Medical Intensive Care Unit Cram Sheets

A collection of critical care topics in easily digestible format

Table of Contents:

MICU: How I do it

Anemia:

1. Think about its cause;
2. Transfuse when Hgb falls below 7 g/dL;
3. Don't use epo;
4. The data supporting restrictive transfusion are less robust in patients with active coronary ischemia, but they probably benefit from withholding blood until Hgb < 8;

Ventilation:

1. Most patients have acute lung injury and should be ventilated with 6cc/kg ideal body weight using volume assist-control;
    a. Inspiratory flow rate should be about 60L/min;
    b. Respiratory rate should be about 30 ± 6;
    c. PEEP can be judged by the stress index or by the ARDSNet tables;
2. In patients with primarily obstructive lung disease, avoid excessive ventilation that amplifies autoPEEP;
3. The peak and plateau airway pressures should be measured and interpreted routinely, since they inform regarding physiology and response to treatment (this is a major reason to use volume modes);
4. Ventilatory settings should be guided by your goal (rest vs work; lung protection) and your interpretation of the waveforms, not generally by blood gases;
5. The SpO2 goal should generally be .88 – 0.95 (neither lower nor higher) in ALI/ARDS;
6. Oxygenation should be reported as an SpO2 / Fio2 ratio as this may identify patients in whom advanced therapies should be considered

Weaning:

1. Nearly all patients should have a daily spontaneous breathing trial. This consists of pressure-support of 5-7 cm on whatever PEEP is set (a T-piece trial is an acceptable alternative, but is more labor-intensive and gives less information). Protocolized weaning by the RT speeds extubation so please support their protocol to do this. Some patients who fail the RT readiness assessment may, nevertheless, benefit from an SBT (eg, obtunded, on vasoactive Rx);
2. A f/Vt < 105 during a readiness assessment predicts a successful SBT;
3. SIMV impedes weaning and should not be used;

Judging the adequacy of perfusion:

1. If the patient is thinking, peeing, and pink (good capillary refill) and has normal vital signs, he is probably perfused adequately, but few of our patients meet all of these criteria;
2. Vitals signs alone are NOT sensitive indicators of hypoperfusion;
3. Lactic acid levels will identify some, but not all, patients who are poorly perfused;
4. The ScvO2 is not a perfect metric of perfusion but it's better than blood pressure and lactic acid. When there is a question of perfusion, a central line is generally indicated and ScvO2 should be measured;

Fluids:

1. "Maintenance fluids" are almost never appropriate; most of our patients need furosemide;

2. If a patient is well-perfused (see above), they generally do not need fluids;
3. Patients with acute lung injury (ALI/ARDS) who are adequately perfused should be diuresed to a goal CVP of < 4cm;
4. Patients not well-perfused will respond to a fluid bolus 40-50% of the time. If the risk of fluids is small (kidneys and lungs not very impaired), give a fluid bolus. If the risk of fluids is not small (eg, ALI, ARF), use a dynamic predictor of fluid-responsiveness and withhold fluids in those predicted not to respond. If there's no time for predictors or you aren't sure of the pre-conditions for a valid fluid-responsiveness predictor, give a fluid bolus, but be skeptical about its impact (measure something relevant before and immediately following the bolus) and re-assess the patient often;
5. A fluid bolus is at least 1L normal saline wide-open (in the setting of obvious acute volume loss, a larger bolus is appropriate);
6. There is no role for hetastarch or albumin (there is very weak support for albumin to reduce the risk of HRS during large-volume [>5L] paracentesis);
7. Balanced crystalloids (e.g. Lactated Ringers) should be considered if more than 1-2 liters are required.

Vasoactive drugs:

1. The preferred vasoconstrictor is norepinephrine. It is more effective than dopamine, phenylephrine (Neosynephrine), or vasopressin;
2. Epinephrine is the preferred second line vasoconstrictor especially in septic shock
3. Vasopressin occasionally succeeds as a rescue vasoconstrictor, but provides no benefit in sepsis compared simply to higher-dose norepinephrine. It is reasonable to try vasopressin when the dose of NE is very high (eg. > 30) and epinephrine is contraindicated by extreme tachycardia (e.g. 140, NOT 120);
4. Recent cost increases for vasopressin further diminish its attractiveness. AVP shoud NEVER be ordered "just in case".
5. Dobutamine is the preferred inotrope. It is more effective than dopamine;
6. Tachycardia on vasoactive drugs is expected to some degree. If it's a lot, the patient may be hypovolemic. Tachycardia should prompt a switch from NE to phenylephrine once in a blue moon;

Electrolytes:

1. A K+ of 3.0 is generally just fine. Patients die from hyperkalemia, not hypokalemia;
2. Hypocalcemia probably does not benefit from treatment (even ionized hypocalcemia, so don't measure it). Calcium may be harmful so is generally indicated only for life-threatening hyperkalemia;
3. Intravenous bicarbonate is almost never indicated in the critically ill;

Nutrition:

1. How early to feed is controversial, but we generally choose early feeding;
2. Enteral nutrition is preferred;
3. Absence of bowel sounds, high residuals, and abdominal distention are not absolute contraindications to feeding the gut. If a patient's gut doesn't work today, try again tomorrow. There is an evidence-based nursing protocol to guide this;
4. Starvation is probably better than CVN, at least for the 1st couple of weeks;

Glycemic control:

1. Blood sugar should be kept between 120 and 180 in nearly all critically ill patients (80 – 110 is too low). This requires an infusion (not sliding scale) in many;

Sedatives:

1. use boluses first, especially in cirrhotics.
2. start infusions only after more than three boluses are needed in an hour.
3. Interrupt all infusions (benzo's, propofol, and narcotics -- cold turkey) daily in nearly all patients;
4. Restart when patient demonstrates need (not just because they are on a ventilator);
5. Avoid benzos

Venous access:

1. Use full barrier precautions during insertion of central lines;
2. Measure ScvO2 and CVP immediately after placing a central line. These may not determine fluid responsiveness, but do demonstrate physiology that is helpful information.
3. PICC's are rarely appropriate in the critically ill;
4. Decide daily if a central line is still essential – if not, get it out;

Transport for imaging:

1. Transports are risky -- sometimes disrupted by loss of lines; exhaustion of continuous infusions; or unpredicted change in patient status. Occasionally, these disruptions are lethal; They also decrease the number of nurses available to respond to other crises in the ICU.
2. Only transport patients for essential imaging, meaning that
    a. there is a clinically real chance of diagnosing a new problem;
    b. it will change management if positive (or negative);
    c. it will affect outcome if management is changed;
    d. there's not a simpler way to get the information;
3. Curiosity is a wonderful attribute in a physician but is rarely a sufficient basis for performing a test with risk.

Blood Cultures:

1 Cultures should be obtained before starting antibiotics.
2 Avoid culturing from central lines unless no other option is available. If peripheral cultures are negative, the false positive rate from central lines is higher than the true positive rate. If peripheral cultures are positive, strongly consider removing all lines present.

Labs:

1 Avoid ongoing scheduled panels (e.g. daily BMP)
    a. consider which components you need (e.g creatinine and potassium rather than BMP)
    b. More than one BMP per day is rarely appropriate
2 A daily creatinine and platelet count will help will a) identify changes in renal function that change drug dosing; b) avoid BPAs for patients on prophylactic heparinoids; c) allow for other tests to be added on if new problems arise
3 Consider daily glucoses in unconscious patients as they may not be able to tell us they are hypoglycemic.

Problem-Based Presentations in the MICU

Concise but thorough presentations are critical to efficient information transfer between caregivers, including during rounds with an attending physician. Key components of an appropriate presentation include:

1) **An introductory summary** that relates the current problems and working diagnoses;
2) **Presenting symptoms** for new patients
3) For each problem (assessment), then include
    a. **Data** that supports your diagnosis, including physical exam, physiologic monitoring, labs, imaging
    b. **Changes** over time (hours or days, as appropriate)
    c. **Treatment** rendered and adequacy of treatment as appropriate
    d. **Plans** to continue or change treatment

TIPS:

1) Start new patient presentations with chief complaint and working critical care diagnosis. Do NOT start presentations with a disorganized list of co-morbid conditions that the listener will not know how to relate to pressing problems.
2) When presenting new patients, generally DO NOT include excessive laboratory data scattered across organ systems (or not relevant at all). Save these data for the focused problem assessment.

Problem-specific information commonly addressed MICU patients (not an exhaustive list):

Cardiovascular: Be sure to include

1. Presence of shock, and an etiology justified by objective findings
2. Vasoactive infusions, dose and trend. BP is rarely informative as the infusions are titrated to MAP 65 mm Hg (reportable if not 60-70!)
3. adequacy of perfusion, usually including extremity color and warmth, capillary refill, blood lactate and ScvO2, and Point-of-care Ultrasound (POCUS). CVP may be helpful in many patients especially sepsis and ARDS.

Pulmonary (ventilated patients):

1. Mode and set parameters
2. Oxygenation: Usually an SaO2/FiO2 ratio and PEEP
3. Lung Mechanics: Assess if normal, obstructive, restrictive, or mixed physiology, using Peak and Plateau Pressures to justify
4. Lung imaging, including POCUS
5. Assessment of readiness to extubate, including f/Vt during spontaneous breathing

Bleeding (GI or otherwise):

1. First address presence or absence of shock (perfusion, lactate, scvo2, pressors)
2. Hgb, current and baseline, units of PRBC in past 24 hours; transfusion target
3. Coagulation (platelets, prothrombin time, other blood products received)
4. Diagnostic and therapeutic interventions performed and/or planned

EXAMPLE 1:

Summary: Mr. Jones is a 72 year old man admitted 2 days ago with urinary tract infection and septic shock complicated by acute respiratory failure and ARDS. His problems include:

1) Septic shock, as evidenced by warm extremities, brisk capillary refill, and hyperdynamic LV on POCUS. Antibiotics were initiated upon presentation. He currently is well perfused on exam as described, but also lactate is 1.8 and ScvO2 is 75%, and CVP is 12. He is currently on norepi at 8 mcg/min, decreased from yesterday when he was on 20 mcg/min. With adequate perfusion and an IVC 2cm without respiratory variation on ultrasound, additional fluids are unlikely to decrease his vasopressor requirements. We will continue to titrate vasopressors to keep MAP 65.
2) Acute Respiratory Failure with ARDS: current ventilator settings include Volume Control, Vt 420cc (6cc/kg), FiO2 60%. He has severe respiratory failure as evidenced by an ***S/F ratio*** *154*, worse than yesterday. His Peak pressure is 42, plateau pressure 30, PEEP 10 confirming ***restrictive physiology*** consistent with ARDS, also worse than yesterday. CXR yesterday showed diffuse infiltrates. Ultrasound today demonstrated 3-4 **B-lines anteriorly bilaterally**. We will continue supportive care with lung protective ventilation, add cisatracurium given the severe hypoxemia, and obtain an ECMO consultation. We will pursue conservative fluid management and currently give diuresis given the CVP of 12 and evidence of adequate perfusion. He is **not ready to extubate** as we will initiate paralysis.

EXAMPLE 2:

Ms. Smith is a 68 year old woman who presented yesterday with melena. She has relevant history of coronary artery disease and STEMI 3 weeks ago and takes aspirin and Plavix for DES placed during her STEMI.

