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2021 CA-1 TUTORIAL TEXTBOOK  15th Edition

STANFORD UNIVERSITY MEDICAL CENTER
DEPARTMENT OF ANESTHESIOLOGY

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CA-1 Mentorship Intraoperative Didactic Lectures

1. Standard Monitors
2. Inhalational Agents
3. MAC and Awareness
4. IV Anesthetic Agents
5. Rational Opioid Use
6. Intraoperative Hypotension & Hypertension
7. Neuromuscular Blocking Agents
8. Difficult Airway Algorithm
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11. Hypoxemia
12. Electrolyte Abnormalities
13. Hypothermia & Shivering
14. PONV
15. Extubation Criteria & Delayed Emergence
16. Laryngospasm & Aspiration
17. Oxygen Failure in the OR
18. Anaphylaxis
19. Local Anesthetics
20. Malignant Hyperthermia
21. Pre-Operative Evaluation
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23. Perioperative Antibiotics
24. Topics for Discussion
25. CA-1 Exams, Dates & Preparation
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27. COVID Resources
INTRODUCTION TO THE CA-1 TUTORIAL MONTH

We want to welcome you as the newest members of the Department of Anesthesia at Stanford! Your first weeks and months as an anesthesia resident are exciting, challenging, stressful, and rewarding. Regardless how much or how little experience you have in the field of anesthesiology, the learning curve for the next few months will be steep. Luckily, there are countless people and resources here in the department to help you succeed.

Several years ago, before the development of this mentoring and tutorial system, CA-1s had little structure to their first month. While there were regular intra-operative and didactic lectures, the nuts and bolts of anesthesiology were taught with little continuity. CA-1s worked with different attendings each day and spent as much time adjusting to their particular styles as they did learning the basics of anesthesia practice. Starting in 2007, the first month of residency was overhauled to include mentors: each CA-1 at Stanford was matched with an attending or senior resident for a week at a time. In addition, a tutorial curriculum was refined to give structure to the intra-operative teaching and avoid redundancy in lectures. By all accounts, the system has been a great success!

There is so much material to cover in your first couple months of residency, and the number of resources available to you can be overwhelming. This booklet serves as a launching point for independent study. While you review the tutorial with your mentor, use each lecture as a starting point for conversations or questions. From there, senior residents and faculty will be happy to help point you in the direction of other useful resources and textbooks.

During your mentorship, we hope you can use your mentor as a role model for interacting with patients, surgeons, consultants, nurses and other OR personnel. This month, you will interact with most surgical specialties as well as nurses in the OR, PACU, and ICU. We suggest you introduce yourself to them and draw on their expertise as well.

Nobody expects you to be an independent anesthesia resident after just one month of training. You will spend the next three years at Stanford learning the finer points of anesthesia practice, subspecialty anesthesiology, ICU care, pre-operative and post-operative evaluation and management, etc. By the end of this month, we hope you attain a basic knowledge and skillset that will allow you to understand your environment, know when to ask for help, and determine how to direct self-study. Sprinkled throughout this book, you’ll find some light-hearted resident anecdotes from all the good times you’ll soon have, too.

CA-1 Introduction to Anesthesia Lecture Series:

The Introduction to Anesthesia Lecture series, given by attendings, is designed to introduce you to the basic concepts of anesthesia. Topics covered include basic pharmacology of anesthetics, basic physiology, and various clinical skills and topics. You will be relieved of all clinical duties to attend these lectures. You can find copies of all major Anesthesia textbooks in the anesthesia library or online through Lane Medical Library, and a wealth of subspecialty resources on the Stanford Ether website.
ACKNOWLEDGEMENTS

Thanks to Janine Roberts for her hard work and assistance in constructing the CA-1 Mentorship Textbook.

Thanks to Dr. Pearl for his support and assistance with this endeavor. His guidance is appreciated by all.

Thanks to Dr. Macario, our Residency Program Director, who will be one of the first attendings to know each of you by your first name.

Special thanks to Dr. Ryan Green, Class of 2008, founder of the CA-1 mentorship program, and principal editor of the first edition of the CA-1 Mentorship Textbook.

Lastly, thanks to all of the resident and faculty mentors at Stanford University Medical Center, Palo Alto VA, and Santa Clara Valley Medical Center for all their time and effort spent teaching Stanford anesthesia residents.

As you start this July, don’t be too hard on yourself if you miss an IV or an intubation. If it were that easy, no one would need residency. Just stay positive, embrace a growth mindset, and enjoy the incredible learning opportunities that are ahead of you. Try to go with the flow if plans change on you suddenly; flexibility is very important in this field. May your first month be a smooth transition to your anesthesia career.

Welcome to Stanford Anesthesia. We hope you love it as much as we do! Please do not hesitate to contact us with any questions or concerns.

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ACKNOWLEDGEMENT TO MENTORS

We also want to specifically thank all of the faculty and resident mentors who invest the extra amount of effort to train CA-1s in the month of July. Their designation as mentor is a rewarding and challenging opportunity. As Ralph Waldo Emerson said, “Our chief want in life is somebody who will make us do what we can.” These mentors will serve a key role in the rapid transformation that takes place as you commence your career and obtain the knowledge and skills required to become a successful anesthesiologist.

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<th>2020 MENTORS</th>
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KEY POINTS AND EXPECTATIONS

Key Points:
- The program will last 4 weeks.
- Mentors will consist of faculty members and senior residents (CA-2s and CA-3s).
- CA-1s scheduled to start in the Stanford GOR will be assigned a different mentor each week (CA-1s scheduled to begin at the Palo Alto VAMC or Santa Clara Valley Medical Center will be mentored according to local program goals and objectives).
- Faculty will provide one-on-one mentoring while senior residents will provide one-on-one mentoring with oversight by a supervising faculty member.
- All CA-1s (including those starting at Stanford, VAMC, and SCVMC) will receive the syllabus of intra-operative mini-lecture topics to be covered with their mentors. These mini-lectures provide goal-directed intra-operative teaching during the first month. CA-1s will document the completion of each mini-lecture by obtaining their mentors’ initials on the “Checklist for CA-1 Mentorship Intra-operative Didactics.”
- CA-1s will receive verbal feedback from their mentors throughout the week, as appropriate, as well as at the end of each week. Mentors will communicate from week to week to improve longitudinal growth and mentorship of the CA-1.

Expectations of CA-1 Residents:
- Attend the afternoon CA-1 Introduction to Anesthesia Lecture Series.
- Participate in goal-directed learning by completing the CA-1 Mentorship Intra-operative Didactics with your mentors.
- Discuss cases with your mentor the night before.
- CA-1s at SUH are not expected to take weekend call with your mentor (for those at the Valley and VA, discuss with your mentor).

Expectations of Senior Resident Mentors:
- Senior mentors will take primary responsibility for discussing the case, formulating a plan, and carrying out the anesthetic with their CA-1; if concerns arise, the senior mentor will discuss the case with the covering faculty member.
- Instruct CA-1s in the hands-on technical aspects of delivering an anesthetic.
- Participate in goal-directed learning by completing the CA-1 Mentorship Intra-operative Didactics with your CA-1.
- Provide timely feedback to your CA-1 every day and at the end of the week.
- Provide continuity of teaching by communicating with the CA-1’s other mentors.

Expectations of Faculty Mentors:
- Participate in goal-directed learning by completing the CA-1 Mentorship Intra-operative Didactics with your CA-1.
- Provide timely feedback to your CA-1 every day and at the end of the week.
- Provide continuity of teaching by communicating with the CA-1’s other mentors.
GOALS OF THE CA-1 TUTORIAL MONTH

Anesthesia is a “hands-on” specialty. Acquiring the fundamental knowledge, as well as cognitive and technical skills necessary to provide safe anesthesia, are essential early on in your training. The CA-1 Mentorship Program and the CA-1 Introduction to Anesthesia Lecture Series will provide you with the opportunity to achieve these goals. The following are essential cognitive and technical skills that each CA-1 resident should acquire by the end of their first month.

I. Preoperative Preparation:
   a. Perform a complete safety check of the anesthesia machine.
   b. Understand the basics of the anesthesia machine including the gas delivery systems, vaporizers, and CO2 absorbers.
   c. Set up appropriate equipment and medications necessary for administration of anesthesia.
   d. Conduct a focused history with emphasis on co-existing diseases that are of importance to anesthesia.
   e. Perform a physical examination with special attention to the airway and cardiopulmonary systems.
   f. Understand the proper use of laboratory testing and how abnormalities could impact overall anesthetic management.
   g. Discuss appropriate anesthetic plan with patient and obtain an informed consent.
   h. Write a pre-operative History & Physical with Assessment & Plan in the chart.

II. Anesthetic Management
   a. Placement of intravenous cannula. Central venous catheter and arterial catheter placement are optional.
   b. Understanding and proper use of appropriate monitoring systems (BP, EKG, capnography, temperature, and pulse oximeter).
   c. Demonstrate the knowledge and proper use of the following medications:
      i. Pre-medication: Midazolam
      ii. Induction agents: Propofol, Etomidate, Ketamine
      iii. Neuromuscular blocking agents: Succinylcholine and at least one non-depolarizing agent
      iv. NMBA reversal agents: Neostigmine/Glycopyrrolate & Sugammadex
      v. Local anesthetics: Lidocaine
      vi. Opioids: Fentanyl and at least one other opioid
      vii. Inhalational anesthetics: Nitrous oxide and one other volatile anesthetic
      viii. Vasoactive agents: Ephedrine and Phenylephrine
   d. Position the patient properly on the operating table.
   e. Perform successful mask ventilation, endotracheal intubation, and LMA placement.
   f. Recognize and manage cardiopulmonary instability.
   g. Spinal and epidural anesthesia are optional.
   h. Record intra-operative note and anesthetic data accurately, punctually, and honestly.

III. Post-operative Evaluation
   a. Transport a stable patient to the Post Anesthesia Care Unit (PACU)
   b. Provide a succinct anesthesia report to the PACU resident and nurse.
   c. Complete the anesthesia record with proper note.
   d. Leave the patient in a stable condition.
   e. Make a prompt post-operative visit and leave a note in the chart (optional but strongly encouraged).
SUGGESTED CHECKLIST FOR CA-1 MENTORSHIP
INTRAOPERATIVE DIDACTICS

Mentors *initial* completed lectures

First Days  _____ Discuss GOR Goals and Objectives for CA-1
           _____ Discuss etiquette in the OR
           _____ Discuss proper documentation
           _____ Discuss proper sign out
           _____ Discuss post-op orders
           _____ Machine check

Week One  _____ Standard Monitors
           _____ Inhalational Agents
           _____ MAC & Awareness
           _____ IV Anesthetic Agents
           _____ Rational Opioid Use
           _____ Intra-operative Hypotension & Hypertension
           _____ Neuromuscular Blocking Agents

Week Two  _____ Difficult Airway Algorithm
           _____ Fluid Management
           _____ Transfusion Therapy
           _____ Hypoxemia
           _____ Electrolyte Abnormalities
           _____ Hypothermia & Shivering
           _____ PONV
           _____ Extubation Criteria & Delayed Emergence

Week Three _____ Laryngospasm & Aspiration
               _____ Oxygen Failure in the OR
               _____ Anaphylaxis
               _____ Local Anesthetics
               _____ ACLS
               _____ Malignant Hyperthermia
               _____ Perioperative Antibiotics
# CA-1 Introductory Lectures – July 2021

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<td>Dr. Fred Milhm (Group 1)</td>
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<td>Principles of Pharmacology</td>
<td>Dr. Steve Shafer (Group 2)</td>
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<td>Dr. Amit Josephh</td>
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<td>The Drugs in the Drawer</td>
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<td>Positioning and Associated Risks</td>
<td>Dr. David Drewer</td>
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<td>Anesthesia Machine Round 2</td>
<td>Dr. Albert Lin</td>
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<td>Devising an Anesthetic Plan</td>
<td>Dr. Cliff Schmiesing</td>
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<td>Wellness Program and Retreat</td>
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<td>Introduction to Libero Lecture App</td>
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<td>De-Escalation Training</td>
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<td>Pharmacology of Inhalational Agents</td>
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<td>Pearls and Pitfalls</td>
<td>Drs. Milag Haikolla and Kyle Catabay</td>
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<td>Intro to POCUS</td>
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<td>Ethics and Professionalism</td>
<td>Dr. Alyssa Burgart</td>
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<td>Substance Use Disorders Talk</td>
<td>Dr. Darryl Oakes</td>
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<td>iStat Training</td>
<td>Dr. Fiana Zeng (Group 1 &amp; 2)</td>
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<td>Airway Management</td>
<td>Dr. Brita Mittal</td>
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*Miller’s Anesthesia is the reference text for these lectures

**All lectures held in Anesthesia Conference Room and Anesthesia Library**
Basic Anesthetic Monitoring

ASA Standards for Basic Anesthetic Monitoring

STANDARD I
"Qualified anesthesia personnel shall be present in the room throughout the conduct of all general anesthetics, regional anesthetics and monitored anesthesia care."

STANDARD II
"During all anesthetics, the patient’s oxygenation, ventilation, circulation, and temperature shall be continually evaluated."

OXYGENATION
- If using anesthesia machine: Inspired gas FiO2 analyzer + low O2 concentration alarm
- All anesthetics: quantitative method of assessing oxygenation (pulse oximetry with variable pitch tone)

VENTILATION
- Capnography (with expired Vt)
- Disconnect alarm required if mechanically ventilated

CIRCULATION
- EKG: Minimum 3 lead; 5 lead if any cardiac concern
- BP: Minimum cycle q5 minutes
- At least one additional continual circulatory assessment: pulse ox tracing, a-line tracing, palpable pulse, auscultation, doppler

TEMPERATURE
- Temperature probe if clinically significant changes in body temperature are anticipated

ITE tip: continuous vs. continual
- "continual" is defined as “repeated regularly and frequently in steady rapid succession”
  - Eg: the patient’s blood pressure shall be continually evaluated q5 min
- "continuous" means “prolonged without any interruption at any time”
  - Anesthesia personnel shall be continuously present during an anesthetic
  - During mechanical ventilation continuous use of a device to detect disconnection shall be used
  - EKG monitoring shall be continuously displayed

Pulse Oximetry

Terminology
- S\textsubscript{a}O\textsubscript{2} (Fractional Oximetry) = O2Hb / (O2Hb + Hb + MetHb + COHb)
- S\textsubscript{p}O\textsubscript{2} (Functional Oximetry/Pulse Oximetry) = O2Hb / (O2Hb + Hb)

Fundamentals
- The probe emits light at 660 nm (red, for Hb) and 940 nm (infrared, for O2Hb); sensors detect the light that passes undisturbed at each wavelength.
- Photoplethysmography is used to identify arterial flow (alternating current = AC) and cancels out the absorption during non-pulsatile flow (direct current = DC); the patient is their own control!
- The ratio (R) is used to derive the S\textsubscript{p}O\textsubscript{2} (R = 1:1 ratio = S\textsubscript{p}O\textsubscript{2} 85% → why a pulse ox not connected to the patient reads usually 85%).

Pulse Oximetry Pearls
- Methemoglobin (MetHb) - Similar light absorption at 660 nm and 940 nm (1:1 ratio) → at high levels S\textsubscript{p}O\textsubscript{2} approaches 85%. PaO\textsubscript{2} typically remains normal.
  - When true S\textsubscript{p}O\textsubscript{2} is >85% you get a falsely LOW S\textsubscript{p}O\textsubscript{2} reading
  - If the true S\textsubscript{p}O\textsubscript{2} is actually <85%, S\textsubscript{p}O\textsubscript{2} will be falsely HIGH
  - Causes: prilocaine/benzocaine topicalization, metoclopramide, dapsone, nitric oxide, nitroglycerine
  - Treatments: methylene blue, vitamin C (in G6PD deficiency)
- Carboxyhemoglobin (COHb) - Similar absorbance to O2Hb. Higher affinity to Hgb than O2
  - At 50% COHb, S\textsubscript{p}O\textsubscript{2} may be 95% despite a low SaO\textsubscript{2} = 50% on ABG, thus producing a falsely HIGH S\textsubscript{p}O\textsubscript{2}
  - Causes: smoke inhalation, volatile anesthetic degradation, desiccated baralyme/soda lime
  - Treatments: 100% FiO\textsubscript{2}, hyperbaric O2
- Cyanide toxicity: Clinical cyanosis despite HIGH S\textsubscript{p}O\textsubscript{2}. ABG and VBG will show similar PO\textsubscript{2} values due to uncoupling of oxidative phosphorylation. Lactate will be very high.
  - Hgb remains oxygenated, but tissues cannot use it
  - Causes: sodium nitroprusside, smoke inhalation
  - Treatment: hydroxocobalamin (previously sodium/amyl nitrile)
Pulse Oximetry Pearls

- Other factors producing a falsely LOW \( S_2O_2 \):
  - dyes (methylene blue > indocyanine green > indigo carmine)
  - blue nail polish
  - shivering/other motion,
  - ambient light
  - malpositioned sensor
  - low perfusion (low cardiac output, profound anemia, hypothermia, elevated SVR)
- Factors with NO EFFECT on \( S_2O_2 \) = bilirubin, \( HbF \), \( HbS \), acrylic nails, fluorescein dye.
- Cyanosis - clinically apparent with 5 g/dl desaturated Hb. Typically seen at an \( S_2O_2 \) below 85%.

EKG

3-Electrode System
- Allows monitoring of Leads I, II, and III
- but only one lead (i.e. electrode pair) can be examined at a time while the 3rd electrode serves as ground
- Lead II is best for detecting P waves and sinus rhythm

Modified 3-Electrode System
- If you have concerns for anterior wall ischemia, move L arm lead to V5 position, and monitor Lead I for ischemia

5-Electrode System
- Four limb leads + V5 (left anterior axillary line, 5th ICS)
- allows monitoring of 7 leads simultaneously.
- II + V5 is 75% sensitive for detecting ischemic events
- II + V5 is 80% sensitive
- II + V4 + V5 together is 98% sensitive

Noninvasive Blood Pressure

- Automated, microprocessor-assisted interpretation of oscillations in the NIBP cuff
- MAP is primary measurement; SBP and DBP are derived from algorithms
- Bladder should encircle >80% of extremity
- Bladder Width should be > 40% arm circumference
- Cuff too small = falsely HIGH BP
- Cuff too big = falsely LOW BP
  *Small cuffs have a more detrimental effect than large cuffs on BP accuracy

MAP = \( SBP + 2 \cdot DBP \)
\[ \frac{3}{\text{pulse pressure}} \]

Invasive Blood Pressure

Indications
- Moment-to-moment BP changes anticipated and rapid detection is vital
- Planned pharmacologic or mechanical manipulation
- Repeated blood sampling
- Failure of NIBP (e.g. due to positioning with arms tucked or lateral positioning with up arm and down arm)
- Supplementary diagnostic information (e.g. pulse pressure variation to guide volume status)

Transducer Setup
- Zeroing = exposes the transducer to air-fluid interface, thus establishing \( P_{\text{a}} \) as the "zero" reference pressure
  - If you are zeroing at the transducer, it does not matter what heightlevel the transducer is at (there is little change in \( P_{\text{a}} \) between the floor and the ceiling)
- Leveling = assigns the zero reference point to a specific point on the patient
  - by convention, the transducer is "levelled" at the right atrium
  - can level at any area of interest (e.g. in neurosurgical cases, level at circle of Willis to assess cerebral perfusion)

Blood pressure, cont

- BP varies by position:
  - The difference in blood pressure (mm Hg) at two different sites of measurement equals the height of an interposed column of water (cm H2O)
  - multiplied by a conversion factor (1 cm H2O = 0.74 mm Hg, or 15 cm height = 10 mm Hg)

Mnemonic: \( \text{pH} \text{ 7.410} \)
A change in "p" pressure of 7.4 mm Hg coincides with a "H" height change of 10 cm
In the Beach chair position, the BP cuff on leg may read 120/80. But if the brain is 60cm vertically higher than the cuff, what is the BP in the brain?

Answer: the BP in the brain would be closer to 75/35

**Effect of Patient & Transducer Position on BP Measurement**

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Remember “pH=7.410”: 7.4 mm Hg = 10 cm H$_2$O

**Arterial line tracings**

**Systolic amplification:** increase in peak systolic pressure as you move away from proximal aorta (caused by reflected waves) is offset by the narrowing of the systolic pressure wave, so the mean arterial pressure remains unchanged.

So the further from the aorta you are:
- Later dicrotic notch
- Higher systolic pressure, so pulse pressure widens
- MAP is unchanged

**Pulse Pressure Variation**

- Pulse pressure (PP) increases with increased stroke volume and decreased vessel wall compliance.
- The variation in PP seen on arterial line tracing can be used to guide volume resuscitation.
- Diagram below illustrates changes seen during positive pressure ventilation.
- In spontaneously breathing patients PP decreases with inspiration.

**Capnography**

- Measures exhaled CO$_2$
- Time delay exists due to length and volume of sample tube as well as sampling rate (50-500 ml/min)
- Anything distal to your Y-piece contributes to dead space

**Capnography Phases**

I. Dead space gas exhaled
II. Transition between dead space and alveolar gas
III. Alveolar plateau
IV. Inspiration
Capnography Pearls

Both the number and tracing provide much physiologic information

- Bronchospasm (upsloping trace)
- Significant hypotension can be associated with a drop in ETCO2
- Pulmonary embolism (decreased ETCO2 but increased A-a gradient between ETCO2 and PaCO2)
- Adequacy of CPR and indicator of ROSC (ETCO2 goal during CPR>10; if sudden increase in ETCO2, then likely have ROSC)
- Esophageal intubation, circuit disconnected (no ETCO2 tracing)
- Exhausted CO2 absorbent (ETCO2 does not return to 0-5)

Clinical pearl:
- When apneic: expect ETCO2 to increase by 6 mm Hg after 1 minute, and to increase by 3 mm Hg every minute thereafter

3 reasons for a drop in ETCO2

1. Decreased CO2 elimination:
   - Acute cardiovascular collapse (reduced cardiac index)
   - Massive venous air embolism (increased ET nitrogen)
   - Large PE (ECG showing S1,Q3,T3)
   - Kinked, dislodged, or esophageal ETT
2. Decreased CO2 production:
   - Hypothermia
   - Hypothyroidism
   - Neuromuscular blockade
3. Circuit sampling line disconnect

Capnography Pearls

ITE tip
During diagnostic laparoscopy, an intubated and anesthetized patient is placed in Trendelenburg. Over the next 20 minutes SpO2 decreases from 100% to 95%, and ETCO2 increases from 35 to 40 without changes in ventilator settings. The most likely reason is:

A. Decreased diaphragmatic excursion
B. Compression of vena cava
C. Carbon dioxide embolism
D. Pneumothorax

answer: A

Example Traces

A. Spontaneous ventilation
B. Mechanical ventilation
C. Prolonged exhalation (spontaneous)
D. Emphysema (notice upsloping plateau)
E. Sample line leak
F. Exhausted CO2 absorbant
G. Cardiogenic oscillations
H. Electrical noise

Capnography Pearls

Temperature

Monitoring is required if clinically significant changes in body temperature are anticipated

Sites

- Pulmonary artery = “Core” temperature (gold standard)
- Tympanic membrane = correlates well with core; approximates brain/hypothalamic temperature
- Nasopharynx = correlates well with core and brain temperature (careful with coagulopathy; can get refractory epistaxis)
- Oropharynx = good estimate of core temperature; recent studies show correlation with tympanic and esophageal temperatures
- Esophagus = correlates well with core (avoid esophageal varices, bleed); approximates core when urine flow is high; may be significant delay between bladder temp reading and true temp
- Axillary = inaccurate; varies by skin perfusion
- Rectal = not accurate (temp affected by LE venous return, enteric organisms, and stool insulation)
- Skin = inaccurate; varies by site

Major mechanisms of heat loss with GA are redistribution as vasodilation causes blood to shunt from core to periphery, then radiation (but other forms include conduction, convection, and evaporation)

Clinical pearl: using low fresh gas flows during anesthesia helps maintain body temperature and reduce water loss
Other Monitors/Adjuncts to Consider

Depth of anesthesia:
• BIS monitor/Sedline

Circulation/Fluids:
• PA catheter +/- Continuous Cardiac Output
• Central venous pressure (CVP)
• Intracranial Pressure (ICP)
• Transesophageal Echo (TEE)
• Precordial doppler (if risk of air embolus is high)
• Cerebral oximetry (NIRS)
• Esophageal stethoscope
• Foley
• OG tube

AAAHH!! I just intubated, now what?!

Remember your A’s
• Airway (ETT secured, vent settings)
• Anesthesia (volatile, infusions)
• Access (a-line, PIV, CVC, etc.)
• Another thing in the mouth (OG tube, bite block, TEE probe)
• Arms (positioning okay?)
• Air (forced air, aka Bair Hugger + temp probe)
• ABG/ACT (check baseline ABG and/or ACT if applicable)
• Antibiotics
• Analgesia (redose pain med prior to incision?)

References
Inhalational Agents

Pharmacokinetics

- Pharmacokinetics of inhalational agents divided into four phases
  - Uptake
  - Distribution (to CNS = site of action)
  - Metabolism (minimal)
  - Elimination

- Goal: produce partial pressure of gas in the alveolus that will equilibrate with CNS to render anesthesia
  - PARTIAL PRESSURE yields effect, not concentration
  - At higher altitudes where P_{atm} < 760 mmHg, the same concentration of soluble gases are present

- At equilibrium the following applies
  \[ P_{alveolus} = \frac{P_{in} \times F_{alveolus}}{F_{in} \times P_{artery}} \]

PK: F_{I}, F_{A}, and Uptake

- F_{I} (inspired concentration)
  - Determined by fresh gas flow, volume of breathing system, and absorption by machine/circuit
    - ↑ fresh gas flow, ↓ circuit, and ↓ circuit absorption allow actual Fi to be close to delivered Fi

- F_{A} (alveolar concentration)
  - Determined by uptake, alveolar ventilation, and concentration/second gas effects
  - P_{a} (alveolar partial pressure) is determined by input (delivery) minus uptake (loss)

- Uptake: gas taken up by the pulmonary circulation.
  - Affected by blood solubility, alveolar blood flow (i.e. cardiac output), alveolar-venous partial pressure difference
    - ↓ blood solubility, ↓ CO, ↓ alveolar-venous partial pressure difference → ↓ uptake
    - ↑ uptake → ↑ F_{I}, → ↑ uptake
  - Highly soluble gases = more gas required to saturate blood before it is taken up by CNS
  - High CO = equivalent to a larger tank, have to fill the tank before it is taken up by CNS

- Rate of rise in FA/FI ratio is a marker of anesthetic uptake by the blood.
  - More uptake means slower rise of FA/FI
  - Gases with the lowest solubilities in blood (e.g. Desflurane) will have fastest rise in FA/FI

PK: More on Uptake

- Alveolar Blood Flow:
  - In the absence of any shunt, alveolar blood flow = cardiac output
  - Poorly soluble gases are less affected by CO (so little is taken up into blood)

- Shunt States:
  - Right to Left Shunt (intracardiac or transpulmonary, i.e. mainstem intubation)
    - Shunted blood (containing no volatile anesthetic) mixes with blood coming from ventilated alveol (contains volatile), distorting the arterial anesthetic partial pressure = slower onset of induction
    - will have more significant delay in onset of poorly soluble agents
  - Left to Right Shunt
    - little effect on speed of induction for IV or volatile anesthetics

- Concentration effect:
  - ↑ F_{A} not only ↑ F_{I}, but also ↑ rate at which F_{A} approaches F_{I} (see following graph)

- Second Gas Effect:
  - concentration effect of one gas augments another gas (questionably clinically relevant with nitrous both during induction and emergence)
  - rapid intake of nitrous into blood → ↑ relative concentration of second gas

Historical Facts

- Several accounts of various forms of anesthesia in the BCE era using everything from cannabis and other herbs to carotid compression.

Modern anesthesia

- 1842 - Dr. Crawford Long had been using ether for fun with its exhilarating effects on what were known as ether clinics.
- Dr. Long used ether to anesthetize a friend to excise some neck tumors (not reported until 1849)
- 1845 - Dr. Warren (famous surgeon) was skeptical of Dr. Morton's offer to keep the patient from pain after Dr. Wells's failed demonstration with nitrous. Dr. Warren called it "Humbug".
- Dr. Morton stayed up all night with Dr. Gould (instrument maker) to construct a device to deliver ether that was more sophisticated than a rag. They arrived for the schedule vascular tumor removal on Mr. Abbott 15 minutes late. Dr. Warren remarked "Well, Sir, your patient is ready". After inducing anesthesia Dr. Morton fired back "Sir, your patient is ready!". After the surgery Dr. Warren commented, "Gentlemen, this is no humbug"
- 1846 - First public demonstration of ether at MGH in what is now called the ether dome by Dr. Warren.
- Dentist Horace Wells successfully uses nitrous oxide for dental extractions; however, public demonstration fails.
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- Shunt States:
  - Right to Left Shunt (intracardiac or transpulmonary, i.e. mainstem intubation)
    - Shunted blood (containing no volatile anesthetic) mixes with blood coming from ventilated alveol (contains volatile), distorting the arterial anesthetic partial pressure = slower onset of induction
    - will have more significant delay in onset of poorly soluble agents
  - Left to Right Shunt
    - little effect on speed of induction for IV or volatile anesthetics

- Concentration effect:
  - ↑ F_{A} not only ↑ F_{I}, but also ↑ rate at which F_{A} approaches F_{I} (see following graph)

- Second Gas Effect:
  - concentration effect of one gas augments another gas (questionably clinically relevant with nitrous both during induction and emergence)
  - rapid intake of nitrous into blood → ↑ relative concentration of second gas

Historical Facts

- Several accounts of various forms of anesthesia in the BCE era using everything from cannabis and other herbs to carotid compression.

Modern anesthesia

- 1842 - Dr. Crawford Long had been using ether for fun with its exhilarating effects on what were known as ether clinics.
- Dr. Long used ether to anesthetize a friend to excise some neck tumors (not reported until 1849)
- 1845 - Dental Horace Wells successfully uses nitrous oxide for dental extractions; however, public demonstration fails.
- 1846 - First public demonstration of ether at MGH in what is now called the ether dome by Dr. Warren.
- Dentist Horace Wells successfully uses nitrous oxide for dental extractions; however, public demonstration fails.
- Dr. Warren remarked "Well, Sir, your patient is ready". After inducing anesthesia Dr. Morton fired back "Sir, your patient is ready!". After the surgery Dr. Warren commented, "Gentlemen, this is no humbug"

Inhalational Agents

- Several accounts of various forms of anesthesia in the BCE era using everything from cannabis and other herbs to carotid compression.

Modern anesthesia

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Anesthetic Gas Properties

<table>
<thead>
<tr>
<th>Anesthetic</th>
<th>Blood Gas Partition Coefficient</th>
<th>Vapor Pressure (mmHg) at 20°C</th>
<th>MAC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nitrous Oxide</td>
<td>0.46</td>
<td>48.775</td>
<td>104%</td>
</tr>
<tr>
<td>Desflurane</td>
<td>0.45</td>
<td>69</td>
<td>8%</td>
</tr>
<tr>
<td>Sevoflurane</td>
<td>0.65</td>
<td>160</td>
<td>1.85%</td>
</tr>
<tr>
<td>Isoflurane</td>
<td>1.46</td>
<td>240</td>
<td>1.15%</td>
</tr>
<tr>
<td>Enflurane</td>
<td>2.54</td>
<td>244</td>
<td>0.76%</td>
</tr>
<tr>
<td>Halothane</td>
<td>1.9</td>
<td>172</td>
<td>1.63%</td>
</tr>
</tbody>
</table>

Example: Blood gas partition coefficient of nitrous = 0.46 + at steady state 1ml of blood contains 0.46 x 1ml of alveolar gas. In other words, at steady state if your fraction inspired gas is 50% N2O then 1ml of blood will contain 0.46x0.5ml's of N2O or 0.23 ml (Jaffe)

Fat: blood partition coefficient is >1. Therefore, things that increase fat in the blood (e.g. postprandial lipemia) will increase the overall blood:gas partition coefficient > slows induction

Nitrous Oxide

- Low potency (MAC 104% - can never reach 1 MAC)
- Low solubility in blood facilitates rapid uptake and elimination
- Commonly administered as an anesthetic adjuvant
- Does not produce skeletal muscle relaxation
- Can potentially contribute to PONV (but can be controlled with antiemetics)
- Can diffuse into air filled cavities and cause expansion of these structures (pneumothorax, bowel, middle ear, ET tube balloons, pulmonary blebs, etc.)
- Nitrous oxide can enter cavities faster than nitrous can leave
  - Often contraindicated in these settings
- Myocardial depression may be unmasked in CAD or severe hypotension
- Can cause pulmonary hypertension if used for prolonged period
- NMDA antagonist → may have analgesic effects
- Prolonged exposure can result in bone marrow depression and peripheral neuropathies
- NOT a trigger for MH (unlike volatile agents)
- Should periodically let air out of the ETT cuff if using nitrous to avoid tracheal injury

Isoflurane

- Highly pungent
- Least expensive among clinically used volatile anesthetics
- Second most potent of the clinically used inhalational agents (MAC 1.15%)
- Previously implicated for causing "coronary steal" (more recent studies have disputed this)
  - Dilation of "normal" coronary arteries causing blood to be diverted away from maximally dilated/stenotic vessels, to vessels with more adequate perfusion
- Causes vasodilation
  - Decreases BP
  - Increases CBF (usually seen at 1.6 MAC)
- Minimal compared to halothane
- Increases ICP (usually at above 1 MAC; short lived)
- Minimal compared to halothane
- At 2 MAC produces electrically silent EEG

Pharmacodynamics

- No clear mechanism
- Direct binding to amphiphilic cavities in proteins, but unclear how this produces anesthesia
- Likely enhancement of inhibitory channels and attenuation of excitatory channels
  - GABA, NMDA, glycine receptor subunits have all been shown to be affected
- Potency of anesthetic has been roughly linked to lipid solubility

ITE tip

- Things to Remember:
  - Factors that increase the rate of rise of FA/FI
    - Relatively low blood gas partition coefficient (solubility) for the volatile
    - Low cardiac output (affects soluble gasses more)
    - High minute ventilation
    - Low (Partial – Pvenous), meaning less blood uptake
  - Increase in cardiac output would decrease rate of rise in FA/FI for relatively soluble inhaled anesthetics (but would NOT produce much effect for insoluble agents)
  - Shunts on the other hand, typically affect insoluable agents more than soluble agents

Which of the following is true about FA/FI when cardiac output is doubled?
- A. increasing cardiac output has no significant effect on anesthetic uptake.
- B. FA/FI ratio rises faster for soluble agents than insoluble agents.
- C. FA/FI ratio rises slower for soluble agents than insoluble agents.
- D. the rate of rise is the same for insoluble and soluble agents.

