | No statistically significant difference found (null hypothesis not rejected) | Correct | Type II error (a.k.a. beta error) |

- **p-value**: "the alpha level at which we would be indifferent between accepting or rejecting the null hypothesis."[3] For an alpha level of 0.05, a p-value less than 0.05 would be considered statistically significant. There would be a 5% chance of an alpha error.
- **One-tailed vs. two-tailed p-value**: Assuming the null hypothesis is true (with the p-value set as the threshold to reject the null hypothesis): Two-tailed (or two-sided) p value: "the probability that the difference between two treatments…is as large or larger than observed, with either treatment being superior to the other. One-tailed p value: "the probability that the difference observed would have occurred by chance alone, with one treatment being superior to the other as specified in the alternative hypothesis."[2]
- **Confidence interval**: An XX% confidence interval (95% being common) "represents a range of values that will include the true population parameter in [XX%] of all cases."[2] The p=0.05 threshold is an arbitrary convention,[4] and there has been a growing movement to reduce the number of p-values reported in a manuscript and replace this with 95% confidence intervals.[5]

- **Power** = 1 – (beta error) = the probability of a statistically significant difference being detected, based on a sample size *n*, if a true difference exists.[3,6]
  - Alternatives that may increase power, for a given alpha level, if you are unable to increase sample size: (1) Use continuous instead of binary endpoints; (2) Use a paired data analysis instead of an unpaired one; (3) use a more common outcome or composite outcome (example: "death or major complication" as the outcome instead of just "death."[6]

**References**: 1. Montreuil et al. PMID: 16248140. 2. Guller et al. PMID: 14992748. 3. Rosner B. Fundamentals of Biostatistics, 8th Ed. 4. Ridgway et al. PMID: 19476801. 5. Harrington et al. PMID: 31314974. 6. Guller et al. PMID: 15834629.

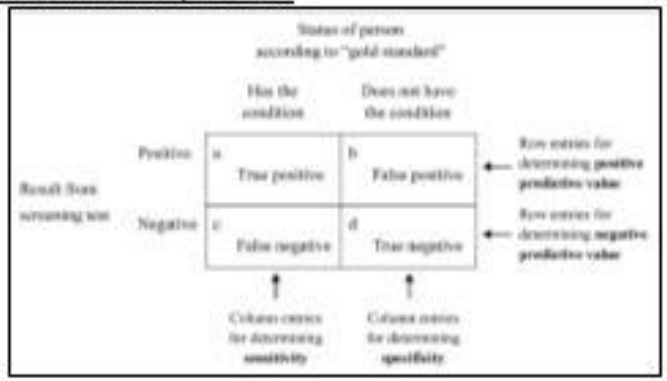
- Other basic statistical terms: Mean: (sum of all observed values)/(number of observed values). Median: middle value (or average of middle value and the one after it if even number of observations). Mode: most frequently occurring value. Standard Deviation (SD) vs. Standard Error of the Mean (SEM): "The SD is a measure of the variability (scatter) of a data distribution. It is a measure of the degree to which the individual values deviate from the population mean….Regardless of sample size, the SD will be large if the data are highly scattered. The SEM reflects the variability in the distribution of sample means from the population mean….Contrary to the SD, the SEM is an inferential statistic strongly dependent on sample size. The larger the sample size, the smaller the SEM, and the more precisely the sample mean estimates the overall population mean….The SEM can be obtained by dividing the SD by the square root of the number of patients in the sample (SEM= SD/√n)." [Guller U et al. J Am Coll Surg 2004; 198: 441-458]

# High-Yield Mathematics/Statistics Handout (4 of 4)



**Diagnostic Testing and Screening Tests: Sensitivity, Specificity, Positive Predictive Value, Negative Predictive Value, Prevalence:**