1. Cardiovascular: despite bloodloss, she has no evidence of shock currently and is well perfused with warm extremities and brisk capillary refill, and a lactate of 1.4. She is not having chest pain and her EKG is unchanged from previous admission.
2. GI bleed: on presentation to outside hospital her hgb was 5.2. overnight she has received 3 units of PRBCs, and her current hgb is 8.0. We will transfuse to keep hgb $\geq$ 8 given her recent coronary ischemia. EGD revealed a duodenal ulcer that was clipped. Aspirin and Plavix are being held, and coags were normal. She is on protonix infusion, which can be changed to intermittent dosing today.

Mechanical Ventilation

Modes and Dials

Basic Terms:

Mean Airway Pressure (MAP)—the average pressure across the respiratory cycle

Compliance (C)—the change in lung volume for a change in pressure ($C = \Delta V / \Delta P$)

Dynamic Compliance (C_{dyn})—compliance measured during gas flow

Static Compliance (C_{stat})—compliance measured without gas flow

Tidal Volume (V_t)—the volume changed with each breath

Minute Ventilation—the volume of gas exchanged each minute. $V_E = Vt * RR$

Expired Minute Ventilation (V_E)—gas return to the ventilator, most dependable?

General Principles:

Increase a patient's oxygen through increase in FiO2 or increase in Mean Airway Pressure (achieved through increase PEEP, increased inspiratory time)

Increase CO_2 elimination through increase in minute ventilation (RR or Vt)

Pressure Control:

1. set PEEP, PiP
2. Tidal Volume (V_t) dependent upon PiP and compliance ($C = \Delta V / \Delta P$), also T_i
    a. Change in compliance leads to change in Vt
    b. Compliance by change due to position, inflammation, edema, etc
3. Set Inspiratory Time (T_i)
    a. I:E generally 1:~3
    b. Longer expiratory time ($T_i$exp) in obstructive lung diseases
    c. Shorter I:E ratio increases mean airway pressure
    d. Inverse Ratio refers to I:E greater than 1
    4. Flow variable due to changes in alveolar pressure

Pressure Support

1. Set PEEP, PS
2. Fully supportive mode
3. Flow variable
4. T_i dependent upon flow decay, adjustable
5. SBT PS 5/5, 30-120 minutes
    a. f / Vt = RSBI = SBI $\leq$ 105
    b. causes of apnea in SBT: sedation, neuro injury, overventilation

Volume Control:

1. set PEEP, Vt
    a. Vt 6cc/kg ideal body weight (determined by height)
    b. IBW = 2.3 kg/inch over 5 feet plus:
        1. 50 kg (men)
        2. 45 kg (women)
    c. set inspiratory time
        1. flow = Vt / T_i ~ 60 liters/minute
    d. set RR
        1. ~28/minute +/- 6 depending upon severity of illness
        2. adjust to V_E, synchrony
    e. Measure $P_{plateau}$ with inspiratory hold button (bottom right)

Mechanical Ventilation with Volume Control

Mechanical ventilation is simply a technique to push medical gas into a patient's lungs. We can program how hard the ventilator will push (pressure targeted modes) or how much to push (volume targeted modes). The laws of physics dictate that pressure is proportional to volume, thus there may not be much difference between pressure targeted and volume targeted modes. However, in the Medical Intensive Care Unit, we choose to ventilate most patients with the Volume Control mode for the following reasons:

1) **Limiting tidal volume reduces mortality.**
2) **Volume Control mode provides easily interpretable information regarding respiratory physiology.**
3) **Consistent practice improves performance.**

Controlling Tidal Volume

In patients with ARDS, limiting tidal volume (V_t) to 6cc/kg reduces mortality.[1] Limiting V_t also decreases systemic inflammation[2] and the development of ARDS in patients at risk.[3] Many if not most MICU patients have risk factors for ARDS including sepsis, aspiration, and shock.

Practical Approach to Mechanical Ventilation with Volume Control Ventilation

- Most patients should be ventilated with Volume Control mode.
- V_t should be set at 6cc/kg of *ideal body weight*, calculated from height and gender.
- Set RR 30 +/- 6 breaths per minute. To preserve adequate minute ventilation, low Vt should generally be compensated with higher RR. Sicker patients (metabolic acidosis, high deadspace/CXR involvement) demand higher RR.
- Set inspiratory flow 60 lpm
- Initiate at FiO2 1.0 and titrate down as tolerated
- Set PEEP at 5, increase if SpO2 < 0.88 with FiO2 > 0.6
- Measure plateau pressure P_{plat} with a **temporary inspiratory hold** early and often
- Record and report information in three categories
    - Respiratory mechanics (compliance) including P_iP, P_{plat}, PEEP, C_{stat}
    - Oxygenation, incl PEEP and SpO_2/FiO_2 ratio
    - Chest Imaging, incl CXR and ultrasound
- Stop sedation and assess for extubation daily *every patient, every day (rare exceptions, incl NMB)*[4]
- Consult PT for early mobility on day 1.[5]
- Use the ventilator order set for all ventilated patients

How to use an Insp Hold

Fine-tuning the Mode

Suboptimal gas exchange

Remember that gas exchange may be less important than optimal respiratory mechanics. In the ARMA trial of low Vt vs high Vt, the low Vt arm had lower SpO2 and higher PaCO2, but lower mortality compared to the high Vt arm. Resist changes that result in higher Vt, including a change in modes.

Asynchrony

Asynchrony is often due to unmatched metabolic demand (acidosis) or intrinsic neural inspiratory time. Asynchrony often results in "double-stacked breaths" which are probably injurious and should be minimized. Switching modes may also result in injurious breaths.[6] Consider the following to improve synchrony (in this order):

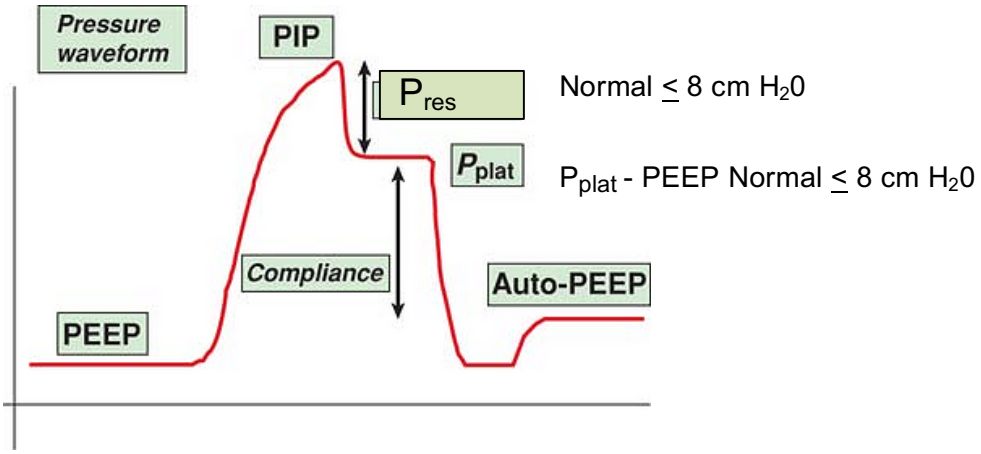
1) Increase respiratory rate (assess for auto-PEEP)
2) Decrease inspiratory flow slightly (usually not effective)

3) Institute an inspiratory pause of 0.1-0.15 seconds (more effective than sedation)[6]
4) Temporary increase in Vt to 8cc/kg for 1-2 hours only!
5) Increase sedation (less effective than insp pause) only if other evidence of agitation
6) Neuromuscular blockade

Recognizing Physiology during Volume Control Ventilation

Peak inspiratory pressure (P_iP) is the sum of three pressures: 1) PEEP; 2) Pressure related to V_t and compliance; and 3) Pressure to overcome airway resistance (P_{res}). An **Inspiratory Hold** allows the ventilator to deliver a breath, then stop flow. The resulting **plateau pressure (**P_{plat}**,** see figure**)** is the total pressure that is transmitted to the alveoli, and allows one to differentiate between abnormal compliance and abnormal resistance. This helps confirm or refute clinical diagnoses such as COPD (high P_{res}, normal P_{plat}) or interstitial lung disease (high P_{plat}, normal P_{res}). Static compliance (Cstat) equals V_t / (P_{plat} – PEEP). Remember P_{plat} is not related to flow, as it is measured in the absence of flow. P_{res} *is* dependent upon flow, but this pressure is not transmitted to the alveoli, and does not contribute to injury. Resist urges to change flow to affect P_{res} as this has many unintended consequences.

View simulation of Pplat here.



References:

1. The National Heart L, and Blood Institute Acute Respiratory Distress Syndrome (ARDS) Clinical Trials Network. Ventilation with lower tidal volumes as compared with traditional tidal volumes for acute lung injury and the acute respiratory distress syndrome. The Acute Respiratory Distress Syndrome Network. *N Engl J Med.* 2000;342(18):1301-1308.
2. Determann RM, Royakkers A, Wolthuis EK, et al. Ventilation with lower tidal volumes as compared with conventional tidal volumes for patients without acute lung injury: a preventive randomized controlled trial. *Crit Care.* 2010;14(1):R1.
3. Su F, Nguyen ND, Creteur J, et al. Use of low tidal volume in septic shock may decrease severity of subsequent acute lung injury. *Shock.* 2004;22(2):145-150.
4. Kress JP, Pohlman AS, O'Connor MF, Hall JB. Daily interruption of sedative infusions in critically ill patients undergoing mechanical ventilation. *N Engl J Med.* 2000;342(20):1471-1477.
5. Schweickert WD, Pohlman MC, Pohlman AS, et al. Early physical and occupational therapy in mechanically ventilated, critically ill patients: a randomised controlled trial. *Lancet.* 2009;373(9678):1874-1882.
6. Chanques G, Kress JP, Pohlman A, et al. Impact of ventilator adjustment and sedation-analgesia practices on severe asynchrony in patients ventilated in assist-control mode. *Crit Care Med.* 2013;41(9):2177-2187.

Patient-Ventilator Asynchrony

An over-arching goal of mechanical ventilation is to maintain homeostasis through both improved gas exchange and decreased work of breathing, while minimizing the potential for ventilator-induced lung injury. Careful attention to patient-ventilator interactions, and resolution of asynchrony if present, is paramount to achieving these goals.

Ventilator asynchrony causes an increased work of breathing which may result in:

1) Lactic acidosis
2) Altered distribution of bloodflow away from other organs and toward diaphragm
3) Injurious tidal volumes
4) Diaphragm dysfunction
5) Injurious distribution of tidal volume resulting in regional hyperinflation

Asynchrony that results in double-triggered breaths results in **injurious tidal volumes** averaging 1.6x the target V_t (>10cc/kg IBW when 6cc/kg is the goal).[1] Increased frequency and intensity of electrical activity of the diaphragm leads to **diaphragm dysfunction** (thickening). The extent of diaphragm electrical activity (patient effort) correlates with the extent of diaphragm dysfunction, which imparts an increased risk of death.[2] Finally, compared to passive ventilator breaths, spontaneous breaths result in heterogeneous pleural pressures that generate **injurious regional hyperinflation** in dependent zones of the already injured lung.[3]

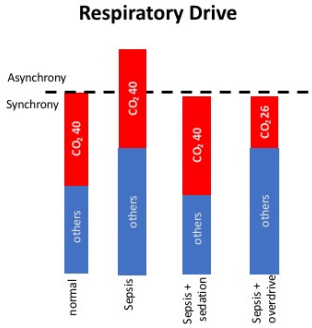


Figure 1. Overdrive. Asyncrhony develops when respiratory drive is higher than that delivered by the vent. Respiratory drive is affected by P_aCO_2, but also many other factors which are usually increased in critical illness. Sedation can reduce drive and improve asynchrony, but may not be ideal. Overdrive can reduce the drive caused by CO2 and improve synchrony

Asynchrony should NOT be viewed as discomfort. Asynchrony is most often due to a miss-match between a patient's neurologic drive to breath and the breath delivered by the ventilator. Practitioners may decrease neural drive through ventilator overdrive,-- increased rate and/or V_t. However, overdrive may 1) lead to autoPEEP; 2) create injurious V_t; 3) not be effective.