Answer: C
Sevoflurane

- 2/3rds as potent as isoflurane (MAC 1.85%)
- Rapid uptake and elimination
- Sweet smelling, non-pungent
  - Popular for inhalational induction (often used in pediatrics)
- When exposed to CO₂ absorbent, sevoflurane breaks down to compound A (nephrotoxic in rats, however no human clinical evidence of nephrotoxicity)
  - Some guidelines recommended to keep fresh gas flows >2 L/min to prevent rebreathing of compound A (not formation of it), however this is disputed
  - Occurs in alkali such as barium hydroxide lime (Baralyme) or soda lime but NOT calcium hydroxide

Desflurane

- Lowest blood:gas solubility coefficient (lower than N₂O)
- Low potency (MAC 6%)
- High vapor pressure (669 mmHg) is close to atmospheric pressure therefore boils at sea level
  - Must be stored in a heated, pressurized vaporizer so pressure stays constant (the vaporizer is set to 2 atm) and Desflurane vaporizers are set to deliver a constant volume of anesthetic.
  - **Remember that the anesthetic affect (MAC) correlates to the partial pressure, NOT the concentration.
- Very pungent
  - Can cause breath-holding, bronchospasm, laryngospasm, coughing, salivation when administered to an awake patient via face mask
  - Can form CO in desiccated CO₂ absorbent (more so than other volatiles)
  - Can cause an increased sympathetic response (tachycardia, hypertension) when inspired concentration is increased rapidly

Delivery of Volatile Anesthetics

- Modern anesthetic machines use vaporizers that take a reservoir of liquid anesthetic and create saturated vapor in equilibrium with the liquid.
- A portion of the fresh gas flow or carrier gas then passes through the vaporizer chamber and becomes saturated with anesthetic vapor, which then is carried to the patient as a mix of fresh gas and anesthetic vapor.
- Liquid anesthetic evaporates in chamber up to its saturated vapor pressure (SVP).
  - SVP: the partial pressure of anesthetic vapor at a given temp, where the anesthetic liquid and its vapor are in equilibrium.
- Partial pressure of the anesthetic vapor in the carrier gas is equal to the SVP of the anesthetic
  \[
  \text{SVP} = \frac{\text{VA}}{\text{PT} - \text{SVP}}
  \]
  \[
  \text{SVP} = \text{agent vapor volume}, \quad \text{PT} = \text{total pressure (usually atmospheric pressure)}, \quad \text{VA} = \text{carrier gas volume}
  \]
- A portion of the fresh gas flow or carrier gas then passes through the vaporizer (¼ * 200 = 50) you can estimate that about 50 mL of sevo will be picked up by the carrier gas, and the volume concentration will then be: 50/(3000 + 50) x100 = 1.6% sevo

ITE tip

There is a shortcut for calculating vaporizer output!

- If you can remember the ratio generated from the equation SVP/(PT – SVP), assuming PT = 760, you can just multiply that ratio by the fresh gas flow through the vaporizer to get the volume of volatile anesthetic (this is just another way of thinking about the equation on the last slide!)... see fractions below.

<table>
<thead>
<tr>
<th>AGENT</th>
<th>SVP (mm Hg)</th>
<th>SVP/(PT - SVP)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sevoflurane</td>
<td>160</td>
<td>~1/4</td>
</tr>
<tr>
<td>Enflurane</td>
<td>172</td>
<td>~1/3</td>
</tr>
<tr>
<td>Isoflurane</td>
<td>240</td>
<td>~1/2</td>
</tr>
<tr>
<td>Halothane</td>
<td>244</td>
<td>~1/2</td>
</tr>
<tr>
<td>Desflurane</td>
<td>669</td>
<td>N/A</td>
</tr>
</tbody>
</table>

Delivery of Volatile Anesthetics

- Using the SVP and total pressure, you can calculate the volume of anesthetic delivered in a volume of fresh gas to determine how much anesthetic you are delivering to a patient.
  - Rearrange previous equation to:
    \[
    \text{VA} = \text{SVP} \times \text{VC}
    \]
    \[
    \text{SVP} = \frac{\text{PT} \times \text{VC}}{\text{VA}}
    \]
- Once VA or volume of anesthetic is calculated, the total % concentration delivered can then be determined.
  - % Volatile anesthetic = \[\frac{\text{VA}}{\text{FGF} + \text{VA}}\] x 100

ITE tip

Anesthesia in Denver?

- For Sevo and Iso:
  - Remember modern vaporizer output is a function of saturated vapor pressure of the anesthetic in proportion to atmospheric pressure... so dropping atmospheric pressure will increase the output (volume) of your vaporizer, but the partial pressure of your anesthetic gas remains the same.
  - In terms of volume, altitude has significant effect on vaporizer output.
    - At higher altitude the volume (%) delivered will be higher than what the dial is set to
    - But the partial pressure will remain the same
      - Remember partial pressure of an anesthetic gas in the alveoli is what determines how anesthetized your patient is
      - Therefore, in Denver to give 1 MAC of Sevo you still turn the dial to 2% because the vaporizer compensates with more output (a higher % at a lower atmospheric pressure will give you the same partial pressure of volatile)
  - But also remember...
    - Desflurane uses a DIFFERENT heated vaporizer system that delivers anesthetic at a fixed percent concentration and NOT at a fixed partial pressure (like sevo and iso vaporizers do).
    - At higher altitudes the partial pressure of Des is reduced due to lower barometric pressure. So Des required dial setting = desired % x (760 mmHg/curent atmospheric pressure).
      - To deliver the equivalent of 1 MAC of Des at 380 ATM, you must turn the dial to 12%. 
During a robotic prostate case where the lights were dimmed, the anesthetic machine alarmed that the delivered MAC was low. I checked the circuit for leaks – nothing. I sniffed around – no smell of sevo. I checked the vaporizer – it was closed tight. Where was the sevo going?! I pushed bits of propofol to buy time while I called the anesthesia tech for help. He scanned the machine with a flashlight and focused on the vaporizer – the meniscus was super low. It was nearly empty. Turned out the sevo wasn’t refilled between cases...

Never drive on an empty tank.
**MAC & Awareness**

**Minimum Alveolar Concentration**

Alveolar concentration of a gas at 1 atm at steady-state concentration at which 50% of subjects do not respond to surgical incision

**Important Points**

- Remarkably consistent across species
- MAC mirrors brain partial pressure of agent
- At equilibrium, brain anesthetic partial pressure = alveolar partial pressure
- MAC is population average, thus not true predictor of individual response (MAC = ED\(_{50}\))
- the ED\(_{50}\) is ± 20% - so at 1.2 MAC, 95% of patients will not respond to incision
- MAC values are additive (e.g. 0.5 MAC iso + 0.5 MAC N\(_2\)O = 1 MAC)
- MAC is inversely related to anesthetic potency (lipid solubility)
- Potency (and lipid solubility) are determined by oil:gas partition coefficient (NOT blood:gas partition coefficient)

**MAC of Inhaled Anesthetics**

<table>
<thead>
<tr>
<th>Gas</th>
<th>Blood:Gas Partition Coefficient</th>
<th>Oil:Gas Partition Coefficient</th>
<th>MAC*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Halothane</td>
<td>2.5</td>
<td>197</td>
<td>0.75%</td>
</tr>
<tr>
<td>Enflurane</td>
<td>1.9</td>
<td>98.5</td>
<td>1.7%</td>
</tr>
<tr>
<td>Isoflurane</td>
<td>1.4</td>
<td>90.8</td>
<td>1.2%</td>
</tr>
<tr>
<td>Sevoflurane</td>
<td>0.65</td>
<td>50</td>
<td>2.0%</td>
</tr>
<tr>
<td>N(_2)O</td>
<td>0.47</td>
<td>1.3</td>
<td>104%</td>
</tr>
<tr>
<td>Desflurane</td>
<td>0.45</td>
<td>19</td>
<td>8.0%</td>
</tr>
</tbody>
</table>

*MAC values for adults 36-49 years old

- MAC is indicator of anesthetic potency, which is measured by a volatile’s Oil:gas partition coefficient (higher the coefficient, the more potent the agent)
- Blood:gas partition coefficient is indicator of solubility, which affects rate of induction and emergence. It is NOT related to MAC.

**ITE tip**

The potency of an inhalational agent can be estimated by knowing its solubility in_____.

- a. olive oil
- b. deionized water
- c. ethylene glycol
- d. coconut water

Answer: a. olive oil. This discovery was made in the 1800s, by Hans Meyer and Ernest Overton independently, also known as the Meyer-Overton correlation.

**ITE tip**

- True or False?
  - Anesthetics with greater blood:gas partition coefficients have lower solubility in blood.
  - Blood gas coefficient is an important determinant of speed of anesthetic induction and recovery.
  - Oil gas partition coefficient has been correlated to anesthetic elimination.
  - Tissue: blood partition coefficients are important to describe redistribution of a chemical in the body
  - MAC is highest at 6 months old, then begins to decline
  - After age 40, MAC declines ~6% per decade (i.e. MAC for 80 year old is about 75% that of 40 year old)

**Effect of Age on MAC**
**Factors Decreasing MAC**

<table>
<thead>
<tr>
<th>Medications</th>
<th>Alcohol</th>
<th>Physiologic Conditions</th>
<th>Pathophysiologic Conditions</th>
<th>Genetic Factors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Opiates</td>
<td>Acute ethanol ingestion</td>
<td>Increasing age for patients &gt;1 year of age pregnancy</td>
<td>Hypothermia</td>
<td>None established</td>
</tr>
<tr>
<td>Benzodiazepines</td>
<td>Verapamil</td>
<td>Propofol</td>
<td>Hypercarbia</td>
<td></td>
</tr>
<tr>
<td>Barbiturates</td>
<td>Ketamine</td>
<td>Chronic meth use</td>
<td>Severe anemia (Hb &lt; 5)</td>
<td></td>
</tr>
<tr>
<td>Alpha-2 agonists</td>
<td>Verapamil</td>
<td>Local anesthetics</td>
<td>Hyponatremia</td>
<td></td>
</tr>
</tbody>
</table>

**Factors Increasing MAC**

<table>
<thead>
<tr>
<th>Inhibition of catecholamine reuptake</th>
<th>Chronic ethanol abuse</th>
<th>First months of life for infants &lt;6mo of age</th>
<th>Hyperthermia</th>
<th>Genotype related to red hair</th>
</tr>
</thead>
<tbody>
<tr>
<td>(amphetamines, ephedrine, L-dopa, TCA)</td>
<td></td>
<td></td>
<td>Hypernatremia</td>
<td></td>
</tr>
</tbody>
</table>

---

**More MAC Definitions**

**MACAware (a.k.a. MAC-Aware)**
- MAC necessary to prevent response to verbal/tactile stimulation
- Volatiles: ~0.4 MAC; N2O: ~0.6 MAC

**MACMovement**
- ~1.0 MAC

**MACc (a.k.a. LS, IT, or LMI = laryngoscopy, intubation, LMA insertion)**
- MAC necessary to prevent laryngeal response to "endotracheal intubation"
- Prevents movement in 95% of patients (ED95)
- ~1.3 MAC

**MACBAR**
- MAC necessary to "blunt autonomic response" to noxious stimulus
- Opiates (even small amounts) and N2O often added to achieve this level and thus spare requirement of high concentrations of halogenated anesthetics
- ~1.6 MAC

---

**Awareness**

- Estimated to be 1-2 per 1000 GA cases
  - Higher incidence in pediatrics – up to 2.7% in kids over 6 years old but psychological sequelae are fewer
  - Twice as likely to happen when neuromuscular blockade is used
  - More common if chronically using alcohol, opiates, meth, cocaine
  - More common in high-risk surgeries where deep anesthesia may be dangerous to an unstable patient (e.g. trauma 11-43%, cardiac 1-1.5%, cesarean section 0.4%)
  - Most common sensation is hearing voices
  - Mostly occurs during induction or emergence
  - Early counseling after an episode is very important (needed by 40-60%)
  - Patient handout available at: [www.asahq.org/patientEducation/Awarenessbrochure.pdf](http://www.asahq.org/patientEducation/Awarenessbrochure.pdf)
  - Dreaming can also occur and be confused for awareness if it is disturbing to the patient; dreaming is not related to anesthetic depth

---

**ITE tip**

Which of the following is LEAST likely to be associated with an increased risk of intraop awareness?

a. cesarean delivery under GA
b. emergency damage-control lap chole under GA
c. history of opioid abuse
d. red hair

**Answer:** d. Red hair is associated with distinct mutations on the melanocortin-1 receptor. MAC may be altered in these patients, however hair color has never been identified as a risk factor for intraoperative recall.

---

**ITE tip**

___ causes the LEAST reduction in MAC of volatile anesthetics.

a. fentanyl
b. morphine
c. remifentanil
d. nalbuphine

**Answer:** d. Nalbuphine. Unlike volatile anesthetics and other IV induction agents such as propofol, opioids have ceiling effects that prevent them from being used as sole induction agents. This is evidenced by reports of recall and awareness in cases using high-dose fentanyl and even combinations of opioids and nitrous. Combining opioids with volatiles can significantly decrease MAC but there is a sub-MAC ceiling effect at which there is not further reduction in MAC despite increasing opioid doses.

---

**Signs of Light Anesthesia**

- Tearing
- Sympathetic activation: Dilated pupils, sweating
- Coughing or bucking
- Patient movement
- Increase in HR or BP by 20% above baseline (albeit these do not reliably predict awareness)
- Signs of consciousness on EEG monitor (Bispectral Index or Sedline, see below)
Preventing Awareness

- Consider administering an amnestic premedication
- Avoid or minimize muscle relaxants when able
- Choose potent inhalational agents rather than TIVA if possible -> use at least 0.5-0.7 MAC
- Monitor brain activity using BIS or SedLine if using TIVA
- Consider different treatment for hypotension other than decreasing anesthetic concentration
- Redose IV anesthetic when delivery of inhalational agent is difficult (ie during long intubation or rigid bronchoscopy)

BIS & Sedline

- Both use processed EEG signals to produce numbers (0-100) relating to depth of anesthesia.
  - BIS index ideally 40-60
  - Sedline (PSI) ideally 25-50
- Both have been shown to be fairly good predictors of loss and regaining consciousness. However, no monitoring device is 100% effective.
- Significant variability based on age
- Changes in EEG with medications (e.g. NDMB, ephedrine, ketamine), conditions (elderly with low amplitude), and other events (ischemia)
- Both have ~2 minute time lag
- It is possible to display the raw EEG in real time on either device, and be able to interpret on your own (highly encouraged - http://icetap.org/)

ITE tip

- Procedures associated with awareness
  - 1. Major trauma with significant blood loss
  - 2. Cardiac surgery
  - 3. Cesarean section under GA
  - 4. procedures done under pure TIVA
- Awareness facts:
  - Awareness is twice as likely when neuromuscular blocking drugs are used.
  - The amount of volatile anesthetic is what matters most.
  - MAC of 0.8 with mostly N2O is more likely to result in awareness than MAC of 0.7 of volatile alone.
  - Other risk factors for awareness
    - h/o substance abuse
    - h/o difficult intubation or anticipated difficult intubation
    - Chronic pain patients
    - Clinical pearl: Red hair is associated with higher MAC requirement but not increased risk of awareness.

Management

If you suspect your patient may be aware:

- Immediately deepen the anesthetic with fast-acting agents (e.g. propofol)
- Talk to the patient, reassure them that everything is OK (hearing is the last sense to be lost)
- Consider a benzodiazepine for amnesia
- Talk to the patient after the case to assess if they had any awareness
- Set up counseling if necessary
- Contact Patient Services and Risk Management (potential lawsuit?)

References

IV Anesthetic Agents

CNS Targets of IV Anesthetics

- **GABA receptors** (most common target)
  - GABA is the primary inhibitory neurotransmitter in CNS
  - Activation causes increase in chloride conductance, and therefore hyperpolarization of neuron (inhibiting nerve transmission)
  - Propofol and Barbiturates decrease the rate of dissociation of GABA and its receptor (increasing the duration of chloride channel opening)
  - Benzodiazepines facilitate the attachment of GABA to its binding site on the receptor (increasing the frequency of chloride channel openings)

- **NMDA receptors**
  - NMDA receptors are glutamate, glycine, and D-serine activated excitatory ion channels
  - Ketamine is an uncompetitive antagonist

- **Alpha-2 receptors**
  - Dexmedetomidine is an alpha-2 agonist: inhibits NE release which results in 1. CNS inhibition via the locus ceruleus (primary site for brain release of NE) in brain stem and 2. analgesia via decreased substance P release at the dorsal horn of the spinal cord.

### Induction Characteristics and Dosage Requirements for the Currently Available Sedative–Hypnotic Drugs

<table>
<thead>
<tr>
<th>DRUG NAME</th>
<th>INDUCTION DOSE (mg/kg)</th>
<th>ONSET (sec)</th>
<th>DURATION (min)</th>
<th>EXCITATORY ACTIVITY*</th>
<th>PAIN ON INJECTION*</th>
<th>HEART RATE†</th>
<th>BLOOD PRESSURE†</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thiopental</td>
<td>3–6</td>
<td>&lt;30</td>
<td>5–10</td>
<td>+</td>
<td>0–+</td>
<td>↑↓</td>
<td>↓↓</td>
</tr>
<tr>
<td>Methohexital</td>
<td>1–3</td>
<td>&lt;30</td>
<td>5–10</td>
<td>+</td>
<td>++</td>
<td>0–</td>
<td>0–↓↓</td>
</tr>
<tr>
<td>Propofol</td>
<td>1.5–2.5</td>
<td>15–45</td>
<td>5–10</td>
<td>+</td>
<td>++</td>
<td>1–2</td>
<td>1–2</td>
</tr>
<tr>
<td>Midazolam</td>
<td>0.2–0.4</td>
<td>10–30</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Ketamine</td>
<td>0.3–0.6</td>
<td>45–80</td>
<td>15–30</td>
<td>+</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Lorazepam</td>
<td>0.03–0.05</td>
<td>60–120</td>
<td>60–120</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Etomidate</td>
<td>0.2–0.3</td>
<td>15–45</td>
<td>3–12</td>
<td>+++</td>
<td>+</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

*0 = none; + = minimal; ++ = moderate; +++ = severe.
†↓ = decrease; ↑ = increase.

(Clinical Anesthesia 6th Edition; Barash, P.; Lippincott Williams and Wilkins; 2011)

### Pharmacokinetic Values for the Currently Available Intravenous Sedative–Hypnotic Drugs

<table>
<thead>
<tr>
<th>DRUG NAME</th>
<th>DISTRIBUTION HALF-LIFE (min)</th>
<th>PROTEIN BINDING (%)</th>
<th>DISTRIBUTION VOLUME AT STEADY STATE (L/kg)</th>
<th>CLEARANCE (mL/kg/min)</th>
<th>ELIMINATION HALF-LIFE (h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thiopental</td>
<td>2–4</td>
<td>85</td>
<td>2.5</td>
<td>3.4</td>
<td>11</td>
</tr>
<tr>
<td>Methohexital</td>
<td>5–6</td>
<td>85</td>
<td>2.2</td>
<td>4</td>
<td>11</td>
</tr>
<tr>
<td>Propofol</td>
<td>2–4</td>
<td>98</td>
<td>2–10</td>
<td>2.6</td>
<td>4–23</td>
</tr>
<tr>
<td>Midazolam</td>
<td>7–15</td>
<td>94</td>
<td>1.1–1.7</td>
<td>6.4–11</td>
<td>1.7–2.6</td>
</tr>
<tr>
<td>Ketamine</td>
<td>10–15</td>
<td>98</td>
<td>0.7–1.7</td>
<td>20–45</td>
<td>20–50</td>
</tr>
<tr>
<td>Lorazepam</td>
<td>3–10</td>
<td>95</td>
<td>0.8–1.5</td>
<td>20–14</td>
<td>11–22</td>
</tr>
<tr>
<td>Etomidate</td>
<td>7–15</td>
<td>75</td>
<td>2.8–4.5</td>
<td>30–60</td>
<td>22–52</td>
</tr>
<tr>
<td>Ketamine</td>
<td>11–16</td>
<td>12</td>
<td>2.8–5.5</td>
<td>60–120</td>
<td>2–4</td>
</tr>
</tbody>
</table>

(Clinical Anesthesia 6th Edition; Barash, P.; Lippincott Williams and Wilkins; 2011)

### Pharmacodynamics

- All hypnotics also affect other major organ systems besides brain:
  - dose-dependent respiratory depression
  - hypotension and cardiac depression
  - *(Etomidate causes least cardiac depression)*

  *Profound hemodynamic effects can be seen with hypovolemia since higher drug concentration is achieved within central compartment

  *Large hemodynamic depressant effect can be seen in elderly and those with pre-existing cardiovascular disease

  *These patients often exhibit decreased dose requirement*

- Propofol
  - Produced in egg lecithin emulsion (egg yolk—not egg white—which is relevant to patient allergies, which is typically to egg white protein) because of high lipid solubility
  - Formulations support growth of bacteria, good sterile technique and labeling of expiration times (typically 12 hours) is critical
  - Pain on injection occurs in 32–67% of subjects; attenuated with IV lidocaine or administering drug in larger vein

  *Induction dose 1.5–2.5 mg/kg

  *Children require higher doses (larger Vd and higher clearance)

  *Elderly require lower doses (smaller Vd and decreased clearance)

  *Infusion doses ~100–200 mcg/kg/min for hypnosis and ~25–75 mcg/kg/min for sedation (depends on desired level of consciousness and infusion duration)

  *Decreases CMRO2, CBF, and ICP; CPP may decrease depending on effect on SBP

  *Anticonvulsant properties

  *Counterintuitively a cerebral vasoconstrictor!

  *Decreases SVR (arterial and venous), direct myocardial depressant

  *Dose-dependent respiratory depression

  *Has anti-emetic properties – often used for TIVA cases and as background infusion for patients with PONV

  *Propofol infusion syndrome (PRIS): Risk in critically ill patients receiving high dose propofol infusions (>4mg/kg/hr) for prolonged periods of time. Causes severe metabolic acidosis, rhabdomyolysis, cardiac failure, renal failure, and hypertriglyceridemia. High mortality, especially in children. Treatment is supportive.
**ITE tip**

**True or False regarding propofol:**

➢ Propofol can produce bronchodilation in patients with COPD.
➢ Propofol inhibits pulmonary vasoconstriction.
➢ Premedication does not affect the speed to apnea after administration of propofol.
➢ Propofol produces depression of central respiratory drive that is dose-independent.

**Answer:** T, F, F, T

---

**ITE tip**

**True or False regarding Etomidate**

➢ Etomidate is metabolized by hepatic ester hydrolysis to inactive metabolite, which is then renally secreted.
➢ Reduced dose is required in renal insufficiency.
➢ Etomidate reduces cerebral perfusion pressure.
➢ Etomidate is a GABA(B) agonist.

**Answer:** T, F (no need for renal dosing), F (Cerebral blood flow and cerebral metabolic rate are reduced resulting in a decrease in ICP. However, cerebral perfusion pressure is preserved), F (GABA-A agonist)

---

**ITE tip**

**Thiopental**

➢ Highly alkaline (pH 9)
➢ Can precipitate in acidic solutions (DO NOT MIX with Rocuronium)
➢ Induction dose: 0.2-0.3 mg/kg
➢ Rapid onset due to high lipid solubility and large non-ionized fraction at physiologic pH
➢ Myocardiac, hiccups, thrombophlebitis
➢ Decreases CMRO2, CBF, ICP: CPP maintained because less decrease in SBP
➢ Anticonvulsant properties; but minimal effect on duration of ECT-induced seizure activity
➢ Maintains hemodynamic stability (even in the presence of pre-existing disease)
  – Does not induce histamine release
➢ Inhibits adrenocortical synthetic function (11-beta-hydroxylase)
  – Inhibition for 4-8 hours even after a single induction dose, more prominent with infusions
➢ Increased incidence of PONV

---

**ITE tip**

**Ketamine**

➢ Produces a dissociative anesthetic state
  – Profound analgesia and amnesia despite maintenance of consciousness
  – High incidence of psychomimetic reactions (attenuated by co-administration of midazolam)
➢ Induction dose: 1-2 mg/kg
➢ NMDA antagonist (medications in prevention/treatment of chronic pain)
➢ Increases CMRO2, CBF, ICP
➢ Most likely to preserve airway reflexes among the IV anesthetics
➢ Minimal respiratory depression
➢ Cardio-stimulating effects secondary to direct sympathetic stimulation
  – Produces increase in BP, HR and CO
  – Negatively affects myocardial oxygen supply-demand ratio
➢ Intrinsic myocardial depressant, may be significant in severely ill patients with depleted catecholamine reserves
➢ Causes bronchodilation
➢ Causes increased oral secretions (consider co-admin of glycopy)
➢ Useful for chronic pain patients (common dose for intra-operative management is 0.5-1 mg/kg prior to incision (after intubation, unless using for induction) and then 0.25 mg/kg each hour (infusion or bolus)
➢ Common side effect is nystagmus
**ITE tip**

True or False regarding Ketamine

➢ Ketamine is a racemic mixture, and R(−) is more potent than S(+)
➢ Ketamine is secreted in the urine with a half-life of 2-3 hrs
➢ Ketamine is highly protein bound
➢ Norketamine is the metabolite of ketamine and has no clinical effect

Answer: **F** (is more potent), **T**, **F** (highly lipid soluble), **F** (Norketamine is ⅓ as potent)

---

**ITE tip**

After being given 0.2mg flumazenil, the patient becomes responsive and ready to leave, he should be observed for ______ hrs.

Answer: 2-3hrs. Flumazenil is a short acting competitive antagonist of benzos. It has the shortest half-life of all benzos (45mins-1hr) which means that anyone who has received it should be observed for recurrent sedation. Flumazenil has a high portion of free drug when injected with little protein binding. This leads to a very quick onset of action (peak effect in 1-3mins) and allows for quick clearance by the liver. The duration of action from shortest to longest are: flumazenil<midazolam<lorazepam<diazepam.

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**ITE tip**

Dexmedetomidine

➢ Selective α₂ adrenergic agonist (primarily central-acting)
➢ Hypnotic and analgesic
➢ Opioid-sparing effect; does not significantly depress respiratory drive
➢ Usual infusion concentration is 4 mcg/ml
➢ Loading dose 0.5-1 mcg/kg over 10 min
➢ Infusion rate 0.4-1.2 mcg/kg/hr (ask your attending)
➢ Rapid onset (<5 min) and terminal half-life of 2 hours
➢ Decrease dosage for patients with hepatic impairment
➢ Main side effects are bradycardia, heart block, hypotension
➢ Can be utilized for sedation during awake FOB intubations
➢ Useful when managing delirium in pediatric or ICU patients

---

**ITE tip**

Dexmedetomidine is an α2 agonist with α2:α1 receptor selectivity of ______. In comparison, clonidine's α2:α1 receptor ratio is 220:1.

Other key pharmacokinetic parameters include pKa of 7.1, 94% protein binding, and complete ______ (hepatic/renal) biotransformation to inactive metabolites via ______, ______, and ______.

The elimination half-life is ______ hrs and the context-sensitive half-time is ______ min after 10min infusion and ______ min after an 8hr infusion. This medication has no CYP450 drug interactions.

A 62yo male is undergoing a right ganglion cyst excision under local anesthesia with sedation. ABG is taken 30min after starting sedation and the PaCO₂ is 38mmHg, unchanged from a preop baseline ABG. RR is 10, down from 12 bpm. ______ (dexmedetomidine/midazolam/propofol/remifentanil) is most likely administered.