- "Gold standard": definitive indicator of person having (or not having) the target condition (ref: Trevethan). Some instead say **Reference Standard** given the potential imperfection of a "gold standard." Sensitivity and specificity assess the screening test against the reference standard.
- Sensitivity (i.e. of the people who have the condition, what proportion test positive on the screening test?): [a/(a+c)]
  - A highly sensitive test is capturing the vast majority of people who have the condition and has a low proportion of false negatives. If you test negative with a highly sensitive test, it is unlikely you have the condition. Hence, a highly SENSITIVE test (assuming that specificity is not overly low) is good to RULE OUT a disease (mnemonic "SNOUT").
- Specificity (i.e. of the people who do not have the condition, what proportion test negative on the screening test?): [d/(b+d)]
  - A highly specific test is capturing the vast majority of people who DO NOT have the condition and has a low proportion of false positives. If you test positive with a highly specific test, it is likely you have the disease. Hence, a highly SPECIFIC test (assuming sensitivity is not overly low) is good to RULE IN a disease ("SPIN").
- Positive Predictive Value (PPV): [a/(a+b)] • Negative Predictive Value (NPV): [d/(c+d)]
  - PPV and NPV assess whether the actual patient being tested is predicted to have the disease. In order to use the PPV and NPV formulas for a 2x2 table, the prevalence of disease for your patient (in terms of medical history and risk factors) has to be representative of the prevalence of disease in the 2x2 table. This is referred to as determining your patient's *pre-test probability*. PPV and NPV are metrics of *post-test probability*. **As prevalence increases, PPV increases and NPV decreases (and vice versa).**
- Likelihood ratio positive (LR+) = sensitivity/(1-specificity). Likelihood ratio negative (LR-) = (1-sensitivity)/specificity.
  - If you know a patient's pre-test probability (by looking at the prevalence of the condition in patients with risk factors similar to your patient) and the likelihood ratio, there are nomograms to mathematically convert this into the patient's post-test probability.




Trevethan R. Sensitivity, Specificity, and Predictive Values: Foundations, Pliabilities, and Pitfalls in Research and Practice. Front Public Health 2017; 20: S: 307. Open Access article; Figure 1 used via Creative Commons License CC BY 4.0: https://creativecommons.org/licenses/by/4.0/. Other references: Tenny S, Hoffman MR. Prevalence. StatPearls/NCBI Bookshelf; https://www.ncbi.nlm.nih.gov/books/NBK430867/. Hunick M et al. Decision making in health and medicine: Integrating evidence and values. Cambridge University Press, 2009.

**Other Basic Math and Statistical Terms:**

- Logarithms: $\log_x Y=z \rightarrow x^z=Y$ (in words: "log base x of Y equals z"). Example: $\log_2 16=x \rightarrow 2^x=16 \rightarrow x=4$. Second example: log 1,000 = $\log_{10}1{,}000=3$ (note: there are 3 zeros in 1,000; when the base number is not provided, it is implied to be 10). Third example: $\log_x 1=? \rightarrow \log_x 1=0$ (any base number x raised to the 0 power will equal 1). Fourth example: ln 1 = $\log_e 1$. $\log_e 1=? \rightarrow e^x=1 \rightarrow x=0 \rightarrow$ ln 1 = 0. Khan Academy intro video on logarithms: "Intro to logarithms": https://youtu.be/ZSmyI8dg_rM. Additional popular intro video on logarithms: "Logarithms...How?": https://youtu.be/ZwSt6BTQYRU.
  - Henderson-Hasselbalch equation: pH = 6.1 + log[ ($HCO_3^-$)/($PCO_2$ x 0.03) ]. $HCO_3^-$: plasma bicarbonate (mmol/L); PCO2: partial pressure $CO_2$ (mmHg). [Miller 9thEd/Ch48] If $PCO_2$=66 and $HCO_3^-$=20, pH = 6.1 + log [20/(66 x 0.03)] = 6.1 + log [20/2] = 6.1 + log [10] = 6.1 + 1 = 7.1.
- Graph of simple equations and Common Biologic Curves: Khan Academy video linear, quadratic, and exponential models: https://youtu.be/CxEFOozrMSE. Other common curves: Sigmoidal (the sigmoidal curve of the oxygen-hemoglobin dissociation curve has a section that appears exponential, and another section that appears linear), and Quadratic.

