SARI CLINICAL CARE TRAINING

INVASIVE MECHANICAL VENTILATION FOR ACUTE RESPIRATORY DISTRESS SYNDROME (ARDS)

DELIVER LUNG PROTECTIVE VENTILATION

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Learning objectives

At the end of this lecture, you will be able to:

- Recognize acute hypoxaemic respiratory failure.
- Know when to initiate invasive mechanical ventilation.
- Deliver lung protective ventilation (LPV) to patients with ARDS.
- Describe how to manage ARDS patients with conservative fluid strategy.
- Discuss three potential interventions for severe ARDS.

Five principles of ARDS management

1. Recognize ARDS early.

	Acute Respiratory Distress Syndrome (ARDS)
Timing	Within 1 week of a known clinical insult or new or worsening respiratory symptoms
Chest imaging*	Bilateral opacities – not fully explained by effusions, lobar/lung collapse, or nodules
Origin of edema	Respiratory failure not fully explained by cardiac failure or fluid overload Need objective assessment (e.g. echocardiography) to exclude hydrostatic edema if no risk factor present.
Oxygenation**	
Mild	200mm Hg < PaO_2/FiO_2 ≤ 300 mm Hg with PEEP or CPAP ≥5cm H_2O***
Moderate	100mm Hg < PaO_2/FiO_2 ≤ 200 mm Hg with PEEP ≥5cm H_2O
Severe	PaO_2/FiO_2 ≤ 100 mm Hg with PEEP ≥5cm H_2O

Five principles of ARDS management

2. Initiate ventilatory support without delay:
   - high-flow oxygen versus noninvasive ventilation (NIV)
   - IMV with lung protective ventilation strategy:
     - manage acidosis
     - manage asynchrony
   - use fluid conservative strategy if not in shock
   - manage pain, agitation and delirium (next lecture)
   - conduct daily SBT assessment (next lecture).

Five principles of ARDS management

3. Treat underlying cause.

4. Monitor-record-interpret-respond.

5. Deliver quality care.

Recognize non-hypercapneic, hypoxaemic respiratory failure

- Rapid progression of severe respiratory distress and hypoxaemia (SpO_2 < 90%, PaO_2 <60 mmHg or <8.0 kPa) that persists despite escalating oxygen therapy.
- SpO_2/FiO_2 < 300 while on at least 10 L/min oxygen therapy (and $PaCO_2$ < 45 mmHg).
- Cardiogenic pulmonary oedema not primary cause.

Hypoxaemic respiratory failure is an indication for ventilatory support.

High flow oxygen systems



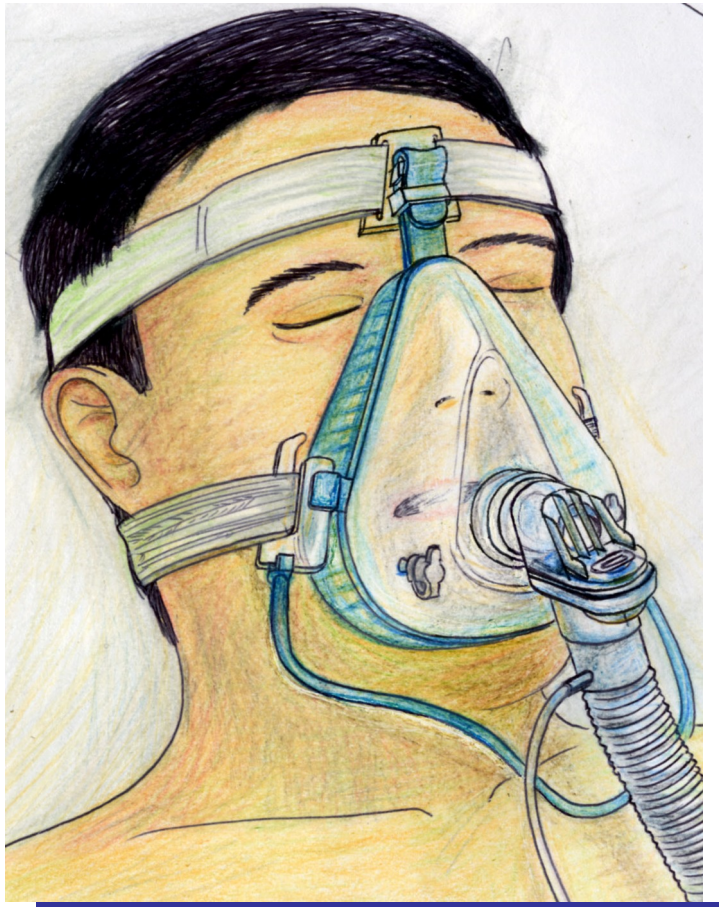


If high flow tried and unsuccessful DO NOT delay intubation.