Answer: 1600:1, hepatic, glucuronidation, hydroxylation, N-methylation, 2-3hrs, 4min, 250min, dexmedetomidine
### Summary

<table>
<thead>
<tr>
<th>Drug</th>
<th>Induction Dose (mg/kg)</th>
<th>Effects</th>
<th>Pearls</th>
</tr>
</thead>
<tbody>
<tr>
<td>Propofol</td>
<td>1.5-2.5</td>
<td>Decreases cerebral blood flow, intracranial pressure</td>
<td>Pain on injection (32-67%) can be attenuated with lidocaine and injection into larger veins. Anticonvulsant properties.</td>
</tr>
<tr>
<td>Etomidate</td>
<td>0.2-0.3</td>
<td>Decreases CMRO₂, CBF, ICP</td>
<td>Pain on injection. High incidence of PONV. Myoclonus. Inhibits adrenocortical axis.</td>
</tr>
<tr>
<td>Thiopental</td>
<td>3-5</td>
<td>Decreases CMRO₂, CBF, ICP</td>
<td>Anticonvulsant properties. Can precipitate when injected with acidic fluids (i.e. LR).</td>
</tr>
<tr>
<td>Ketamine</td>
<td>1-2</td>
<td>Increases CMRO₂, CBF, ICP</td>
<td>Analgesic effects. Intrinsic myocardial depressant effects which may unmasked in those with depleted catecholamines.</td>
</tr>
</tbody>
</table>

### References


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**I was in the preop area at the VA, and introduced myself to the patient as Dr. Taylor*. He quickly replied, "What was your name?", to which I said my first name, "Victoria". He looked at me amazed and said, "I can’t believe it. I have your name tattooed on my a**." I asked if he was willing to show me. As he rolled over, the words "your name" appeared on his left butt cheek.**

*Names have been changed*

---

It was the 4th week of CA-1 year, and I knew I was going to need 2 PIVs for a relatively bloody case. That morning I prepared the fluid warmer with a blood pump, ready to go once I got the 2nd PIV inside the OR. In pre-op, I placed a PIV on the RIGHT side, then brought him in to the OR, connected the monitors and started giving fentanyl and propofol through the stop cocks on the LEFT blood pump. No change in the patient or vital signs–my attending and I were puzzled. I came to realize that I was basically feeding meds into the fluid warmer (which had the capacity to absorb the meds without causing significant resistance or dripping onto the floor). Yeah, I remember my attending giving me a smile, shaking his head and saying, "Give me the blood pump and connect it over here." Regardless, the patient was induced and we played it off cool.
Rational IV Opioid Use

Basic Opioid Pharmacology

- Analgesia produced by mu (µ) opioid receptor agonism
  - In the brain (periaqueductal gray matter)
  - In the spinal cord (substantia gelatinosa)
- Well-known side effect profile:
  - sedation
  - respiratory depression
  - chest wall rigidity
  - bradycardia
  - hypotension
  - itching, nausea, ileus, urinary retention
  - miosis (useful to assess patients under GA)
- Opioids are hemodynamically stable when given alone, but cause CO, SV and BP in combination with other anesthetics
- Reduces MAC of volatile anesthetics

Opioid Receptor Subtypes and Their Effects

<table>
<thead>
<tr>
<th>Receptor</th>
<th>Clinical effect</th>
<th>Agonists</th>
</tr>
</thead>
<tbody>
<tr>
<td>µ</td>
<td>Supraspinal (µ1)</td>
<td>Morphine, Met-enkephalin, B-Endorphin</td>
</tr>
<tr>
<td></td>
<td>Respiratory depression (µ2)</td>
<td>Fentanyl</td>
</tr>
<tr>
<td></td>
<td>Physical dependence</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Muscle rigidity</td>
<td></td>
</tr>
<tr>
<td>κ</td>
<td>Sedation</td>
<td>Morphine, Nalbuphine, Butorphanol, Dynorphin, Oxycodone</td>
</tr>
<tr>
<td>δ</td>
<td>Analgesia, Behavioral effects</td>
<td>Leu-enkephalin, B-Endorphin</td>
</tr>
<tr>
<td>σ</td>
<td>Dysphoria, Hallucinations</td>
<td>Pentazocine, Nalorphine, Ketamine</td>
</tr>
</tbody>
</table>

Opioid comparison

<table>
<thead>
<tr>
<th>Drug</th>
<th>Approximate analgesic equivalent</th>
<th>Peak onset</th>
<th>Duration of action (single bolus only)</th>
<th>Used as infusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alfentanil</td>
<td>150-250 mcg</td>
<td>1 – 2 min</td>
<td>5 – 10 min</td>
<td>Not common</td>
</tr>
<tr>
<td>Fentanyl</td>
<td>50 mcg</td>
<td>3 – 5 min</td>
<td>30 – 60 min</td>
<td>Use with caution*</td>
</tr>
<tr>
<td>Hydromorphone</td>
<td>0.75 mg</td>
<td>5 – 15 min</td>
<td>2 – 4 hours</td>
<td>ICU</td>
</tr>
<tr>
<td>Meperidine</td>
<td>37.5 mg</td>
<td>5 – 15 min</td>
<td>2 – 4 hours</td>
<td>No</td>
</tr>
<tr>
<td>Morphine</td>
<td>5 mg</td>
<td>10 – 20 min</td>
<td>4 – 5 hours</td>
<td>ICU (comfort care)</td>
</tr>
<tr>
<td>Methadone</td>
<td>2.5 mg</td>
<td>10 min</td>
<td>24 hours</td>
<td>No</td>
</tr>
<tr>
<td>Remifentanil</td>
<td>50 mcg</td>
<td>3 – 5 min</td>
<td>5 – 10 min</td>
<td>OR</td>
</tr>
<tr>
<td>Sufentanil</td>
<td>5 mcg</td>
<td>3 – 5 min</td>
<td>20 – 45 min</td>
<td>OR</td>
</tr>
</tbody>
</table>

*Infrequently used given long context-sensitive half-life

Single bolus pharmacokinetics

[Graph showing pharmacokinetics of different opioids after a single bolus injection]

Infusion pharmacokinetics

[Graph showing time to 50% drug in concentration at different infusion rates]
Special considerations

Fentanyl
- Easily titratable given rapid onset and short duration of action of single bolus
- Frequently used during induction to blunt sympathetic response to laryngoscopy or LMA placement
- Shorter duration of action can be desirable for analgesia on emergence if concerns for airway protection, delirium, PONV, etc.
- However, very long context-sensitive half-life limits use as an infusion
  - Cut dose in half about every 2 hours
  - Can also lead to prolonged duration of action with repeated boluses intraoperatively

Special considerations

Hydromorphone
- Often used for post-op pain control due to longer duration of action
- Titrate near end of case for smooth wakeup and adequate pain control on emergence
  - Be patient since peak effect can take 15 minutes
- If expected surgical stimulation is relatively constant, can also be given early in case to provide stable analgesia
- Metabolite hydromorphone-3-glucuronide has no analgesic properties, but may cause neuroexcitation
  - No histamine release

Special considerations

Remifentanil
- Most commonly used as infusion when significant intraoperative stimulation but minimal post-operative pain is expected (i.e. analgesic tail is NOT needed)
  - Rapid metabolism by plasma esterases causes no context-sensitivity of half-life
    - i.e. lasts 5 – 10 min regardless of infusion duration
- Typical infusion dosing
  - Start at 0.05 – 0.1 mcg/kg/min
  - Titrate as needed (rarely need more than 0.3 mcg/kg/min)
  - Wean near end of surgery to assess if boluses of long-acting opioids are needed
*do not confuse with sufentanil dosing which is mcg/kg/HOUR!!!

Special considerations

Remifentanil
- Also useful to prevent movement when neuromuscular blockade is contraindicated (i.e. during neuromonitoring)
- Bradycardia is common
  - If giving as bolus, have glycopyrrolate or atropine ready
- Sudden cessation at end of case can lead to acute opioid tolerance
  - Develops within minutes
  - Treatable with more opioid
- Long infusions of higher doses (>0.15 mcg/kg/min) also associated with opioid-induced hyperalgesia
  - Develops within hours/days, can last days-weeks+
  - Less responsive to additional opioid

ITE tip (a short tangent – Esterase metabolism)

- Remifentanil is an introduction to esterase metabolized medications
- Esterases are a group of enzymes that are found in plasma, NMJ, RBC and hepatic sinusoids
- In general all are non-organ dependent metabolic pathways (except that very severe hepatic disease decreases production of plasma cholinesterases)
- RBC esterases
  - Esmolol
    - *Remifentanil in small proportions
- Plasma esterases
  - Remifentanil – fixed and context independent metabolism
  - Atracurium/cisatracurium
  - Etomidate (plasma and hepatic)
- Pseudocholinesterase *aka plasma cholinesterase or butyrylcholinesterase
  - Succinylcholine – fyi this occurs in the plasma (not at the NMJ)
  - Mivacurium
  - Ester local anesthetics

Special considerations

Sufentanil
- Most commonly used as infusion when both significant intraoperative stimulation and post-operative pain are expected (i.e. analgesic tail is desirable)
  - Context-sensitive half-life allows some accumulation (in contrast to remifentanil), but is much more forgiving than a fentanyl infusion
- Typical infusion dosing
  - Divide expected case duration into 3rds
    - 0.3 mcg/kg/h → 0.2 → 0.1
  - Turn off 15 – 30 minutes prior to end of surgery
*don’t confuse with Remifentanil dosing which is mcg/kg/MIN
Opioids

Alfentanil
- Most commonly used as a bolus to treat brief periods of intense stimulation
  - E.g., immediately prior local injection by surgeon during MAC case
- Fastest onset time of all opioids (~90 seconds); pKa = 6.5, so it crosses the blood-brain barrier rapidly despite high protein binding
- Brief duration of action due to rapid redistribution
- Also causes more N/V, chest wall rigidity, and respiratory depression

Morphine
- Slower peak time and long duration of action often less desirable in acute surgical setting
- Active metabolite, morphine-6-glucuronide, has analgesic properties and is renally excreted (not clinically relevant unless patient has renal failure, but common boards question)
- Can cause histamine release

Methadone
- Longest terminal half-life (about 1 day)
- May accumulate during titration to steady state
- L methadone is an opioid agonist
- D methadone is an NMDA antagonist
- Underutilized in anesthesia practice
- As a rule of thumb, many attendings will not give methadone as part of an anesthetic unless the patient will be monitored in the hospital for at least 1 night

Meperidine (Demerol)
- Commonly used to treat shivering upon emergence
- Originally discovered as a local anesthetic ("pethidine")
- Toxic metabolite (normeperidine) lowers the seizure threshold; renally excreted
- Anticholinergic side effects: tachycardia
- Avoid using with MAOIs
  - can cause CNS excitation (agitation, hyperpyrexia, rigidity) or CNS depression (hypotension, hypoventilation, coma)
  - Libby Zion Law: instituted resident physician work hour restrictions after the death of an 18-year-old patient due to serotonin syndrome caused by interaction of a MAOI and meperidine
- Causes histamine release
- Has a euphoric effect with less respiratory depression than other opioids

ITE tip

Rational Opioid Use

Note: All anesthesiologists (attendings & residents alike) have different theories and opinions on the optimal choice and dose of opioids in different situations. The strategies presented here are simply suggestions, something to get you thinking rationally about how and when you use opioids for analgesia. Discuss the merits of these strategies with your attending before or during each case, but do not take these suggestions as firm guidelines for how all anesthetics should be done!

With that disclaimer in mind, continue reading…
Strategies for Opioid Use

- For a standard GETA induction, use fentanyl to blunt the stimulation and subsequent hemodynamic effects caused by DL and intubation
  - Fyi: esmolol is a reasonable alternative
- For brief, intense stimulation (e.g. retrobulbar block, Mayfield head pins, rigid bronchoscopy), consider a bolus of short-acting opioid like alfentanil or remifentanil
- For intra-op analgesia:
  - Fentanyl is rapidly titratable but requires frequent redosing; it may be more "forgiving" if overdosed. Repeated boluses will lead to long duration of action due to long context-sensitive half-life
  - Morphone has a long time to peak effect, but gives prolonged analgesia during the case and into the post-op period
  - Hydromorphone is titratable (like fentanyl) with prolonged analgesia (like morphine)

Strategies for Opioid Use

- For ENT cases, consider an opioid infusion (e.g. remifentanil or sufentanil):
  - Stable level of analgesia
  - Induced hypotension
  - "Narcotic wakeup" reduces bucking on ETT
  - Smooth transition to post-op analgesia
- For chronic opioid users (e.g. methadone, MS Contin, OxyContin, etc.), continue the patient’s chronic opioid dose intraoperatively PLUS expect higher opioid requirements for their acute pain
  - Preop suboxone use and dosing is debated
  - Adjuncts may be helpful (tylenol, lidocaine, ketamine, gabapentin, etc)
  - Use morphine and meperidine cautiously in renal patients (renal excretion of active metabolites)

Strategies for Opioid Use

- Meperidine is usually reserved for treatment/prevention of postoperative shivering
  - Common in younger patients
- For post-op pain control (i.e. PACU):
  - Consider fentanyl (rapid onset, easily titratable, cheap, and the nurses are familiar with its use)
  - Consider hydromorphone (rapid onset, easily titratable, prolonged effect, nurses are familiar with its use, and it is a good transition to PCA)
  - If surgery is ambulatory and/or patient is tolerating POs, give PO (i.e. oxycodone or hydrocodone)

Strategies for Opioid Shortages

- Recommend preop multimodal analgesics:
  - Acetaminophen 1000mg PO (unless liver dz)
  - Gabapentin 600mg PO (reduce dose for impaired renal fxn)
  - One of:
    - Tramadol 100mg PO (unless codeine doesn’t work for the patient, i.e. poor 2D6 metabolizer)
    - Oxycodone 10mg PO
  - Intraop opioid boluses (comparable to fentanyl 150 μg for induction, then fentanyl* 50 μg Q 60 min)

    | Induction | Hourly |
    |-----------|--------|
    | Alfentanil (μg) | 500 | 250* |
    | Meperidine (mg) | 100 | 25 |
    | Methadone (mg) | 5 | 2.5 |

  *for fentanyl and alfentanil: first dose at 30 min

ITE tip: mixed opioid agonists and antagonists

- Mu opioid agonist and kappa receptor antagonist
- Mu agonist and nmda antagonist
- Partial mu antagonist and kappa opioid receptor agonist
- Mu opioid agonist and Ach receptor antagonist
- Mixed mu opioid receptor agonism and antagonism plus kappa receptor agonism
- Mu, kappa, and delta agonists

MEAC = minimum effective analgesic concentration
ITE tip: anticholinergic side effects
Which of the following opioid-receptor agonists has anticholinergic properties?

a. Morphine  
b. Hydromorphone  
c. Sufentanil  
d. Meperidine

Answer: d. Meperidine

References
Intraoperative Hypotension & Hypertension

Determinants of Blood Pressure

Blood Pressure (BP)
- BP represents the force exerted by circulating blood on the walls of blood vessels
- Determined by cardiac output and SVR:
  - \((\text{MAP} - \text{CVP}) = \text{CO} \times \text{SVR}\)

Cardiac Output (CO) = HR x SV
- CO / BSA = Cardiac Index (normal range 2.6–4.2 L/min/m²)
- Dependent on the interplay between the sympathetic and parasympathetic nervous systems
- Infants: SV is relatively fixed; CO depends mainly on HR
- Adults: SV plays a much more important role, particularly when increasing HR is not favorable (e.g. CAD, HOCM, aortic stenosis)

Determinants of Blood Pressure

Stroke Volume (SV):
- Dependent on 1) preload 2) afterload and 3) myocardial contractility

Preload
- Volume of blood in the ventricle at end-diastole (LVEDV)

Afterload
- Resistance to ejection of blood from the ventricle
- SVR accounts for 95% of the impedance to ejection
- SVR (Wood units) = \((\text{MAP}-\text{CVP})/\text{CO}\) (reference range 9-20)
- \(\text{SVR} \times 80 = \text{dyn} \cdot \text{s} / \text{cm}^5\) (reference range 70-160)

Contractility
- The force and velocity of ventricular contraction when preload and afterload are held constant
- Ejection fraction (EF) is one of the most clinically useful indices of contractility (normal left ventricle EF is ~60%).

Components of Blood Pressure

- Systolic, Diastolic, and Mean Arterial Pressures
- Pulse Pressure
  - PP = SBP - DBP
  - Normal PP is ~40 mm Hg at rest, and up to ~100 mm Hg with strenuous exercise.
  - Narrow PP (e.g. < 25 mm Hg) may represent aortic stenosis, coarctation of the aorta, tension pneumothorax, myocardial failure, shock, or damping of the system.
  - Wide PP (e.g. > 40 mm Hg) = aortic regurgitation, atherosclerotic vessels, PDA, high output state (e.g. thyrotoxicosis, AVM, pregnancy, anxiety)
Blood Pressure Measurement

Non-Invasive Blood Pressure (NIBP)
- Oscillometric BP determination: oscillations in pressure are detected through the cuff as it deflates.
- MAP is measured as the largest oscillation; it is the most accurate number produced by NIBP.
- SBP and DBP are calculated by proprietary algorithms in the machine.
- Inaccurate in conditions with variable pulse pressure (e.g. atrial fibrillation) and noncompliant arteries (severe PVD).
- Readings may be affected by external pressure on cuff (e.g. surgeon leaning on arm, moving arm for positioning).

Invasive Arterial Blood Pressure (IABP)
- Most accurate method of measuring BP.
- If system is zeroed, leveled, and properly dampened, SBP, DBP, and MAP are very accurate.

Intraoperative Hypertension: DDx
- "Light" anesthesia
- "Pain" (i.e. sympathetic activation from surgical stimuli)
- Chronic hypertension
- Ilicit drug use (e.g. cocaine, amphetamines)
- Hypermetabolic state (e.g. MH, thyrotoxicosis, NMS)
- Elevated ICP (Cushing’s triad: HTN, bradycardia, irregular respirations)
- Autonomic hyperreflexia (spinal cord lesion higher than T5 = severe; lower than T10 = mild)
- Endocrine disorders (e.g. pheochromocytoma, hyperaldosteronism)
- Hypervolemia
- Drug contamination - intentional (e.g. local anesthetic + Epi) or unintentional
- Hypercarbia

Treatment of Hypertension
- Temporize with fast-onset, short-acting drugs
- Diagnose and treat the underlying cause.
- Pharmacologic Interventions:
  - Deeper anesthesia:
    - Propofol or volatile anesthetics
    - Opioids (increase analgesia, histamine release causes hypotension)
  - Short-acting vasodilators:
    - Clevidipine
      - Calcium-channel blocker.
      - In a lipid emulsion (looks like propofol)
    - Nitroglycerin (venous > arterial dilatation)
      - Avoid both NTG and NTP in setting of intracerebral hemorrhage (cerebral vasodilator)
    - Beta-blockers:
      - Labetalol
      - Esmolol, affects HR >> BP
  - Long-acting vasodilators:
    - Hydralazine - Less predictable pharmacokinetics & pharmacodynamics

Antihypertensive comparison

<table>
<thead>
<tr>
<th>Drug</th>
<th>Initial bolus dose</th>
<th>Onset</th>
<th>Time to peak</th>
<th>Duration of action</th>
<th>Infusion rate range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clevidipine</td>
<td>50 – 100 mcg</td>
<td>1 min</td>
<td>2 – 4 min</td>
<td>5 – 15 min</td>
<td>0.5 – 32 mcg/hr</td>
</tr>
<tr>
<td>Nitroglycerin</td>
<td>10 – 50 mcg</td>
<td>1 min</td>
<td>1 – 3 min</td>
<td>3 – 5 min</td>
<td>0.1 – 1 mcg/kg/min</td>
</tr>
<tr>
<td>Nitroprusside</td>
<td>10 – 50 mcg</td>
<td>&lt;1 min</td>
<td>1 min</td>
<td>1 – 10 min</td>
<td>0.1 – 1 mcg/kg/min</td>
</tr>
<tr>
<td>Labetalol</td>
<td>5 – 10 mcg</td>
<td>&lt;1 min</td>
<td>1 min</td>
<td>45 min – 6 hours</td>
<td>N/A</td>
</tr>
<tr>
<td>Esmolol</td>
<td>10 – 20 mg</td>
<td>1 min</td>
<td>2 min</td>
<td>10 min</td>
<td>50 – 300 mcg/kg/min</td>
</tr>
<tr>
<td>Hydralazine</td>
<td>5 mg</td>
<td>5 – 20 min</td>
<td>15 – 30 min</td>
<td>2 – 6 hours</td>
<td>N/A</td>
</tr>
</tbody>
</table>

Intraoperative Hypotension: DDx
- Measurement error: confirm cuff size and position, for invasive BP confirm transducer level & correlate with non-invasive BP readings
- Hypovolemia: Blood loss, dehydration, diuresis, sepsis
- Drugs: Induction and volatile agents, opioids, anticholinesterases, local anesthetic toxicity, vancomycin, protamine, vasopressor/vasoconstrictor infusion problem, syringe swap or drugs given by surgeon
- Regional/Neuraxial Anesthesia: Vasodilation, bradycardia, respiratory failure, local anesthetic toxicity, high spinal
  - Ensure: Volume loading, vasopressors, airway support, left uterine displacement during pregnancy
- Surgical Events: Vagal reflexes, obstructed venous return, pneumoperitoneum, retractor and positioning
  - Communicate with surgeon and ensure surgical team is aware
- Cardiopulmonary Problems: Tension PTX, hemothorax, tamponade, embolism (gas, amniotic fluid, or thrombotic), sepsis, myocardial depression (from drugs, ischemia, electrolytes, trauma)

Treatment of Hypotension
- Temporize with fast-onset, short-acting drugs, but ultimately diagnose and treat the underlying cause.
- Turn down (sometimes turn off) the anesthetic—give versed if indicated
- Call for help & inform surgical team
- Drugs:
  - Vasoconstrictors: phenylephrine, vasopressin, norepinephrine
  - Positive Inotropes: ephedrine, epinephrine
  - HR control: glycopyrrolate, atropine, pacing?
- Volume:
  - Reevaluate EBL; replace with crystalloid, colloid, or blood, as needed
  - Consider arterial line
  - Other monitoring options: CVP, PAC, or TEE
- Ventilation:
  - Reduce PEEP to improve venous return
  - Decrease I:E ratio to shorten inspiratory time
  - Rule out PTX
- Metabolic:
  - Treat acidosis and/or hypocalcemia

  * Important: Most vasoactive drugs will not work effectively if patient is acidic or hypocalcemic; surviving sepsis guidelines recommend considering bicarbonate use if pH < 7.15
### Pressor/Ionotrope comparison

<table>
<thead>
<tr>
<th>Drug</th>
<th>Initial bolus dose</th>
<th>Onset</th>
<th>Time to peak</th>
<th>Duration of action</th>
<th>Infusion rate range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phenylephrine</td>
<td>50 – 100 mcg</td>
<td>&lt;1 min</td>
<td>1 min</td>
<td>10 – 15 min</td>
<td>0.2 – 2 mcg/kg/min</td>
</tr>
<tr>
<td>Vasopressin</td>
<td>0.5 – 1 unit</td>
<td>&lt;1 min</td>
<td>1 min</td>
<td>30 – 60 min</td>
<td>0.01 – 0.04 units/min</td>
</tr>
<tr>
<td>Norepinephrine</td>
<td>5 – 10 mcg</td>
<td>&lt;1 min</td>
<td>1 min</td>
<td>1 – 2 min</td>
<td>0.02 – 0.3 mcg/kg/min</td>
</tr>
<tr>
<td>Ephedrine</td>
<td>5 – 10 mg</td>
<td>1 – 2 min</td>
<td>2 – 5 min</td>
<td>60 min</td>
<td>N/A</td>
</tr>
<tr>
<td>Epinephrine</td>
<td>5 – 10 mcg</td>
<td>&lt;1 min</td>
<td>2 min</td>
<td>&lt;5 min</td>
<td>0.02 – 0.3 mcg/kg/min</td>
</tr>
</tbody>
</table>

### ITE tip:

**Vasopressor receptors**

<table>
<thead>
<tr>
<th>Vasopressor / Inotrope</th>
<th>Receptor</th>
<th>alpha-1</th>
<th>beta-1</th>
<th>beta-2</th>
<th>Dopaminergic</th>
<th>Physiologic Effects</th>
</tr>
</thead>
<tbody>
<tr>
<td>Norepinephrine</td>
<td>++</td>
<td>++</td>
<td>0</td>
<td>0</td>
<td>++</td>
<td>SVR, +A-CO</td>
</tr>
<tr>
<td>Dobutamine</td>
<td>++</td>
<td>++</td>
<td>0</td>
<td>0</td>
<td>++</td>
<td>++</td>
</tr>
<tr>
<td>Epinephrine</td>
<td>++</td>
<td>++</td>
<td>++</td>
<td>++</td>
<td>++</td>
<td>SVR (low dose)</td>
</tr>
<tr>
<td>Dopamine (ng/kg/min)</td>
<td>++</td>
<td>++</td>
<td>++</td>
<td>++</td>
<td>++</td>
<td>++</td>
</tr>
<tr>
<td>Phenylephrine</td>
<td>++</td>
<td>++</td>
<td>0</td>
<td>0</td>
<td>++</td>
<td>SVR, +A-CO</td>
</tr>
</tbody>
</table>

### References


### ITE tip

A 56-year-old patient with a history of liver disease and osteomyelitis is anesthetized for tibial debridement. After induction and intubation, the wound is inspected and debrided with a total blood loss of 300 mL. The patient is transported intubated to the recovery room, at which time the systolic blood pressure falls to 50 mm Hg. HR is 120 bpm, ABG reads 7.3/45/103, with SpO2 97% on 100% FiO2. VBG reads 7.25/50/60. Which of the following diagnoses is MOST consistent with this clinical picture?

a. Hypovolemia
b. CHF
c. Cardiac tamponade
d. Sepsis with ARDS

**Answer:** d. The patient has an abnormally high mixed venous PO2 (50, versus a normal value of 40). This is consistent with a high cardiac output state, such as sepsis.
Neuromuscular Blocking Agents (NMBAs)

Introduction
- NMBAs facilitate intubation, mechanical ventilation, and surgical relaxation
- There are two categories of NMBAs with distinct properties:
  - Depolarizing (succinylcholine)
  - Non-depolarizing (e.g. rocuronium, vecuronium, cisatracurium)
- Postoperative residual paralysis occurs frequently. Monitoring of neuromuscular blockade and pharmacological reversal are standard of care.
- NMBAs should be used carefully; there are also many surgical and patient-specific contraindications. Neuromuscular blocking agents play a prominent role in the incidence of adverse reactions that occur during anesthesia.
- The Committee on Safety of Medicines in the United Kingdom reported that 10.8% (218 of 2014) of adverse drug reactions and 7.3% of deaths (21 of 286) were attributable to neuromuscular blocking drugs.
- Nondepolarizing agents account for >50% cases of intraoperative anaphylaxis (incidence <0.1%).
- Cross-reactivity has been reported between neuromuscular blocking drugs and food, cosmetics, disinfectants, and industrial materials (anaphylaxis can happen on a patient’s first exposure to the drug).

Neuromuscular Transmission
- Action potential depolarizes motor neuron → Ca++ influx → vesicles fuse and release ACh
- ACh diffuses across synaptic cleft → binds α-subunit of the nicotinic receptors
- When ACh binds both α subunits, receptor ion channel opens
  - Na+ and Ca++ influx
  - K+ efflux

Depolarizing NMBA: Succinylcholine
- Structure: two ACh molecules joined by methyl group
- Mechanism of action: nAChR agonist, prolonged muscle depolarization
- Intubating Dose: 1-1.5 mg/kg
  - 1.5-2 if using a defasciculating dose of rocuronium
- Onset: 30-60 sec
- Duration: ~10 min, depending on dose
- Diffuses away → rapidly metabolized by pseudocholinesterase (aka plasma cholinesterase, butyrylcholinesterase)
- Pseudocholinesterase deficiency
  - In reality, abnormal (nonfxn'l) pseudocholinesterase
  - Heterozygous: incidence ~1/480; paralysis extended 50-100%
  - Homozygous: ~1/3200; paralysis extended 4-8 hrs
  - Consider checking twitches after sux before nondepolarizers
- Dibucaine number: % of normal pseudocholinesterase inhibited by dibucaine (does not inhibit abnormal pseudocholinesterase)
  - Normal 80; Heterozygous 50; Homozygous 20

Contraindications to Succinylcholine
- Hyperkalemia → cardiac arrest
- Induction dose typically > K+ 0.5 mEq/L
- Normokalemic ESRD is NOT contraindication
- Upregulated junctional & extrajunctional AChR → hyperK
- Burn injury >24 hrs, muscular dystrophy, myotonia, prolonged immobility, upper motor neuron dz (spinal cord injury, stroke, tumor, MS, GBS)
- Hx malignant hyperthermia
- Open globe (anterior chamber): transient increase IOP

Additional Side Effects
- Fasciculations (can be decreased with defasciculating dose of rocuronium = 0.03 mg/kg, 3 minutes prior to sux)
- Myalgia: Less frequent in children, ages 50-60yo, those with good muscular training.
- Bradycardia (especially in children -- often given with atropine)
- Tachycardia
- Anaphylaxis (approx. 1:5000 – 1:10,000)
- Trismus
- Increased ICP & IOP
- Increased intragastric pressure and lower esophageal sphincter pressure

Nondepolarizing NMBA
- Mechanism of action: competitive inhibition of nAChR
  - NMBAs also block postsynaptic nAChR, which help mobilize ACh-containing vesicles. Blockade results in the "fade" seen on train-of-four
  - May interact with nicotinic and muscarinic cholinergic receptors within the sympathetic and parasympathetic nervous systems when given at large doses = "autonomic margin of safety"
    - Rocuronium: ED₅₀ >3.5 mg/kg to block vagal, >10 to block sympathetic
- Two structural classes:
  1. Benzylisoquinolinium = "urium"
    - Pancuronium, Doxacurium, Atracurium, Mivacurium, D-Tubocurarine
    - More likely to cause histamine release (d-Tubocurarine >> Atracurium and Mivacurium), can attenuate with slower administration
  2. Aminosteroid = "onium"
    - Pancuronium, Vecuronium, Rocuronium, Pipecuronium
    - Vagolytic effects (Pancuronium > Rocuronium > Vecuronium)
- Most used nondepolarizing agents are of intermediate duration: rocuronium, cisatracurium, vecuronium
Nondepolarizing NMBA (cont.)

- Intubating doses ~2x ED95
  - ED95 = average dose to achieve 95% suppression of twitch height in 50% of population
- Larger intubating dose speeds onset time, lengthens duration
- Priming dose: increase speed of onset
  - 10% of intubating dose 3-5 minutes prior (efficacy debatable)
- Wide inter-individual response to nondepolarizing agents
  - Monitor twitches and adjust doses accordingly
- Rocuronium can be used for RSI (1-1.2 mg/kg) when sux cannot, though roc is still slower and has much longer duration

<table>
<thead>
<tr>
<th>Agent</th>
<th>ED95 (mg/kg)</th>
<th>Intubating Dose (mg/kg)</th>
<th>Onset (min)</th>
<th>Duration to 25% recovery (min)</th>
<th>Intra-op Maintenance</th>
<th>Metabolism</th>
<th>Excretion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Succinylcholine</td>
<td>0.3</td>
<td>1</td>
<td>1-1.5 min</td>
<td>6-8 min</td>
<td>Rarely done</td>
<td>plasma cholin-esterase</td>
<td></td>
</tr>
<tr>
<td>Rocuronium</td>
<td>0.3</td>
<td>0.6</td>
<td>1.5-2</td>
<td>30-40</td>
<td>0.1-0.2 mg/kg prn</td>
<td>&gt;70% Liver</td>
<td>Bile + Urine</td>
</tr>
<tr>
<td>Vecuronium</td>
<td>0.05</td>
<td>0.1-0.2</td>
<td>3-4</td>
<td>35-45</td>
<td>0.01-0.02 mg/kg prn</td>
<td>50% Liver</td>
<td>Bile + Urine</td>
</tr>
<tr>
<td>Cisatracurium</td>
<td>0.05</td>
<td>0.15-0.2</td>
<td>5-7</td>
<td>35-45</td>
<td>0.3 mg/kg q20min prn</td>
<td>Hoffman elimination</td>
<td></td>
</tr>
</tbody>
</table>

*Vecuronium’s 3-OH metabolite (50% potency) accumulates in renal failure. Rocuronium however does not have any active metabolites.

**Recovery of neuromuscular function takes place as plasma concentrations decline, and the greater part of this decrease initially occurs primarily because of distribution after initial drug administration. After a large or repeated dose, recovery relies more on elimination.

N.B. Neostigmine will potentiate a phase I block but will reverse a phase II block if there is a low enough concentration of sux left.

NMBA Monitoring

- Train-of-four (TOF)
  - Most common modality
  - TOF count = # of twitches (out of 4)
  - TOF ratio = height of 4th compared to 1st
- Intraop, often monitored subjectively (visual or tactile)
  - Can’t distinguish TOF ratio >0.4
  - Much less accurate than mechanomyography or accelerometry
- Full recovery
  - TOF ratio 0.9 (e.g. with accelerometer)
  - 5 seconds sustained tetany at 50-100 Hz without fade

Phase I and Phase II blocks

- **Phase I** – depolarization block
  - Often preceded by muscle fasciculation, and is result of pre-junctional action of succinylcholine stimulating receptors on the motor nerve and causing repetitive firing at neurons
  - Channels remain inactive until sux diffuses away to the plasma and is metabolized by plasma cholinesterase
- **Phase II** – desensitization block
  - Repeated or prolonged agonism of the Ach receptor causes it to no longer open and close to stimulation
  - Caused by repeated or high doses of sux
  - Continuous stimulation of the receptor leads to ongoing shifts of K and Na so the blockade effect is prolonged
  - Features of this block are similar to a non-depolarizing blockade, meaning there is fade on TOF, block is antagonized by anticholinesterases (unpredictable though)
  - Seen clinically at >4 mg/kg, but some features present at >0.3 mg/kg

ITE tip
Variability in NMBA Monitoring

- Variability in muscle blockade (most resistant → most sensitive):
  - Vocal cords > diaphragm > corrugator supercilii > abdominal muscles > adductor pollicis > pharyngeal muscles
- To assess deep blockade (i.e. ablate diaphragmatic movement intraop): monitor corrugator supercilii
- To assess return of function of pharyngeal muscles (i.e. readiness for extubation): monitor adductor pollicis
- Caution: differentiate between nerve stimulation and direct muscle stimulation

Recovery after rocuronium (0.6 mg/kg)

- CS = corrugator supercilii
- Abd = Abdomen
- OO = orbicularis oculi
- GH = geniohyoid
- AP = adductor pollicis

Nondepolarizing NMBA Reversal

- Use acetylcholinesterase inhibitors as “reversal agents”: less acetylcholinesterase working → more Ach in NMJ → overcomes the competitive inhibition by rocuronium & allows muscle firing
- Acetylcholinesterase inhibitor-based reversal should not be given until spontaneous recovery has started (the patient should have 2 twitches before reversal)
- Acetylcholinesterases can theoretically paradoxically slow recovery if given too early

Nondepolarizing NMBA Reversal: Sugammadex

- γ-cyclodextrin, directly traps NMBA to reverse its action
- Designed specifically for rocuronium
- Also works for vecuronium (though 2.5x stronger affinity for roc)
- Possible indications:
  - “Cannot intubate, cannot ventilate”: after rocuronium 1.2mg/kg, sugammadex 16mg/kg decreases time to full recovery, 122 min → <2 min
  - Blockade too deep or inadequately reversed by neostigmine
  - During pregnancy (unlike neostigmine, sugammadex does not cross the placenta)
  - Increasing popularity as routine reversal agent given less side effects, faster onset, cheaper cost (institution-dependent) than neostigmine + glycopyrrolate
  - Emerging evidence that reversal with sugammadex may reduce the risk of post-op pulmonary complications (STRONGER trial)

ITE tip: Nondepolarizing NMBA Metabolism

- Has an active metabolite almost as potent as its parent drug, accumulates in renal failure and causes prolonged blockade
- This drug undergoes no clinically significant metabolism and is cleared primarily by the liver via bile excretion
- This drug is metabolized through Hofmann elimination and non-specific ester hydrolysis
- This drug has metabolite laudanosine that can cause neuroexcitation and seizures
- This drug causes sympathomimetic response by blocking Ach receptors

Nondepolarizing NMBA Reversal:

- Anticholinesterase inhibitors:
  - Neostigmine, Pyridostigmine, Edrophonium: do NOT cross BBB
  - Physostigmine: crosses BBB, can treat central anticholinergic syndrome/atropine toxicity
- Pair acetylcholinesterase inhibitor and anticholinergic based on speed of onset to appropriately block muscarinic effect:
  - Edrophonium (rapid) w/ Atropine
  - Neostigmine (intermediate) w/ Glycopyrrolate
  - Pyridostigmine (slow) w/ Glycopyrrolate

- Does reversal increase the risk of PONV? A metanalysis says no (Cheng CR, 2005).
### Sugammadex (cont.)