# Popular Statistics and Related Topics



Are you comparing means of normally distributed data (or looking for non-parametric analogue)?

Yes

How many means?

More than 2

**ANOVA & its variations** (*nonparametric analogue: **Kruskal Wallis Test***)

2

Are the 2 samples independent?

Yes

**Paired t-test** (a.k.a. paired Student's t-test, matched pairs t-test, t-test for dependent samples). *Nonparametric analogue: **Wilcoxon signed-rank test** (a.k.a. Wilcoxon matched pair test; general "sign test": less powerful version requiring less assumptions)*

No (e.g. pre-post in same subjects)

**Unpaired t-test** (a.k.a. independent sample t-test).
Options: 1. Student's unpaired t-test (a.k.a. equal variances unpaired t-test) if variances of the two samples are not significantly different.
2. Unpaired t-test for unequal variances (a.k.a. Welch's t-test) if the variances of the two samples are significantly different.
- *Nonparametric analogue: **Wilcoxon rank sum test (a.k.a. Mann-Whitney-U test**, Mann-Whitney Wilcoxon test**)**.*

1 mean, comparison of sample mean to known population mean *mu* (μ)

Options:
1. 1-sample z-test (if population variance *sigma* [σ] is known).
2. 1-sample t-test (if σ is unknown).

Is this a contingency table? (i.e. 2x2 table; Row x Column [RxC])

Yes

Are samples independent?

2 dependent samples (e.g. 2x2 table, matched pairs)

**McNemar's test**

2 or more independent samples

Are all expected values ≥ 5?

No

**Fisher's Exact test** (intense calculations if table > 2x2)

Yes

Options:
1. **Chi-square test** (variations include Pearson's chi-square test, Yates chi-square test).
2. Mantel-Haenszel test (a.k.a. Cochran-Mantel-Haenszel test) for 2x2 table while adjusting for confounding).
3. Chi-square test for trend (a.k.a. Cochran-Armitage test for trend) if a 2xk contingency table (k>2), looking for trend over k, and no adjustment for confounding (if confounding, can do Mantel Extension Test).
4. Two-sample test for binomial proportions (if 2x2 table).

Is this a Survival Analysis? (i.e. time-to-event data, which may include loss-to-follow-up and/or censoring [i.e. participants who do not reach the outcome endpoint during their time of follow-up])

Yes

Popular Options include:
1. **Log-Rank Test**
- Can be used to compare 2 survival curves (common non-parametric curve: **Kaplan-Meier estimator curve**), with limited to no adjustment for other risk factors
2. **Cox-Proportional Hazards Model** (or other multivariate survival analysis): can be used for more complex models that take multiple risk factors into consideration.

Is this a Regression Analysis? (such as one outcome variable and more than one predictor of interest)

Yes

Options include:
1. Logistic Regression: can be considered for a binary outcome & more than one predictor. Variations include Ordinal Logistic Regression (ordinal outcome) and Conditional Logistic Regression (can take stratification and matching into account).
2. Multiple regression methods (including multiple linear regression): can be considered for continuous outcome and more than one predictor.
3. Segmented regression of an interrupted time series: compares data measured preintervention and postintervention over multiple time points (type of model depends on type of outcome variable and model fit).
4. Layperson description of other regression models: https://en.wikipedia.org/wiki/Regression_analysis .

Other Popular Terms:
- **Pearson's Correlation Coefficient**: assess correlation of 2 continuous variables that have a linear relationship (*nonparametric analogue: **Spearman-Rank-Correlation Coefficient***).
- Cohen's kappa coefficient: asses for inter-rater reliability between 2 categorical variables.
- **Bland Altman Plot**: can be used to assess agreement between two methods of clinical measurement (example: noninvasive blood pressure vs. blood pressure from arterial line).
- **Meta-analysis**: a statistical technique for combining results from multiple trials (results often graphically displayed using a **Forest Plot**). These are often combined with a systematic review.
- Propensity score: probability that a given subject will be in the treatment group (instead of control group) conditional on the many baseline covariates. This score is often generated using a regression model and then placed into a separate statistical model. Propensity scores are sometimes used in non-randomized studies to reduce the effect of selection bias.
- Poisson Distribution: distribution measuring the probability of a certain number of events occurring over a certain period of time, assuming that (1) the events occur with known average rate, and (2) the events are independent. Statistical tests and/or regression models can be made/done for data that follows this distribution.
- Tests on data where incidence rates remain constant over time: various tests exist; sometimes with *Rate Ratio* as the effect measure (do not confuse with Risk Ratio [aka Relative Risk]).