Factors that influence respiratory drive include blood oxygen and carbon dioxide, but also complex factors including lung stretch, metabolic demands, inflammation, and pain. Thus, normal P_aCO_2 does not exclude asynchrony (Fig. 1). In fact, **attempts to normalize P_aCO_2 often worsen asynchrony.**

Trigger Asynchrony

Ineffective triggering (i.e. failure of the ventilator to deliver a supported breath when the patient initiates inspiratory effort) can occur when trigger sensitivity is set less sensitive, although this should be a rare situation. Despite appropriate sensitivity, ineffective triggering may occur in up to 25% of patients. Ineffective triggering occurs when negative pleural pressure is unable to lower an exaggerated alveolar pressure below set airway pressure. Accordingly, inward (positive) flow is insufficient to trigger the ventilator. This often occurs in obstructive lung diseases and obesity. Similarly, in most patients, non-triggered breaths generally follow breaths that are larger and with shorter expiratory times than breaths that precede appropriately triggered breaths (Fig 2). **Trigger asynchrony can be addressed** by 1) increasing PEEP to counterbalance autoPEEP; 2) overdrive 3) trigger off the

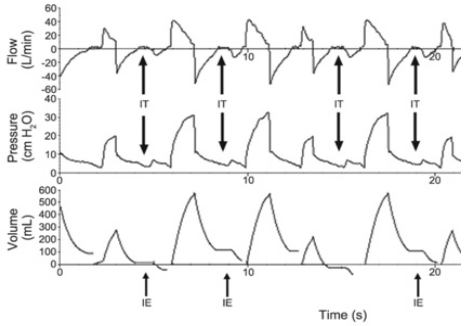


Fig 2. Ineffective Triggering (IT) is demonstrated by upward deflections of Flow and Pressure tracings, without delivery of tidal volume. IT often follows incomplete exhalation (IE). {figure from de Wit, *Respir* Care, 2011}

diaphragm (NAVA mode); 4) sedate or paralyze the patient. All of these may have other unwanted effects, at times leading one to accept the asynchrony.

Flow Asynchrony

Most critically ill patients have elevated respiratory drive that demands inspiratory flow near 60 L/min.[4] At times, any set flow may be insufficient for respiratory demand. This results in a scalloped inspiratory curve, caused by the patient creating relatively negative pressure to achieve higher than set flow, characteristic of **flow asynchrony** (Fig 3). Inadequate flow thus risks 1) flow asynchrony and increased work of breathing (harms previously described); as well as 2) auto-PEEP due to lengthening of inspiratory time and subsequent shortening of expiratory time. Flow asynchrony is commonly seen when flow < 50L/min. Increased flow can also be deleterious through a complex reflex resulting in overdrive tachypnea causing auto-PEEP despite the shortened i-time.

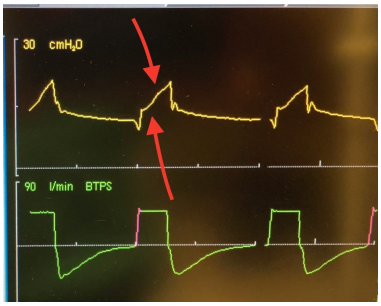


Figure 3. Flow asynchrony due to inadequate insp flow (set 43 L/m).

Cycle Asynchrony

The term cycle asynchrony refers to a discrepancy between patient and ventilator switching from inspiratory to expiratory portions of the respiratory cycle (aka cycle-off). Most commonly this occurs when the neural time constant of the patient exceeds the inspiratory time of the ventilator, resulting in persistence of patient respiratory effort after the ventilator has stopped inspiratory flow. This can be detected by an upsloping deflection of the expiratory flow tracing (Fig. 4), or downward deflection in pressure curve. The extreme of cycle asynchrony results in sufficient positive flow to trigger an additional breath delivered in the expiratory phase, a.k.a double triggered or double-stacked breaths.

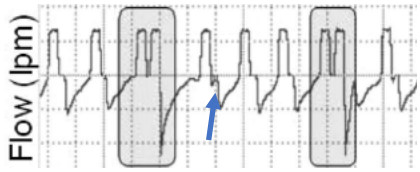


Fig 4. Cycle Asynchrony. At the beginning of expiration, a positive deflection of the flow curve indicates cycle asynchrony (arrow). If flow is sufficient to trigger a breath, stacked-breaths occur (grey boxes).[1]

Cycle asynchrony can be addressed by

1. Overdrive;
2. increased insp-time through decreasing flow (often risks flow asynchrony);
3. increased insp-time with inspiratory pause of 0.1-0.2s (no change in flow);

These **ventilator adjustments are more effective than sedation at reducing stacked breaths**.[5] Increasing tidal volume will decrease stacked breaths,[6] but likely conflicts with lung-protective strategies. Changing to Pressure Support mode will decrease breath stacking, but will likely increase V_t by ~2cc/kg IBW despite attempts to minimize V_t.[5]

REFERENCES

1. Pohlman MC, McCallister KE, Schweickert WD, et al. Excessive tidal volume from breath stacking during lung-protective ventilation for acute lung injury. *Crit Care Med.* 2008;36(11):3019-3023.
2. Goligher EC, Dres M, Fan E, et al. Mechanical Ventilation-induced Diaphragm Atrophy Strongly Impacts Clinical Outcomes. *Am J Respir Crit Care Med.* 2018;197(2):204-213.
3. Yoshida T, Nakahashi S, Nakamura MAM, et al. Volume-controlled Ventilation Does Not Prevent Injurious Inflation during Spontaneous Effort. *Am J Respir Crit Care Med.* 2017;196(5):590-601.
4. Tobin MJ. Physiologic Basis of Mechanical Ventilation. *Ann Am Thorac Soc.* 2018;15(Supplement_1):S49-S52.
5. Chanques G, Kress JP, Pohlman A, et al. Impact of ventilator adjustment and sedation-analgesia practices on severe asynchrony in patients ventilated in assist-control mode. *Crit Care Med.* 2013;41(9):2177-2187.
6. Figueroa-Casas JB, Montoya R. Effect of Tidal Volume Size and Its Delivery Mode on Patient-Ventilator Dyssynchrony. *Ann Am Thorac Soc.* 2016;13(12):2207-14

ARDS

Acute Respiratory Distress Syndrome (ARDS) is defined as a respiratory disorder with all of the following criteria:[1]

1) Acute onset within one week of a known clinical insult;
2) Bilateral opacities on chest imaging not explained by effusions, collapse, or nodules;
3) Respiratory failure not explained by cardiac failure or fluid overload, and need objective assessment to exclude hydrostatic edema if no risk factor present;
4) Severe hypoxemia with $P_aO_2 \leq 300$ mm Hg with PEEP ≥ 5 cm H_2O.

The severity of ARDS can be determined by a measure of hypoxia (P_aO_2/F_iO_2, or P/F ratio):

Mild: $200 < P/F \leq 300$
Moderate: $100 < P/F \leq 200$
Severe: $P/F \leq 100$ mm Hg

In addition to hypoxemia, categorization of severe ARDS requires PEEP $\geq$ 10cm H_2O, $V_E \geq 10$ L/min, and respiratory compliance $\leq$40 mL/cm H_2O.
Common clinical insults that result in ARDS include 1) direct pulmonary insults such as pneumonia and aspiration, 2) indirect insults usually from systemic inflammation commonly resulting from sepsis, trauma, and pancreatitis. To date, there are no direct antidotes to reverse lung injury beyond treating the underlying insult. Treatment is thus limited to supportive care, but outcomes are improved with strategies to decrease iatrogenic injury from supportive cares.

Conservative Fluids

ARDS pathophysiology includes injuries to both endothelium (excessive capillary permeability) and epithelium (decreased alveolar fluid resorption) that leads to pulmonary edema. Thus, edema resolution is entirely dependent upon minimizing hydrostatic pressure. **Well-perfused patients should be diuresed as often as every 4 hours to achieve CVP =4 cm H_2O**. This strategy leads to decreased time on the ventilator without an increase in need for dialysis.[2]

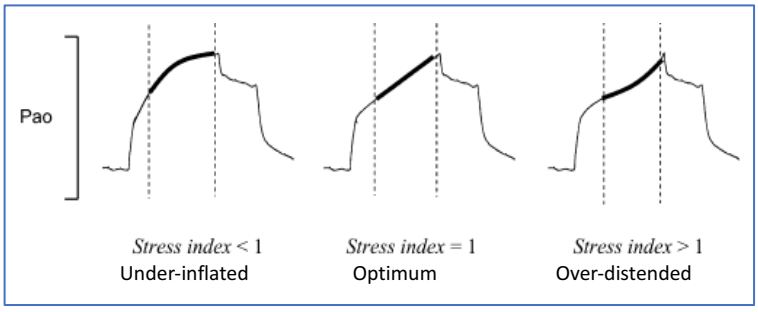
Preventing ventilator induced lung injury by limiting tidal volumes (V_t)

Patients with (or at risk of developing) ARDS should all be ventilated as follows:

1) V_t 6cc/kg of *ideal body weight* calculated from height and gender;
2) $P_{plat} \leq 30$ cm H_2O;
3) Reduction of V_t as low as 4cc/kg when $P_{plat} > 30$cm H_2O.

This ventilator strategy reduces mortality and thus is the standard of care.[3] ARDS often leads to increased dead space, and many patients have an increased metabolic demand due to systemic inflammation. This combination requires a minute ventilation ($V_E = V_t$ * Respiratory Rate) often in excess of 10 liters/min. Thus low V_t requires high RR to maintain the V_E. **The average RR for ARDS patients is 30 breaths/minute.** Refer to "Mechanical Ventilation with Volume Control" for more details. This ventilator strategy may result in lower S_pO_2 and higher P_aCO_2; attempts to improve gas exchange outside of this strategy may lead to further injury.

Best ventilator practices for ARDS[4]



PEEP

The optimum PEEP strategy in ARDS remains elusive. Large clinical trials of PEEP titration based upon oxygenation have failed to improve outcomes. In contrast, strategies of PEEP adjusted to lung mechanics show preliminary but promising results. The stress index refers to the shape of the ventilator pressure curve (temporarily decrease flow to 30 L/m to improve resolution. With optimum PEEP, the pressure increases linearly during constant flow (Stress Index, SI =1). Ventilation of under-inflated lungs recruits alveoli without an increase in pressure (SI < 1), whereas overdistended lungs will cause abrupt increase

in pressure (SI >1). SI- guided PEEP has not been evaluated in large studies, but titration of PEEP to SI =1 leads to decreased systemic inflammation[5] and thus is a logical and effective strategy.