**Table: Recommended Dosages**

<table>
<thead>
<tr>
<th>Indication</th>
<th>Dose (total body weight)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cannot intubate, cannot ventilate</td>
<td>16 mg/kg</td>
</tr>
<tr>
<td>Deep reversal (1 twitch OR, if recovery has reached at least post tetanic count of 2)</td>
<td>4 mg/kg</td>
</tr>
<tr>
<td>Standard reversal [1-2 twitches in TOF]</td>
<td>2 mg/kg</td>
</tr>
</tbody>
</table>

After inadequate neostigmine reversal sugammadex dose depends on TOF (same as indicated in the above table).

- Caution:
  - Patients using hormonal contraceptives must use an additional, non-hormonal method of contraception for the next 7 days
  - Not recommended in patients with severe renal insufficiency or dialysis (theoretical risk of complex dissociating), though complex can be hemodialyzed using high-flow filter
  - PTT and PT will be prolonged by ~25% for up to 60 minutes (no change in coags clinically)
  - Precipitates if given with ondansetron, verapamil, or ranitidine
  - Anaphylaxis reported as 0.3% (seen in 1 healthy volunteer with study N=375)
  - During post-marketing use, reports of anaphylaxis occurred in ~0.01% cases

### Clinical Pearls

- **Conditions with nAChR upregulation (SENSITIVE to succinylcholine; RESISTANT to NMBA):**
  - Spinal cord injury, stroke, burns, prolonged immobility, prolonged exposure to NMBA, multiple sclerosis, Guillain-Barré syndrome
- **Conditions with nAChR downregulation (RESISTANT to succinylcholine; SENSITIVE to NMBA):**
  - Myasthenia gravis, Lambert-Eaton syndrome, anticholesterase poisoning, organophosphate poisoning

- **Factors ENHANCING block by NMBA:**
  - Volatile anesthetics, aminoglycosides, tetracycline, clindamycin, Mg (watch on OB), IV local anesthetics, CCBs, Lasix, Dantrolene, Lithium, anticoagulants, sux, acidosis, hypokalemia, hypothermia, ketamine

### Intra-op Discussion Topics

- How do you induce a patient with full stomach and open globe?
- Can you use sux with increased ICP?
- What degree of immobility can cause hyperkalemia with sux?
- Can you use rocuronium for a renal transplant?
- Does reversal cause PONV?
- You just gave reversal and there is a lap in the abdomen. How do you paralyze the patient?
- Why is repeated sux doses associated with bradycardia?
- Does a defasciculating dose of roc correspond to decreased myalgia in the setting of using sux?
- When do you use neostigmine vs. sugammadex to reverse NDMB?
- How do you decide what dose of reversal to administer?

### References

For a while, one of the surgery residents referred to me as Superman. Not because of anything good, but because I woke his patient up and he emerged a little goofy. He insisted on keeping his arms stretched perfectly straight out in front of him, and despite many attempts to get him to relax, he wouldn't put them down. We sat the head of the bed up, thinking that might help, but it just made it more obvious to everyone we drove past on the way to the PACU, with this old guy holding his Superman pose.
Difficult Airway Algorithm

According to the ASA, “a difficult airway is defined as the clinical situation in which a conventionally trained anesthesiologist experiences difficulty with facemask ventilation of the upper airway, difficulty with tracheal intubation, or both. The difficult airway represents a complex interaction between patient factors, the clinical setting, and the skills of the practitioner.”

“Remember: patients do not die from an inability to intubate the trachea… they die from a lack of oxygenation. If the pulse ox is dropping, fall back to whatever strategy allows you to oxygenate your patient.

STEPS: (verbatim from the 2013 ASA Practice Guidelines)
1. Assess the likelihood and clinical impact of basic management problems:
   - Difficulty with patient cooperation or consent
   - Difficulty with mask ventilation
   - Difficulty with supraglottic airway placement
   - Difficulty with laryngoscopy
   - Difficulty with intubation
   - Difficulty with surgical airway access
2. Actively pursue opportunities to deliver supplemental oxygen throughout the process of difficult airway management.
3. Consider the relative merits and feasibility of basic management choices:
   - Awake intubation vs. intubation after induction of general anesthesia
   - Non-invasive technique vs. invasive techniques for the initial approach to intubation
   - Video-assisted laryngoscopy as an initial approach to intubation
   - Preservation vs. ablation of spontaneous ventilation
4. Develop primary and alternative strategies (continued…)

Difficult Airway Algorithm

STEPS: (continued…)
Please note:
• First decide: awake or asleep?
• Call for help after initial unsuccessful intubation
• Use SGA after intubation and facemask unsuccessful
• Emergency invasive airway access is listed last; but do not postpone this possible life-saving procedure when indicated.

Difficult Airway Algorithm

BE PREPARED!
• Oxygenation is paramount
• Difficult mask ventilation is more dangerous than difficult intubation
• So long as you can mask, you can oxygenate the patient through almost any anesthetic
• Preparation is key! Set yourself up for success.
   - Do a thorough airway exam
   - Ensure the airway equipment you need is readily available and tested.
   - Take the time to correctly position your patient. Poor positioning can turn a Cormack-Lehane grade 1 view into a grade 4 view.
• Proper positioning is worth your effort, even at the start of an emergent case.

Difficult Airway Algorithm

STEP 1: Assess the Likelihood of Airway Management Problems:

Any possible difficulty with:
• Patient cooperation (awake vs. asleep)
• Mask ventilation
• Laryngoscopy or intubation
• Supraglottic airway placement
• Difficulty with surgical airway access
STEP 1: Assess the Likelihood of Airway Management Problems

**Difficult Mask Ventilation**

If at least 3 of the following predictors of difficult or impossible face mask ventilation are present, be wary:

**DIFFICULT Mask Ventilation**

- Mallampati III or IV
- Mandibular protrusion decreased
- Board
- Obesity (BMI >30 kg/m^2^
- Age >57-58
- Teeth (lack of)
- Booring

**IMPOSSIBLE Mask Ventilation**

- Mallampati III-IV
- Mallampati IV
- Board
- OSA or Upper Airway Surgery
- Radiation changes (neck)

And of course... history of prior difficulty

**Difficult Intubation**

Successful direct laryngoscopy requires aligning the oral, pharyngeal, and laryngeal axes (see image). There are known predictors of difficult laryngoscopy and intubation:

- Mallampati III-IV
- Short, thick neck
- Thyromental distance < 3 (patient’s) finger breadths
- Long incisors, inter-incisor distance < 3 cm (i.e. small mouth opening)
- Prominent “overbite”
- Decreased TMJ mobility, inability to prognath
- Limited cervical range of motion
- Highly arched or very narrow palate
- Poor submandibular compliance (stiff, indurated, occupied by a mass)
- Underlying pathology (e.g. laryngeal stenosis, epiglottis, tumor)

And of course... history of prior difficulty

**Other Difficulties**

STEP 1: Assess the Likelihood of Airway Management Problems

**Difficulty with Patient Cooperation**

- Age
- Mental capacity
- Level of consciousness
- Intoxication

**Difficult Surgical Airway Access**

- Obesity
- Facial hair
- Prior ENT surgery
- Prior radiation to neck
- Gutter

**Predictors of Supraglottic Airway Failure**

- Restricted mouth opening
- Obstruction at or below larynx
- Distorted anatomy
- Stiff lungs

**Mallampati Score Assessment**

**Oxygenation Options**

STEP 2 on the algorithm: Attempt to Oxygenate the Patient throughout the Process

- Mask ventilate in the sniffing position (see next slide)
- Place an oral airway or nasal trumpet
- Place an SGA
- Nasal cannula
- Including high-flow (e.g. Optiflow, “THRIVE”) apneic oxygenation
- When using a fiberoptic bronchoscope:
  - Use an endoscopic mask (e.g. Patil-Syracuse) to allow PPV with a face mask while using the bronchoscope
  - Use a swivel adapter to allow oxygenation via the ETT (if in place) while performing fiberoptic bronchoscopies
- Use the rigid bronchoscope’s side port for oxygen delivery
- Jet ventilation

**Options**

STEP 3: Think Broadly About Your Management Options

A: Awake intubation vs. Asleep (post-induction) intubation

B: Non-invasive technique for initial approach to intubation vs. Invasive technique for initial approach to intubation

C: Video-assisted laryngoscopy as an initial approach to intubation

D: Preservation of spontaneous ventilation vs. Ablation of spontaneous ventilation

**Optimize Positioning**

**Obtaining the Sniffing Position**

- Requires flexion at C7 with extension at C5-C6
- Ramp obese patients until the line between the tragus and the sternal notch is parallel to the floor
- And then verify you are still in the sniffing position. If not, elevate the head

**Heel elevation helps to align PA & LA before DL.**

**Ramp obese patients until tragus is aligned with sternum.**
**Awake Options**

**STEP 4: Awake vs. Post-induction Algorithms**

**Awake Intubation – key is topicalization**

- Non-invasive options:
  - Conventionally, fiberoptic intubation
  - Also consider laryngoscopy (direct, video)
  - Topicalize airway with local anesthetic or perform select nerve blocks
  - A fully-awake patient can tolerate a GlideScope if the airway is properly topicalized!

- Invasive options:
  - Tracheostomy
  - Cricothyroidotomy
  - Retrograde intubation

**Airway topicalization**

- There are many ways to topicalize the airway. Whichever method you choose, make sure to take your time and that your patient is thoroughly topicalized before you attempt the awake intubation
  - Atomizer
  - Viscous lidocaine swish and spit
  - Lidocaine nebulizer
  - "Lollipop" method
  - PICS

---

**Asleep**

**STEP 4: Awake vs. Post-induction Algorithms**

**Post-Induction Intubation**

- If your initial attempt is unsuccessful...
  - Call for help!
  - Attempt to mask ventilate
    - If you can mask, head down the non-emergency pathway
  - If you cannot mask, place an SGA
    - If successful, head down the non-emergency pathway
  - If you cannot mask or place an SGA, head down the Emergency Pathway

---

**Asleep: Non-Emergent**

**STEP 4: Awake vs. Post-induction Algorithms**

**Post-Induction Intubation – Non-emergency Pathway**

- Ventilation is adequate, so you may wake the patient up, or try alternatives
  - **Alternative approaches:**
    - SGA (as bridge to ETT or destination throughout case)
    - Video laryngoscopy
    - Fiberoptic intubation
    - Light wand
    - Blind nasal intubation
  - **Limit direct laryngoscopy attempts**
    - Don’t repeat same DL attempt – change blade, positioning, provider
    - Be very careful to avoid causing airway trauma
    - Oropharynx and larynx are delicate
    - Bleeding and swelling can turn a maskable airway into a "Cannot intubate, Cannot Oxygenate" emergency

---

**Asleep: Emergent**

**STEP 4: Awake vs. Post-induction Algorithms**

**Post-Induction – EMERGENCY PATHWAY (CANT VENTILATE, CANT OXYGENATE)**

- If at any time, ventilation becomes inadequate, you enter the Emergency Pathway:
  - You should already have called for help. If not, do so now.
  - Perform emergency noninvasive airway ventilation
    - Different SGA
    - Combitube
    - Apraxic oxygenation (e.g. Optiflow)
    - Rigid bronchoscopy
  - Perform emergency invasive airway access before SpO2 drops
    - Cricothyrotomy
    - Surgical tracheostomy
    - Trans-tracheal jet ventilation

---

**The Vortex Approach**

- Multidisciplinary approach to the difficult airway
- No more than 3 attempts for each technique (facemask, LMA, ETT)
  - At least one by most experienced clinician
  - Then proceed to surgical airway
  - Do something differently each attempt to optimize (airways, positioning, devices)
  - If you’re even thinking about a cric kit, call for one early!
    - Better to have it and not need it, than need it and not have it.
Surgical Airways

• From an ENT Chief Resident:
  • Even in an emergency, always invest 20 seconds to:
    • Identify someone to assist
    • Place a shoulder roll to expose the trachea
    • Direct a light source at the neck
  • Cannula-based (aka percutaneous) techniques have a far higher failure rate than surgical techniques, which are successful >90% of the time
  • Know how and where to get the tools you need
  • Cricothyroidotomy can be performed in under 60 seconds:
    • Scalpel, #10 or #11 blade
    • +/- Trousseau dilator or Kelly clamp
    • Bougie introducer
    • 6.0 cuffed ETT
  • You will get to practice the procedure on an animal model during your training!

Scalpel-Bougie Surgical Airway Technique

• Identify the cricothyroid membrane
• Make a vertical midline incision
• Palpate the cricothyroid membrane, make a horizontal stab incision and extend to the edge of the cricothyroid membrane
• Turn scalpel 180 degrees and extend incision to the opposite edge
• Use your finger to palpate the incision you just created, and pass the bougie through
• Railroad an endotracheal tube over the bougie, advancing until the balloon is in the trachea but being careful not to advance too deeply
• Confirm placement with end tidal CO2

Clinical Pearls

• Call for help early!
• Anticipate difficulties
• Be prepared in both equipment and mindset
• Always pre-oxygenate to buy yourself safe apneic time
• First DL attempt is the best attempt
• If two DL attempts fail, move on to a different approach
• Remember the pharmacokinetics of your induction and paralytic meds

References

• Holmes et al. 1998 paper “Comparison of 2 Cricothyrotomy techniques”
Fluid Management

Intraoperative Intravascular Assessment

Monitor trends and compare multiple modalities to confirm clinical impressions

Vitals
- HR and BP trends, though consider the impact of positive pressure ventilation and anesthetics when interpreting these parameters
- Pulse Oximetry: waveform changes from baseline (assuming patient normothermic and not in shock)
  - Pulse oximetry: waveform changes from baseline (assuming patient normothermic and not in shock)
  - Pulse pleth variability index (PVI): >12-16% volume responsive

Foley Catheter
- UOP: consider that ADH levels may be increased due to stress response (less reliable measure of volume status intraop)

Arterial Line
- Serial ABGs (pH, Hct, electrolytes)
- Pulse Pressure Variation (PPV): indicator of preload responsiveness; in essence it’s a small fluid challenge with each respiratory cycle from pooled blood in lungs going to left ventricle.
  - PPV = \[\text{Pulse Pressure (Max)} - \text{Pulse pressure (Min)} / \text{Pulse Pressure (Mean)}\]
  - PPV >10% suggests patient is volume responsive
  - Not reliable if not sinus rhythm, open chest, not on PPV, or if TV > 8cc/kg

Central Venous Catheter
- Absolute CVP: unreliable measure of volume status, though trend can be meaningful (still debated)

Pulmonary Artery Catheter
- Most commonly used in RV dysfunction, pulmonary HTN, valvular pathology (AS, MR), LV dysfunction
- Consider risks/benefits of PAC placement

Transesophageal Echocardiogram
- Most commonly used in major cardiac surgeries and liver transplants
- Transgastric view gives most accurate assessment of volume status
- Valuable in narrowing differential of hemodynamic instability

Physiologic Regulation of Extracellular Fluid Volume

Aldosterone
- Enhances sodium reabsorption
- Increases intravascular volume

Antidiuretic Hormone/Vasopressin
- Enhances water reabsorption

Atrial Natriuretic Peptide
- Enhances sodium and water excretion

Body Fluid Compartments

Males: Total Body Water = weight x 60%
Females: Total Body Water = weight x 50%

Total Body Water Components:
- 67% intracellular + (25% interstitial + 8% intravascular)

Intracellular fluid volume 45% of body weight (28 L water*)
Interstitial fluid volume 15% of body weight (10 L)
Intravascular volume 5% of body weight (3.5 L)

*Values shown for a 70kg male

Remember the 5 – 15 – 40 Rule:
5% weight is intravascular water, 15% is interstitial, 40% is intracellular
All other calculations can be extrapolated from this

Evaluation of Intravascular Volume

HPI
- Hypovolemia: vomiting, diarrhea, fever, sepsis, trauma
- Hypervolemia: weight gain, edema, acute renal failure, ascites

Physical Exam
- Hypovolemia: skin turgor, thready pulse, dry mucous membranes, tachycardia, orthostasis, decreased UOP
- Hypervolemia: pitting edema, rales, wheezing, elevated JVP

Labs/Studies
- Hypovolemia: rising Hct, contraction alkalosis then metabolic acidosis, Ur specific gravity > 1.010, Urine Na < 10, Urine Osm > 450, hyponatremia, BUN:Cr > 10:1; bedside ultrasound (IVC <1.7cm OR 1.7cm with >50% IVCCI)
- Hypervolemia: increased pulmonary vascular markings on CXR

Intracellular fluid volume 45% of weight (28 L water*)
Interstitial fluid volume 15% of weight (10 L)
Intravascular volume 5% of weight (3.5 L)

*Values shown for a 70kg male

Remember the 5 – 15 – 40 Rule:
5% weight is intravascular water, 15% is interstitial, 40% is intracellular
All other calculations can be extrapolated from this
Caveat:

Ongoing Losses

Preexisting Fluid Deficits

- Preferred in brain injury/swelling
- More physiologic ("balanced"

LR

Normosol

D5W

Advantages

NS

- Preferred in brain injury/swelling (hyponormal)
- Preferred for diluting pRBCs
- More physiologic ("balanced crystalloid")

LR

- More physiologic ("balanced crystalloid")
- Lactate is converted to HCO₃⁻ by liver

Advantages

Colloids

Albumin (5% and 25%)

- Derived from pooled donated blood after cold ethanol extraction and ultrafiltration; heat-treated (60 degree C x 10 hrs)
- Use 5% for hypovolemia; 25% for hypovolemia in patients with restricted fluid and Na intake
- Minimal risk for viral infection (hepatitis or HIV); theoretical risk of prion transmission
- Expensive; occasional shortages
- Minimal risk for viral infection (hepatitis or HIV); theoretical risk of prion transmission
- Use 5% for hypovolemia; 25% for hypovolemia in patients with restricted fluid and Na intake

Hetastarch (6% hydroxyethyl starch, HES)

- Solution of highly branched glucose chains (average MW 450 kD)
- Degraded by amylase, eliminated by kidney
- Side effects:
  - Can increase PTT (via factor V III/vWF inhibition) and clotting times
  - May interfere with platelet function
  - Contraindications: coagulopathy, heart failure, renal failure
- Newer starch formulations called tetrastarches are less likely to cause coagulopathy and anaphylaxis and can be given in larger doses. Maximum dose: 300 mg/kg/day

Buffer

Glucose

Osm

(mOsm/L)

Na⁺

(mEq/L)

Cl⁻

(mEq/L)

K⁺

(mEq/L)

Ca²⁺

(mEq/L)

Crystalloids

Crystalloid or Colloid?

Advantages

Disadvantages

Crystallloid

- Lower cost
- Readily available
- Requires more volume for the same hemodynamic effect
- Expensive
- Coagulopathy (dextran > HES)

Colloid

- Restores IV volume and HD with less volume, less time
- Longer IV t½
- Maintains plasma oncotic pressure
- Less cerebral edema (in healthy brain tissue)
- Less intestinal edema
- Potential renal complications
- May cause cerebral edema (in areas of injured brain where BBB not intact)

Suggestions for Fluid Management

Tailor management to patient, surgery, and clinical scenario

Use a balanced approach

- Typically start with normosol, NS or LR
- Consider switch from NS to LR, except in neuro cases (because of decreased osmolality) and hyperkalemic patients
- Be wary of using too much NS in hyperkalemic patients as the hyperchloremic metabolic acidosis can increase serum potassium as well
- Type and Cross for pRBC and other blood products prior to surgery if anticipating significant blood loss (ie. trauma, coagulopathy)
- Consider that rapid volume resuscitation with only RBC may still create dilutional coagulopathy
- If receiving > 2 units RBC, consider FFP use

“Classical” Fluid Management

Maintenance

- “4-2-1 Rule” = 4 ml/kg/hr for the 1st 10 kg, 2 ml/kg/hr for the next 10-20 kg, and 1 ml/kg/hr for each additional kg above 20 kg
- To simplify this rule if patient is >20kg, maintenance = 40 + weight

Preexisting Fluid Deficits

- Multiply maintenance requirement by # of hours NPO
- Give 1/2 over 1st hour, 1/4 over 2nd hour, and 1/4 over 3rd hour
- Patients no longer undergo bowel preparation, so deficit decreased

Ongoing Losses

Surgical and Intestinal Losses (capillary leak)

- Minimal tissue trauma (e.g. hema repair) = 0.2 ml/kg/hr
- Moderate tissue trauma (e.g. cholecystectomy) = 2-4 ml/kg/hr
- Severe tissue trauma (e.g. bowel resection) = 4-8 ml/kg/hr

Blood Loss

- EBL = (suction canister - irrigation) + “laps” (100-150 ml each) + 4x4 sponges (10 ml each) + field estimate (very approximate estimation)
- Replace with pRBCs, colloid, or crystalloid

Urine Output: Be aware of losses from increased urine output (diuretics, etc.)

Caveat: This is a general guide to help consider sources of volume loss and replacement, by no means the rule and not data driven as limited data exist
**Liberal vs. Restrictive Management**

**Consequences of Volume Overload**
- Increased mortality and length of ICU/hospital stay
- Increased myocardial morbidity
- Increased pulmonary, periorbital, and gut edema
- Decreased hematocrit and albumin
- Worsened wound healing/ increased anastomosis dehiscence due to edema

**Suggestions for Rational Fluid Management**
- Use good clinical judgment
- Tailor management to patient, surgery, and clinical picture
- Use balanced fluid therapy: use crystalloid for maintenance, consider use of colloid as discussed
- Consider conservative replacement of interstitial losses or UOP unless vital signs unstable or other signs of inadequate perfusion

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**Intraoperative Oliguria**

**Pre-renal (decreased renal perfusion)**
- Hypovolemia
- Decreased CO (LV dysfunction, valvular disease)
- Decreased MAP
- Perfusion is compromised with increased intra-abdominal pressure (e.g. laparoscopy & pneumoperitoneum)

**Post-renal (post-renal obstruction)**
- Foley kinked, clogged, displaced, or disconnected
- Surgical manipulation of kidneys, ureters, bladder, or urethra

**Renal**
- Neuroendocrine response to surgery (i.e. activation of renin-angiotensin-aldosterone system with increased ADH), is age dependent
- Baroreceptor response to PPV also activates neuroendocrine response

**Treatments**
1. Relieve obstruction: check Foley; consider IV dyes (e.g. indigo carmine, methylene blue) to check for patency of ureters (i.e. Urology cases)
2. Increase renal perfusion: fluids (bolus vs increased maintenance rate), vasopressors/inotropes, or furosemide

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**Burns**

- Increased evaporative losses
- H₂O, electrolytes, and protein shift from normal to burned tissue causing intravascular hypovolemia
- Volume to infuse is calculated by the Parkland Formula:
  \[ \text{Volume} = \frac{\%\text{BSA} \times 4 \text{ ml/kg x kg}}{2} \]
- Give 1/2 over the first 8 hours
- Give 1/2 over the next 16 hours
- Replace with Lactated Ringers
- %BSA is determined by the "Rule of Nines"

ITE tip: Burns injuries cause upregulation of extrajunctional acetylcholine receptors, so avoid using succinylcholine >24h after a burn injury due to risk of hyperkalemia

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**ITE Tip**

**IVF components**

**ITE tip**

Fluid resuscitation during major abdominal surgery with which of the following agents is associated with the BEST survival data?

- a. 5% albumin
- b. 6% Hydroxyethyl starch
- c. Dextran 70
- d. None of the above

Answer: d. There is controversy not only as to which intravenous fluid is the best but also how much to give. Most would suggest that lactated Ringers should be the initial resuscitative fluids to any trauma patients, and they are certainly less expensive than 5% albumin, 6% hydroxyethyl starch and dextran 70. Clear advantages of one fluid over another are hard to find.

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**References**

Transfusion Therapy

Packed Red Blood Cells

Definition, Use, & Storage
• Single donor; volume 250-300 ml with Hct ~70%
• 1 unit pRBCs: increases adult Hgb ~1 g/dl or Hct ~3%
• 10 ml/kg pRBC increases Hct 10%
• Always run in with bag of NS or normosol on blood pump
• Solutions not compatible with pRBC:
  • LR (theoretical clot formation due to calcium)
  • D5W, hypotonic solutions (RBC hemolysis)
• Stored at 4˚C in CPD (lasts 21 days), CPDA (lasts 35 days), or Acdsol (lasts 42 days)
• Run through a warmer (Slow rates: Ranger; Fast rates: Belmont or Level 1)
• CPDA:
  • Citrate (anticoagulant): metabolized by liver to bicarb; at high transfusion rates, excess citrate binds to calcium (resulting in hypocalcemia)
  • Phosphate (buffer)
  • Dextrose (energy source)
  • Adenine (precursor to ATP synthesis)

Indications (ASA Guidelines)
1. Hg < 6 in young, healthy patients
2. Usually unnecessary when Hg >10
3. At Hgb 6-10 g/dl, the decision to transfuse is based on:
   • Ongoing indications of organ ischemia
   • Potential for ongoing blood loss
   • Volume status
   • Risk factors for complications of inadequate O2
     – Example: myocardial ischemia

Platelets

Definition, Use, & Storage
• Platelet Concentrate (PC)
  • Platelets from one donated unit, vol = 50-70 ml; plt ~5,000-10,000
  • “6-pack” = 6 pooled PCs from different donors (rarely used anymore)
  • Apheresis Unit
  • Platelets from a single donor; vol = 200-400 ml; plt ~50,000
  • Document as 250ml (no exact number written on unit)
  • Can give ABO-incompatible platelets, Rh tested only
  • However, contain a small amount of RBCs so Rh sensitization can occur for some
  • Stored at room temperature for ≤5 days.
  • Hang separately (on blood pump with NS) – Do not run through fluid warmer, Level 1, or Belmont (heating can injure the platelets but studies have challenged this theory)

Indications (ASA Guidelines)
1. Rarely when plt > 100,000
2. Usually when plt < 50,000 (spontaneous bleed at < 20K)
3. When plt 50-100,000, based on risk of bleeding
4. With platelet dysfunction (e.g. CPB, plt inhibitors, renal dysfunction)

Fresh Frozen Plasma

Definition, Use, & Storage
• Fluid portion from whole blood
• Contains all coagulation factors (except platelets)
• 1 unit increases clotting factors 2-3%
• Use ABO-compatible; Rh-incompatible is OK
• AB blood type is the universal donor
• All blood type is the universal donor
• Stored frozen; takes 30 min to thaw; use within 24 hrs of thawing

Indications (ASA Guidelines)
1. Correction of excessive microvascular bleeding with INR > 2
2. During massive transfusion (before lab results available)
3. Urgent reversal of warfarin (or can use Prothrombin Complex Concentrate)
4. Correction of known factor deficiency, when specific factor concentrates are unavailable
5. Heparin resistance (i.e. antithrombin III deficiency) in patients requiring heparinization

Cryoprecipitate

Definition, Use, & Storage
• Fraction of plasma that precipitates when FFP is thawed
• Contains Factors I (fibrinogen), VIII, XIII and vWF
• 1 unit contains ~5X more fibrinogen than 1 unit FFP
• Typically, 0.1 units/kg would be expected to increase the fibrinogen concentration by 100 mg/dL
• Use within 4-6 hours after thawed if you want to replace Factor VIII

Indications (ASA Guidelines)
1. Rarely when fibrinogen >150 mg/dl
2. When fibrinogen <100 mg/dl with microvascular bleeding
3. During massive transfusion when fibrinogen level not available
4. Bleeding patients with von Willebrand Disease
5. Congenital fibrinogen deficiency
ITE Tip

The administration of FFP in patients on warfarin is MOST appropriate in which of the following scenarios?

a. Elective cataract surgery with INR of 3.0
b. Urgent ruptured appendectomy with INR of 1.8
c. Emergent ex lap with INR of 1.3
d. Femur fracture ORIF that needs to proceed within 48hrs with INR 2.5

Answer is B.

- Warfarin Reversal, Urgent Surgery:
  - INR 1.5-1.9: treat with FFP
  - INR 1.9-5: FFP + 1-3 mg IV vitamin K
  - INR 5-9: FFP + 2-5 mg IV vitamin K

- Warfarin Reversal, Surgery 24-48 Hours Later:
  - INR 1.5-1.9: 1 mg PO vitamin K
  - INR 1.9-5: 1 - 2.5 mg PO vitamin K, if INR still elevated 24 hours after dose give 1 - 2 mg PO vitamin K.
  - INR 5-9: 2.5 - 5 mg PO vitamin K, if INR still elevated 24 hours after dose give 1 - 2 mg PO vitamin K.

- For non-surgical patients, the use of FFP for warfarin reversal is based on bleeding. FFP is not used in non-surgical patients to reverse warfarin if there is no bleeding, even for an INR > 9. Further, FFP is used only to supplement after vitamin K administration in non-surgical patients with bleeding and a supratherapeutic INR.

ITE Tip

Which of the following is NOT an indication for cryoprecipitate administration?

a. Factor VII deficiency
b. Factor XIII deficiency
c. Factor VIII deficiency
d. Surgical bleeding in patients with vWD

Answer is A, cryoprecipitate does not contain factor VII.

Equations

**Arterial O2 Content**

\[
C_aO_2 = O_2-Hb + \text{Dissolved O}_2
= (Hb \times 1.36 \times S_aO_2/100) + (P_aO_2 \times 0.003)
= (15 \times 1.36 \times 100\%) + (100 \times 0.003)
= 20 \text{ cc O}_2/\text{dl (normal)}
\]

**Allowable Blood Loss**

\[
ABL = \left[ \frac{\text{Hct (start)} - \text{Hct (allowed)}}{\text{EBV}} \right] \times \text{EBV}
\]

**Volume to Transfuse**

\[
\text{Volume} = \left[ \frac{\text{Hct (desired)} - \text{Hct (current)}}{\text{EBV}} \right] \times \text{EBV}
\]

Hct (transfused blood)

Ordering Products

- Consider special needs of the patient:
  - Special populations to consider:
    - Cancer patients, BMT recipients, pregnant patients, solid organ transplant patients, those at risk of volume overload, patients with immunodeficiencies
  - Examples of special requests of blood products with certain populations:
    - CMV tested, Irradiated, leukocyte reducted, washed, fresh, volume reduced
  - If you anticipate the patient may require a transfusion, ask them if they will accept blood products during your pre-op discussion
  - If patients refuse transfusion they must sign a special form before going to the OR

Type and Screen

**Type and Screen** (takes 30-120 min, lasts 72 hr)

- **Type:** test ABO-Rh antigens on RBC
  - Recipient RBCs tested with anti-A&B and anti-O (Rh) antibodies
- **Screen:** indirect Coomb’s test to assess for antibodies in recipient’s serum
  - Recipient serum mixed with RBCs of known antigens
  - no agglutination = negative screen
  - If antibody screen is positive: the serum is tested further
  - Use when there is a low likelihood of transfusion. If you give blood in an emergency situation (only a T&S and no crossmatch available), risk of a serious hemolytic reaction is <1%

Type and Crossmatch

**Type and Crossmatch** (if T&S negative, takes 30-60 min)

- **Immediate phase**
  -Recipient serum + donor cells test for recipient antibodies to donor
  - Takes 5 minutes
- **Incubation phase**
  - Incubate products from first test to look for incomplete recipient antibodies to Rh, Kell, Duffy, and Kidd
  - At Stanford, an electronic crossmatch is used instead of a physical crossmatch
  - Use when it is very likely you will transfuse (this actually reserves blood products)
Massive Transfusion

Definition and Use
- Administration of greater than 1 blood volume (~10 units) in 24 hours
- At Stanford, calling the blood bank for the Massive Transfusion Guideline (MTG) will get you 6 pRBCs, 4 FFP, and 1 unit of platelets
- May take up to 30 minutes to have blood prepared and picked up for OR use.
- Typically will utilize Belmont, Level 1, or both for rapid infusion

Lethal Triad of Trauma:
- Hypothermia
- Acidosis
- Coagulopathy

Massive Transfusion

Complications
1. Hypothermia
   - Blood products are stored cold!
   - This worsens coagulopathy and is why you need to run blood through a warming device
2. Coagulopathy
   - Dilutional thrombocytopenia
     - Platelet count likely <100,000 after ~10 units pRBCs
   - Dilutional coagulopathies
     - Factors V & VIII (“labile factors”) in stored blood
3. Citrate Toxicity
   - Citrate is in CPDA storage solution as a Ca²⁺ chelator (why you often give Ca²⁺ with transfusion)
   - Rapid transfusion (>65cc/min in a healthy adult with healthy liver) can cause an acute hypocalcemia
   - Citrate also binds magnesium causing hypomagnesemia

Massive Transfusion

Complications
4. Acid-Base Abnormalities
   - At 21 days, stored blood has pH <7.0, due mostly to CO₂ production, which can be rapidly eliminated with respiration
   - Acidosis more commonly occurs due to tissue perfusion
5. Hyperkalemia
   - K⁺ moves out of pRBCs during storage
   - If EKG changes occur, stop transfusion and treat hyperkalemia
6. Impaired O₂-Delivery Capacity
   - 2,3-DPG decreases in stored blood, causing a left-shifted O₂-Hb dissociation curve rendering Hgb to hold on to & not release as much oxygen at target sites

Transfusion Diagnostics

Thromboelastography (TEG) measures the dynamics of clot formation, stabilization, and dissolution. Assuming the body’s ability to achieve hemostasis is a function of these clot properties, TEG provides specific, real-time indicators of a patient’s in vitro hemostatic state.