**References**: PMID's: 14992748, 19624816, 31008746. Barash 8thEd, Ch 7 (Experimental Design and Statistics). Rosner B. Fundamentals of Biostatistics, 4th & 8th Ed.

**Selected Example Studies of Popular Statistical Tests:**

| Statistical Test | Reference & Title of Example Study | Summary Relevant to the Statistical Test |
|---|---|---|
| 1-sample t-test | Agarwal et al. A longitudinal survey of adult spine and peripheral nerve case entries during neurosurgery residency training. J Neurosurg Spine 2018; 29: 442-7. | Analysis of ACGME case logs for national sample of graduating neurosurgical residents (n=877) compared to ACGME minimum requirements (which was taken as a proxy for the population mean). Among other results, the authors found a national average of 125.7 lumbar discectomies compared to the ACGME required minimum of 25 (one-sample t-test p<0.0001). |
| Unpaired t-test | Min et al. Randomized trial comparing early and late administration of rocuronium before and after checking mask ventilation in patients with normal airways. Anes Analg 2019; 129: 380-6. | Randomized trial of 114 patients with normal airways receiving IV rocuronium either before ("early"; n=58) or after ("late"; n=56) checking mask ventilation. The average mask expiratory tidal volume after apnea was larger in the early (552mL) rocuronium group than the late (393mL) group: "mean difference, 160mL/breath; 95% CI, 98-221 mL/breath; p<0.001, unpaired t test." |
| Analysis of Variance (ANOVA) | Christiansen et al. Volume of ropivacaine 0.2% and common peroneal nerve block duration: a randomized, double-blind cohort trial in healthy volunteers. Anaesthesia 2018; 73: 1361-1367. | Randomized trial of 60 volunteers allocated to receive one of five volumes of ropivacaine 0.2% (2.5, 5, 10, 15, or 20mL) for ultrasound-guided block of the common peroneal nerve. Differences of mean duration of sensory block (in hours) between the five groups were assessed via the one-way ANOVA test. Mean sensory block durations were 9.2h (2.5mL), 12.5h (5mL), 15.5h (10mL), 17.3h (15mL), and 17.3h (20mL); one-way ANOVA p<0.0001. |
| Fisher's Exact Test | Ferschl et al. A comparison of spinal anesthesia versus monitored anesthesia care with local anesthesia in minimally invasive fetal surgery. Anesth Analg 2020; 130: 409-15. | Retrospective observational study of anesthetic characteristics of 136 pregnant patients undergoing minimally invasive fetal surgery under spinal anesthesia (n=56) or monitored anesthesia care (n=80) over 6 years (2011-2016). One of the findings: the authors observed that remifentanil was given in 0/56 spinal anesthesia patients and 5/80 monitored anesthesia care patients (Fisher's Exact test p=0.08). |
| McNemar's Test | Ramsingh et al. Auscultation versus point-of-care ultrasound to determine endotracheal versus bronchial intubation: A diagnostic accuracy study. Anesthesiology 2016; 124: 1012-20. | Randomized study of 42 patients allocated to have their ETT intentionally placed via fiberoptic guidance into one of the mainstem bronchi or trachea. A blinded anesthesiologist assessed location of the ETT by auscultation. Each assessment was matched to a second blinded anesthesiologist who assessed the ETT location of the same patient via an ultrasound exam of the pulmonary tree and lung expansion. The four matched combinations were as follows: (1) Auscultation correct and ultrasound correct: 26/42; (2) Auscultation correct and ultrasound incorrect: 0/42; (3) Ultrasound correct and auscultation incorrect: 14/42; (4) Ultrasound incorrect and auscultation incorrect: 2/42. McNemar's test p<0.0001. |
| Conditional Logistic Regression | Clifford et al. Risk factors and clinical outcomes associated with perioperative transfusion-associated circulatory overload. Anesthesiology 2017; 126: 409-18. | Case-control study of 163 adults undergoing noncardiac surgery who developed perioperative transfusion-associated circulatory overload (matched to 726 transfused controls who did not develop respiratory complications). A conditional logistic regression multivariable model revealed the following predictors of the binary outcome of transfusion-associated circulatory overload: emergency surgery (p<0.001), chronic kidney disease (p=0.007), left ventricular dysfunction (p=0.028), previous beta-adrenergic receptor antagonist use (p=0.027), blood product type (p=0.011), and increasing intraoperative fluid administration (p<0.001). |
| Survival Analysis: Kaplan Meier estimator curve and Log-rank test. | Sharpe et al. Intrathecal morphine versus intrathecal hydromorphone for analgesia after cesarean delivery: A randomized trial. Anesthesiology 2020; 132: 1382-1391. | Randomized trial of 138 parturients undergoing scheduled cesarean delivery allocated to receive intrathecal morphine (150 micrograms) or intrathecal hydromorphone (75 micrograms) as part of a spinal anesthetic. Median time to first request for postoperative opioid was displayed using a Kaplan Meier estimator curve with data censored at 24 hours for patients who did not request opioids by 24 hours postop. The median time to first opioid request was 5.4 hours for hydromorphone and 12.1 hours for morphine (log-rank test p=0.2). |