Paralysis

In patients with moderate to severe ARDS with P/F < 150 (S/F < ~180), cisatracurium infusion may decrease mortality[6] when initiated within 48 hrs of ARDS onset, and infused for 48 hrs. Infuse 15 mg bolus then 37.5 mg/hr. The mechanism of benefit is unclear but may be due to decrease in injurious V_t caused by asynchrony. Sufficient sedation is mandatory and can be determined by repeated clinical evaluations of response to a glabellar tap. Do NOT increase sedation beyond unresponsiveness with goal to achieve passive ventilation—use cisatracurium to achieve passive ventilation. While paralyzed, do not decrease sedation. If tachycardia and hypertension develop, consider a bolus of sedation and adjust sedative infusions based upon the response.

Prone ventilation

In patients with moderate to severe ARDS, prone ventilation decreases mortality.[7] Data in the literature are mixed regarding the benefits of prone ventilation in ARDS, but benefits are most apparent when prone ventilation is applied longer (at least 16 hr/day) and to sicker patients (S/F < ~180). Important contraindications include 1) hemodynamic instability (but not merely the use of vasopressors); 2) abdominal, thoracic, or facial wounds that my not tolerate prone position). Turn patients supine $\geq$ 1x/day, and remain supine if S/F > 180 maintained over 4 hours.

Percutaneous access for Extracorporeal Support

Referral to an ECMO specialist is associated with decreased mortality.[8] A subsequent trial of ECMO in severe ARDS (P/F < 80 for 6 hours) resulted in an 11% absolute reduction in survival compared to lung protective ventilation alone.[9] 28% of the control group crossed over to ECMO, such that initial ECMO was associated with a 23% reduction of treatment failure (RR 0.62, [0.47-0.82]). Survival on extracorporeal support is most likely when applied early in young patients with acute reversible illnesses, and can be estimated by a RespScore (www.respscore.com). Theoretical benefits of ECMO include 1) less ventilator-induced lung injury; 2) less need for sedation and paralysis with less neuromuscular/cognitive effects; and 3) increased ability to participate in early ICU mobility. Because the benefits of ECMO are likely dependent upon early application, consult the ECMO physician whenever any of the above advanced supportive techniques are initiated. Beware that decreased F_iO_2 and PEEP during prone ventilation likely do not indicate a clinical improvement and should not prevent discussions regarding the potential benefits of ECMO.

References

1. ARDS Definition Task Force, Ranieri VM, Rubenfeld GD, et al. Acute respiratory distress syndrome: the Berlin Definition. *JAMA.* 2012;307(23):2526-2533.
2. NHLBI Acute Respiratory Distress Syndrome Clinical Trials Network, Wiedemann HP, et al. Comparison of two fluid-management strategies in acute lung injury. *N Engl J Med.* 2006;354(24):2564-2575.
3. Acute Respiratory Distress Syndrome Network, Brower RG, Matthay MA, et al. Ventilation with lower tidal volumes as compared with traditional tidal volumes for acute lung injury and the acute respiratory distress syndrome. *N Engl J Med.* 2000;342(18):1301-1308.
4. Fan E, Del Sorbo L, Goligher EC, et al. An Official American Thoracic Society/European Society of Intensive Care Medicine/Society of Critical Care Medicine Clinical Practice Guideline: Mechanical Ventilation in Adult Patients with Acute Respiratory Distress Syndrome. *Am J Respir Crit Care Med.* 2017;195(9):1253-1263.
5. Grasso S, Stripoli T, De Michele M, et al. ARDSnet ventilatory protocol and alveolar hyperinflation: role of positive end-expiratory pressure. *Am J Respir Crit Care Med.* 2007;176(8):761-767.
6. Papazian L, Forel JM, Gacouin A, et al. Neuromuscular blockers in early acute respiratory distress syndrome. *N Engl J Med.* 2010;363(12):1107-1116.
7. Guerin C, Reignier J, Richard JC, et al. Prone positioning in severe acute respiratory distress syndrome. *N Engl J Med.* 2013;368(23):2159-2168.
8. Peek GJ, Mugford M, Tiruvoipati R, et al. Efficacy and economic assessment of conventional ventilatory support versus extracorporeal membrane oxygenation for severe adult respiratory failure (CESAR): a multicentre randomised controlled trial. *Lancet.* 2009;374(9698):1351-1363.
9. Combes A, Hajage D, et al. Extracorporeal Membrane Oxygenation for Severe Acute Respiratory Distress Syndrome. N Engl J Med. 2018; 378:1965-75.

Consideration of ECMO

- ECMO **should be** consulted if any of the following:
  - Paralyzed for ARDS
  - Prone ventilation
  - PEEP > 12 cm H_2O
  - Severe Hypoxemia
    - S/F < 190
    - P/F < 150
  - Severely reduced compliance < 30 mL / cm H_2O
  - pH < 7.2 despite optimized ventilator settings
  - Referring physician requests ECMO consultation

Criteria based upon: Murray LIS ≥ 3, and/or CESAR Trial

- ECMO may be consulted for other indications
- Obvious exclusions
  - Active malignancy
  - Catastrophic Bleeding
  - Bed or chairbound prior to acute illness
  - Most are relative, call if in doubt
- The ECMO managing physician will discuss and document advantages and disadavantages of ECMO for the patient in question. Decisions will be made as a team, may include
  - Proceed with ECMO
  - Not an ECMO candidate
  - Re-evaluation within set hours with discreet criteria to proceed or reject ECMO

Murray, *Am Rev Respir Dis*, 1988;4:720-3
Peek, *Lancet*, 2009;374:1351-63

Critical Care Management while on VenoVenous ECMO

Understanding the ECMO circuit

The circuit drains deoxygenated blood from the intrahepatic IVC (assuming a **dual lumen IJ catheter**). A **pump** drives blood into an **oxygenator** membrane. **Sweep gas** (usually 100% O2) bubbles through the oxygenator, which oxygenates the blood and removes CO2. Blood exits the oxygenator and returns to the catheter, exiting near the tricuspid valve. The ECMO circuit generally has continuous sensors of venous (pre-oxygenator) oxyhemoglobin saturation as well as pressures pre-pump (a.k.a "venous") and pre- and post- oxygenator.

"Venous" pressure in the ECMO circuit refers to pressure before the pump. Pre-pump flow is dependent upon delta pressure from CVP to pump. Thus ECMO venous pressures must be lower than CVP, and are almost always negative values. Higher flow rates require more negative venous pressures (generated through higher pump rpm). If flow is constant, increasingly negative venous pressures indicates a fall in CVP and thus a fall in pre-load. This often leads to the ECMO team administering fluids (or requesting this from the ICU team).

The ECMO circuit also measures pressures pre- and post- oxygenator; the delta-pressure is an indicator of resistance to flow across the oxygenator. Rising delta-P may be an indicator of impending oxygenator failure. Delta-P is also dependent upon set flows, so no one value of Delta-P is a clear signal of oxygenator failure.

Gas exchange

Oxygenation

SaO_2 is determined by $ScvO_2$ and relative rates of pump flow and cardiac output (flow of deoxygenated blood back to the right heart). Increasing pump flow increases SaO_2. Sweep gas flows > 0.5 lpm have neglible additive effects upon SaO2, rather post-oxygenator blood is almost always SO_2 1.0. Maximum pump flow rates are limited by venous pressure, as well as cannula size and position. Pump flows are generally in the 2-4.5 lpm range. See example at end***.

Recirculation refers to highly oxygenated blood that exits the ECMO cannula and returns to the ECMO circuit, and cannot be completely eliminated. Recirculation increases measured $ScvO_2$, and decreases patient SaO_2. For this reason, $ScvO_2$ may not be a reliable marker of oxygen extraction or adequacy of perfusion on VV ECMO.

CO_2 removal

Sweep gas flow rate determines $PaCO_2$. Higher sweep removes CO_2 from the oxygenator faster, facilitates diffusion of CO_2 out of blood, and decreases $PaCO_2$. Sweep ranges 1-15 liters per minute, most commonly in the 2-10 range. Sweep gas flow rates may change dramatically and rapidly based upon minute-to-minute assessments by the ECMO bedside specialist.

Anticoagulation

Patients on ECMO have significant anticoagulation needs. This is largely done with heparin, managed by the ECMO team using a variety of indicators including PTT, ACT, and TEG scans. The anticoagulation goals may vary day-to-day depending upon the relative concerns of bleeding vs clot formation (and catastrophic ECMO failure). While the ECMO team manages anticoagulation, ICU clinicians should be aware of anticoagulation goals and recognize when they are not met. The ICU team should be hyper-vigilant for signs of bleeding (sometimes occult). Problematic bleeding has occurred from common ICU interventions including NG placement, IV sticks, and foleys. Minimize these interventions.

Mechanical ventilation

Appropriate ventilation strategies during ECMO are clearly more art than science. Historically, A/C modes have been used with a tendency for early tracheotomy to facilitate ventilation and frequent bronchoscopic pulmonary toilet. The trend is toward less controlled ventilation, less bronchoscopy, and consideration of early extubation while still on ECMO support.

Commonly, we will ventilate patients with PS ventilation, PEEP 10 to prevent atelectasis, and PS 10 higher than PEEP. PS may be titrated down to avoid over-distension and lung injury, but generally should not be increased. Try to avoid affecting gas exchange or patient synchrony with the ventilator or sedation. Rather, communicate with the ECMO team to consider changing the sweep gas flow. Tolerate ultra-low tidal volumes (these may be ultra-protective).

ECMO can provide complete gas exchange for most patients. Patients with agitation on the ventilator have high cardiac outputs, high oxygen consumption, and low $ScvO_2$, making ECMO gas exchange less effective (see above). One strategy is to sedate the patient. Another strategy may be to extubate the patient and remove the source of agitation. In general, this requires a patient that is awake enough to protect his/her airway. Deciding which patients are appropriate to extubate while still on ECMO is not yet based upon evidence.

The ECMO circuit can suddenly fail (air in circuit, clot in oxygenator, others). If this occurs, the ventilator should be returned to emergency ventilator settings (most commonly the settings used just prior to ECMO initiation). Emergency ventilator settings should always be posted on the ventilator. **If off ECMO, the ICU team should manage the patient and ventilator**, allowing the ECMO team to get ECMO functional.

Hemodynamics

Veno-venous ECMO is pressure neutral, volume neutral, and thus should not affect hemodynamics at all. The caveat to that is that extremes of oxygenation and acid/base status may affect cardiovascular function, and thus ECMO may actually have some effect in extreme circumstances (e.g. SaO_2 60%, PCO_2 140). Outside of this, hemodynamics should be managed in the same fashion as for patients not on ECMO. Because V-V ECMO returns oxygenated blood to the right heart, pulmonary hypertension may decrease the effectiveness of V-V ECMO. This may be managed medically with inotropes, but can lead to consideration of conversion to V-A ECMO or compassionate withdrawal of support.