Massive Transfusion

Complications
7. Acute Hemolytic Reaction
   - Due to ABO incompatibility
   - Symptoms: fever, chills, flank pain usually masked by GA; watch for unexplained tachycardia and hypotension, diffuse ooze drainage and brown urine; monitor for ARF and DIC
   - Treatment: Stop blood products, Maintenance alkaline UOP (bicarb, mannitol, lasix/crystalloid), supportive care

Transfusion Reactions

*Whenever you suspect a transfusion reaction, STOP THE TRANSFUSION IMMEDIATELY and alert attending, surgeon, and blood bank

- Febrile Non-Hemolytic Reaction
  - Due to recipient reaction to residual WBCs or platelets
  - Benign; occurs with 0.5-1% of transfusions
  - Treatment: Tylenol, Benadryl, slow transfusion, prevention by giving a patient leukoreduced blood
- Anaphylactic Reaction
  - Occurs within minutes; life-threatening
  - Usually associated with IgA deficiency; they have IgA antibodies
  - Signs/Symptoms: shock, angioedema, ARDS
  - Treatment:
    1) Stop blood
    2) Give fluids, Epi, antihistamines, ACLS
  - In a patient with known IgA deficiency, get washed blood (it reduces the amount of plasma proteins and immunoglobins)

- Delayed Hemolytic Reaction
  - Due to antibodies (not anti-A or anti-B) to antigens on donor RBCs
  - More insidious, develops on day 2-21
- TACO (Transfusion Associated Circulatory Overload)
  - Can order volume reduced blood for those with severe CHF
**Transfusion-Related Acute Lung Injury (TRALI)**

- Occurs 4-6 hours after transfusion
- Due to plasma-containing products (platelets and FFP > pRBCs) - usually donor antibodies reacting to recipient leukocytes
- Incidence: 1:1100 (but likely under-reported)
- Mortality 5-10% - Leading cause of transfusion-related mortality
- Signs & symptoms
  - Dyspnea, hypoxemia, hypotension, fever, pulmonary edema
- Diagnosis of exclusion
  - First rule out sepsis, volume overload, and cardiogenic pulmonary edema
- Treatment
  - Supportive care, similar to ARDS (O₂, mechanical ventilation, tidal volume 6-8 cc/kg)
  - Diuretics are not indicated (etiology = microvascular leak, not fluid overload)

**Transfusion Reactions**

**Presenting With Fever**

<table>
<thead>
<tr>
<th>Acute</th>
<th>Delayed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acute Hemolytic</td>
<td>Delayed Hemolytic</td>
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<tr>
<td>Febrile Non-hemolytic</td>
<td>TA-GVHD</td>
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<tr>
<td>Transfusion-related Sepsis</td>
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</table>

**Presenting Without Fever**

<table>
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<tr>
<td>Allergic</td>
<td>Delayed Serumologic</td>
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<tr>
<td>Hypotensive</td>
<td>Post-transfusion Purpura</td>
</tr>
<tr>
<td>Tx-associated Dyspnea</td>
<td>Iron Overload</td>
</tr>
</tbody>
</table>

**ITE Tip**

What is the primary mechanism behind delayed hemolytic transfusion reaction?

a. ABO incompatibility
b. Cytokines and Ab to HLA
c. Donor lymphocytes reacting against recipient
d. Donor RBC Ag

**Answer:** D

**ITE Tip**

A 30 year-old male undergoes an exploratory laparotomy. He receives 4 RBC, 2 FFP and 2 hours after the surgery, he becomes hypoxemic and hypotensive. A CXR shows bilateral pulmonary edema and PCWP is 8 mmHg (normal is 6-12). Which of the following is the most appropriate management of this patient?

a. Corticosteroids to reduce inflammation
b. Diuresis with lasix
c. IV fluid bolus
d. Start a course of antibiotics

**Answer** is C. The treatment of TRALI is very similar to that of ARDS, which is mainly supportive.

- Oxygenation can be maintained using non-invasive or invasive methods. Those that are on mechanical ventilation should have "lung protective" low tidal volume settings.
- Counterintuitively, patients with TRALI are typically hypovolemic with resultant hypotension. Intravenous fluids can be used to resuscitate without worsening the pulmonary status. However, fluids should not be aggressively replaced and vasopressors are another option.
- Since TRALI patients are not volume overloaded, the benefit of diuretics is questionable and their use should be avoided.
- The use of corticosteroids is avoided just as it is in ARDS.
- TRALI is not due to infectious sources and the use of antibiotics treatment is not recommended.

**ITE Tip: Differentiating TACO vs. TRALI**

**TRALI**

- Acute lung injury (ALI)
- Acute onset
- Hypoxemia (PaO₂/FiO₂ < 300 mm Hg or SpO₂ < 90% on room air, or other clinical evidence of hypoxia)
- Bilateral infiltrates on chest radiograph
- Evidence of left atrial hypertension on the EKG
- New onset or exacerbation of three or more of the following within 6 hours of transfusion:
  - Acute respiratory distress (dyspnea, cough, orthopnea)
  - Increased brain natriuretic peptide (BNP)
  - Increased central venous pressure (CVP)
  - Evidence of left heart failure
- Evidence of positive fluid balance
- Radiographic evidence of pulmonary edema

**TACO**

- Acute renal injury (ARI)
- Acute onset
- Hypoxemia (PaO₂/FiO₂ < 300 mm Hg or SpO₂ < 90% on room air, or other clinical evidence of hypoxia)
- Bilateral infiltrates on chest radiograph
- Evidence of left atrial hypertension on the EKG
- New onset or exacerbation of three or more of the following within 6 hours of transfusion:
  - Acute respiratory distress (dyspnea, cough, orthopnea)
  - Increased brain natriuretic peptide (BNP)
  - Increased central venous pressure (CVP)

**Risk-Related Infections**

<table>
<thead>
<tr>
<th>Risk factor/infectious agent</th>
<th>Risk of TTI in blood products released</th>
</tr>
</thead>
<tbody>
<tr>
<td>Virus</td>
<td></td>
</tr>
<tr>
<td>CMV</td>
<td>&gt; 1 in 100</td>
</tr>
<tr>
<td>HIV</td>
<td>1 in 2.135,000</td>
</tr>
<tr>
<td>HCV</td>
<td>1 in 1,920,000</td>
</tr>
<tr>
<td>HBV</td>
<td>1 in 277,000</td>
</tr>
<tr>
<td>HTLV-II</td>
<td>1 in 2,593,000</td>
</tr>
<tr>
<td>Bacterial contamination</td>
<td></td>
</tr>
<tr>
<td>RBC</td>
<td>1 in 38,500</td>
</tr>
<tr>
<td>Platelets</td>
<td>1 in 5,000</td>
</tr>
</tbody>
</table>

*Bacterial contamination is most common with platelets due to their storage in dextrose at room temperature, pRBCs are less common cause due to their storage at 4 C, but *Yersinia* is most likely organism.

Blood is screened for HCV, HBV core Ab, HIV-1, HIV-2, HTLV, syphilis, and zika.
Alternative Strategies for Management of Blood Loss During Surgery

- Autologous transfusion
  - Blood can be taken and self-donated if a patient’s Hct is >34
  - Should be taken 4-5 week prior to surgery
  - Reduces the risk of infection and transfusion reactions
- Cell saver
  - Blood that is shed during the operation is aspirated into a reservoir, mixed with heparin, concentrated, and removed of debris
  - Useful if there are blood losses >1000-1500mL
  - Relative contraindications: septic wound, cancer
  - Heparinized, and provides packed RBCs only, so remember that patients may still require transfusion of other products for coagulopathy
- Normovolemic hemodilution
  - 1-2 units of a patient's blood are removed and stored in a CPD bag and replaced with crystalloid for goal Hct 20-25%
  - Blood is given back after blood loss

It was my first week of anesthesia residency and my mentor asked me to hang some blood to transfuse. I reached up and removed the spike from the bag of fluid that was already hanging...I was immediately soaked by the open IV fluid bag. My mentor later told me that he knew that would happen, but let me do it anyway so that I would always remember to bring the bag down first. I haven’t forgotten.

References

- [http://transfusionmedicine.stanford.edu/](http://transfusionmedicine.stanford.edu/)
Hypoxemia

Causes of Hypoxemia

<table>
<thead>
<tr>
<th>P_{CO_2}</th>
<th>A-a Gradient</th>
<th>DLCO</th>
<th>Corrects w/ supplemental O2?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low inspired O2</td>
<td>Normal</td>
<td>Normal</td>
<td>Normal</td>
</tr>
<tr>
<td>Hypoventilation</td>
<td>↑</td>
<td>Normal</td>
<td>Normal</td>
</tr>
<tr>
<td>Diffusion Impairment</td>
<td>Normal</td>
<td>↑</td>
<td>↓</td>
</tr>
<tr>
<td>Shunt</td>
<td>Normal</td>
<td>↑</td>
<td>Normal</td>
</tr>
<tr>
<td>V/Q Mismatch</td>
<td>Normal</td>
<td>↑</td>
<td>Normal</td>
</tr>
</tbody>
</table>

Shunt: perfusion without ventilation (V/Q=0), see pCO2. No increase in pCO2 (chemoreceptor mediated hyperventilation) until shunt fraction >50%. Dead Space: ventilation without perfusion (V/Q=∞), see pCO2.

Equations

Alveolar-arterial (A-a) Gradient

\[ P_{A-a}O_2 = P_{A}O_2 - P_{a}O_2 \]

Alveolar Gas Equation

\[ P_{A}O_2 = F_{O_2} \left( P_{atm} - P_{H_2O} \right) - \left( P_{a}CO_2 / 0.8 \right) \]

\[ \approx 100 \text{ mm Hg} \]

Normal A-a Gradient: < 10 mm Hg

Normal P_{O_2}: < 105 - age/3

Causes of Hypoxemia

1. Low inspired O2
   - Altitude (normal F_{O_2}, decreased barometric pressure)
   - Hypoxic F_{O_2} gas mixture (crossed gas lines, loss of pipeline pressure)

2. Hypoventilation
   - Drugs (opioids, benzodiazepines, barbiturates), chest wall damage (e.g. splinting from rib fx, neuromuscular diseases, obstruction (e.g. OSA, upper airway compression)
   - Very responsive to supplemental O2 - (PaCO2/0.8) term of alveolar gas equation becomes insignificant at higher FiO2 even with relatively high PaCO2.
   - FiO2 21%
   - PaCO2 40 \rightarrow PAO2 = 0.21(760-47) - 40/0.8 \approx 100 \text{ mmHg} \rightarrow SpO2 100%
   - PaCO2 80 \rightarrow PAO2 = 0.21(760-47) - 80/0.8 \approx 50 \text{ mmHg} \rightarrow SpO2 80%

3. Diffusion Impairment
   - Increased diffusion pathway (e.g. pulmonary edema, fibrosis)
   - Decreased surface area (e.g. emphysema, pneumonectomy)
   - Decreased rate of O2-Hb association (e.g. high CO, anemia, PE)

4. V/Q Mismatch
   - Often multifactorial
   - COPD, ILD
   - Atelectasis (mucus plugging, GA)
   - Endobronchial intubation (ETT is "mainstemmed")

5. Shunt
   - Congenital (e.g. TOF, TA, ASD/VSD/PDA w/ Eisenmengers)
   - AVM (AVF, congenital)
   - Pulmonary fluid (pneumonia, CHF, ARDS, NPPE, TACO, TRALI)
   - Atelectasis (mucus plugging, GA)

6. Mixed Process
   - Hypoxemia is often due to multiple causes.
   - Example: A tourist with COPD is visiting Denver, overdoses on heroin, now s/p MVA with chest wall trauma, pulmonary hemorrhage, Hct = 15%, and LV contusion. What is the cause of hypoxemia?

Hypoxemia in the OR

Use a systematic approach to the Dx/Rx of intra-op hypoxemia

Suggestion: trace a path from the alveoli to the anesthesia machine

1. Listen to the lungs
   - Atelectasis (rales)
   - Pulmonary edema (rales, decreased BS)
   - Bronchoconstriction (rales, shark-fin end-tidal CO2 tracing)
   - Mucus plug or secretions (PAP, TV, mucus in ETT, bronchi)
   - Right mainstem ETT (SpO2 ~90%, PAP, TV, unilateral BS. Caused by repositioning, insufflation with laparoscopic procedures)
   - Pneumothorax (unilateral BS, PAP, TV, HD instability, tracheal deviation if tension physiology)
   - Esophageal intubation (no end-tidal CO2 tracing, BS in stomach & not lungs)

2. Check ETT
   - Cuff deflation
   - Kinked/bitten or detached ETT
   - Extrusion (ENT/Neuro cases when bed turned 180, surgeons near head, leaning on ETT/circuit)
Hypoxemia in the OR

3. Check circuit
   - ETT disconnect
   - Circuit disconnect (check inspiratory/expiratory limbs at machine, connection near ETT, gas sampling line)

4. Check machine
   - Inspiratory & expiratory valves
   - Bellows
   - Minute ventilation
   - \( P_{F2} \)
   - Pipeline & cylinder pressures

5. Check monitors to confirm (you will probably do this 1st!)
   - Pulse oximeter waveform
   - Look at the patient! Are they cyanotic? mottled?
   - Gas analyzer

Management of Hypoxemia

Assuming accurate SpO2/pulse oximetry:
- 100% \( F_{O2} \), high flow
- Manual ventilation: assess compliance, leaks
- Recruitment maneuver if suspected atelectasis & hemodynamics can tolerate
- Auscultate: lung sounds, ETT position
- Bronchodilators if bronchospasm
- Fiberoptic bronchoscopy to further eval ETT position
- Suction airway and ETT
- Consider cardiovascular causes
  - Restore volume, RBCs and/or cardiac output
  - Send ABG/VBG
  - Consider CXR

ITE tip

Differentiating intraoperative Hypoxemia causing changes in ventilator pressures:

<table>
<thead>
<tr>
<th>Airway Resistance</th>
<th>Pulmonary Compliance (Elastic Resistance)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Increased ( P_{Plat} ), Unchanged Pplat</td>
<td>Increased ( P_{Pav} ), Increased ( P_{Plat} )</td>
</tr>
<tr>
<td>Airway compression Bronchospasm Foreign body</td>
<td>Abdominal insufflation, Atelectes, Innominate lung disease</td>
</tr>
<tr>
<td>Kinked endotracheal tube</td>
<td>Obesity</td>
</tr>
<tr>
<td>Mucus plug</td>
<td>Pulmonary edema</td>
</tr>
<tr>
<td>Secretions</td>
<td>Tension pneumothorax, Trendelenburg position</td>
</tr>
</tbody>
</table>

\( P_F \) = peak inspiratory pressure
\( P_{Plat} \) = plateau pressure

O2-Hb Dissociation Curve

Useful "anchor" points:
- \( S_O2 \) 50%  \( P_{O2} \) (mm Hg) 27
- 75%  40
- 97%  100

Note: \( P_{Plat} = 27 \) mm Hg

O2-Hb Curve Shifts

Left Shift

- Alkalosis
- Hypothermia
- Hypocarbia
- Decreased 2,3-DPG
- CO-Hb
- Met-Hb
- Sulf-Hb
- Fetal Hb
- Myoglobin

HB has higher affinity for \( O_2 \) = decreased unloading at tissues

Right Shift

- Acidosis
- Hyperthermia
- Hypercarbia ("Bohr Effect")
- Increased 2,3-DPG
- Sickle cell
- Pregnancy
- Volatile anesthetics
- Chronic anemia

HB has lower affinity for \( O_2 \) = increased unloading at tissues

\( S_O2 = P_{O2} \) mm Hg

P50 is lowest in newborns (18) and highest in children over 12mo of age (30). After 10 years of age, P50 decreases to adult level ~27
Factors Affecting Tissue Oxygenation

- O₂ delivery
- Cardiac output
- Hb (concentration & O₂-Hb dissociation)
- O₂ saturation
- Dissolved O₂ in plasma (little effect)
- O₂ consumption

Equations

**Arterial O₂ Content**

\[
CaO₂ = Hb \times 1.36 \times \frac{SaO₂}{100} + (PaO₂ \times 0.003) \\
= (15 \times 1.36 \times 100\%) + (100 \times 0.003) \\
= 20 \text{ cc O₂/dl}
\]

**Mixed Venous O₂ Content**

\[
CvO₂ = Hb \times 1.36 \times \frac{SvO₂}{100} + (PvO₂ \times 0.003) \\
= (15 \times 1.36 \times 75\%) + (40 \times 0.003) \\
= 15 \text{ cc O₂/dl}
\]

**O₂ Delivery**

\[
DO₂ = CO \times CaO₂ \\
= 5 \text{ L/min} \times 20 \text{ cc O₂/dl} \\
= 1 \text{ L O₂/min}
\]

**O₂ Consumption (Fick Equation)**

\[
VO₂ = CO \times (CaO₂ - CvO₂) \\
= 5 \text{ L/min} \times 5 \text{ cc O₂/dl} \\
= 250 \text{ cc O₂/min}
\]

**O₂ Extraction Ratio**

\[
ERO₂ = \frac{VO₂}{DO₂} \times 100 \\
= \frac{250}{1000} \\
= 25\% \text{ (normal 22-30\%)}
\]

Other Concepts

**Diffusion Hypoxia** (usually with N₂O, due to high inspired % needed)
- Hypoventilation + diffusion of N₂O from blood to alveoli \(\rightarrow\) displaces O₂ \(\rightarrow\) \(P_{2}O_{2}\)

**Absorption Atelectasis**
- Poorly soluble N₂ normally stents alveoli open
- O₂ readily absorbed; 100% FiO₂ predisposes toward atelectasis

**Bohr Effect**
- \(\uparrow PCO₂ \rightarrow \downarrow pH \rightarrow \) right shift of O₂-Hb dissociation curve \(\downarrow O₂-Hb affinity \rightarrow \) \(\uparrow O₂\) release (e.g. at peripheral tissue)

**Haldane Effect**
- \(\uparrow PO₂ \rightarrow \downarrow CO₂-Hb affinity\)
- i.e. O₂-Hb binding \(\rightarrow\) CO₂-Hb dissociation (e.g. when blood enters the lungs)

ITE tip

Which of the following mechanisms is most frequently responsible for hypoxia in the recovery room?

a. Ventilation/perfusion mismatch
b. Hypoventilation
c. Hypoxic gas mixture
d. Intracardiac shunt

Answer: a. The most common cause is uneven V/Q distribution caused by loss of lung volume and atelectasis.
In one of my first days of residency (I was at the Valley, where there are 5 or 6 different kinds of anesthesia machines), it took me about 10 minutes in the morning to find the power button for the ventilator. I felt pretty dumb. The problem ended up being that I had a towel draped over the tray and it was obscuring the otherwise direct view of the right button. But it’s a humbling reminder that our job is a mix of complex physiology / pharmacology / etc. and very practical, mundane details. You can master all the ventilator physiology you want, but it won’t do you much good if you can’t turn the ventilator on.

References


Electrolyte Abnormalities

Hyperkalemia

Definition
- Mild: K+ = 5.5-6.5 mEq/L
- Moderate: K+ = 6.6-7.5 mEq/L
- Severe: K+ > 7.5 mEq/L

Contributing Factors
- Renal disease (esp GFR <15)
- Drugs (ACEI/ARBs, NSAIDs, K-sparing diuretics, digoxin, β-blockers)
- Acidosis
- Hyponatremia, hypocalcemia
- Hemolysis, transfusions (esp old PRBCs – [K+] of 50 or greater!)
- Release from muscle
  - Succinylcholine: acute, transient ↑ 0.5-1 mEq/L (*may be greater in certain diseases)
  - Tourniquet, trauma, rhabdomyolysis
  - Malignant hyperthermia (do not administer verapamil with dantrolene)

Signs and Symptoms
- Cardiac: dysrhythmias, conduction abnormalities, cardiac arrest
  - Classically associated with giving succinylcholine to immobilized (ICU), spinal cord injury, neurological diseases (e.g. MS, ALS), burn patients – upregulated extrajunctional AChR (fetal AChR)
  - Usually with [K+] >6.0 mEq/L
  - Progression with increasing K concentration:
    1. Tall peaked T waves, esp precordial leads
    2. Long PR interval, low P wave amplitude
    3. Wide QRS complex → sine wave → VF arrest, asystole

  - [K+] >7.0 mEq/L: ascending flaccid paralysis, inability to phonate, respiratory arrest

EKG Progression of Hyperkalemia

Hyperkalemia

Treatment
- Stabilize cardiomycocyte membrane
  - Ca gluconate (peripheral IV): 10% calcium gluconate (10cc over 5 min; repeat q5min pm)
  - Ca chloride (central line)
  *Do not use calcium for digitalis toxicity
- Shift K intracellular (temporary)
  - Sodium bicarbonate: 50-100 mEq over 5-10 minutes
  - Regular insulin: bolus 10 units with D50 (25 g = 50 mL)
  - Albuterol
- Remove potassium from body
  - Diuretics (proximal or loop)
  - Kayexalate (PO/PR): oral 30g in 20% sorbitol (50cc); rectal 50g in 20% sorbitol (200cc)
  - Dialysis
**Hyperkalemia**

**Anesthetic Considerations**
- Consider cancelling elective cases if K >5.5
- Avoid succinylcholine
- EKG monitoring
- Avoid hypoventilation (respiratory acidosis)
- Treat acidosis
- Monitor for increased sensitivity to neuromuscular blockers

<table>
<thead>
<tr>
<th></th>
<th>K (mEq/L)</th>
<th>pH</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.9% NaCl</td>
<td>0</td>
<td>5.5</td>
</tr>
<tr>
<td>Lactated Ringer’s</td>
<td>4</td>
<td>6.5</td>
</tr>
<tr>
<td>Normosol, Plasma-Lyte</td>
<td>5</td>
<td>7.0</td>
</tr>
</tbody>
</table>

- Classical teaching favors NS (no K⁺), but hyperchloremic metabolic acidosis worsens hyperkalemia. Negligible [K⁺] in other crystalloids (e.g. LR) would bring serum K closer to 4

**Hypokalemia**

**Definition**
- Mild: K⁺ = 3.1-3.5 mEq/L
- Moderate: K⁺ ≤ 3 mEq/L with PACs
- Severe: K⁺ < 3 mEq/L with PVCs

**Contributing Factors**

- **Preoperative**
  - GI losses (NGT, N/V, diarrhea)
  - Lasix, RTA
  - Magnesium deficiency

- **Intraoperative**
  - Alkalosis (metabolic or respiratory)
  - Insulin
  - Hypothermia

**Signs & Symptoms**
- Cardiac: hyperpolarization → ventricular escape, re-entrant phenomena, ectopic tachycardias, conduction delay
  - PACs, PVCs
  - SVTs (esp afib, aflutter)
- Metabolic alkalosis
- Autonomic lability
- Weakness, DTRs
- Ileus
- Digoxin toxicity
- Increased sensitivity to neuromuscular blockers

**EKG Progression of Hypokalemia**
- Flattened/inverted T wave → U waves, ST depression

**Hypokalemia**

**Signs & Symptoms**
- Cardiac: hyperpolarization → ventricular escape, re-entrant phenomena, ectopic tachycardias, conduction delay
  - PACs, PVCs
  - SVTs (esp afib, aflutter)
- Metabolic alkalosis
- Autonomic lability
- Weakness, DTRs
- Ileus
- Digoxin toxicity
- Increased sensitivity to neuromuscular blockers

**Treatment**

**Acute hypokalemia** = likely from cellular shifts
- Reverse underlying cause (e.g. alkalosis from mechanical hyperventilation)

**Chronic hypokalemia** = total body K⁺ depletion (1 mEq/L = 175-350 mEq total body deficit)
- Peripheral IV: 10 mEq/hr
- Central line: 10-20 mEq/hr
- Life-threatening: 5-6 mEq bolus

**Anesthetic Considerations**
- Consider cancelling elective cases if K⁺ <3-3.5 (based on chronicity of deficit)
- EKG monitoring
- If arrhythmias develop, check/replete K
- Avoid hyperventilation (respiratory alkalosis)
- Consider reduce dose of neuromuscular blocker by 25-50%
Hypercalcemia

Contributing Factors
- Hyperparathyroidism
- Malignancy (esp lung, ENT, GU, GYN, multiple myeloma)
- Immobilization
- AKI
- Drugs (thiazide diuretics, lithium)

Signs & Symptoms
- EKG changes (short QT)
- Hypertension
- Polyuria

Treatment
- Hydration (bolus crystalloid) + Lasix diuresis
- Dialysis

Anesthetic Considerations
- Consider cancelling elective cases
- Avoid acidosis (Increased H+-albumin binding reduces Ca²⁺-albumin binding)
- Check serial K⁺ and Mg²⁺

Hypocalcemia

Contributing Factors

Preoperative
- Hypoparathyroidism
- Renal failure (decreased vitamin D activation)
- Sepsis
- Magnesium deficiency (decreased end-organ response to PTH)

Intraoperative
- Alkalosis (increased Ca²⁺-albumin binding)
- Massive PRBC transfusion (due to citrate binding)
- Drugs (heparin, protamine, glucagon)

Signs & Symptoms
- EKG (prolonged QT, bradycardia)
- Hypotension (vasodilation, decreased contractility, LV failure); usually when iCa <0.65
- Respiratory (laryngospasm, stridor, bronchospasm, respiratory arrest)
- Neuro (cramps, tetany, f/DTRs, perioral numbness, seizures, Chvostek’s sign, Trousseau’s sign)

Treatment
- Calcium gluconate 1 g = 4.5 mEq Ca²⁺ (PIV or central line)
- Calcium chloride 1 g = 13.6 mEq Ca²⁺ (central line only)
- Do NOT give Ca²⁺ and NaHCO₃ together in the same IV - it will precipitate!
- Replace magnesium

Anesthetic Considerations
- EKG monitoring
- Avoid alkalosis
- Monitor paralysis with muscle relaxants
- Monitor iCa with transfusions

Hypermagnesemia

Contributing Factors
- Renal failure
- Hypothyroidism
- Iatrogenic (OB tocolysis)

Signs & Symptoms
- EKG (wide QRS, long PR interval, bradycardia)
- Hypotension (vasodilation, myocardial depression)
- Neuro (excess muscle relaxants, weakness, enhanced neuromuscular blockade)

Treatment
- Hydration (bolus crystalloid) + Lasix diuresis
- Ca²⁺ administration
- Diuresis

Anesthetic Considerations
- EKG monitoring
- Consider reducing dose of neuromuscular blocker by 25-50%

Hypomagnesemia

Contributing Factors
- GI/renal losses
- β-agonists (intracellular shift)
- Drugs (diuretics, theophylline, aminoglycosides, ampho B, cyclosporin A)

Signs & Symptoms
- Usually asymptomatic alone, but contributes to other electrolyte abnormalities (e.g. hypokalemia, hypocalcemia, hypophosphatemia)
- EKG (long QT, PACs, PVCs, asf)
- Neuro (neuromuscular excitability, AMS, seizures)

Treatment
- Replete with MgSO₄ to [Mg²⁺] > 2 mg/dl
- Watch for hypotension & arrhythmias with rapid administration!

Anesthetic Considerations
- EKG monitoring
- Check for coexistent electrolyte deficiencies
### Summary of EKG Changes

<table>
<thead>
<tr>
<th>Electrolyte</th>
<th>PR Interval</th>
<th>QRS</th>
<th>QT Interval</th>
<th>T Waves</th>
</tr>
</thead>
<tbody>
<tr>
<td>↓ Ca</td>
<td>short</td>
<td>narrow</td>
<td>prolonged</td>
<td>inversion</td>
</tr>
<tr>
<td>↑ Ca</td>
<td>prolonged</td>
<td>widened</td>
<td>shortened</td>
<td>--</td>
</tr>
<tr>
<td>↓ Mg</td>
<td>short</td>
<td>narrow</td>
<td>prolonged</td>
<td>--</td>
</tr>
<tr>
<td>↑ Mg</td>
<td>prolonged</td>
<td>widened</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>↓ K</td>
<td>short</td>
<td>narrow</td>
<td>prolonged</td>
<td>flat, U waves</td>
</tr>
<tr>
<td>↑ K</td>
<td>prolonged</td>
<td>widened</td>
<td>--</td>
<td>peaked</td>
</tr>
</tbody>
</table>

**Rule of thumb:** ↓ electrolyte → short PR, narrow QRS, prolonged QT

---

### ITE tip

**What is the suspected electrolyte abnormality?**

- **Answer:** hypercalcemia (short QT and J wave within QRS)

---

### ITE tip

**What is the suspected electrolyte abnormality?**

- **Answer:** hyperkalemia (super peaked T waves)

---

### ITE tip

**What is the suspected electrolyte abnormality?**

- **Answer:** hypokalemia (inverted T waves and prominent U wave)

---

### ITE tip

**What is the suspected electrolyte abnormality?**

- **Answer:** hypocalcemia (prolonged QT interval)

---

### ITE tip

**What is the suspected electrolyte abnormality?**

- **Answer:** worsening hyperkalemia – wide bizarre QRS and prolonged PR
I was in the middle of a long, stable but tedious endometriosis case in the ASC. I tried to open my next vial of dilaudid and blam! It shattered in my hand and I had 2mg of dilaudid dripping down my fingers. Not wanting to be pegged as a CA-1 with a drug problem, I quietly called the pharmacy to ask them how to document the incident. The discussion took about a minute or so, and when I hung up, I realized the attending surgeon had stopped the case and was staring at me, as was everyone else in the room. He told me he gets "easily distracted" and so he was patiently waiting until I was off the phone!

CSI tip: In July, keep your eyes peeled for distinctive splatter patterns of white stuff on new residents' scrubs, badges, or other paraphernalia. It is a sign that they, too, have been sprayed with either Propofol or Kefzol while trying to draw up a syringe. The needle tip has to stay inside the vial.

CSI tip: Don't believe it if another CA1 has a BandAid on their finger or hand and they tell you they cut themself in the kitchen or have a paper cut. Odds are they stabbed themself with a needle drawing up drugs in the morning.
Hypothermia & Shivering

Definition and Measurement

- Hypothermia: a core body temperature less than 36 degrees Celsius
- Many places to measure temperature...
  - Some accurately reflect core temperature:
    - Nasopharynx- risk cause epistaxis
    - Distal Esophagus- strictures and varices are a relative contraindication
    - Tympanic Membrane- lead may perforate the ear drum
    - Thermistor of a Pulmonary Artery Catheter- the gold standard
  - Some lag behind core temperature during thermal perturbations:
    - Bladder- especially when urine output is low
    - Rectum- inaccurate with stool in rectum; contraindicated with neutropenia
- Skin is generally much cooler than core temperature

Pathways of Thermoregulation

- Afferent Sensing
  - Nerve endings are found in the skin, deep abdominal and thoracic tissues, spinal cord, brain matter, and the hypothalamus
  - These thermal inputs travel along A-delta fibers (cold sensation) and C fibers (warm sensation) to the brain via the spinothalamic tracts

- Central Control
  - Thermal inputs are pre-processed within the spinal cord and brainstem.
  - Ultimately, the preoptic-anterior hypothalamus is the central autonomic thermoregulatory center that sums these various inputs.

- Efferent Responses
  - Behavioral responses are triggered by skin temperature.
  - Autonomic responses are triggered by core temperature.