**Odds Ratio, Risk Ratio, Absolute Risk Reduction, Number Needed to Treat**:

**Reference Terms:** Risk: "the probability that an event will occur within a stated period of time."[1] Some refer to this probability using the letter "p." Odds = a numerical expression of relative probabilities. Formula: p/1-p, or risk/(1-risk). Example: for **10:1** odds, p=**10**/11, and 1-p= **1**/11.

Classic 2 x 2 table:

| | | **Outcome** | |
|---|---|---|---|
| | | Yes | No |
| **Exposed** | Yes | a | b |
| | No | c | d |

Note that a,b,c, and d are arranged as if you were reading left → right, then up → down.

• Risk of the exposed group experiencing the outcome: a/(a+b). Risk of the unexposed group experiencing the outcome: c/(c+d)

• **Risk Ratio (i.e. relative risk)** = [a/(a+b)]/[c/(c+d)]. Reporting a risk ratio in words: The risk of developing the outcome for exposed subjects is XX times that of unexposed subjects.

• Absolute risk reduction (ARR): [a/(a+b)] – [c/(c+d)]. In words: ARR: proportion of patients who didn't have the outcome due to lack of exposure.

• Number needed to treat: 1/(ARR). In words: Number of subjects who need to be treated (or have the exposure removed) in order to prevent one case from occurring.

• **Odds ratio**: [(a/b)]/[(c/d)]. This formula can be derived by taking the ratio of odds in the exposed versus unexposed, where odds = risk/(1-risk). In words: The odds of the outcome in the exposed group are XX times that of the unexposed group.

• **Note**: Odds ratio is approximately the same as the risk ratio for a rare outcome (i.e. if risk is very low, the term "1-risk" approaches zero). Conversely, the odds ratio can substantially differ from the risk ratio when the outcome is common.[1,2]

**Type I Error, Type II Error, Power, and Sample Size:**

| | | **Reality/Truth** | |
|---|---|---|---|
| | | No difference exists | A true difference exists |
| **Study Finding** | Statistically significant result (null hypothesis rejected) | Type I error (a.k.a. alpha error) | Correct |
| | No statistically significant difference found (null hypothesis not rejected) | Correct | Type II error (a.k.a. beta error) |

• **p-value**: "the alpha level at which we would be indifferent between accepting or rejecting the null hypothesis."[3] For an alpha level of 0.05, a p-value less than 0.05 would be considered statistically significant. There would be a 5% chance of an alpha error.