Renal Replacement Therapy

Acute renal failure is common on VV-ECMO. This is largely due to the disease process or nephrotoxic therapies, and not due to ECMO itself. Volume management is often complex and problematic. Periodic furosemide makes ECMO pump management challenging due to swings in venous pressures affecting pump flows. CRRT can be managed by placing a dialysis filter in the ECMO circuit (no HD catheter necessary). For this reason, ECMO teams often prefer early initiation of CRRT to provide effective fluid removal at a constant but controllable rate.

Communication

The MICU team should formally meet with the ECMO managing physician at least twice daily, and more frequently with bedside ECMO specialist (seek their input). Remember that changes in fluids, vasopressors, sedation, and mechanical ventilation all can affect the ECMO circuit. Thus changes in management should all be discussed with the ECMO team day or night. The bedside ECMO specialist can help guide conversations with the ECMO managing physician.

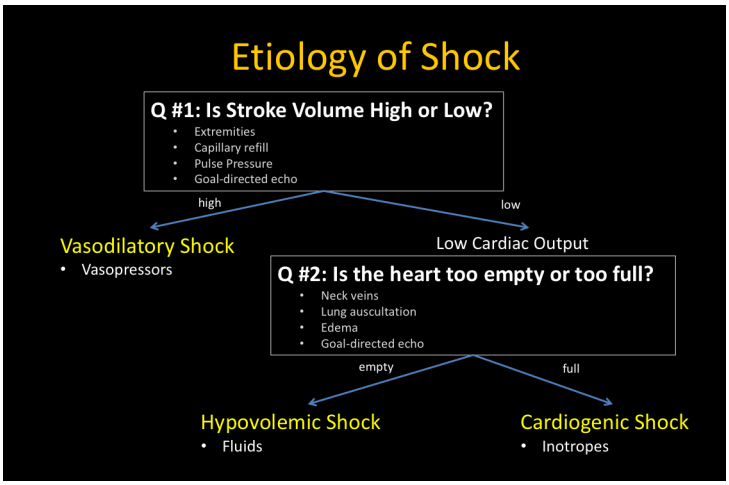
***Oxygenation example:
Example: 1) Cardiac Output = 6 lpm; 2) ECMO flow 2 lpm; 3) $ScvO_2$ 40%; 4) assume lungs do not perform any gas exchange. Total venous return to the heart must equal cardiac output, but venous return is divided into ECMO and non-ECMO portions. In this case venous return includes 2 lpm of fully oxygenated blood (1.0), plus 4 liters per minute of poorly oxygenated blood (0.4). When these two combine, the resulting SaO2 will be 0.6. Turning the ECMO pump flow up to 3lpm (half of cardiac output and total venous return) results in even mixture of 0.4 and 1.0 saturated oxyhemoglobin, so SaO_2 = 0.7; pump flow of 4 lpm results in SaO_2 0.8. Increasing $ScvO_2$ through decreased patient activity (sedation) may also increase SaO_2 but may not be in the patients best interests. ScvO2 may also be increased with inotropes, but increased cardiac output increases the proportion of non-ECMO blood to the heart (inotropes may be important for tissue perfusion independent of SaO2). Similarly, decreasing CO, thereby increasing the relative proportion of ECMO flow could help, but likely will decrease ScvO2 and be counterproductive.

Shock

Shock is acute circulatory failure threatening multiple organ systems and survival. Most but not all patients will be hypotensive. Because delays in resuscitation may be lethal, shock demands prompt diagnosis and urgent resuscitation.

Etiology of Shock

Shock is divided into three types: hypovolemic, cardiogenic, or distributive. It is often possible to categorize the type of shock within minutes based on a concise history and targeted examination. However, some patients may be at risk for many of these, e.g. a patient with cardiomyopathy (cardiogenic) who develops fevers (septic) and diarrhea (hypovolemic). A systematic assessment of the etiology of shock is therefore critical to adequate resuscitation. **A two-question system will accurately determine the etiology of shock in most patients.**



Question 1: Is the stroke volume high or low? In a patient with shock, a wide pulse pressure accompanied by warm extremities and brisk capillary refill is evidence of high cardiac output (distributive shock). Alternatively, a narrow pulse pressure, cool extremities, and delayed capillary refill suggest low cardiac output.

Question 2: Is the heart empty or too full? Low stroke volume and thus low cardiac output shock is comprised of hypovolemia and pump failure. In the subset of low output shock, an assessment of intravascular volume can further differentiate these two etiologies of shock. Bedside goal-directed echocardiography (GDE) should be performed to clarify or confirm the etiology of shock.

Certainly there may be overlapping causes, as in the patient with septic shock who has both hypovolemic and distributive components; or following calcium channel blocker overdose when there may be both cardiogenic and distributive contributors. These more complex cases can generally be recognized by a systematic approach of performing GDE; identifying fluid-responsiveness; estimating global perfusion and repeating these measures until shock remits or a diagnosis is established.

Tools for Diagnosis and Monitoring of Response

Lactic Acid Levels and Clearance

Shock elevates blood levels of lactic acid; sometimes this precedes hypotension. Successful resuscitation typically reduces these values. In a trial of early goal-directed therapy, targeting a lactate clearance of 10% was as good as aiming for normal $S_{cv}O_2$. Moreover, normalization of lactate is strongly associated with survival. For this reason, **elevated blood lactate should prompt aggressive resuscitation and repeat values** after no more than six hours (the higher the lactate, the shorter the interval, e.g. lactate $\geq$ 8 should be repeated in 1-2 hours).

Venous Oximetry

Venous oximetry entails measuring the oxyhemoglobin saturation of central or mixed venous blood. Venous oximetry relies on the Fick Principle--the difference between arterial and

venous oxygen contents is inversely related to the cardiac output. Low $S_{cv}O_2$ suggests low cardiac output as seen in cardiac or hypovolemic shock, but may also be found in sepsis (especially prior to resuscitation). **A high $S_{cv}O_2$ strongly suggests vasodilatory shock** and effectively rules out cardiogenic or hypovolemic shock *as the sole etiology*.

Central Venous Pressure

CVP, especially extreme values, can provide important clues to the etiology of shock. CVP $\geq$ 20 suggests against vasodilatory shock; while CVP < 5 argues against pure cardiogenic shock. All patients in shock should have CVP measured immediately after the central line is placed. Importantly, a static measure of CVP does not predict fluid responsiveness.

Management of Shock

Minutes matter when resuscitating shock. The appropriate endpoints of shock resuscitation remain elusive--an arbitrarily set mean arterial blood pressure (MAP) of at least 65 mm Hg is not sufficient and possibly not necessary. A comprehensive assessment of the adequacy of perfusion, rather than merely an arbitrary MAP, is critical to optimum resuscitation. Serial assessments within hours are valuable.

Identify and treat reversible causes

Several causes of shock require specific identification and early treatment, because general supportive measures will surely fail. Examples (and their treatments) include: sepsis (early antibiotics), tension pneumothorax (decompression), PE (thrombolysis), tamponade (pericardiocentesis).

Restore intravascular volume

Rapid restoration of intravascular volume is essential when hypovolemia is present. Fluids should be infused very rapidly to 1) improve perfusion; 2) to determine response to the volume while minimizing confounders of time. Lactated ringers may cause less kidney injury than normal saline, especially when multiple liters are infused.

Vasoactive Infusions

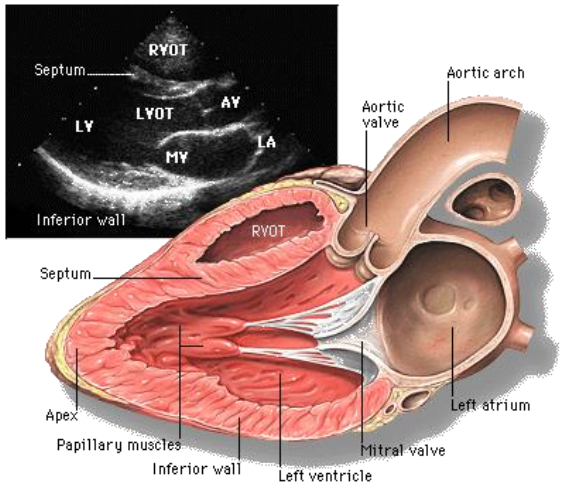
Many patients in shock require vasoactive infusions. Norepinephrine is the preferred agent given its potency, low propensity to induce arrhythmias, and association with survival. Vasoactive infusions should not be delayed because central access is not yet available. Similarly, vasopressors should not be delayed until circulating volume is fully restored, rather severely ill patients should be resuscitated simultaneously with vasopressors and fluids, with titration of the vasopressors as circulating volume is restored.

The initiation of vasopressors may also provide additional important clues to the underlying physiology. Norepinephrine consistently raises blood pressure, but a concomitant rise in lactate and fall in $S_{cv}O_2$ should prompt evaluation for hypovolemic or cardiogenic shock. When cardiogenic shock is suspected, dobutamine may be useful. Like norepinephrine, careful examination during dobutamine initiation may identify additional physiologic perturbations. A rise in MAP after initiating dobutamine supports cardiogenic shock physiology. Because dobutamine also causes some arteriolar dilation, if arterial pressure falls with dobutamine one may suspect inadequate preload or, alternatively, a severely dysfunctional myocardium.

Mechanical Ventilation in Shock

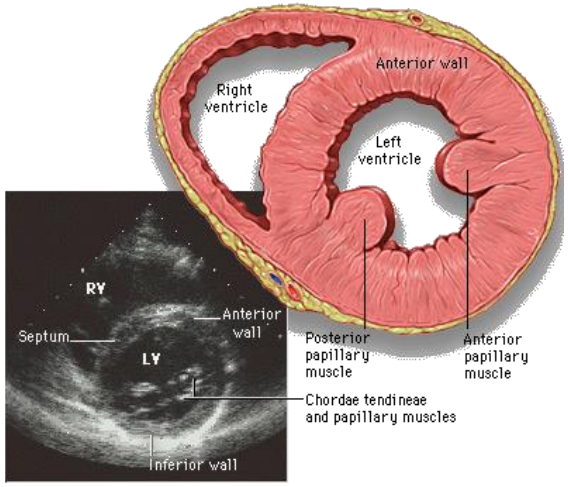
In severe shock, lactic acidosis increases respiratory effort, which subsequently increases lactate production, diverts blood flow to respiratory muscles and away from other vital organs. Mechanical ventilation (either invasive or non-invasive) may decrease oxygen consumption and increase vital organ blood flow and should be considered even in the absence of encephalopathy.