Mechanisms to Control Body Temperature

- Behavioral Responses
  1. Seeking shelter or clothing
  2. Voluntary movement

- Autonomic Responses – there are only 3 things the body can do:
  1. Shivering
  2. Sweating
  3. Modulating vascular tone to redirect blood flow

Interthreshold Range

- Interthreshold Range: the core temperature range between cold-induced and warm-induced responses, usually as narrow as 0.2°C
- General anesthesia
  - inhibits thermoregulation globally
  - increases the interthreshold range 20-fold to around 4°C
- Regional anesthesia
  - inhibits thermoregulation to the lower half of body
  - increases the interthreshold range 4-fold to around 0.8°C

Development of Hypothermia

Phases of Anesthetic-impaired thermoregulation
1. Redistribution hypothermia
2. Heat loss > heat production
3. Heat loss = heat production
   - heat balance is at steady state

Heat transfer in an Icy Operating Room
(in order of importance)
1. Radiation
2. Convection
3. Evaporation
4. Conduction
Benefits of Hypothermia

- Metabolic rate decreases by 8% per 1°C decrease in temperature
- Confers myocardial protection as a lower total body metabolic rate requires less oxygen delivery to tissues, leading to lower demands on the heart to provide cardiac output
- The CNS has partial protection from ischemic and traumatic injuries
- Targeted cooling improves neurologic outcomes after cardiac arrest, and allows deep hypothermic circulatory arrest (i.e., all blood flow ceases) to be induced for certain cardiac surgeries e.g., complex aortic arch repairs
- Possibly provides some protection against malignant hyperthermia

Drawbacks of Hypothermia

- Increases infection rates up to 3-fold
- Delays wound healing and increases risk of surgical graft failure
- Induces a coagulopathy as platelet function fails and coagulation factor function slows (part of the trauma’s “lethal triad”)
- Leads to increased surgical blood loss and greater transfusion rates
- Delays emergence from general anesthesia
- Prolongs the activity of many anesthetic drugs
- Consider rewarming the patient prior to emergence
- Left-shifts the oxygen-hemoglobin dissociation curve, which impairs delivery of O2
- While it decreases cardiac output requirements, hypothermia has a negative effect on inotropy and chronotropy, leads to dysrhythmias, and increases systemic vascular resistance.
- Increases the systemic stress response
- Increases postoperative shivering rates
- Prolongs PACU stays

Warming Strategies

Active Warming
- Forced air (e.g., Bair Hugger)
- Heating pad with circulating water
- Breathing circuit heating & humidification
- IV Fluid warmer (e.g., Ranger)
- Bladder irrigation with warm fluids
- Heating lamp or raising room temp

Passive Insulation
- Cotton blankets
- Surgical drapes
- Heat-reflective “space” blanket

Also...
- Preoperative skin warming is excellent prophylaxis!

Prevention of hypothermia is much more effective than treatment!

Rhythmic Muscular Activity

- Shivering in the PACU
  - Generally due to hypothermia
- Shivering may occur in normothermic patients
  - e.g.: uncontrolled pain can cause non-thermoregulatory driven shivering
- Pure clonic movements
- Seen in patients as volatile MAC drops to the 0.15 – 0.3 range, regardless of temperature
- Fevers
- Seizures

Consequences of Shivering

- Dramatic increase in O2 consumption
  - Up to 500% in some studies
- Increased CO2 production
  - Can greatly increase minute ventilation requirements
- Not all patients can tolerate the increased metabolic and respiratory demands!
  - Also associated with shivering:
    - Trauma
    - Elevated intraocular pressure
    - Elevated intracranial pressures
    - Distressing or even painful
    - Disrupts monitoring, especially oscillometric blood pressure measurements and pulse oximetry

Treatment of Shivering

- Prevention is by far the most important step you can take!
- Warm the patient aggressively
  - Typically, forced air and blankets suffice
- Pharmacologic interventions:
  - Meperidine 12.5-25 mg IV
    - Caution as normeperidine accumulates in renal insufficiency, which then leads to seizures
  - Non-depolarizing muscle relaxants
    - Obviously, only in anesthetized, mechanically ventilated patients
  - And be mindful of the differential of rhythmic muscular activity...
    - e.g. ensure pain is well controlled, patient is not seizing, etc.
ITE tip

What is the most effective way to reduce amount of heat lost due to redistribution from core to periphery during the first 30 min after induction?

Answer: preoperative forced air warming to torso and legs 30 min before induction.

References

- Dr. Pearl’s lectures.
Postoperative Nausea & Vomiting (PONV)

Why do we care about PONV?

- Up to 1/3 of patients without prophylaxis will experience PONV (up to 80% among high-risk pts)
- Causes patient discomfort - patients report avoidance of PONV as a greater concern than post-op pain
- Leading cause of delay of discharge from PACU
- Causes unanticipated hospital admission
- Possible aspiration risk and airway compromise
- Can lead to dehydration and electrolyte changes
- Can cause increased CVP, ICP, suture or mesh disruption, venous HTN and bleeding, or wound dehiscence

Chemoreceptor Trigger Zone

Major Risk Factors

Patient-Related
- Female > male
- History of PONV or motion sickness
- Young > old
- Non-smoker > Smoker

Anesthetic-Related
- Volatile anesthetics including N₂O
- Drugs (postoperative narcotics, neostigmine)
- Aggressive hydration (gut edema)

Surgery-Related
- Duration of surgery – higher risk if > 2 hours
  - Type of surgery shown to have MINIMAL effect (laparoscopic, ENT, neuro, breast, plastics, strabismus)

Evidence Based Risk Factors (Apfel et al., 2012)

- Christian Apfel (UCSF PONV guru) meta-analysis of 22 PONV studies (>95,000 pts)
- Highest risk factors:

<table>
<thead>
<tr>
<th>Risk Factor</th>
<th>OR (versus not having risk factor)</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Female Gender</td>
<td>2.57 (2.32-2.84)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>History of PONV/Motion Sickness</td>
<td>2.09 (1.90-2.29)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Non-smoking Status</td>
<td>1.82 (1.68-1.98)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Younger Age</td>
<td>0.88 per decade</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Use of Volatile Anesthetics</td>
<td>1.82 (1.56-2.13)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Post-op Opioids</td>
<td>1.39 (1.20-1.60)</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>

Simplified Apfel Score

<table>
<thead>
<tr>
<th>Risk factors</th>
<th>Points</th>
</tr>
</thead>
<tbody>
<tr>
<td>Female gender</td>
<td>1</td>
</tr>
<tr>
<td>Non-smoker</td>
<td>1</td>
</tr>
<tr>
<td>History of PONV or motion sickness</td>
<td>1</td>
</tr>
<tr>
<td>Postoperative opioids</td>
<td>1</td>
</tr>
<tr>
<td>Sum =</td>
<td>0-4</td>
</tr>
</tbody>
</table>

PONV Prophylaxis Based on Apfel Score

<table>
<thead>
<tr>
<th>Risk Score</th>
<th>Prevalence PONV</th>
<th>Prophylaxis: No/Yes of Anti-emetics</th>
<th>Examples*</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>9%</td>
<td>0-1</td>
<td>Ondansetron 4 mg + Dexamethasone 4 mg</td>
</tr>
<tr>
<td>1</td>
<td>20%</td>
<td>1</td>
<td>Ondansetron 4 mg + Dexamethasone 4 mg + Propofol infusion</td>
</tr>
<tr>
<td>2</td>
<td>39%</td>
<td>2</td>
<td>Ondansetron 4 mg + Dexamethasone 4 mg + Propofol infusion + Scopolamine patch</td>
</tr>
<tr>
<td>3</td>
<td>60%</td>
<td>3</td>
<td>Ondansetron 4 mg + Dexamethasone 4 mg + Propofol infusion + Scopolamine patch</td>
</tr>
<tr>
<td>4</td>
<td>78%</td>
<td>4</td>
<td>Ondansetron 4 mg + Dexamethasone 4 mg + Propofol infusion + Scopolamine patch</td>
</tr>
</tbody>
</table>

- Combinations should be with drugs that have a different mechanism of action
- Try not to order agents for treatment in PACU that have already been used for ppx (e.g. Re-administration of Zofran in PACU not as effective as first dose used for ppx)

Antiemetic Classes

**5-HT3 Antagonists (e.g. Ondansetron, Granisetron)**
- Serotonin receptor antagonist
- More effective at preventing emesis than preventing just nausea
- Zofran 4-8 mg IV or Kytril 0.1-1 mg IV before end of case (usually given ~30 minutes before emergence)
- Side effects: Headache, QT prolongation

**Steroids**
- Cheap and effective; for prolonged PONV relief
- Uncertain mechanism of action
- Weigh risks/benefits in diabetics and sepsis
- Decadron 4-10 mg IV anytime during case (give post-induction and not when awake: s/e at time of administration is severe perineal itching)

**Induction agents**
- Propofol 10-20 mg IV bolus in PACU vs low-dose infusion during case
- Consider volatile sparing TIVA

**Anticholinergics (e.g. Scopolamine patch)**
- Centrally acting
- Transdermal administration requires 2-4 hours for onset. (give pre-op)
- Anticholinergic side effects (“mad as a hatter”, “blind as a bat”, “dry as a bone”, “red as a beet”) - potentially worse than N/V for some patients
- Scopolamine patch 1.5 mg TD q72hr, place posterior to ear lobe
- Warn patients not to touch patch and wipe eyes → dilate affected pupil
- Avoid in elderly as it can contribute to post-op confusion/ delirium

**Phenothiazines (e.g. Promethazine, Prochlorperazine)**
- Dopamine antagonist (promethazine also exhibits H1 antagonism as well)
- Given IV or IM
- Can cause sedation and extrapyramidal side effects
- Phenergan 12.5-25 mg at end of case

**Gastrokinetic (e.g. Metoclopramide)**
- Dopamine antagonist: can cause extrapyramidal SEs
- Increases GI motility and LES tone, avoid in patients with bowel obstruction
- Reglan 10-20 mg IV before end of case
- Contraindicated in Parkinson’s patients

**Butyrophenones (e.g. Droperidol, Haloperidol)**
- Central dopamine antagonist
- Droperidol cheap and very effective, but a “black box” warning regarding QT prolongation has caused it to fall out of favor (based on data when given at doses 50-100x than standard dosing)
- Contraindicated in Parkinson’s patients
- Droperidol 0.625-1.25 mg IV at end of case.

**Substance P antagonists (e.g. Aprepitant, fosaprepitant)**
- NK1 receptor antagonist; more effective when given with Zofran ATC
- Expensive: typically for posterior fossa neurosurgical cases & chemotherapy-related nausea and vomiting
- Also useful for patients with refractory PONV
- Can be given IV or PO (PO should be given 3 hours before induction)
- Must be ordered from pharmacy

**Other Antiemetic Agents**

**Vasopressors**
- Ephedrine 50 mg IM
- Prevents intestinal hypoperfusion

**Antihistamines (H1-blockers)**
- Cimetidine 300 mg IV
- Ranitidine 50 mg IV
- Often given pre-operatively

**IMPACT Trial: Results**

<table>
<thead>
<tr>
<th>Intervention</th>
<th>RR Reduction</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dexamethasone (vs. none)</td>
<td>26.4%</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Ondansetron (vs. none)</td>
<td>26.0%</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Droperidol (vs. none)</td>
<td>24.5%</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Nitrogen carrier (vs. N2O)</td>
<td>12.1%</td>
<td>0.003</td>
</tr>
<tr>
<td>Propofol gtt (vs. volatiles)</td>
<td>18.9%</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Remifentanil gtt (vs. fentanyl)</td>
<td>-5.2%</td>
<td>0.21</td>
</tr>
</tbody>
</table>

- Interventions acted independently of each other; relative risk reduction (RRR) of combined therapy can be estimated by multiplying individual RRIs
- Average PONV = 34% (59% with volatile + N2O + remi + no antiemetics; 17% with propofol + N2 + fentanyl + antiemetics x 3)
- Use the safest and cheapest antiemetic first; use combined therapy only in moderate or high-risk patients
**Strategies to Reduce PONV**

- Use regional anesthesia vs. GA  
- Use propofol for induction and maintenance of anesthesia (TIVA)  
- Avoid N₂O and/or volatile anesthetics  
  - N₂O’s role in PONV is controversial, possibly related to duration of exposure  
- Minimize opioids (consider Tylenol, NSAIDs, etc.)  
- Maintain euvolemia; avoid hypervolemia (gut edema)  
- Avoid hypotension and cerebral hypoxia  
- Use a combination of antiemetics in different classes  
- Consider acupuncture, acupressure, or transcutaneous electrical nerve stimulation (rarely used)  

**ITE tip**

Which of the factors in adults listed below is the strongest independent predictor of PONV in most adults?  

a. Female gender  

b. History of PONV  

c. History of migraines  

d. History of cigarette smoking

Answer: a

**References**

Extubation Criteria & Delayed Emergence

Extubation Overview

- 12% of the closed claim cases with perioperative difficult airway were from the time of extubation
- ASA Practice Guidelines for Management of the Difficult Airway: has not decreased the number of claims arising from injury at extubation
- Incidence of respiratory complications may be higher with extubation than intubation.
- Most common complications with extubation: coughing, difficult ventilation through facemask, desaturations.
- Extubations are almost always elective with adequate time to methodically plan, organize, and communicate essential interventions.

Extubation Overview (cont)

- As a result, Difficult Airway Society (DAS) published 2012 guidelines with low & high risk algorithm
  - Low Risk: awake vs. deep extubation
    - Awake: usual way of extubating
    - Deep: more advanced, ask your attending, usually has specific indications, others may use it to expedite transfer to PACU and room turnover
  - High Risk: awake (with possible Airway Exchange Catheter (AEC), LMA, or remifentanil technique) vs. postponing extubation vs. tracheostomy
    - AEC: hollow catheters similar in shape to bougie. Can be placed through an ETT in an intubated patient and left in place while the patient is extubated. This allows you to both ventilate through the AEC and easily reintubate if needed by railroading an ETT over the AEC

Extubation Risk Stratification:

- Airway Risk Factors
  - Known difficult airway
  - Airway deterioration:
    - consider bleeding, trauma, edema (surgical site, prone or Trendelenburg positioning, large volume resuscitation)
  - Restricted airway access
  - Obesity and OSA
  - Aspiration Risk

- General Risk factors
  - Cardiovascular, Respiratory, & Neuromuscular diseases
  - Metabolic derangements
  - Special surgical requirements

Deep Extubation

- Deep extubation can be performed when the patient demonstrates adequate depth of anesthesia (e.g. no response to pharyngeal suctioning or jaw thrust, breath holding, etc.)
- Compared to an awake extubation, a deep extubation does not result in tachycardia, hypertension, or coughing and can reduce the risk of wound dehiscence, bleeding and bronchospasm
- However, patients extubated deeply remain at risk for laryngospasm as they emerge from anesthesia, which can occur during transport or in the PACU

“Routine Extubation Criteria”

1. Vital signs stable
   - BP/HR stable within acceptable ranges (on minimal pressors)
   - T > 36.5°C
   - Spontaneous RR >6 and <30, SpO2 > 90%
2. ABG “reasonable” with FiO2 ≤ 40%
   - pH ≥ 7.30, PaO2 ≥ 60 mmHg, PaCO2 ≤ 50-60, normal electrolytes
   - As a surrogate, ETCO2 can be used and should be ≤50
3. Adequate reversal or neuromuscular blockade
   - TOF 4/4, TOF ratio ≥ 0.7-0.9, tetany >5 secs
   - The “direct palpation” method cannot determine if the TOF ratio is ≥ 0.9.
   - Sustained head lift or hand grasp >5 secs (sensitive but not specific)
   - Not adequate to rule out residual paralysis or incomplete reversal
4. Respiratory mechanics adequate
   - Spontaneous VT ≥5 mL/kg, Vital Capacity ≥15 mL/kg
5. Protective reflexes (gag, swallowing, cough) returned
6. Awake, alert, able to follow commands
7. Optimize the patient: 100% O2, consider positioning in slight reverse Trendelenburg, suction oropharynx, consider small dose of fentanyl to reduce coughing

*These need not be present in the case of a deep extubation
Causes of Failed Extubation

<table>
<thead>
<tr>
<th>Causes</th>
<th>Checklist prior to extubation (to help avoid failure)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Failure to oxygenate</td>
<td>TV &gt; 5cc/kg &amp; VC &gt; 15cc/kg</td>
</tr>
<tr>
<td>Failure to ventilate</td>
<td>Same TV parameters above</td>
</tr>
<tr>
<td>Inadequate clearance of pulmonary secretions</td>
<td>Oropharynx suctioned?</td>
</tr>
<tr>
<td>Loss of airway patency</td>
<td>Soft bite block or oral airway placed?</td>
</tr>
<tr>
<td>Loss of airway patency</td>
<td>If aspiration risk, OG tube suction and consider emergence in lateral decubitus position</td>
</tr>
<tr>
<td>Loss of airway patency</td>
<td>If edema a concern, is cuff leak &gt; 10-15%</td>
</tr>
<tr>
<td>Loss of airway patency</td>
<td>Placed in optimal position (sniffing position, head up)</td>
</tr>
<tr>
<td>Loss of airway patency</td>
<td>Reduced risk of laryngospasm? (not in stage 2, airway suctioned)</td>
</tr>
<tr>
<td>Loss of airway patency</td>
<td>Airway exchange catheter for high risk patient?</td>
</tr>
</tbody>
</table>

Cuff Leak Test

- While the patient is ventilated on volume control mode, deflate the ET T cuff
- In the absence of significant airway edema, a leak should be present
- Calculate the difference between your programmed tidal volume and the observed expiratory tidal volume. This is your cuff leak.
- Suggested cutoff for an adequate cuff leak is at least 10-15% of your tidal volume

Standard preparation any extubation

1. Ensure back-up airway/re-intubation equipment available
   - LMA, bougie, Mac/Miller blade nearby on hand
2. Pre-oxygenate with 100% O2; consider recruitment maneuver to reduce atelectasis
3. Reverse neuromuscular blockade
4. Turn off primary anesthetic agent
5. Insert a soft bite block (rolled gauze); suction as appropriate
6. Position patient and bed appropriately
   - Is the patient still turned 180 degrees? Lithotomy position?
   - Consider reverse Trendelenburg positioning to improve ventilation
7. Minimize touching patient during Stage 2 (“light”) anesthesia
8. Confirm that all “Routine Extubation Criteria” are met
9. **Exubate:**
   - Deflate cuff, remove tube with positive pressure
   - Provide 100% O2, ensure patent airway, adequate breathing
   - Use an oral airway or nasal trumpet if needed
10. Transport to PACU on continuous oxygen

Stages of Anesthesia

Described by Guedel in 1937 to describe depth of anesthesia, originally from ether. Classification still used today despite newer agents and delivery techniques.

- **Stage 1 – Amnesia**
  - Ranges from awake to loss of consciousness, amnestic throughout
  - Hypertension, tachycardia, dilated/non-conjugate pupils
- **Stage 2 – Delirium/Excitement** *
  - Potential for vomiting, laryngospasm, breath-holding
  - Constricted pupils, regular respirations, cardiovascular stability (e.g. prevention of tachycardia and/or hypotension)
- **Stage 3 – Surgical Anesthesia**
  - Absence of movement
  - Constricted pupils, regular respiration, cardiovascular stability (e.g. prevention of tachycardia and/or hypotension)
- **Stage 4 – Overdose**
  - Shallow or no respiration, dilated/non-reactive pupils, cardiovascular collapse (e.g. hypotension)
  - Avoid extubation during Stage 2 to reduce risk of laryngospasm

Diagnosis and Treatment

**Stanford Protocol for Delayed Emergence**

- **Anesthesia Related**
  - Rapid shallow breaths? MAC still showing?
  - Time since propofol turned off?
- **Excessive narcotics**
  - Recent administration? Pinpoint pupils?
  - Residual muscle relaxant, pseudocholinesterase deficiency.
- **Metabolic**
  - Hypothermia (T<34°C)
  - Hypoxemia
  - Hypercapnia/hypernatremia/hypokalemia/hypoglycemia
  - Renal/hepatic failure
- **Intracranial event**
  - Stroke/CVA (2.5-5% in high risk patients)
  - Seizure
  - Intracranial HTN
- **Diagnosis and Treatment**
  - Confirm that all anesthetic agents (inhalational/IV) are off
  - Check for residual NMB paralysis, reverse as appropriate
  - Consider opiate reversal (medications delivered, evaluate pupils & respiratory rate)
  - Start with 40mcg naloxone IV, repeat Q2 mins up to 200mcg total
  - Consider inhalational anesthetic reversal (rare)
    - 1.25 mg of physostigmine IV
  - Consider benzodiazepine reversal
    - Start with 0.2mg Midazolam IV, repeat Q1 min up to 1mg total
  - Check blood glucose level & treat hypo or hyperglycemia
  - Check ABG and electrolytes
  - rule out CO2 narcosis and hypox or hyponatremia
  - Check patient temperature and actively warm if <34 degrees C
  - Perform neuro exam if possible: examine pupils, symmetric motor movements, gag reflex/cough
  - Obtain stat head CT and consult neurology/neurosurgery to rule out possible CVA
  - If residual sedation/coma persists despite the evaluating all possible causes, ICU admit with neurology follow up, frequent neuro exams, repeat head CT in 6-8hrs if no improvement
References

Laryngospasm & Aspiration

Airway Anatomy Review

- Pharynx - passage that connects posterior nasal and oral cavities to the larynx and esophagus.
  - Nasopharynx
  - Oropharynx
  - Laryngopharynx – starts at epiglottis and extends to cricoid cartilage at the level of C6 vertebrae

Airway Innervation Review

Larynx is innervated by CNX – RLN and SLN are branches of the vagus nerve (CNX)

- Recurrent Laryngeal Nerve
  - Provides sensation to pharynx, middle ear, posterior one third of the tongue and the carotid body/sinus
  - Provides sensation to larynx from the glottis (vocal cords) and below
  - Provides motor innervation on all intrinsic muscles of the larynx **except the cricothyroid muscle**

- Superior Laryngeal Nerve
  - Internal branch
    - Sensory nerve innervating larynx above the glottis (vocal cords) up to the epiglottis.
    - Afferent sensory input between epiglottis and vocal cords
  - External branch
    - Motor nerve to cricothyroid muscle which tenses and adducts the vocal cords

**Glossopharyngeal nerve does not innervate the larynx**

Laryngeal Anatomy

Laryngeal Anatomy: Innervation

<table>
<thead>
<tr>
<th>Nerve</th>
<th>Motor</th>
<th>Sensory</th>
</tr>
</thead>
<tbody>
<tr>
<td>Recurrent Laryngeal</td>
<td>Thyroarytenoid (tensor)</td>
<td>Subglottic mucosa</td>
</tr>
<tr>
<td>(from CN X)</td>
<td>Lateral Cricoarytenoid (adductor)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Transverse Arytenoid (adductor)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Posterior Cricoarytenoid (adductor, tensor)</td>
<td></td>
</tr>
<tr>
<td>Superior Laryngeal</td>
<td>None</td>
<td>Epiglottis/Tongue Base</td>
</tr>
<tr>
<td>(from CN X)</td>
<td></td>
<td>Supraglottic mucosa</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
| **Note:** The RLN innervates all of the intrinsic muscles of the larynx except for the cricothyroid muscle (innervated by the external branch of SLN). RLN injury produces unopposed superior laryngeal n. activity (adduction) on the vocal cord.
Laryngospasm

What is laryngospasm?
- Closure of the true vocal cords (+/- the false vocal cords) from the action of laryngeal muscles → occlusion of the glottis/laryngeal inlet
- Mediated by Superior Laryngeal Nerve
- Consequences include hypoxia, hypercapnia, and negative pressure pulmonary edema (NPPE)

Predisposing Factors
- Stage 2 of anesthesia (excitement/delirium)
- Light anesthesia relative to surgical stimulation
- Mechanical irritants to the airway
  • Blood, mucous, vomit, secretions
  • ETT (RR 12) > LMA (RR 7) > facemask
  • Suctioning
- Reactive airway disease, eczema, asthma, rhinitis, smoking exposure
- Recent upper respiratory tract infection (< 1 month); (RR 3.4)
- Pediatrics ~3x more likely than adults

Prevention
- Ensure adequate anesthetic depth before manipulation or movement of patient
- Clear secretions before extubation- suction
- Topicalize larynx with local anesthetic (LTA)
- Adequate reversal of muscle relaxants to assist in secretion management

Detection
- Inspiratory stridor/ airway obstruction
- Increased inspiratory effort/tracheal tug
- Paradoxical chest/abdominal movements
- Auscultate with stethoscope over trachea to listen for degree of obstruction & airway patency
- Poor EtCO₂ tracing, desaturation, bradycardia, central cyanosis

Management - CALL FOR HELP EARLY!
1. Jaw thrust, head tilt, oral or nasal airway
   • Larson’s Maneuver: a jaw thrust with bilateral pressure on the body of the mandible anterior to the mastoid process
2. Suction oropharynx
3. CPAP via bag-mask ventilation with 100% O₂ May need pressure ~40 mmHg
4. Deepen anesthesia with IV agent (e.g. Propofol)
5. Succinylcholine 10-20 mg IV, maintain airway with bag-mask or ETT until spontaneously breathing
6. Reintubation vs. prepare for surgical airway
7. Monitor for post-obstructive negative pressure pulmonary edema (NPPE)

Negative Pressure Pulmonary Edema

Causes
- Laryngospasm
- Upper airway obstruction/ETT obstruction (e.g. biting on tube)
- Incidence: 0.1% of anesthetics

Risk Factors
- Laryngospasm
- Young (20-40 years), healthy (ASA I-II), male (80%)

Presentation
- Laryngospasm, chest wall retraction
- Frothy, serosanguinous or bloody airway secretions
- SPO₂, ET CO₂, hypotension, large P(A-a) gradient
- CXR with pulmonary edema

Pathogenesis
- Negative intrathoracic pressure (up to -100 cmH₂O)
- RV preload → pulmonary hydrostatic pressure
- RV preload → interventricular septum shift → LV diastolic dysfunction → PCWP
- Hypoxia, hypercapnea, acidosis → Hypoxic Pulmonary Vasoconstriction (HPV) & RV afterload
- Stress response → SVR and LV afterload
- Alveolar-capillary membrane leak → protein loss

Treatment
- Supportive care (O₂, IPPV, PEEP/CPAP)
- Conservative management until process reverses (usually quickly); consider volume and/or pressors PRN.
- Lasix is usually NOT helpful
- Severe cases may require reintubation or ECMO

Pulmonary Aspiration

Predisposing Conditions
- Full stomach or unknown NPO status (e.g. trauma)
- Intra-abdominal process (bowel obstruction, ileus, inflammation)
- Gastroparesis (narcotics, DM, uremia, ETOH, infection, severe pain/trauma)
- GE junction incompetence (GERD, hiatal hernia, scleroderma)
- Pregnancy, obesity
- Neuromuscular disease processes
- Difficult intubation and/or prolonged bag-mask ventilation
Pulmonary Aspiration

Prevention
- Follow NPO guidelines for routine elective cases
- Use metoclopramide, H2-blockers, and antacids in high-risk patients
- Consider awake, regional anesthetic (e.g. spinal or epidural for c-sections)
- Consider awake, upright intubation and/or RSI
- If present, leave NGT to suction
- Apply cricoid pressure until ETT position confirmed
  - Although this practice is debated, one could contend it is considered the ‘standard of care.’
- Minimize bag-mask PPV and/or keep pressure ≤20 cmH2O
- Extubate after recovery of protective reflexes
- Remain vigilant: aspiration occurs during emergence and maintenance and not just during induction

Aspiration Pneumonitis
- Sterile, chemical pneumonitis caused by aspiration of acidic and particulate material
- Highest risk in patients with gastric volume >25 ml and pH <2.5.

Management
- Place patient in head-down position (allow to drain from lungs)
- Immediately suction pharynx and trachea before PPV
- 100% O2, intubate (if needed), apply PEEP or CPAP
- Supportive care - monitor for chemical PNA/ARDS
- Antibiotics are not necessary unless subsequent infection develops (i.e. as happens more commonly in pediatrics, fecal matter is aspirated)
- Steroids are not indicated

NPO Guidelines

<table>
<thead>
<tr>
<th>Ingested Material</th>
<th>Minimum Fasting Period</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

ITE tips

- Pt has hoarsness and weak voice after extubation, which nerve is injured?
  - Unilateral RLN injury
    - Cords assume a paramedian position
    - Cannot move laterally on the affected side
    - Can still move air usually
  - Bilateral RLN injury

- Which nerve is the afferent limb of laryngospasm reflex?
  - SLN

- Pt has aphony and airway obstruction after extubation, which nerve/nerves are injured?

References

- Practice guidelines for preoperative fasting and the use of pharmacologic agents to reduce the risk of pulmonary aspiration: application to healthy patients undergoing elective procedure: an updated report by the American Society of Anesthesiologists Committee on Standards and Practice Parameters. Anesthesiology. 2011 Mar;114(3):495-511
Oxygen Failure in the OR

Etiology

Loss of Pipeline Oxygen
- Exhaustion of central O₂ supply.
- Obstruction of central O₂ supply line to OR.
- O₂ shutoff valve in OR is off.
- Obstruction or disconnection of O₂ hose in the OR.
- Failure of O₂ regulator in the anesthesia machine.

Faulty Oxygen Supply
- Crossing of pipelines during construction/repairs.
- Incorrect connection of gas hoses.
- Non-O₂ cylinder at the O₂ yoke.
- Wrong gas in the O₂ cylinder.
- Broken flowmeter.

Prevention of O₂ Failure is KEY

Selected Daily Pre-anesthesia Machine Checks
- Verify Auxiliary Oxygen Cylinder (with regulator) and Self-Inflating Manual Ventilation Device (ie AMBU) are Available and Functioning
- Verify pipeline gas pressure ≥50 psi.
- Verify that pressure is adequate (>50%) on the spare oxygen cylinder mounted on the anesthesia machine
- Verify calibration of O₂ analyzer and that the low O₂ alarm is audible
  - Self-calibrating O₂ monitors should read 21% when sampling room air

Supply-Side Safety Features
- Color-coded gas tanks
- DISS, PISS, and Quick Connects

Anesthesia Machine Safety Features
- Flow-meter arrangement
- O₂:N₂O ratio controller
- Oxygen supply failure protection device ("fail-safe valve")

Medical Gas Cylinders

- Designations A (smallest) through H (largest)
- E-cylinders most common in the OR (portable)
- H-cylinders most common in central pipeline
- O₂ E-cylinders are used as backup in case of pipeline supply failure (2200 psi)
  - Attached to anesthesia machine via pin index safety system (PISS) and must be checked prior to delivering anesthetics (maintain in closed position unless needed to avoid depletion)

Gas Cylinders

<table>
<thead>
<tr>
<th>Gas</th>
<th>E-Cylinder Capacity (L)</th>
<th>Pressure (psi)</th>
<th>Color (USA)</th>
<th>Color (Int’l)</th>
<th>Form</th>
</tr>
</thead>
<tbody>
<tr>
<td>O₂</td>
<td>660</td>
<td>1900</td>
<td>Green</td>
<td>White</td>
<td>Gas</td>
</tr>
<tr>
<td>Air</td>
<td>625</td>
<td>1900</td>
<td>Yellow</td>
<td>White &amp; Black</td>
<td>Gas</td>
</tr>
<tr>
<td>N₂O</td>
<td>1590</td>
<td>745</td>
<td>Blue</td>
<td>Blue</td>
<td>Liquid + Gas*</td>
</tr>
<tr>
<td>N₂</td>
<td>650</td>
<td>1900</td>
<td>Black</td>
<td>Black</td>
<td>Gas</td>
</tr>
</tbody>
</table>

*Because N₂O is stored as a liquid, the psi of 745 will not decrease until the tank is at 1/4 capacity (400 L); you must weight the tank to know how full it is.

How long can you use an O₂ tank starting at 430 psi running at 5 L/min? (remember 3 psi = 1 liter for oxygen)

Answer = PSI ÷ 3 ÷ Flow rate.
430 ÷ 3 ÷ 5 = 29 minutes

Pin Index Safety System

International Standard:
- Physical barrier to ensure that the correct gas is connected to the correct cylinder type
- Pin positions for each gas is unique
- Do not break or force pins to connect
- Possible to bypass safety check if pins are eroded, damaged, or corroded
**Diameter Index Safety System**

Standard for non-interchangeable, removable connections where color-coded gas hoses at pressures of ≤200psi connect to the wall outlet of each gas with different diameter threaded connectors (tighter connection than Quick Connect).

3 Components: body, nipple, nut

---

**Flowmeter Arrangement**

- A leak in the upstream O₂ flowmeter ("Incorrect sequence") results in a hypoxic gas mixture.
- A leak in the Datex-Ohmeda or Draeger flowmeter arrangements may deliver less Air or N₂O than expected, but the mixture will NOT be hypoxic because O₂ is closest to the FGF outlet.