• **One-tailed vs. two-tailed p-value**: Assuming the null hypothesis is true (with the p-value set as the threshold to reject the null hypothesis): Two-tailed (or two-sided) p value: "the probability that the difference between two treatments…is as large or larger than observed, with either treatment being superior to the other. One-tailed p value: "the probability that the difference observed would have occurred by chance alone, with one treatment being superior to the other as specified in the alternative hypothesis."[2]

• **Confidence interval**: An XX% confidence interval (95% being common) "represents a range of values that will include the true population parameter in [XX%] of all cases."[2] The p=0.05 threshold is an arbitrary convention,[4] and there has been a growing movement to reduce the number of p-values reported in a manuscript and replace this with 95% confidence intervals.[5]

• **Power** = 1 – (beta error) = the probability of a statistically significant difference being detected, based on a sample size *n*, if a true difference exists.[3,4]

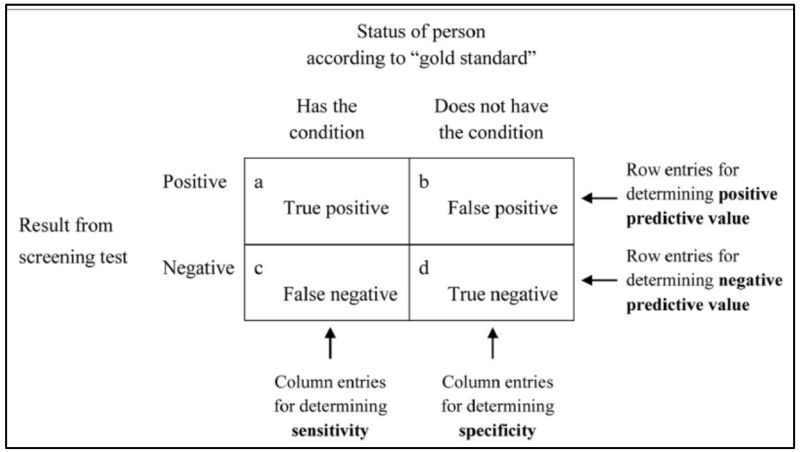
- Alternatives that may increase power, for a given alpha level, if you are unable to increase sample size: (1) Use continuous instead of binary endpoints; (2) Use a paired data analysis instead of an unpaired one; (3) use a more common outcome or composite outcome (example: "death or major complication" as the outcome instead of just "death."[6]

**References**: 1. Montreuil et al. PMID: 16248140. 2. Guller et al. PMID: 14992748. 3. Rosner B. Fundamentals of Biostatistics, 8th Ed. 4. Ridgway et al. PMID: 19476801. 5. Harrington et al. PMID: 31314974. 6. Guller et al. PMID: 15834629.

- Other basic statistical terms: Mean: (sum of all observed values)/(number of observed values). Median: middle value (or average of middle value and the one after it if even number of observations). Mode: most frequently occurring value. Standard Deviation (SD) vs. Standard Error of the Mean (SEM): "The SD is a measure of the variability (scatter) of a data distribution. It is a measure of the degree to which the individual values deviate from the population mean….Regardless of sample size, the SD will be large if the data are highly scattered. The SEM reflects the variability in the distribution of sample means from the population mean….Contrary to the SD, the SEM is an inferential statistic strongly dependent on sample size. The larger the sample size, the smaller the SEM, and the more precisely the sample mean estimates the overall population mean….The SEM can be obtained by dividing the SD by the square root of the number of patients in the sample (SEM= SD/√n)." [Guller U et al. J Am Coll Surg 2004; 198: 441-458]

**Diagnostic Testing and Screening Tests: Sensitivity, Specificity, Positive Predictive Value, Negative Predictive Value, Prevalence:**