Parasternal long axis



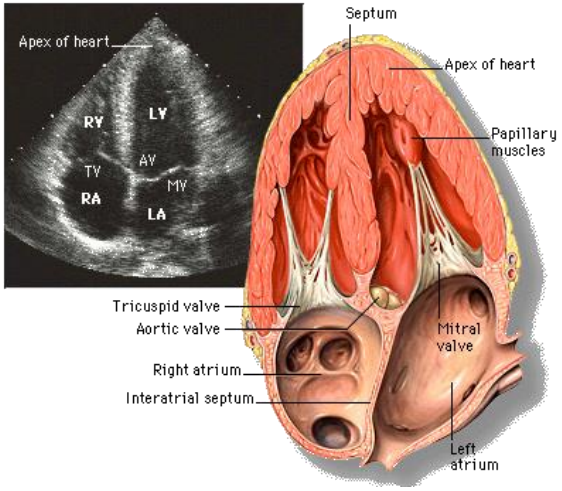
Transducer position: left 2nd-4th ICS
Marker dot towards: pt's right shoulder

Parasternal short axis



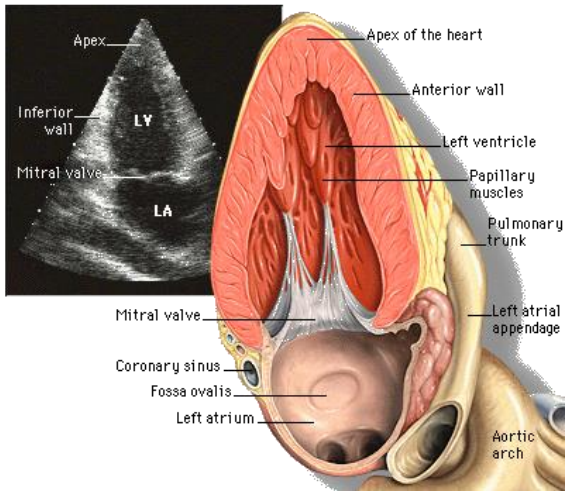
Transducer position: left 2nd-4th ICS
Marker dot towards: pt's left shoulder
The easiest way to get this view is to start with parasternal long axis and then rotate the probe 90 degrees clockwise

Apical 4-chamber



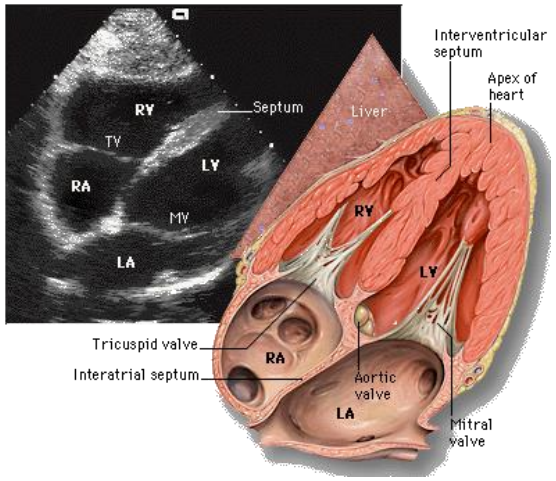
Transducer position: apex of heart
Marker dot towards: pt's left shoulder

Apical 2-chamber



Transducer position: apex of heart
Marker dot towards: left side of pt's neck
The easiest way to get this view is to start with apical 4 chamber. Then rotate slowly counter clockwise (~45 degrees) until the right side of the heart disappears.

Subcostal/subxiphoid



Transducer position: subxiphoid
Marker dot towards: pt's left shoulder

To get the IVC in view, rotate probe ~45 degrees counterclockwise and angle the tail of the probe medially.

Sun-Jung Lim MD and Amy Morris, MD Univ. of Washington
ammo@uw.edu

Images used with permission from
www.yale.edu/imaging/echo_atlas/contents/index.htm

Ultrasound to Assess Shock

Point-of-care ultrasound has become a key tool to assess shock states, helping to answer three basic questions:

1) Does a cardiac pump problem explain the shock?
2) Is the circulation likely to be fluid-responsive?
3) Are there special cases of shock that can be found with non-cardiac ultrasound?

Appropriate POCUS assessment of shock assumes adequate views; conclusions from suboptimal views should be scrutinized carefully. POCUS should complement, not trump, other assessments of shock. Concordant findings are confirmatory, while discrepant findings should prompt further assessment.

1. Goal-directed echocardiography (GDE) seeks a cardiac pump basis for shock:

A. Severe LV systolic dysfunction: Judged best from the A4C, PLAX, or PSAX views. Regional wall motion abnormalities may point to coronary artery disease, but this is beyond GDE. Apical ballooning suggests Takotsubo cardiomyopathy. Global LV systolic dysfunction is assessed using 3 metrics:

I. wall thickening;
II. endocardial motion to gauge fractional area change (Fig 1);
III. E point-septal separation, which should be <6mm (Fig 2).

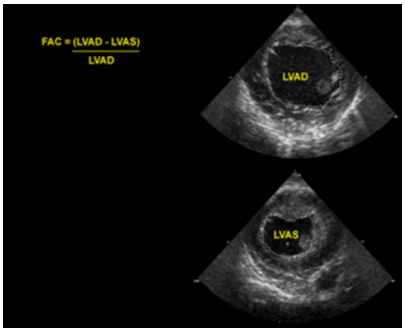


Figure 1. Fractional Area Change, in parasternal short axis view, calculated as (LVAD –LVAS) / LVAD

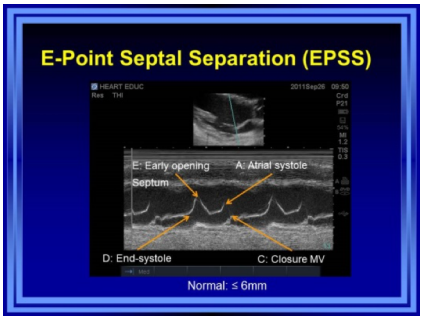


Figure 2. E-Point Septal Separation, visualized in parasternal long axis view, measured in M-mode. Normal ≤ 6mm.

B. Right heart dysfunction: The RV may be the basis for pump failure especially in acute pulmonary embolism, ARDS, RV infarction, or chronic pulmonary hypertension. Judged best from A4C and PSAX views using RV:LV end-diastolic area ratio (should be < 0.6; severe is > 1.0) and tricuspid annular plane systolic excursion (TAPSE), which should be > 15 mm (< 10 is severe). Increased RV free wall thickness (>5mm) suggests chronic elevation of RV systolic pressure.

C. Valve dysfunction: This requires use of color Doppler, a standard part of GDE. Shock is most likely due to severe MR, AI, or AS, or occasionally to dynamic outflow tract obstruction in hypertrophic cardiomyopathy, sometimes with systolic anterior motion of the mitral valve.

D. Tamponade: Pericardial effusions are common, but tamponade much less so. Pericardial fluid must be distinguished from pleural effusion. Best views are subcostal and A4C. Concluding that an effusion is hemodynamically significant is complex, but findings include a dilated IVC,

diastolic RA and RV collapse (RA collapse > 1/3 of the cardiac cycle is especially valuable), and typical respiratory effects on transvalvular flow velocity (>30% inspiratory reduction in mitral flow velocity).

E. Hypovolemic shock: Compatible findings include small end-systolic and end-diastolic volumes, small IVC (see below), and low LV outflow tract velocity-time integral (LVOT-VTI), often with significant respiratory variation in VTI.

F. High output shock (eg, sepsis): GDE findings are often normal, although the heart may appear hyperdynamic. LVOT-VTI will not be severely reduced.

2. Is the circulation likely to be volume-responsive? Many dynamic predictors of fluid-responsiveness are ultrasound-based and these are valid only when the patient is passively ventilated, the tidal volume is raised to 8-12 cc/kg, the rhythm is regular, and there is no cor pulmonale.

A. IVC diameter variation: Inspiration tends to distend the IVC, with greater degrees of change between inspiration and expiration predicting more response to fluid. Using the formula (IVCmax – IVCmin)/[(IVCmax+IVCmin)/2], a value greater than 12% predicts a response.

B. Similarly, passive respiratory variation in LVOT-VTI or in brachial artery flow velocity can also be used.

C. What if the patient is not passive? You have three options: 1) forget predicting, just give an empirical fluid bolus and measure the effect; 2) measure the inspiratory collapse of the IVC; or 3) use passive leg raising (PLR).

1) Give a rapid fluid bolus, but use something better than blood pressure to judge the effect (such as ScvO2)

2) If the IVC is very large (> 2.5 cm), the probability of fluid-responsiveness is low. If < 1cm, the probability of response is high. In between, who knows? In fact, there is not a good evidence base for any of these values in actively breathing patients.

3) PLR is a very accurate predictor, even in actively breathing patients and those in atrial fibrillation. The trick is that you need an objective parameter of response. That can be ScvO2; Flo-Trac; or the LVOT-VTI-derived cardiac output.

3. Special cases of shock amenable to US? Occasionally shock is due to tension pneumothorax and, while tension itself can't be diagnosed with US, pneumothorax can, especially the larger ones likely to impede the circulation. US may also reveal a source of sepsis for patients with vasodilatory shock, such a hydroureter, dilated biliary duct, or free abdominal fluid. Finally, ultrasound is often effective in detecting abdominal aortic aneurysm.

References:

1. Schmidt GA, Koenig S, Mayo PH. Shock: Ultrasound to guide diagnosis and therapy. Chest 2012; 142:1042
2. Krishnan S, Schmidt GA. Acute right ventricular dysfunction: Real-time management with echocardiography. Chest 2015; 147:835.
3. Barbier C, Loubières Y, Schmit C, et.al. Respiratory changes in inferior vena cava diameter are helpful in predicting fluid responsiveness in ventilated septic patients. Intensive Care Med 2004; 30:1740.
4. Monnet X, Marik P, Teboul J-L. Passive leg raising for predicting fluid responsiveness: a systematic review and meta-analysis. Intensive Care Med 2016 (epub ahead of print).

Vasopressors and Inotropes
by Paul Nassar

Shock results from an imbalance between O_2 supply and O_2 demand.

O_2 delivery, DO_2, depends on 1) arterial blood O_2 content, C_aO_2; 2) cardiac output, CO; and 3) perfusion pressure.

The following relationships are important to understanding shock, and subsequent choices of vasoactive infusions to optimize resuscitation of shock:

$DO_2 = CO \times CaO_2 = HR \times SV \times C_aO_2$

C_aO_2 (mL O2/dL) = (1.34 x [hemoglobin] X S_aO_2) + (0.0031 x PaO_2)

Perfusion pressure=CO X SVR (systemic vascular resistance) (Ohm's law)

Shock is caused by insufficient stroke volume, heart rate, C_aO_2, or blood pressure. **The goal of vasoactive therapy is to restore cardiac output, arterial pressure, and ultimately, tissue perfusion**.

Vasoactive medications can be categorized as follows. Many agents fit in more than one category.

- Vasopressors increase vascular resistance (blood pressure)
- Inotropes increase myocardial contractility
- Chronotropes increase heart rate

Mean arterial blood pressure should be maintained above 65 mmHg (the threshold for autoregulation of end organ perfusion for most patients) although MAP 55-60 may result in adequate perfusion for some. MAP targets > 65 mmHg are rarely helpful. At times, vasoactive therapies produce changes at odds to adequate shock resuscitation. For instance, norepinephrine increases blood pressure but may decrease cardiac output (increased afterload). Dobutamine may increase cardiac output but decrease blood pressure through vasodilation. Thus adequacy of resuscitation from vasoactive therapy should not be judged by only one parameter.

Types of adrenergic receptors in cardiovascular system

α1 are ubiquitous in arteriolar smooth muscle, increasing **blood pressure** via vasoconstriction.

β1 receptors predominate in cardiac smooth muscles, and generally increase **bloodflow** through
1) positive chronotropic effects on SA node
2) positive inotropic effects upon atrial and ventricular muscle to produce inotropy.

β2 receptors are found within the vascular smooth muscles; they produce mild vasodilation

Dopamine receptors are located in renal, splanchnic, and coronary vasculature and the central nervous system. They cause vasoconstriction and increased heart rate (especially at higher doses).