Note: Flowmeter governed by viscosity at low "laminar" flows (Poiseuille’s law); density at high "turbulent" flows

\[ Q = \frac{\pi Pr^4}{8n} \]

---

**O₂:N₂O Proportioning System**

"hypoxic guard"

Linkage mechanisms between flow valves can be either mechanical (above), pneumatic, or electronic to prevent FiO₂ <25% when N₂O is used.

CAVEAT! Can still deliver hypoxic mixtures IF there are:
- Incorrect supply gas connections
- Errors in or defective components/links
- Downstream leaks
- Introduction of third inert gas like helium

---

**Detection**

- Pressure gauges fall (pipeline, tanks)
- Low O₂ alarms (O₂ supply failure, FIO₂ analyzer)
- Flowmeters fall (O₂ and other gases)
- O₂ flush inoperative
- Bellows inoperative
- Apnea alarms (spirometer, capnograph)
- Increasing O₂ flow makes the problem worse
- Hypoxemia, hypercarbia
- Arrhythmias, bradycardia, cardiac arrest

---

**Management**

- Notify surgeon, call for help, use emergency manual.
- Verify problem
- Disconnect patient from machine and ventilate with Ambu bag. Do not use auxiliary O₂ on machine as the source is the same. If patient needs higher FIO₂ call for extra E-cylinders early.
- To keep patient connected to anesthesia machine, open O₂ cylinder on the back of the anesthesia machine and disconnect from pipeline O₂.
- Use manual ventilation to conserve O₂.
- D/C supply lines if crossed pipelines suspected.
- Check pipeline gas supply content prior to restarting.
- Consider switching to TIVA/maintain low gas flows to avoid awareness until cause of failure is known.

---

**Oxygen Failure Protection Device**

Fail-safe Valve: If P_O₂ falls <30 psi, N₂O cannot flow AND alarm sounds (Datex-Ohmeda)

Note: Does not prevent 100% N₂O delivery! (this is accomplished by the proportioning system)
Management of O₂ Pipeline Failure

Commonly missed steps:
• Identifying empty O₂ E-cylinder before case start
• Identifying easily accessible self-inflating bag prior to every case
• Conservation of O₂ (use lowest gas flows required and use manual ventilation)
• Electrically powered ventilators do not consume O₂, Pneumatic powered may use O₂!
• Re-test pipeline gas supply if central failure prior to administration to patient

ITE tip
How long can you deliver oxygen at 4L/min flow if the E-cylinder reads 1500 psi?

Answer: about 2 hours

• A full E-cylinder is approximately 1900 psi or 660 liters of oxygen
• An E-cylinder that reads 1500 psi is about 78.9% full, containing about 521 liters of oxygen
• 521 liters/4L/min = 130 minutes (or roughly 2 hours)

ITE tip
The device on anesthesia machines that most reliably detects delivery of hypoxic gas mixtures is the:

a. Fail-safe valve
b. O₂ analyzer
c. Second-stage O₂ pressure regulator
d. Proportion-limiting control system

Answer: b. The O₂ analyzer is located in the inspiratory limb of the breathing circuit to provide maximum safety. Because the O₂ concentration in the fresh-gas supply line may be different from that of the patient’s breathing circuit, the O₂ analyzer should not be located in the fresh-gas supply line.

References

Anaphylaxis

Overview

- Allergic reactions are an important cause of intraoperative morbidity and mortality (3.4% mortality)
- Account for approximately 10% of all anesthetic complications
- More than 90% of reactions occur within 3 minutes, but can be delayed by hours with variable presentation
- Can be difficult to identify cause, as multiple drugs are given early in anesthetic (e.g. antibiotics often given soon after rocuronium)
- Usually the faster the reaction, the more severe the course
- Anaphylaxis involves a combination of systemic (pulmonary, CV, GI) and dermal signs & symptoms, all due to release of vasoactive mediators, which:
  - ↑ mucous membrane secretions
  - ↑ bronchial smooth muscle tone
  - ↑ capillary permeability
  - ↓ vascular smooth muscle tone
- Anaphylactic & anaphylactoid reactions present similarly and are treated IDENTICALLY.

Anaphylaxis vs. Anaphylactoid

**Anaphylaxis**
- IgE-mediated type I hypersensitivity reaction
- Sensitization happens with prior exposure to an antigen, which produces antigen-specific IgE antibodies that bind to Fc receptors on mast cells and basophils
- Upon re-exposure to the antigen, IgE antibodies then cross-links Fc receptors causing degranulation and release of stored mediators (vasoactive)
- Reaction is independent of dose

**Anaphylactoid**
- Direct activation of mast cells and basophils by non-IgE mechanisms, or activation of the complement system
- May occur on first exposure to an antigen
- Reaction is dose-dependent

Sequence of Events

**Histamine**
- Leukotrienes
- Kinins
- Prostaglandins
- Chemotactic factors
- Trypsin

Common Triggering Agents

<table>
<thead>
<tr>
<th>Common Triggering Agents</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Table 1. Drugs Involved in Perioperative Anaphylaxis</strong></td>
</tr>
<tr>
<td>Substance</td>
</tr>
<tr>
<td>Muscle relaxants</td>
</tr>
<tr>
<td>Natural rubber latex</td>
</tr>
<tr>
<td>Antihistamines</td>
</tr>
<tr>
<td>Coclaine</td>
</tr>
<tr>
<td>Opiprane</td>
</tr>
<tr>
<td>Other subcategories</td>
</tr>
</tbody>
</table>

*There is a wide variation in the reported incidence of anaphylaxis amongst common precipitants.
- Rocuronium's incidence of anaphylaxis is quoted anywhere from 1/3,500 to 1/445,000
- Sugammadex: quoted around 1/35,000

Can have variable presentations with some or all of these signs & symptoms
Latex Allergy

- Obtain a careful history:
  - Healthcare workers (frequent exposure)
  - Children with spina bifida (multiple prior medical procedures/exposures)
  - Urogenital abnormalities (h/o multiple urogenital catheters)
  - Food allergies (tropical fruits [mango, kiwi, avocado, passion fruit, bananas], fig, chestnut)

- Establish a latex-free environment:
  - Schedule patient as first case of the day
  - Most equipment & supplies are latex-free; if available, have a cart of latex-free alternatives available
  - Remove tops of multi-dose vials when drawing up drugs with significant latex allergy

- Prophylactic steroids and/or H1-blockers (uncertain benefit)
- Prepare for the worst, hope for the best

Management

Acute Phase

1. Stop administration of offending antigen (muscle relaxants, latex, antibiotics, colloid, blood, contrast, etc.)
2. Notify surgeon AND call for help
3. Increase FiO2 to 100%
4. In hypotensive, consider discontinuation of agents that may augment hypotension. Give another amnestic agent (e.g. midazolam, ketamine)
   1. Inhalated anesthetics cause vasodilation
   2. Narcotic infusions suppress sympathetic response
5. Give IV fluid bolus
   1. May require many liters, 2-4 L or more (compensate for vasodilation, hypotension)
6. Give Epinephrine (α1 → supports BP; β2 → bronchial smooth muscle relaxation)
   1. Start 10-100 mcg IV boluses for hypotension; escalate as needed
   2. Start early epinephrine infusion (0.02-0.3 mcg/kg/min)
   3. If no IV, give 0.3-0.5 mg IM in anterolateral thigh, repeat q5-15 min
   4. ACLS doses (0.1-1 mg) for cardiovascular collapse
7. Consider vasopressin bolus or norepinephrine infusion
8. Treat bronchospasm with albuterol and epinephrine (if severe)

Secondary Treatment

- Intubation, especially if signs of angioedema
- Invasive lines: large-bore IVs, arterial line, central venous catheter, foley catheter
- Drugs to consider after stable
  - H1-blocker: diphenhydramine 0.5-1 mg/kg IV
  - H2-blocker: ranitidine; not a first-line agent, but low risk of harm
  - Steroids: decrease airway swelling, prevent recurrent symptoms in biphasic anaphylaxis
  - Hydrocortisone 0.25-1 g IV, or methylprednisolone 1-2 g IV

Post event

- Send labs
  - Serum tryptase (peaks < 60 min post event)
  - Serum histamine (peaks < 30 min post event)
- Biphasic anaphylaxis is known phenomenon
- Consider monitoring patient for 24 hours post-recovery
- Consider keeping intubated and sedated
- Refer for postoperative allergic testing

Prevention

- Obtain a careful history:
  - Previous allergic reactions?
  - Atopy or asthma?
  - Food allergies?
- Give a test dose, followed by slow administration
- Use blood products judiciously
- Use prophylactic steroids and/or H1-blockers
  - H1-blockers: no clear benefit; may blunt early signs before presenting as full-blown episode
  - If no alternative agent, may pursue desensitization
- Obtain consultation from an allergist if necessary

Testing for an Allergy

- Testing may not be necessary if there is a clear temporal association between drug and reaction
- Measurement of serum mast cell tryptase levels can help establish the diagnosis in uncertain cases of anaphylaxis (although can be negative in ~35% of pts)
- Follow up with an allergist may be useful for establishing a diagnosis (e.g. skin testing)

ITE tip

Evidence of an anaphylactic reaction to atracurium 1 to 2 hours after the episode could be best established by measuring blood levels of:

a. Tryptase
b. Laudanosine
c. Histamine
d. Bradykinin

Answer: a.
References

Local Anesthetics

Local Anesthetics (LA)
- Provide anesthesia and analgesia by disrupting the conduction of impulses along nerve fibers
- LAs block voltage-gated sodium channels
  - Reversibly bind intracellular alpha subunit
  - Inhibit the influx of sodium, thus preventing an action potential from being reached
  - Resting membrane and threshold potentials are not affected

Physiochemical Properties
- Local anesthetics are weak bases in equilibrium:
  \[
  \text{Nonionized (lipid-soluble)} \leftrightarrow \text{ionized (water-soluble)}
  \]
  \[
  B (\text{neutral}) + H^+ \rightarrow BH^+
  \]
  Lower pKa \quad \text{Higher tissue pH}
  \quad \text{Higher pKa} \quad \text{Lower pH}
  \]
  \[
  \text{pK}_a = pH - \log \left[ \frac{[B][H^+]}{[BH^+]} \right]
  \]

Mechanism of Action & Physiochemical Properties
1) Nonionized (base, lipid-soluble) form crosses neuronal membrane
2) Re-equilibration in axoplasm between the 2 forms
3) Ionized (cationic, water-soluble) form binds to the Na+ channel

Having a pKa closer to physiologic pH means a greater fraction of nonionized form (able to cross the neuronal membrane) for a faster onset
- Conversely, in an infected (acidic) environment, the pKa will be further from the environmental pH and have a slower onset

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Association</th>
</tr>
</thead>
</table>
| Speed of onset       | 1. pKa (degree of ionization)  
                       | 2. Concentration
                       | *procaine and chlorprocaine have a high pKa, but quick onset due to concentration effect |
| Potency              | Lipid solubility  
                       | Lipid solubility  
                       | Lipid solubility  
                       | Amide linkage  
                       | Ester linkage  
                       | Aminoester linkage  
                       | Aminoester linkage |
| Duration of action   | Protein binding
                       | alpha-1 amino glycoprotein binds drug and carries it away for metabolism |

Local Anesthetic Structure
- 3 Major Chemical Moieties
  1. Lipophilic aromatic benzene ring
  2. Ester OR Amide linkage
  3. Hydrophilic tertiary amine

Local anesthetics are weak bases pKa > 7.4
**Categories**

<table>
<thead>
<tr>
<th>Category</th>
<th>Drugs</th>
<th>Metabolism</th>
</tr>
</thead>
<tbody>
<tr>
<td>Esters</td>
<td>Cocaine&lt;br&gt;2-Chloroprocaine&lt;br&gt;Procaine&lt;br&gt;Tetracaine</td>
<td>Plasma pseudocholinesterase&lt;br&gt;metabolism &amp; RBC esterase (hydrolysis at ester linkage)</td>
</tr>
<tr>
<td>Amides (<em>i before caine</em>)</td>
<td>Lidocaine&lt;br&gt;Bupivacaine&lt;br&gt;Ropivacaine&lt;br&gt;Mepivacaine&lt;br&gt;Etidocaine&lt;br&gt;Levobupivacaine</td>
<td>Liver metabolism: Aromatic hydroxylation, N-dealkylation, Amide hydrolysis&lt;br&gt;*methylparaben preservative is metabolized to p-Aminobenzoic acid (PABA), which can induce allergic-type reactions in a small percentage of patients</td>
</tr>
</tbody>
</table>

**Routes of Delivery**

- **Topical**
- **IV**
  - Systemic local anesthetics inhibit inflammation
  - Decrease the hemodynamic response to laryngoscopy
  - Decrease postoperative pain and opioid consumption
  - Can reduce MAC requirements by 40%
- **Epidural**
- **Intrathecal (Spinal)**
- **Perineural (Regional)**
  - Small diameter (A delta) and myelinated nerves (more concentrated effect at nodes of Ranvier) are most susceptible, thus sensory loss precedes motor weakness

**Drug Onset Max dose (mg/kg) Max dose with Epi (mg/kg)**

<table>
<thead>
<tr>
<th>Drug</th>
<th>Onset</th>
<th>Max dose</th>
<th>Max dose with Epi</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lidocaine</td>
<td>Rapid</td>
<td>4.5</td>
<td>7</td>
</tr>
<tr>
<td>Mepivacaine</td>
<td>Medium</td>
<td>5</td>
<td>7</td>
</tr>
<tr>
<td>Bupivacaine*</td>
<td>Slow</td>
<td>2.5</td>
<td>3</td>
</tr>
<tr>
<td>Ropivacaine</td>
<td>Slow</td>
<td>4</td>
<td>N/A</td>
</tr>
<tr>
<td>Tetracaine</td>
<td>Slow</td>
<td>1.5</td>
<td>N/A</td>
</tr>
<tr>
<td>Chloroprocaine</td>
<td>Rapid</td>
<td>10</td>
<td>15</td>
</tr>
</tbody>
</table>

*Bupivacaine (Marcaine) is commonly used by surgeons for infiltration at 0.25% (2.5mg/ml), with max dose 2.5mg/kg
*I.e. can use a max volume of 1cc/kg (70kg patient gets max 70cc)

**LAST (Local Anesthetic Toxicity)**

- Systemic absorption by injection site (vasularity)
  - IV > tracheal > Intercostal > Caudal > Epidural > Brachial plexus > Axillary > Lower extremity (sciatic/femoral) > Subcutaneous
  - Mnemonic: ICEBALLS

- Rate and extent of systemic absorption depends on:
  1) dose
  2) the drug's intrinsic pharmacokinetic properties
  3) the addition of a vasoactive agent (i.e. epinephrine)

*Bupivacaine is more cardiotoxic* (high binding to resting or inactivated Na+ channels; also slower dissociation from channels during diastole)

**Treatment of LAST**

- **Initial management:**
  - Call for intralipid kit
  - ABCs: do you need to support circulation/airway?
  - Stop local anesthetic
  - Give benzodiazepines for seizure
  - Reduce individual epinephrine doses to <1 mcg/kg
  - AVOID: vasopressin, Ca channel blockers, Beta blockers, local anesthetics, and propofol (can further decrease cardiac contractility)
  - Initiate early intralipid (IL) therapy
  - Rapidly give 1.5 cc/kg bolus of 20% intralipid IV (*max 3 doses*)
  - Start infusion at 0.25 cc/kg/min (*max rate 0.5 cc/kg/min*)

*If patient remains unstable, may repeat bolus and increase infusion rate

**CNS toxicity**

- Local anesthetics readily cross the blood brain barrier
- Clinical manifestations: lightheadedness, tinnitus, tongue numbness, metallic taste → CNS excitation (block inhibitory pathways) → CNS depression, seizure → coma

**Cardiovascular toxicity**

- Dose dependent blockade of Na channels → disruptions of cardiac conduction system → bradycardia, ventricular dysrythmias, decreased contractility, cardiovascular collapse/circulatory arrest
- Bupivacaine has higher risk of CV toxicity
- Approximately 3x the amount of local anesthetics are required to produce cardiovascular toxicity than CNS toxicity
- Addition of epi allows for early detection of intravascular injection and also increases the max allowable dose
ITE tip

Nerves in order of sensitivity to local anesthetics:
Most sensitive → least sensitive:

B fibers > A fibers > C fibers

Small myelinated fibers (B) are easiest to block, and have least surface area. Unmyelinated nerves (C) are the most resistant because surface area of available channels to block is largest.

ITE tip

The correct arrangement of local anesthetics in order of their ability to produce cardiotoxicity from most to least is:

a. Bupivacaine, lidocaine, ropivacaine
b. Bupivacaine, ropivacaine, lidocaine
c. Ropivacaine, bupivacaine, lidocaine
d. Lidocaine, ropivacaine, bupivacaine

Answer: b.

References

AGRA guidelines for management of local anesthetics toxicity. 2015.
Malignant Hyperthermia

Basics

Definition
- A hypermetabolic crisis that occurs when susceptible patients are exposed to a triggering anesthetic agent (halogenated anesthetics or succinylcholine)
  - Underlying defect is abnormally increased Ca$^2+$ levels in skeletal muscle resulting in sustained muscle contraction
  - Calcium pump attempts clearance $\rightarrow$ increased ATP usage
  - Results of hypermetabolic rate
    - increased O$_2$ consumption, CO$_2$ production, severe lactic acidosis, hyperthermia, risk of rhabdomyolysis, hyperkalemia, and arrhythmia

Genetics
- Genetic hypermetabolic muscle disease
  - 80% of cases: RYR-1 receptor mutation (affects calcium release channel in sarcoplasmic reticulum)
    - Autosomal dominant inheritance with variable penetrance and expression
      - but autosomal recessive forms also described (especially that associated with King-Denborough syndrome)
  - At least 6 chromosomal loci identified, but >80 genetic defects associated with MH

Incidence
- Rare, see in 1:15,000 pediatric vs. 1:40,000 adult patients
- Most common in young males
  - Almost no cases in infants; few in adults >50 years old
  - The upper Midwest has highest incidence in US (geographic variation of gene prevalence)
- MH may occur on a patient’s 2nd exposure to triggers
  - nearly 50% of MH episodes had at least one prior uneventful exposure to an anesthetic
  - Risk factors include personal/family history of MH, pediatric age, comorbid myopathies (Central Core disease and King Denborough Syndrome), caffeine intolerance, history of unexplained fevers/cramps/weakness, h/o exercise induced rhabdomyolysis, trismus on induction (precedes 15-30% of MH)

Excitation-Contraction Coupling

MH: Depolarization $\rightarrow$ mutant RYR-1 receptor remains open $\rightarrow$ unregulated calcium from SR into intracellular space $\rightarrow$ sustained contraction & increased activity of Ca-ATPase to remove Ca $\rightarrow$ heat generation, CO$_2$ production, metabolic acidosis, and rhabdomyolysis/hyperkalemia

Sequence of Events

1. Triggers
   - All halogenated inhalational agents (not N$_2$O)
   - Succinylcholine
2. Increased Cytosplasmic Free Ca$^2+$
   - Masseter muscle rigidity *trismus*; more common if succinylcholine used
     - If there is no other reason in addition to trismus, the association with MH is absolute
  - Total body rigidity
3. Hypermetabolism
   - Increased CO$_2$ production (most sensitive and specific sign of MH) and metabolic acidosis
     - Note sympathetic surge of *increased* HR and BP
   - Increased O$_2$ consumption (decreased ScvO$_2$)
   - Body will compensate with *tachypnea*
   - Increased heat production
     - A late sign of MH: temperature can rise 1-2$^\circ$C every 5 minutes
   - Increased utilization of ATP to clear calcium: metabolic acidosis
4. Cell Damage & Rhabdomyolysis
   - Leakage of K$, myoglobin, CK (may see dark-colored urine)
   - *not all patients with trismus will go on to have MH, and not all MH cases will be heralded by trismus*
   - *Earliest recognized signs of MH*: muscle rigidity, tachycardia, and hypercarbia

Sequence of Events (2)

5. Secondary systemic manifestations
   - Rhabdomyolysis $\rightarrow$
     - Acute renal failure
   - Hyperkalemia/Arrhythmias
   - DIC | Hemorrhage / Compartment syndrome
   - Metabolic exhaustion: increased cellular permeability $\rightarrow$
     - Whole body edema & Cerebral Edema
   - Death (due to DIC and organ failure); previously 70% mortality, now 5% with dantrolene

***The signs & symptoms of MH are seen often in the OR and are non-specific***

Clinically, you may first see *trismus*, but often *hypercarbia* will be your first sign
- *Without another reasonable explanation for this (hypoventilation, pneumoperitoneum), you should start looking for other signs*
  - Any increased oxygen consumption? (decreased SpO$_2$ or ScvO$_2$?)
  - Increased metabolic & sympathetic activity? (increased eCO$_2$, HR, temperature, lactate)
  - Signs of rash or any electrolyte abnormalities? (hyperkalemia/arrhythmias, CRMB: urine myoglobin/blood tinged urine)
Who is Susceptible to MH?

- Autosomal dominant inheritance pattern
  - All closely related family members considered susceptible in absence of testing (even if they had prior uneventful anesthetics)
- Several rare musculoskeletal disorders linked to MH
  - Central Core Disease
  - King Denborough Syndrome
  - Multiminicore myopathy
- Other disorders:
  - Malignant hyperthermia and other neuromuscular diseases, upon exposure to triggering agents, have weak associations with MH-like events
  - Avoid succinylcholine as cause rhabdomyolysis; controversial whether to avoid volatile anesthetics
  - Experts believe brief exposure is a small risk (i.e. inhalational induction in pediatric patients)
  - History of exertional heat stroke or exercise-induced rhabdomyolysis - some suggestion that these people may harbor genetic changes found in MH-susceptible individuals

Susceptibility Testing

Caffeine-Halothane Contracture Test (CHCT)
- Takes fresh muscle biopsy and exposes to triggers
  - Gold Standard; used to rule-out MH
  - High Sensitivity ~97%
  - Specificity 80-95%
  - 10-20% false positive rate but zero false negative rate
  - Available at 9 U.S. testing centers

Molecular Genetics
- RYR 1 mutation screening
- Low sensitivity, but high specificity (rule-in criteria)
- Only screens for 25% of recognized mutations
- Typcically reserved for patients with a positive CHCT, relatives of known MH susceptibility, or patients with highly suspicious MH episode

Prevention in Susceptible Patients

1. Machine
- Change circuit and CO₂ absorbent
- Remove or disable vaporizers
- Refer to anesthetic machine regarding time required to flush machine (FGF of 10 L/min for ≥ 20 minutes)
  - During case, keep flows > 10L/min to avoid “rebound phenomenon” (release of dissolved volatile anesthetic)
- During case, keep flows > 10L/min to avoid “rebound phenomenon” (release of dissolved volatile anesthetic)

2. Monitors
- Standard ASA monitors, especially temperature and ET CO₂

3. Anesthetic
- Avoid succinylcholine and volatile agents
- All other non-triggering agents are okay (including N₂O)

4. Emergency
- Know where to find the MH cart
- Have dantrolene or ryanodex available

Differential Diagnosis

<table>
<thead>
<tr>
<th>Differential Diagnosis</th>
<th>Treatment - Acute Phase</th>
</tr>
</thead>
<tbody>
<tr>
<td>Neuretioc Malignant Syndrome (NMAS)*</td>
<td>Immediate Actions</td>
</tr>
<tr>
<td>Thyroid Storm*</td>
<td>• Call for Help &amp; obtain MH cart; inform anesthetist and prepare dantrolene or ryanodex</td>
</tr>
<tr>
<td>Sepsis</td>
<td>• DIC volatile agents and succinylcholine if need to change machine or circuit</td>
</tr>
<tr>
<td>Pheochromocytoma</td>
<td>• Switch to 100% O₂ with high flows; 15 L/min; increase minute ventilation</td>
</tr>
<tr>
<td>Drug-induced</td>
<td>• Halt surgery vs. finish GA but with TIVA; arrange for ICU bed</td>
</tr>
<tr>
<td>Sodium Lignosulfonate</td>
<td>• Labs: ABG, lactate, K⁺/electrolytes, PCP, LID</td>
</tr>
<tr>
<td>RYR1-1 Ca²⁺ channel</td>
<td>• 2.3 mg/kg IV push (gcs)</td>
</tr>
<tr>
<td>Hypertermia from CO₂ insufflation for laparoscopy</td>
<td>• Preeventive actions</td>
</tr>
</tbody>
</table>

Refer patient and family to nearest Biopsy Center for follow-up

Prevention in Susceptible Patients

1. Machine
- Change circuit and CO₂ absorbent
- Remove or disable vaporizers
- Refer to anesthetic machine regarding time required to flush machine (FGF of 10 L/min for ≥ 20 minutes)
  - During case, keep flows > 10L/min to avoid “rebound phenomenon” (release of dissolved residual volatile anesthetic) |
- During case, keep flows > 10L/min to avoid “rebound phenomenon” (release of dissolved volatile anesthetic) |

2. Monitors
- Standard ASA monitors, especially temperature and ET CO₂ |

3. Anesthetic
- Avoid succinylcholine and volatile agents |
- All other non-triggering agents are okay (including N₂O)

4. Emergency
- Know where to find the MH cart |
- Have dantrolene or ryanodex available
ITE tip

Which of the following findings is NOT consistent with a diagnosis of malignant hyperthermia?

a. PaCO₂ 150 mm Hg
b. MVO₂ 50 mm Hg
c. pH 6.9
d. Onset of symptoms an hour after end of operation

Answer: b. MH reflects a hypermetabolic state. Clinical signs include tachycardia, tachypnea, arterial hypoxemia, hypercarbia, metabolic acidosis, hyperkalemia, hypotension, muscle rigidity, trismus after succinylcholine administration, and increased temperature. Mixed venous oxygen tension would be very low (normal MVO₂ is 30-35, so an elevated MVO₂ of 50 would not be consistent with MH, and answer b is incorrect).

References

- Malignant Hyperthermia Association of the United States (MHAUS, http://www.mhaus.org)
- UCLA Department of Anesthesiology (http://www.anes.ucla.edu/dept/mh.html)
Pre-operative Evaluation

• A pre-op template can be found and downloaded at http://ether.stanford.edu/ca1_new/ca1_preop_new1.html
• Link includes a useful guide for chart review and how to assess relevant comorbidities

Chart Review

Pre-op Tips

• Don’t forget to include other pertinent studies, such as PFTs, TTE or stress echo results, Holter or Zio patch results, device interrogations, etc.
• Check the media tab and care everywhere for outside studies
• Review the Anesthesia tab in chart review to see prior anesthetics and airway/procedure notes
• Add the “Pre-Admission/Pre-op Orders” set to your favorites
  • You can use this order set for day-of-surgery labs, rapid COVID-19 testing, pre-op IV placement if appropriate, ordering blood products to be available in blood bank, and medications (e.g. PO analgesics) to be given in pre-op

Anesthetic Plan

• To start, consider referring to Jaffe’s Anesthesiologist’s Manual of Surgical Procedures, or talk with a senior resident
• Who is the surgeon? What is the expected procedure duration?
• Patient positioning
  • This may affect your line and monitor placement
  • May also have hemodynamic implications (e.g. steep Trendelenburg or reverse Trendelenburg)
• Is special monitoring required?
  • Is there an indication for an arterial or central line?
  • Is there an indication for an EEG monitor (Sedline, BIS)?
  • Is neuromonitoring part of the procedure plan?

Anesthetic Plan

• Blood products
  • Based on anticipated blood loss and patient’s pre-operative CBC, consider ordering blood products
  • Add order set “Intra-Operative Blood Product and Lab Orders” to favorites
  • Separate orders to prepare products and send to OR (aka call slip)
Ordering Extra Equipment

• Pre-op navigator → Pre-op eval → Equipment requests
• Equipment requests placed by 10 pm the night before for first cases will be seen by anesthesia techs and equipment will be ready in the OR for your AM setup.

Device Management

• Patients with PPMs and AICDs present unique management challenges
• Important questions to ask about managing AICDs and pacemakers intraoperatively:
  • What is the site of surgery? If above the umbilicus, there is a risk of interference
  • Is the patient pacemaker dependent?
  • What type of device does the patient have, and what were the results of the last interrogation?
  • What effect will placing a magnet over the device have?
  • Does the patient’s device need to be interrogated or reprogrammed before or after surgery?
  • When in doubt, best to contact the device rep
• As a backup, you can also page the “Pacemaker Inpatient Service” through Smartpage

References

OR Setup

Monitors

- Setup:
  - Make sure BP cuff is set to cycle automatically Q1min for induction
  - Add or remove waveforms to your monitor if needed for Art line, CVP, etc.

- You can route video from the Cmac in each 500p OR to the room monitors for intubation

Monitor Tips

Perfusion index is the ratio of pulsatile to non-pulsatile flow. If low, may indicate poor perfusion.

Use this icon to troubleshoot monitor/cable setup.

PVI (or PPV if using an A line) can be used as a surrogate marker of volume status.

Monitoring patient age and weight here.

Ventilator modes and settings can be selected here.

Waveforms for:
- end tidal CO2
- peak airway pressures
- flows [tidal volume]

Set patient age and weight here.

Fraction inspired and end-tidal gases appear here.

The anesthesia machine will calculate MAC based on the age you have entered.

Set your FiO2 and total fresh gas flows here.

Alaris pumps

- Power on → options → anesthesia mode → enable
- To set up channels:
  - You will use either a syringe on a syringe pump with primed microbore tubing, or if using a drip (such as propofol or pressors), you will spike the medication and run it through an Alaris infusion set.
  - Once tubing is primed and placed into the channel, hit channel select → guardrails drugs (most commonly used medications can be found here) → then finish the setup by entering patient weight and starting infusion rate
  - If the medication you're looking for isn't under guardrails drugs, you should be able to find it by name under "all drugs"
- If your patient has a high BMI, consider whether to dose your drips by lean body weight.
  - Ideal body weight = 22 x height (in m)^2
  - Lean body weight = Ideal body weight x 1.2

Alaris pumps, cont.

- Hit pause to leave drips on standby
- If you anticipate running at least 2 drips during a case, consider asking the anesthesia techs for a fluid carrier
- To setup the fluid carrier, place the primed tubing into the channel, select basic infusion, and set your carrier fluid rate
## Medication Dilution Typical

### Drips – Pressors and Ionotropes

<table>
<thead>
<tr>
<th>Medication</th>
<th>Dilution</th>
<th>Typical infusion rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Norepinephrine</td>
<td>10 mcg/mL in 0.9% saline</td>
<td>0.5 mcg/kg/min</td>
</tr>
<tr>
<td>Epinephrine</td>
<td>10 mcg/mL in 0.9% saline</td>
<td>0.5 mcg/kg/min</td>
</tr>
<tr>
<td>Dopamine</td>
<td>50 mcg/mL in 0.9% saline</td>
<td>20 mcg/kg/min</td>
</tr>
<tr>
<td>Nitroglycerin</td>
<td>5 mg/mL in 0.9% saline</td>
<td>0.5 mg/kg/min</td>
</tr>
</tbody>
</table>

### Drips – Analgesics and Anxiolytics

<table>
<thead>
<tr>
<th>Medication</th>
<th>Dilution</th>
<th>Typical infusion rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ketorolac</td>
<td>10 mg/mL in 0.9% saline</td>
<td>Loading dose 1 mg/kg over 10 min</td>
</tr>
<tr>
<td>Hydromorphone</td>
<td>100 mg/mL in 0.9% saline</td>
<td>0.5 mg/kg/min</td>
</tr>
<tr>
<td>Morphine</td>
<td>100 mg/mL in 0.9% saline</td>
<td>0.5 mg/kg/min</td>
</tr>
</tbody>
</table>

### Airway Equipment

- At a minimum, always have an ETT with stylet and 10 mL syringe, either video or standard laryngoscope, and appropriately sized oral airway
- Always have a backup airway plan, with supplies available
- Bougie is available in all ORs
- LMA may also be useful for airway rescue and are stocked in the anesthesia machines
- Video laryngoscope is always available with a Cmax in each 500p OR (also consider whether you need a GlideScope available)
- If you anticipate a difficult airway, talk with your attending about other airway adjuncts and management
- Ambu bag available for anesthesia machine failure
- For any cases you plan to spin 180 or flip prone, the patient should have a soft bite block in place and you should have an accordion and straight connector ready for your circuit

### Drips – Opioids

<table>
<thead>
<tr>
<th>Medication</th>
<th>Dilution</th>
<th>Typical infusion rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Remifentanil</td>
<td>1 mg/mL in 0.9% saline</td>
<td>0.01 mg/kg/min</td>
</tr>
<tr>
<td>Sufentanil</td>
<td>50 mcg/mL in 0.9% saline</td>
<td>0.1 mcg/kg/min</td>
</tr>
<tr>
<td>Fentanyl</td>
<td>100 mg/mL in 0.9% saline</td>
<td>Loading dose 1 mg/kg over 10 min</td>
</tr>
</tbody>
</table>

### Drips – Antihypertensives

<table>
<thead>
<tr>
<th>Medication</th>
<th>Dilution</th>
<th>Typical infusion rate</th>
</tr>
</thead>
</table>
| Lidocaine      | 10 mg/mL in 0.9% saline   | For a standard setup, have rescue drugs immediately available
- Phenylephrine, ephedrine, and glycopyrrolate come in pre-filled syringes
- Lidocaine, atropine, and code-dose epinephrine (100 mcg/mL or 1 mg in 10 mL) come in ready-to-assemble syringes
- If you anticipate needing to give other pressors or antihypertensives, discuss with your attending what to have drawn up and available
- Have induction medications (anxiolytic, opioid, induction agent, and muscle relaxant) and any other meds that need to be given soon after induction (antibiotics, steroids) drawn up and ready

### Drugs

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- Phenylephrine, ephedrine, and glycopyrrolate come in pre-filled syringes
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**Perioperative Antibiotics**

In 1984 a study including 51 acute care hospitals in New York State found that surgical site infection (SSI) was the most common adverse surgical event (and the second most common adverse event overall).