- "Gold standard": definitive indicator of person having (or not having) the target condition (ref: Trevethan). Some instead say **Reference Standard** given the potential imperfection of a "gold standard." Sensitivity and specificity assess the screening test against the reference standard.
- Sensitivity (i.e. of the people who have the condition, what proportion test positive on the screening test?): [a/(a+c)]
  - A highly sensitive test is capturing the vast majority of people who have the condition and has a low proportion of false negatives. If you test negative with a highly sensitive test, it is unlikely you have the condition. Hence, a highly SENSITIVE test (assuming that specificity is not overly low) is good to RULE OUT a disease (mnemonic "SNOUT").
- Specificity (i.e. of the people who do not have the condition, what proportion test negative on the screening test?): [d/(b+d)]
  - A highly specific test is capturing the vast majority of people who DO NOT have the condition and has a low proportion of false positives. If you test positive with a highly specific test, it is likely you have the disease. Hence, a highly SPECIFIC test (assuming sensitivity is not overly low) is good to RULE IN a disease ("SPIN").
- Positive Predictive Value (PPV): [a/(a+b)] • Negative Predictive Value (NPV): [d/(c+d)]
  - PPV and NPV assess whether the actual patient being tested is predicted to have the disease. In order to use the PPV and NPV formulas for a 2x2 table, the prevalence of disease for your patient (in terms of medical history and risk factors) has to be representative of the prevalence of disease in the 2x2 table. This is referred to as determining your patient's *pre-test probability*. PPV and NPV are metrics of *post-test probability*. **As prevalence increases, PPV increases and NPV decreases (and vice versa).**




Trevethan R. Sensitivity, Specificity, and Predictive Values: Foundations, Pliabilities, and Pitfalls in Research and Practice. Front Public Health 2017; 20: 5: 307. Open Access article; Figure 1 used via Creative Commons License CC BY 4.0: https://creativecommons.org/licenses/by/4.0/. Other references: Tenny S, Hoffman MR. Prevalence. StatPearls/NCBI Bookshelf; https://www.ncbi.nlm.nih.gov/books/NBK430867/. Hunick M et al. Decision making in health and medicine: Integrating evidence and values. Cambridge University Press, 2009.

- Likelihood ratio positive (LR+) = sensitivity/(1-specificity). Likelihood ratio negative (LR-) = (1-sensitivity)/specificity.
  - If you know a patient's pre-test probability (by looking at the prevalence of the condition in patients with risk factors similar to your patient) and the likelihood ratio, there are normograms to mathematically convert this into the patient's post-test probability.

**Other Basic Math and Statistical Terms**:

- Logarithms: $\log_x Y=z \rightarrow x^z=Y$ (in words: "log base x of Y equals z"). Example: $\log_2 16=x \rightarrow 2^x=16 \rightarrow x=4$. Second example: log 1,000 = $\log_{10}1{,}000=3$ (note: there are 3 zeros in 1,000; when the base number is not provided, it is implied to be 10). Third example: $\log_x 1=? \rightarrow \log_x 1=0$ (any base number x raised to the 0 power will equal 1). Fourth example: ln 1 = $\log_e 1$. $\log_e 1=? \rightarrow e^x=1 \rightarrow x=0 \rightarrow$ ln 1 = 0. Khan Academy intro video on logarithms: "Intro to logarithms": https://youtu.be/Z5myJ8dg_rM. Additional popular intro video on logarithms: "Logarithms…How?": https://youtu.be/Zw5t6BTQYRU.
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# ITE Gaps in Knowledge Reports

| Video Lectures of Gaps in Knowledge reports from University of Kentucky Anesthesia: | |
|---|---|
| 2020: https://youtu.be/X9NEntK89fE | 2019: https://youtu.be/fpseLaUtDDE |
| 2017/18: https://youtu.be/vAvLdl20orY | 2016: https://youtu.be/qecGo1NyUBg |
| 2015: https://youtu.be/qD_ch5_Z3tE | 2014: https://youtu.be/OqonxKcSEs4 |

**Latest ABA ITE Gaps in Knowledge Report:**



ABA ITE Gaps in Knowledge Reports. Latest update available at http://www.theaba.org

# End