Vasopressin receptors are located in vascular smooth muscle. Their activation results in vasoconstriction by modulating nitric oxide production and potentiating adrenergic receptor activity.

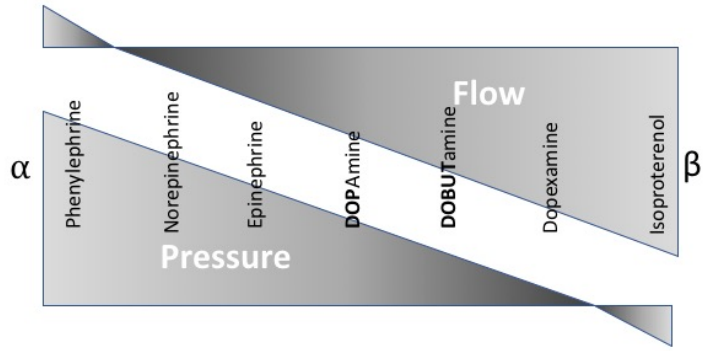


Figure 1. Catecholamines act upon adrenergic receptors, modulating blood pressure and blood flow differentially depending upon the particular agent's specificity for α or β receptors.[1]

Vasoactive agents commonly used in ICU

Norepinephrine (Levophed) has strong α1 agonist activity (increased SVR) and modest β1 activity, resulting in potent vasoconstriction and less potent inotropy. Tachycardia may occasionally occur, while bradycardia may also occur due to a stretch reflex; no change in heart rate is the usual. **It is the first line agent for most types of shock.** [3,6] Infusions greater than 0.1 mcg/kg/min are considered high dose. While there is no maximum dose, infusions greater than 0.4 mcg/mg/min generally do not confer increased efficacy.

Epinephrine works on β1 and β2 receptors at a low dose, and α1 receptors at higher doses. It may cause **lactic acidosis** (type 2), which is NOT due to hypoperfusion. Epinephrine can be added to norepinephrine when an additional agent is needed. It could potentially substitute norepinephrine as well.[4,6]

Vasopressin acts on V1 receptors in vascular smooth muscle to induce vasoconstriction. AVP decreases the needed dose (and side effects) of norepinephrine but does not change outcomes[2]. It is very expensive. It is most useful as a second agent when tachycardia precludes epinephrine.

Dobutamine works on β1 and β2 receptors. It increases inotropy through its β1 effect. It could cause vasodilation and a decrease in SVR through its β2 effect. It should be used in patients with myocardial dysfunction or when the patient continues to have signs of hypoperfusion despite adequate intravascular volume and MAP.

Dopamine effect is dose dependent. Despite increasing diuresis at a low dose, it does not decrease the incidence of renal failure or the need for dialysis. It causes tachyarrhythmias (most commonly atrial fibrillation) and was shown to increase mortality, especially in patients with cardiogenic shock[2]. **Dopamine is NOT recommended except in selected circumstances** (bradycardia, or very low risk for tachyarrhythmias).

Phenylephrine is a pure, but weak, α 1 agonist, producing vasoconstriction. It can be used when norepinephrine is associated with arrhythmias or added as salvage therapy.

Esmolol is a short acting β1 antagonist that is useful to control supraventricular arrhythmias. Initial promising results of esmolol in septic shock[5] have not been reproduced.

Midodrine is an oral α1 agonist, has been shown to decrease need for norepinephrine infusions in persistent shock.[7]

Vasopressors should be administered through central venous access (extravasation carries the risk of tissue necrosis), however appropriate vasopressors should not be delayed by the absence of a central line. When central venous cannulation is difficult or cannot be performed in a timely manner, intraosseus access should be considered.

References: (with hyperlink to journal)

1) Hollenberg S, Vasopressor support in septic shock. Chest 2007; 132:1678-87
2) Russell J, et al. Vasopressin versus norepinephrine infusion in patients with septic shock: N Engl J Med 2008;358(9):877-87
3) DeBacker D, et alComparison of dopamine and norepinephrine in the treatment of shock: N Engl J Med 2010;362(9):779-89
4) Annane D, et al. Norepinephrine plus dobutamine versus epinephrine alone for management of septic shock: a randomised trial. Lancet 2007;370:676-84
5) Morelli A, et al. Effect of Heart Rate Control With Esmolol on Hemodynamic and Clinical Outcomes in Patients With Septic Shock: A Randomized Clinical Trial. *JAMA* 2013;310:1683-1691
6) Rhodes A, et al. Surviving sepsis campaign: International guidelines for Management of Sepsis and Septic Shock: 2016. Crit Care Med; 45:486-552.
7) Anstey M, et al. Midodrine as adjunctive support for treatment of refractory hypotension in the Intensive Care Unit: a multicenter, randomized, placebo controlled trial: BMC Anesth: 2017. 17:47

Clarification of MICU expectations for Targeted Temperature Management after Cardiac Arrest

1) **Patients meeting these criteria should be evaluated for TTM:**
   Inclusion
   A. adult patient with cardiac arrest
   B. Return of spontaneous circulation (ROSC) sustained for at least 20 minutes
   C. Unconsciousness after sustained ROSC

   Exclusion
   1) pregnancy
   2) bleeding diathesis beyond medicine-induced coagulopathy
   3) suspected or confirmed acute intracranial bleeding
   4) suspected or confirmed acute stroke
   5) systolic blood pressure < 80 mm Hg despite fluid loading and vasopressors
   6) location of arrest and initial rhythm have important prognostic implications but should not be considered exclusion criteria for TTM in practice.

2) **The optimum temperature target is 36 degrees**, based upon current best evidence
3) **Intravascular cooling** is our institutional preferred method of TTM. Time to target temp is faster, and has smaller variation about target temperature compared to surface cooling.
4) **TTM should be initiated as early as possible** following sustained ROSC, ideally less than four hours; this may be initiated prior to attending physician involvement
5) **TTM should not be delayed because the patient is already cold** (30-36 degrees), as they will often develop fever in the next 24 hours.
6) **Delayed TTM only after fevers develop is likely not effective and thus not appropriate;** it should be started before fevers develop.
7) **TTM should not be delayed while pursuing goals of care**; they can happen concurrently
8) Surface cooling (e.g. arctic sun) is a reasonable alternative if intravascular cooling is technically not possible (not because of operator choice). Either method should be started without delay as discussed above.

Lung Ultrasound 101

Selecting a transducer and an exam

1. Press the "Transducer" key on the ultrasound machine to select the appropriate probe
    a. Select Low frequency probe for most lung findings, e.g. S4-2 (cardiac) on Phillips Sparq
    b. High frequency Linear probe may be preferred for pleural imaging, e.g. L12-4 on Sparq
2. Then press the "Exam" key and sect "LUNG"

Where to image and probe orientation

- The lung exam consists of 12 regions, 6 on each hemithorax. These regions are anatomically demarcated by the anterior and posterior axillary lines **(Fig 1)**
- The probe indicator should be oriented to the patient's head
- For optimal images, the ultrasound beam should be perpendicular to the pleural surfaces

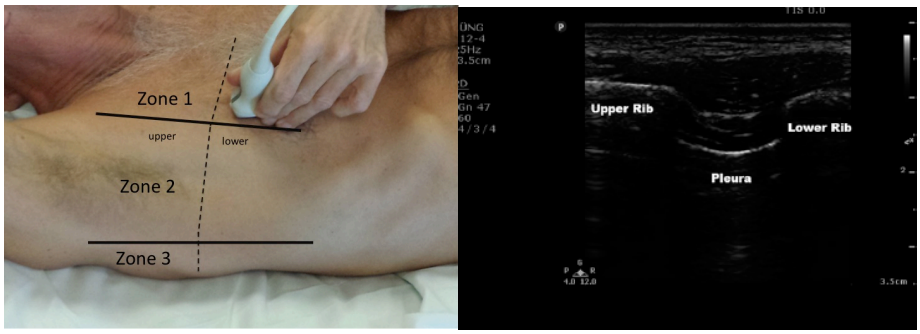


Figure 1. There are 6 ultrasound zones on each hemithorax (left). Pleural and lung findings can be identified between the rib shadows (right).

Pleural artifacts and associated physiology

- Dynamic video images available on-line.[1] https://doi.org/10.1513/AnnalsATS.201308-288OT
- Lung sliding: actually resembles a shimmering motion of the echogenic parietal pleural surface
    - Physiology: during respiration, the visceral pleural surface comes into contact with and slides on the parietal pleural surface on the chest
    - If **lung sliding is present**, the pleural surfaces are in contact thus there is no pneumothorax at that point (need to examine other zones)
    - Lung sliding is absent in pneumothorax, but **sliding may be absent** during regional hypoventilation, e.g. low Vt ventilation, air-trapping in COPD, mainstem intubation.
    - Lung pulse is a finding similar to lung sliding that is less dependent upon ventilation
- A-line pattern: reverberation artifact when the sound wave reflects off the pleura, and then partially off the probe and back to the pleura again. These will be at multiples of the pleural depth **(Fig. 2)**
    - The presence of A-lines indicates air, either in the pleural space or alveolar air**. A-lines appear in pneumothorax!** A-lines plus lung sliding/pulse excludes pneumothorax
    - Probe angle makes A-lines appear (probe perpendicular to pleura) and disappear (tangential)

Abnormal findings

- B-Line pattern: vertically oriented lines that 1) must extend from the pleural surface to the bottom of the image; 2) obliterate A-lines; and 3) move in conjunction with lung sliding **(Fig 2)**
    - Physiology: not entirely clear, but represent an air-fluid interface as seen in pulmonary edema, ARDS, lymphangitic carcinomatosis, or ILD.
    - B-Lines are quantifiable, increase with fluids/inflammation, decrease with diuresis[2,3]
- Lung point: a portion of the pleural surface with normal lung sliding adjacent to a portion with absent lung sliding. This signifies the point of pleural separation in pneumothorax
- Pleural effusion: anechoic or hypoechoic fluid cranial to the diaphragm.