**Perioperative antibiotic prophylaxis** – administration of abx prior to surgery to prevent surgical site infections, but best practice also includes sterility (surgeon and instruments), skin prep (clipping hair, allowing skin antiseptic to dry).

**SSIs** is now a marker of quality of care in the US. Medicare no longer reimburses for certain SSIs (e.g., mediastinitis after cardiac surgery, SSIs post-bariatric surgery & some orthopedic procedures).

**Timing of prophylaxis**

- Antibiotic therapy should be given *within 60 min* (ideally: 15-45 mins) prior to surgical incision for adequate serum drug tissue levels at incision.
- Exception IV vanco/cipro (requires longer infusion)
- If a proximal tourniquet is used, the entire antibiotic dose should be administered before the tourniquet is inflated.
- Exceptions to pre-incision antibiotics: check for active ongoing antibiotic therapy, may not be indicated for surgery, surgeon declined, or delay until after a specimen is sent for culture.

**Types of Wounds (per CDC/NHSN)**

- **Clean procedures** (1.3 to 2.9% rate of surgical site infection)
  - Uninfected operative wound closed primarily in which no inflammation is encountered and respiratory, GI, genitourinary, or urinary tracts are not entered
  - Common skin flora: *CNS, MSSA/MRSA* and *staph*.
- **Clean-contaminated procedures** (2.4 to 7.7% rate of SSI)
  - Operations in which the respiratory, GI, genitourinary, or urinary tracts are entered under controlled conditions and without unusual contamination
  - Common bugs are skin flora, gram-negative rods, *Enterococcus*.
- **Contaminated procedures** (4.6 to 15.2% rate of SSI)
  - Open fresh, accidental wounds. Also, operations with major breaks in sterility, gross spillage from the GI tract, and incisions in which acute nonpurulent inflammation is encountered
- **Dirty or infected** (7.1 to 40.0% rate of SSI)
  - Includes old traumatic wounds with retained devitalized tissue and those that involve existing medical infection or perforated viscera.

**2017 SHC Surgical Antimicrobial Prophylaxis Guidelines**

<table>
<thead>
<tr>
<th>Surgery</th>
<th>Preferred Agent</th>
<th>Alternative Agen</th>
<th>Substitution ally</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cardiac Surgery/Thoracic</td>
<td>Cefazolin</td>
<td>Vancomycin</td>
<td>(preferred)</td>
</tr>
<tr>
<td>Cardiac device insertion (PM implanted)</td>
<td>Clindamycin + Metronidazole</td>
<td>Gentamicin + Lincomycin</td>
<td></td>
</tr>
<tr>
<td>Other General Surgery (hernia, breast, Neurosurgery)</td>
<td>Cefazolin</td>
<td>Vancomycin + Gentamicin</td>
<td></td>
</tr>
<tr>
<td>Orthopedics</td>
<td>Cefazolin</td>
<td>Vancomycin + Gentamicin</td>
<td></td>
</tr>
<tr>
<td>Plastic Surgery</td>
<td>Cefazolin + Metronidazole</td>
<td>Gentamicin + Cefazolin</td>
<td></td>
</tr>
<tr>
<td>Gastrointestinal/Genitourinary</td>
<td>Cefazolin + Metronidazole</td>
<td>Gentamicin</td>
<td></td>
</tr>
<tr>
<td>Gynecological (hysterectomy/Cesarean)</td>
<td>Cefazolin</td>
<td>Clindamycin + Gentamicin</td>
<td></td>
</tr>
<tr>
<td>Head &amp; Neck</td>
<td>Cefazolin + Metronidazole</td>
<td>Clindamycin</td>
<td></td>
</tr>
<tr>
<td>Open or contaminated (include oral mucosa breach)</td>
<td>Cefazolin + Metronidazole</td>
<td>Gentamicin</td>
<td></td>
</tr>
</tbody>
</table>

Based on 2017 consensus guidelines from American Society of Health-System Pharmacists (ASHP), the Infectious Diseases Society of America (IDSA), the Surgical Infection Society (SIS) and the Society for Healthcare Epidemiology of America (SHEA).
### Selected 2017 SHC Dosing and Re-dosing Guidelines

<table>
<thead>
<tr>
<th>Antimicrobial</th>
<th>Recommended Dose</th>
<th>Re-dosing (hrs)</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cefazolin</td>
<td>&lt;120kg - 2g, &gt;120kg - 3g</td>
<td>4</td>
<td>Can be given 15-30 minutes prior to incision (may need line)</td>
</tr>
<tr>
<td></td>
<td>Peds: 30mg/kg, max 2g</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Clindamycin</td>
<td>900mg</td>
<td>6</td>
<td>Slow over 24 minutes</td>
</tr>
<tr>
<td>Vancomycin</td>
<td>&lt;80kg - 1g, 80-99kg - 1.25g, 100-120kg - 1.5g, &gt;120kg - 2g</td>
<td>12</td>
<td>Slow over 20-30 minutes or 1 g/hour, whichever is longer</td>
</tr>
<tr>
<td></td>
<td>Adult and Peds 15mg/kg</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ampicillin-Sulbactam</td>
<td>3g</td>
<td>2</td>
<td>Slow over 15-30 minutes</td>
</tr>
<tr>
<td>Cefuroxime</td>
<td>2g</td>
<td>2</td>
<td>Slow over 15-30 minutes</td>
</tr>
<tr>
<td>Cefuroxime</td>
<td>300mg</td>
<td>8</td>
<td>Slow over 60 minutes</td>
</tr>
<tr>
<td>Ceftriaxone</td>
<td>2g</td>
<td>24</td>
<td>Slow over 30 minutes</td>
</tr>
<tr>
<td>Aztreonam</td>
<td>2g</td>
<td>24</td>
<td>Slow over 24-30 minutes (use of calculated infusion with lines)</td>
</tr>
<tr>
<td>Gentamicin</td>
<td>5 mg/kg (single dose)</td>
<td>24</td>
<td>Slow over 24-30 minutes (risk of ototoxicity)</td>
</tr>
<tr>
<td></td>
<td>1 mg/kg (single dose)</td>
<td>24</td>
<td>Slow over 24-30 minutes (risk of nephrotoxicity)</td>
</tr>
<tr>
<td>Levofloxacin</td>
<td>500mg</td>
<td>24</td>
<td>Slow over 24-30 minutes</td>
</tr>
<tr>
<td>Metronidazole</td>
<td>500mg</td>
<td>12</td>
<td>Slow over 24-30 minutes</td>
</tr>
</tbody>
</table>

*As a general rule, for drugs with a greater therapeutic index, you can administer them faster.*

### Allergies and Interactions

**Penicillins and 1st & 2nd generation cephalosporins have similar side change with some risk of cross-reactivity**
- Cephalothin (1st cephalosporin) marketed in 1964; cross-reactivity with penicillin allergy noted to be 5-10%. This over-generalization of cross-reactivity has resulted in the avoidance of all cephalosporins, not just cephalothin, in patients labeled as penicillin allergic.
- Some of this cross-reactivity is historically thought to be due to cross-contamination during manufacturing.
- True incidence of allergy in patients with a reported history of PCN allergy is less than 10%.
- Only (ige-mediated reaction (type I, immediate hypersensitivity reactions) are true allergic reactions.
- Encourage skin testing to simplify future antibiotic choices.
- The cross-reaction rate between PCN and 1st & 2nd cephalosporins is 1-10%
- Cross-reaction rate between 3rd generation cephalosporins and PCN approaches 0%
- History of PCN allergy is a general risk factor for allergic manifestations to antibiotic administration that may not be specific to cephalosporins.

### Perioperative Antibiotic Decision Algorithm

- If the allergic reaction to PCN is only erythema or pruritis, many attendings still give a cephalosporin, but always check with your attending.
- However, hx of anaphylactic reaction to PCN is an absolute contraindication to cephalosporins.
- Type 1 anaphylactic reaction to antimicrobials occur 30-60 minutes after administration.
- **Test dose:** Not always done. However, it may be prudent to give 1ml of the antibiotic first to see if the patient will have a reaction. This test dose only decreases the anaphylactoid reaction, not anaphylaxis.
- Allergic reactions are more likely from neuromuscular blockers than antibiotics.

### Penicillin Allergy Pathway for Antibiotic Prescriptions

- Antibiotics for PCN allergic patients are listed in the table above.

### Endocarditis Prophylaxis

- Patients at increased risk:
  - Prosthetic cardiac valve (including transcatheter-implanted prostheses and bioprostheses)
  - Native valve material used for cardiac valve repair, including annuloplasty rings and chords
  - Previous history of infective endocarditis
  - Unrepaired cyanotic congenital heart disease or completely repaired congenital heart defect within the first 6 months
  - Cardiac transplant patients who develop cardiac valveopathy
- **Procedures at risk:**
  - Dental procedures that involve manipulation of gingival tissue or the periapical region of teeth or perforation of the oral mucosa (not all dental procedures)
  - Upper respiratory tract only if it is incised or biopsied
- **Bacterial Endocarditis prophylaxis**
  - If PCN allergic, use cefazolin or ceftriaxone 1gm IV, or clindamycin 600mg IV
  - MITRAL valve prolapse/HOCM/Bicuspid AV do not need prophylaxis because, while there is increased risk for IE, the most serious adverse outcomes of IE do not usually occur in patients with these conditions.
ITE tip

Which of the following antibiotics does NOT augment neuromuscular blockade?

a. Clindamycin  
b. Neomycin  
c. Streptomycin  
d. Erythromycin

Answer: d. Cephalosporins also do not affect neuromuscular blockade.
Topics for Discussion

1. Your IV infiltrates during induction. What are your options?
2. You get stuck with a needle. How do you protect yourself and the patient?
3. You can't deliver positive pressure. What are your next steps?
4. You witness an unprofessional exchange between a surgeon and a nurse/med student/resident/etc. Who should you talk to?
5. You encounter an unanticipated difficult airway. You know you're supposed to CALL FOR HELP. Who do you call and what do you ask for?
6. You inadvertently administer the wrong medication. What should you do and who should you tell?
7. Your patient tells you that he wants only the attending to perform invasive procedures. How do you respond?
8. The surgeon insists that the patient is not relaxed enough, even though you just re-dosed a NDMB 5 minutes ago. What are your options?
9. You administer antibiotics after induction. An hour later, incision has still not been made. What should you do?
10. The surgeon appears to be struggling and the patient is rapidly losing blood. The surgeon insists that he does not need help. What should you do?
## Anesthesia Exams & Dates

<table>
<thead>
<tr>
<th>Exam Type</th>
<th>Time</th>
<th>Scoring/Eligibility</th>
</tr>
</thead>
<tbody>
<tr>
<td>ABA In-Training Exam (ITE)</td>
<td>February each</td>
<td>Percentile scoring; important for fellowship programs.</td>
</tr>
<tr>
<td></td>
<td>year</td>
<td>Financial incentive CA-2 and CA-3 years: department awards half the cost of the ABA Advanced Written exam for each year you score &gt;70th percentile</td>
</tr>
<tr>
<td>ABA BASIC Exam</td>
<td>June of CA-1 year</td>
<td>Pass/Fail. No percentile reported.</td>
</tr>
<tr>
<td>ABA ADVANCED Written</td>
<td>Post-training (July &amp; January)</td>
<td>You must pass the Advanced written exam to be eligible to take Applied.</td>
</tr>
<tr>
<td>ABA Applied Exams (Oral Boards &amp; OSCE)*</td>
<td>Post-training (9 sessions offered per year)</td>
<td></td>
</tr>
</tbody>
</table>

*To help better prepare residents for the ABA Oral Boards & OSCE:
- Mock Orals are held in November & May of each year
- Mock OSCEs are held in April of CA3 year

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## What to study?

For the first 1-2 months of CA1 year, it is common to be exhausted after each work day. For this initial period, these resources may provide a lighter study material or reference:

- CA-1 Tutorial Textbook
- Stanford Anesthesia EMERGENCY MANUAL
  - Handheld pocket manuals are also available
- Jaffe’s Anesthesiologist’s Manual of Surgical Procedures
  - Source of clinically relevant information regarding common and not-so-common surgical procedures. It’s a great reference to read the pertinent sections in preparation for your upcoming cases.
- Stanford Anesthesiology iGuide
What to study?

After you have transitioned into CA-1 year, there are many study resources available to prepare for your exams, increase your fund of knowledge, and strengthen your skills in anesthesia. Here are some recommendations to get you started:

• Question Banks
  • Truelearn (https://truelearn.com/) - subscription paid for by the department, you will receive an e-mail to activate
  • Hall’s Anesthesia: A Comprehensive Review

• Online resources
  • Open Anesthesia: http://openanesthesia.org
  • Learnly: https://learnly.org

• Podcasts
  • ACCRaC: http://accrac.com/

• Online library
  • Stanford Anesthesia: http://inkling.com/read - (ask others for the username and password)
  • Lane Library: https://lane.stanford.edu/index.html (access to UpToDate, PubMed, and all major journals)

• Textbooks
  • Faust’s Anesthesia Review (concise short chapters to cover ITE topics)
  • Available through Lane Library: Basics of Anesthesia (Miller), Clinical Anesthesiology (Morgan & Mikhail), Clinical Anesthesia (Barash), Anesthesiology (Yao & Artusio)
Subspecialty Anesthesia: Basic Sciences
Appendix

Techniques
- Ultrasound-guided
  - Primary modality for majority of peripheral nerve localization
  - May be combined with other techniques PRN
  - High frequency sound waves (1-20MHz)
  - Hypoechoic: structures which sound waves pass through easily (appear dark)
  - Hyperechoic: structures which reflect sound waves (appear white)
  - Higher frequency transducer = high-res picture, poor tissue penetration (better for superficial nerves)
- Nerve Stimulation
  - Insulated needle concentrates electrical current at tip
  - Poor evidence to support, but classically:
    - <0.2mA current with muscle contraction = intraneural needle location
    - <0.5mA current with muscle contraction
- Field Block
  - Targets terminal cutaneous nerves
    - Ex. intercostobrachial nerve block, superficial cervical plexus block, ankle block

Regional Anatomy
- Brachial Plexus Anatomy
  - Union of ventral rami C5-T1
  - *Intercostobrachial Nerve (T2) is spared with all brachial plexus blocks but can be supplemented with a subcutaneous injection along the axillary crease for procedures involving the upper arm

Upper Extremity Blocks

<table>
<thead>
<tr>
<th>Approach</th>
<th>Sensory Block</th>
<th>Motor Block</th>
<th>Criticisms</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interscalene</td>
<td>Blocks C5-T2 able to block, upper arm</td>
<td>Subclavian C5-T1</td>
<td>Ulnar nerve sparing + catheter</td>
</tr>
<tr>
<td>Supraclavicular</td>
<td>Thoracic/lumbar, T5-T12</td>
<td>Saphenous nerve</td>
<td>Spinal block (single shot)</td>
</tr>
<tr>
<td>Infraclavicular</td>
<td>C6, C7, C8, T1</td>
<td>Median nerve</td>
<td>Cords are hypoechoic on ultrasound</td>
</tr>
<tr>
<td>Axillary</td>
<td>Terminal branches</td>
<td>Vascular uptake (LAST)</td>
<td>Musculocutaneous nerve sparing</td>
</tr>
<tr>
<td>Intercostobrachial</td>
<td>C8-T2</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Intravenous Regional Anesthesia (aka Bier Block, first use in 1908)
- Mechanism of action: diffusion of local anesthetic extravascularly
- Typically use lidocaine 0.5-1% +/- adjuncts

Regional Lumbarosacral Plexus Anatomy
- Lumbar Plexus (L1-L4, occasionally T12)
  - Lateral Femoral Cutaneous nerve (L1-L3) – sensory only
  - Femoral nerve (L2-4) – sensory and motor
  - Obturator nerve (L2-4) – sensory and motor
- Sacral Plexus (L5-S4)
  - Sciatic nerve (L5-S4) – sensory and motor
  - Posterior femoral cutaneous nerve (S1-S3) – sensory only
  - Sensation to posterior thigh, travels with sciatic nerve near piriformis muscle
**Regional Lower Extremity Blocks**

<table>
<thead>
<tr>
<th>Approach</th>
<th>Anatomy/Sensory/Motor</th>
<th>Other</th>
</tr>
</thead>
<tbody>
<tr>
<td>Femoral</td>
<td>Hip flexors, knee extensors</td>
<td>Sensation of hip, anterior thigh, medial ankle, medial knee</td>
</tr>
<tr>
<td>Sciatic</td>
<td>Cutaneous afflicts femoral and lateral femoral cutaneous nerves (late thigh sensation)</td>
<td>Trans-synaptic through fascia lata and fascia iliaca proximal to femoral art bifurcation</td>
</tr>
<tr>
<td>Adductor Canal</td>
<td>Sensation of anterior thigh, medial leg, medial ankle, underlying sacroiliac muscle</td>
<td>Less motor block than femoral</td>
</tr>
<tr>
<td>Saphenous</td>
<td>Lt-53 root, posterior leg/thigh/low/lower leg</td>
<td>Less motor block associated with fascial plane block</td>
</tr>
<tr>
<td>Fingepal</td>
<td>Vertical and ankle sensation</td>
<td>Less motor block of hamstrings</td>
</tr>
<tr>
<td>Femoral</td>
<td>Hip, knee, perianal</td>
<td>Less motor block from lumbar plexus</td>
</tr>
<tr>
<td>Adductor Plane</td>
<td>Hip, knee, perianal</td>
<td>Less motor block than femoral</td>
</tr>
</tbody>
</table>

**Other common blocks**

- Paravertebral
  - Borders: Conus medullaris to posteriorly, T12, S1 laterally
  - T12: T12, L1 (cutaneous); S1 (cutaneous)
  - L1: T12, L1, S1
  - Anterior border: Ventromedial medulla (somatic)
  - Posterior border: Nociceptive, sympathetic (visceral)
  - Spinal levels: L2, L3
  - Spinoreticular – decussates and ends in reticular formation (affective pain)
  - Spinothalamic– decussates and ultimately ends in somatosensory cortex
  - Inhibitory Neurotransmitters: Glycine, GABA
  - Excitatory Neurotransmitters: Glutamate, Substance P
  - 10 layers of Rexed laminae, esp laminae I, II, III, V in pain
- Perivertebral
  - Targets: Saphenous n (S1), greater saphenous n (S1), lesser saphenous n (S1)
  - Fascial plane block between internal oblique and transverse abdominis plane
  - Anterior to saphenous nerve placement

**Pain Basics**

- Pain = an unpleasant emotional experience associated with actual or potential tissue damage, or described in terms of such damage
- Nociceptive pain = result of tissue damage to non-neural tissue
  - Due to activation of normally functioning nociceptors
  - Somatic:
    - Originates from skin, muscle, joint, bone, connective tissue
  - Somatic: Sharp, throbbing, localized if superficial
  - Somatic: Dull, diffuse
  - Somatic: Originates from skin, muscle, joints, bone, connective tissue
  - Visceral:
    - Via visceral nociceptive afferent fibers that travel with sympathetic efferent fibers
    - Visceral: Dull, diffuse
  - Visceral: Originates from solid or hollow visceral organs
  - Visceral: Pain transmitted via sympathetic fibers
  - Visceral: Cardiac, pulmonary, gastrointestinal, genitourinary, central nervous system
- Neuropathic Pain
  - Damage or dysfunction of PNS or CNS nerves themselves
  - Neurogenic (e.g., burning, pricking) or paresthesia (e.g., stabbing, shooting, electric shock)
  - Involves deafferentation pain (e.g., phantom limb pain), CRPS
  - Emetic (e.g., nausea, vomiting)
  - Polyneuropathies and mononeuropathies
  - Less likely to respond to pharmacologic treatments like opioids

**Pain Terminology**

- Allodynia = pain due to a stimulus that does not normally provoke pain
- Hyperalgesia = increased pain from a stimulus that normally provokes pain
- Hypersensitivity = increased sensitivity to stimulation, excluding the special senses
- Dysesthesia = an unpleasant abnormal sensation, whether spontaneous or provoked
- Paresthesia = abnormal sensation, whether spontaneous or provoked (aka not unpleasant)
- Central sensitization = increased responsiveness of nociceptive neurons in the CNS to their normal or subthreshold afferent input
- Peripheral sensitization = increased responsiveness and reduced threshold of nociceptive neurons in the periphery to the stimulation of their receptive fields

**Pain Pathways**

- Nociceptors:
  - Primarily free nerve endings of Aδ and C fibers transmitting nociception
  - Aδ – thin, myelinated, fast conduction = RAPID, SHARP, localized pain
  - C – very thin, unmyelinated, slower conduction = SLOW, DIFFUSE, DULL pain
- Dorsal Horn of Spinal Cord
  - 10 layers of Rexed laminae, e.g., laminae I, II, III, V in pain
  - excitatory neurotransmitters: glutamate, substance P
  - inhibitory neurotransmitters: glycine, gabaa
- Ascending Tracts
  - Spinohalamic: descussates and ultimately ends in somatosensory cortex (localization of pain)
  - Spinothalamic – descussates and ends in reticular formation (affective aspect of pain)
- Descending Inhibitory Pain Modulation
  - Periaqueductal gray in midbrain and Ventromedial medulla
  - Both contain opioid receptors and endogenous opioids to inhibit pain transmission
  - Also uses norepinephrine and serotonin to modulate
**Neuraxial blockade of nociceptive stimuli via epidural or spinal anesthetics may blunt the metabolic and neuroendocrine stress response to surgery if it is established BEFORE incision and continued post-op.**

- Lidocaine bolus + infusion has analgesic, antihyperalgesic, and antiinflammatory properties (data strongest in colorectal and prostate surgeries).

- Patient-controlled analgesia (PCA) provides better pain control, greater patient satisfaction, and fewer opioid side effects compared to PRN IV opioids.

**Tolerance vs Dependence**

- **Opioid Tolerance** - requirement of increasing doses of opioids to maintain same analgesic effect
  - May result in less sedation, nausea, or respiratory depression
  - Constipation does not develop tolerance
  - Common issue with chronic intrathecal opioids

- **Opioid Dependence** - manifests as withdrawal when the medication is either abruptly discontinued or significantly decreased
  - May be precipitated by opioid antagonists

---

**Pediatric Airway**

<table>
<thead>
<tr>
<th>Anatomy</th>
<th>Pediatric</th>
<th>Adult</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tongue</td>
<td>Large</td>
<td>Normal</td>
</tr>
<tr>
<td>Epiglottic Shape</td>
<td>Floppy, omega shaped</td>
<td>Firm, flatter</td>
</tr>
<tr>
<td>Epiglottis Level</td>
<td>Level of C3 - C4</td>
<td>Level of C5 - C6</td>
</tr>
<tr>
<td>Trachea</td>
<td>Smaller, shorter</td>
<td>Wider, longer</td>
</tr>
<tr>
<td>Larynx Shape</td>
<td>Funnel shaped</td>
<td>Column</td>
</tr>
<tr>
<td>Larynx Position</td>
<td>Angles posteriorly away from glottis</td>
<td>Straight up and down</td>
</tr>
<tr>
<td>Narrowest Point</td>
<td>Sub-glottic region</td>
<td>At level of Vocal cords</td>
</tr>
<tr>
<td>Lung Volume</td>
<td>250 ml at birth</td>
<td>6000 ml as adult</td>
</tr>
</tbody>
</table>

**Fetal Circulation**

- 2 deoxygenated umbilical arteries
- 1 oxygenated umbilical vein
- Shunts:
  - Ductus venosus
  - Foramen ovale
  - Ductus arteriosis

**Pediatric Breathing Circuits**

- Lack unidirectional valves
- No CO2 absorber
- Lower airflow resistance better for peds
- Increased venting
- Efficiency determined by amount of FGF needed to prevent rebreathing:
  - Spontaneous: Mapleson A most efficient
  - Controlled: Mapleson D most efficient

**Maternal Physiology of Pregnancy**

- **CNS**
  - Decreased MAC (40%) for all general anesthetics
  - MAC returns to normal by 3rd day postpartum
    - Likely in part due to progesterone (sedating at high doses!) and β-endorphins
  - MLAC: minimum local analgesic concentration
    - Concentration of LA leading to analgesia in 50% pts
    - Pregnancy increases sensitivity to local anesthetics
  - Increased epidural blood volume (engorgement due to gravid uterus obstruction of IVC)
  - Decreased CSF volume
  - Increased epidural space pressures
Maternal Physiology of Pregnancy

- Respiratory
  - Decreased FRC, Increase O2 consumption leads to poor oxygen reserve and rapid desaturation
  - Sharp decrease in ERV
  - FRC returns to baseline by 48h postpartum
  - Increased minute ventilation (50%)
  - Increased Tidal Volume and Increased RR
  - Decreased PaCO2 due to hyperventilation
  - Respiratory alkalosis compensation with LOWER bicarb
  - Elevated diaphragm but larger AP diameter of chest
  - NO CHANGE in vital capacity and closing capacity
  - Increased upper airway edema

- Cardiovascular
  - Increase cardiac output (40%), Increase SV (30%)
  - Peak CO during active labor and immediately after delivery
  - 2 weeks for CO to return to baseline
  - Increase HR (20%)
  - Decrease SBP (5%), Decrease SVR and DBP (15%)
  - Cardiomyopathy and myocardial hypertrophy
  - Normal to have Left Axis Deviation and T wave changes on EKG
  - Normal to have Systolic flow murmur and Split S1/S3 on exam
  - NO CHANGE in PA pressure, CVP, PCWP
  - Gravid uterus compresses venous return
    - Maintain Left Uterine Displacement if hypotensive

- Hematologic
  - Increase plasma volume (55%)
  - Increase RBC mass (45%)
  - Net dilutional anemia and lower blood viscosity
  - "hypercoagulable" due to
    - LARGE increase in fibrinogen
    - Increase factors VII, VIII, IX, X, XII
    - Decrease only in factor XI
  - Mild thrombocytopenia (10%) drop expected
  - Iron and folate deficiency

- Renal
  - Increase RPF and GFR
  - Decrease Creatinine (aka Cr 1.0 is ABNORMAL)
  - Decreased BUN

- GI
  - Delayed gastric emptying (during labor only)
  - Incompetent lower esophageal sphincter

Fetal Heart Tracings

- Accelerations
  - Increase HR >15bpm from baseline for >15sec
- Early deceleration
  - Head compression (activates vagal response)
- Variable deceleration
  - Cord compression
- Late deceleration
  - Uteroplacental insufficiency
- Bradycardia: mean FHR <110 bpm
- Tachycardia: mean FHR >160 bpm
- Variability: normally 6-25bpm

Uterine Blood Flow

- 10% of cardiac output
- Uterine vasculature is maximally dilated, limiting autoregulation available
  - Sensitive to alpha-adrenergic agonism
- Blood flow depends on Uterine vascular resistance and pressure gradient from artery to veins
- Factors that DECREASE uterine blood flow
  - Hypotension
  - Uterine vasoconstriction
  - Uterine contractions
Common Cardiac Equations

- Cardiac Output (CO) = HR x SV
- Stroke Volume (SV) = EDV – ESV
- Ejection Fraction (EF) = SV/EDV
- Mean Arterial Pressure (MAP) = (2xDBP + SBP)/3
- Systemic Vascular Resistance (SVR) = (MAP-CVP)/CO x 80*
- Pulmonary Vascular Resistance (PVR) = (PAP-PCWP)/CO x 80*
- Coronary Perfusion Pressure (CPP) = AoDP – LVEDP

* Multiply by 80 to convert SVR/PVR units to dynes/sec/cm^5

Electrophysiology

- Cardiac muscle cells resting potential -90mV
- K+ is major determinant of resting potential
  - Gradient determined by Na/K ATPase
- Cardiac ventricular myocytes are FAST:
  - Phase 0 – Na+ channels open cause depolarization
  - Phase 1 – Na+ clamped, K+ diffuses out causes slight repolarization
  - Phase 2 – K+ outflow balanced by Ca+ influx
  - Phase 3 – Ca+ closed, only K+ open
- SA and AV node myocytes are SLOW:
  - No phase 1 or 2 components
  - Phase 4 is Na+ and Ca+ open slow depolarization
  - Phase 0 is Ca+ open

Waveform Component | Phase of Cardiac Cycle | Mechanical Event
--- | --- | ---
a wave | End diastole | Atrial contraction
v wave | Early systole |-Tricuspid bulging (TVC)
v wave | Late systole | VESSEL FILLING PATH
k wave | Diastolic | Atrial relaxation
l wave | Mid systole | Early ventricular filling

Cardiac Cycle

- RCA receives flow in both Systole and Diastole
- LCA and hence LV receives perfusion primarily in Diastole
- CPP = DBP – LVEDP (perfusion in diastole!)

Contractility changes = slope of Frank-Starling curve changes
Volume changes = move along curve (ex: D to E)
COVID RESOURCES

Where do I get a N95?
500p OR front desk
or
any anesthesia tech room

COVID-19 Timeline of Symptoms

Who do I call if I have symptoms?
COVID-19 Healthcare workforce Response Team (HRT):
650-497-9595
Available 24/7*

For assistance with:
• Exposure questions
• Test scheduling
• Symptoms questions
• Contact tracing/exposure management

*after hours calls answered by clinical advice services, who can page on-call HRT provider if needed to arrange urgent testing in ED

Color Self-Swab Testing Program

• All Stanford employees are encouraged to test weekly using this Color Genomics self-swab testing program
• Register here: https://home.color.com/create-account?next=https://ccc.color.com/activation (use Stanford email)
• Pick up kits and drop off your sample at work!
  • Check https://shcconnect.stanfordmed.org for latest on pick up and drop off locations (click on “Latest updates on Novel Coronavirus” and search for “color”)
• More info: https://healthalerts.stanford.edu/covid-19/prevention-care/employee-postdoc-testing/#winterquarter-hours
Other Resources

- Latest COVID-19 updates: https://shconnect.stanfordmed.org
- Stanford COVID ICU Task Force: https://sites.google.com/view/stanford-covid/home (highly recommend for all things ICU)
- Dept of Anesthesia specific information: https://ether.stanford.edu/covid-19/index.html
  - Information on PPE use
  - OR protocols
  - Airway management
  - COVID airway call coverage schedule

RNA Negative Strand Test

RNA Negative Strand Test

Why does this matter?
- When patients test positive for SARS-CoV-2 but are asymptomatic and have a documented history of recent COVID-19, a negative strand test is ordered
- This test can be ordered as an add-on using the already collected sample
- The lab runs this test on Mondays, Wednesdays, and Fridays (under special circumstances you can call the lab and request a test be run on a Saturday)
- The lab needs the order and sample the night before in order to guarantee that the sample will be processed the following day
- Do not expect to get a result back that same day (processing time is variable and sometimes they run the samples at night)

<table>
<thead>
<tr>
<th>COVID REGULAR SWAB</th>
<th>RNA STRAND TEST</th>
</tr>
</thead>
<tbody>
<tr>
<td>Detects: PLUS and/or MINUS STRAND (any viral particles)</td>
<td>Detects: MINUS STRAND</td>
</tr>
<tr>
<td>First Positive Detection: patient is considered infectious</td>
<td>Any Positive Detection: patient is considered infectious</td>
</tr>
<tr>
<td>Positive Detection After Initial Test: patient might be infectious</td>
<td>Not Detected: not infectious</td>
</tr>
<tr>
<td>Patient can be “positive” on the test for weeks and no longer be infectious</td>
<td></td>
</tr>
<tr>
<td>Not Detected: not infectious</td>
<td>No RNA strand test needed if regular swab is negative</td>
</tr>
</tbody>
</table>

RNA Negative Strand Test

MINUS STRAND detected = active infection

Only PLUS STRAND detected = inactive (not replicating) virus