- US can detect smaller effusions that CXR, and can differentiate them from consolidation

- Consolidation: usually appears hyper echoic and similar to liver tissue (hepatization).
  - Consolidation can be confused with atelectasis, but can use absence of volume loss or dynamic air bronchograms to diagnose the former

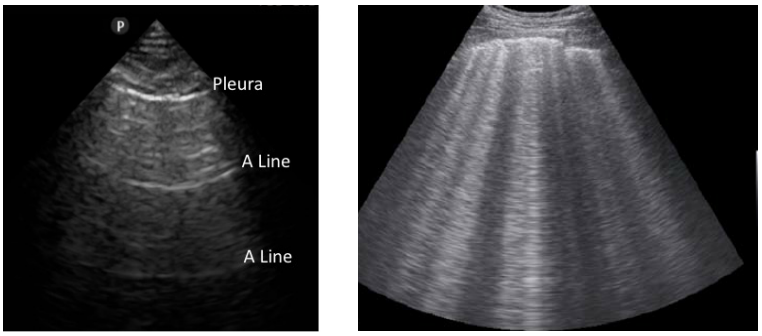


Figure 2. A-lines indicate air (left), which can be normal or abnormal (pneumothorax). B-lines (right) indicate interstitial thickening (abnormal)

Lung ultrasound algorithm

Using these ultrasound skills, one can evaluate patients with respiratory distress and establish an etiology of decompensation for many patients in seconds (Fig 3).[4] If lung sliding is absent with findings exclusively of A-lines, pneumothorax is likely and one must search diligently for a lung point to confirm pneumothorax. If bilateral B-lines are identified, pneumothorax is effectively ruled out. Finally, lung sliding with an A-line pattern (in setting of respiratory failure) suggests obstructive lung disease or pulmonary embolism, thus meriting a search for DVT. Such an ultrasonic evaluation has led to the correct diagnosis in 90% of patients presenting with acute respiratory failure.[4]

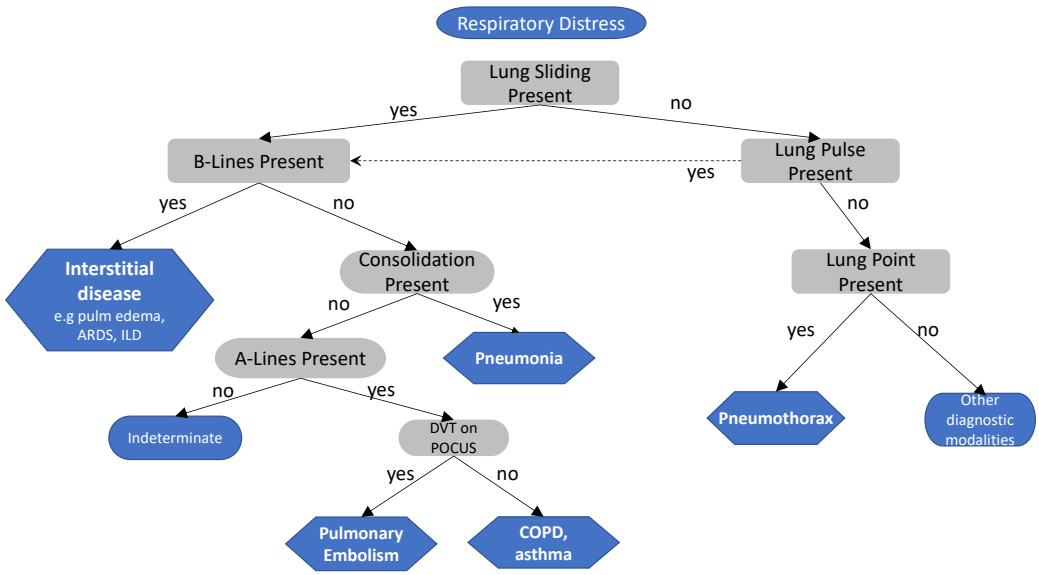


Figure 3. Diagnostic algorithm of lung ultrasound during respiratory distress, adapted from Lichtenstein[4]

REFERENCES

1. Doerschug K, Schmidt G. Intensive Care Ultrasound: III. Lung and Pleural Ultrasound for the Intensivist, *Ann Am Thorac Soc* 2013; 10(6):708-12. Dynamic videos on-line: https://doi.org/10.1513/AnnalsATS.201308-288OT
2. Baldi G, Gargani L, Abramo A, D'Errico L, Caramella D, Picano E, Giunta F, Forfori F. Lung water assessment by lung ultrasonography in intensive care: A pilot study. *Intensive Care Med* 2013;39(1):74-84.
3. Noble VE, Liteplo A, *et al*. Ultrasound assessment for extravascular lung water in patients undergoing hemodialysis. Time course for resolution. *Chest* 2009;135(6):1433-1439.
4. Lichtenstein DA, Meziere GA. Relevance of lung ultrasound in the diagnosis of acute respiratory failure: The blue protocol. *Chest* 2008;134(1):117-125.

Brian Gehlbach, MD

Cardiorespiratory Failure from Sleep Disordered Breathing

Sleep disordered breathing (SDB) refers to a diverse set of disorders characterized by abnormal breathing during sleep. While the most common form of SDB you will encounter is obstructive sleep apnea (OSA), it is important to be aware of other forms of SDB that may contribute to cardiorespiratory failure.

Forms of Sleep Disordered Breathing

- Obstructive sleep apnea
- Central sleep apnea
    - Idiopathic
    - Central sleep apnea with Cheyne-Stokes Respiration (CSA-CSR) from stroke, CHF
    - Due to brain injury/stroke, with or without CSA-CSR
    - Medication-induced
- Sleep-related hypoventilation due to neuromuscular or chest wall disease
- Sleep-related hypoventilation in context of underlying lung disease (COPD)
- Opioid-induced SDB (irregular breathing, central and obstructive apneas, hypoventilation)

Physiology of SDB

Normal sleep is associated with:

- Reduced upper airway dilator tone
- Reduced oxygen stores resulting from the supine position (esp in obesity)
- Reduced CO_2 chemosensitivity (CO_2 rises to approx. 44-46 in normal, healthy individuals)
- Increased respiratory instability, including apneas, during sleep onset and REM sleep)

As a result, patients with COPD, ALS, or a predisposition to OSA (overweight with crowded hypopharynx, Down syndrome, recessed jaw, etc) exhibit worse breathing during sleep.

There are also issues related to control of breathing and susceptibility to arousal that we won't go into here, other than to say that patients with untreated or poorly treated SDB can be highly sensitive to the effects of narcotics and other centrally acting agents.

Phenotypes of Cardiorespiratory Failure in SDB

Acute ventilatory failure

- *Ventilatory failure related to OSA and an acute precipitant*
    - Respiratory illness
    - Nonadherence with CPAP
    - Residual anesthetic/sedative
    - Sleep deprivation
- *Ventilatory failure related to OSA and COPD (so-called "overlap syndrome")*
    - Patients with OSA + COPD have higher risk of death from hospitalization than patients with COPD alone
    - More right heart failure/pulm HTN than with either disease alone
- *Ventilatory failure related to OHS +/- OSA*
    - Most patients with OHS also have OSA (a small percent don't)
    - Risk rises with BMI but not a perfect correlation. Also relates to distribution of body fat, central control of breathing, and "relative" muscle weakness

Acute CHF (increased preload & afterload, increased symp neural outflow, hypoxemia, tachycardia)

Acute right heart failure

Sudden death

- *Arousal failures* (think of this possibility in patients who arrest while receiving narcotics)
- *Arrhythmia*

Mechanisms of decompensation & critical care considerations

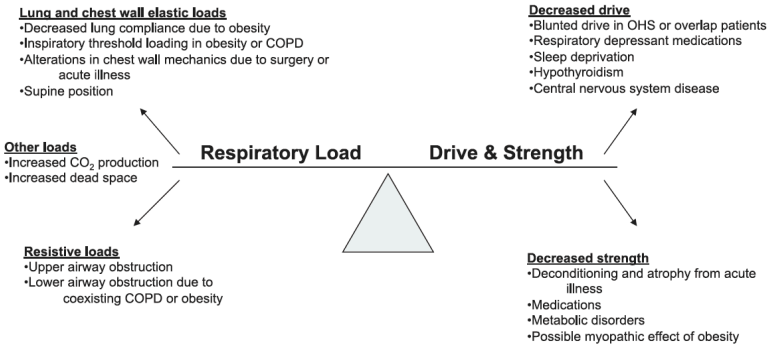


FIGURE 1. Mechanisms of ventilatory failure. OHS = obesity hypoventilation syndrome. (Adapted with permission from Schmidt and Hall[22])

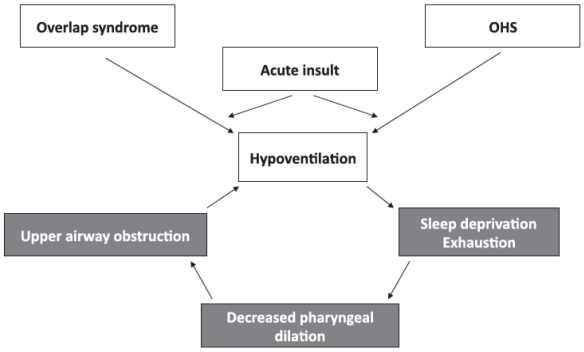


FIGURE 2. Proposed "vicious cycle" of acute ventilatory failure in patients with obstructive sleep apnea (OSA). Diverse acute insults may occur (eg, pulmonary embolism, infection, or abdominal surgery). Because obese patients or patients with overlap syndrome have substantial chronic respiratory loads, they develop hypoventilation with a lower degree of acute insult. OSA compounds this hypoventilation because some patients with OSA have a blunted ventilatory response to hypercapnia. As respiratory failure progresses to somnolence and exhaustion, upper airway tone is compromised, further loading the respiratory system, and reinforcing the deleterious effects of the acute load. See Figure 1 legend for expansion of abbreviations.

Figures from Carr et al, CHEST 2012.

Table 1—*Critical Care Considerations in the Patient With Suspected Sleep-Disordered Breathing*

Recommendation	Rationale
Consider comorbid OSA, OHS, or the overlap syndrome in patients with ventilatory failure.	Many patients with SDB have not received a diagnosis at the time of acute cardiopulmonary failure. Failure to diagnose SDB may lead to increased morbidity or mortality.
Look for and treat OSA in CHF.	NIV may improve left ventricular ejection fraction and outcomes.
Consider OSA in patients who survive cardiac arrest.	Untreated OSA may represent a potentially reversible cause of sudden death.
Consider early empiric NIV for ventilatory failure in appropriate candidates.	SDB is treated directly and complications of endotracheal intubation and sedation are avoided.
Consider extubation to NIV as a liberation strategy when patients require endotracheal intubation.	NIV may reduce postextubation respiratory failure. Some obese patients are capable of spontaneous breathing even though they do not meet the traditional success criteria on spontaneous breathing trials.
Consider performing spontaneous breathing trials on higher CPAP or PEEP levels.	Higher levels of end-expiratory pressure may be necessary to offset increased chest wall elastic load even when lung compliance is acceptable.
Use sedation and analgesia judiciously.	Opiates and benzodiazepines promote pharyngeal collapsibility, blunt respiratory drive, and impair the arousal mechanism.
Limit sleep disruption at night.	SDB is worsened by sleep deprivation.
Arrange close follow-up with sleep specialist.	Chronic SDB should be formally diagnosed and treated.

A practical guide to using CPAP or BiPAP

- In the decompensated patient, we typically use BiPAP.
- Initial settings depend on prior patient experience (check home settings, bring in device/mask!).
- Respiratory therapists have a lot of experience with SDB & are extremely helpful.
- Consider IPAP 10-12/EPAP 5 for short period of time to help with tolerance, followed by upward titration as needed. Usually IPAP is set to 8-10 cm above EPAP. Ensure resulting TV approx. 6ml/kg IBW. For perspective, outpatients with OHS often require IPAP 16-20, EPAP 8-10.
- Attention to mask fit and seal.
- Seen Table 1 at right above for other considerations. Look for precipitant of decompensation.

References

1. Carr GE, Mokhlesi B, Gehlbach BK. Acute cardiopulmonary failure from sleep-disordered breathing. CHEST 2012;141(3):798-808.
2. Correa D, Farney RJ, Chung F, Prasad A, Lam D, Wong J. Chronic opioid use and central sleep apnea: a review of the prevalence, mechanisms, and perioperative considerations. Anesth Analg 2015;120(6):1273-85.