- Consider using high-flow oxygen systems if patient is:
  - awake, cooperative
  - with normal haemodynamics
  - and without urgent need for intubation
  - ($PaCO_2$ < 45 mmHg).
- Safe when compared with NIV in patients with ARDS:
  - may be associated with less mortality
  - nearly 40% of patients still require intubation.
- **Apply airborne precautions.**



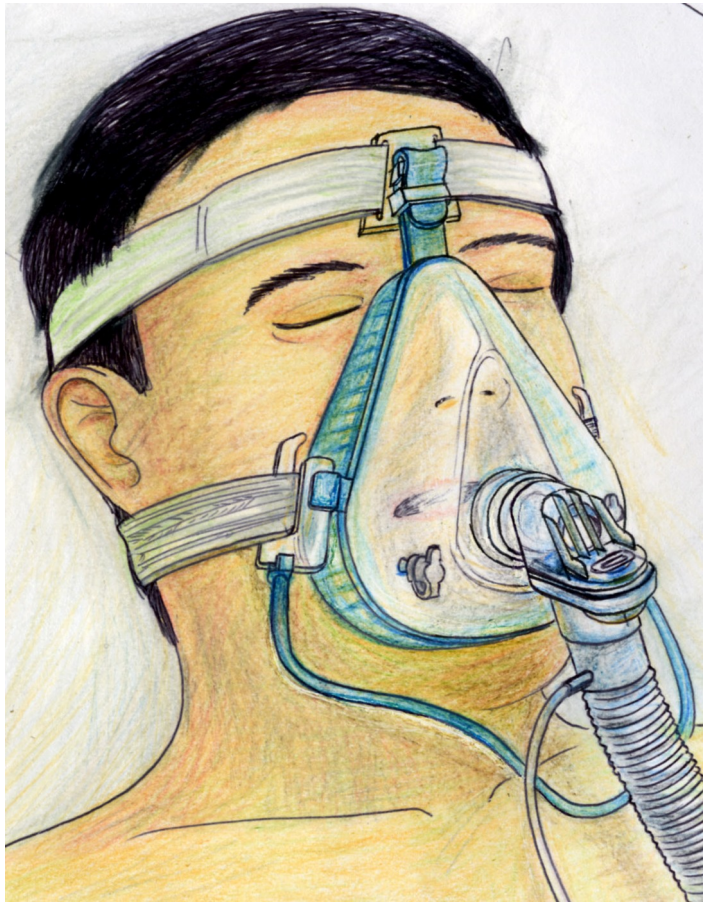
Non-invasive ventilation



It can be difficult to achieve a tight-fit with face masks in children and infants.

- NIV is continuous positive airway pressure (CPAP) or bi-level positive airway pressure delivered via a tight-fitting mask.
- Not generally recommended for treatment of patients with ARDS:
  - may preclude achieving low tidal volumes and adequate PEEP level
  - complications: facial skin breakdown, poor nutrition, failure to rest respiratory muscles.
- If used, apply airborne precautions.

Non-invasive ventilation



- Some experts use NIV in carefully selected patients with mild ARDS:
  - cooperative, stable haemodynamics, few secretions, without urgent need for intubation.
- Can be used as a temporizing measure until IMV is initiated.
- If NIV tried and unsuccessful, do not delay intubation:
  - i.e. inability to reverse gas exchange dysfunction within 2–4 hours.

In most patients with ARDS, IMV with LPV is preferred treatment.

NIV can be used in select patients with mild ARDS.

Clinical trial evidence has shown that implementation of LPV saves lives when compared with usual care.

There are no trials comparing LPV with high flow or NIV.

INVASIVE VENTILATION

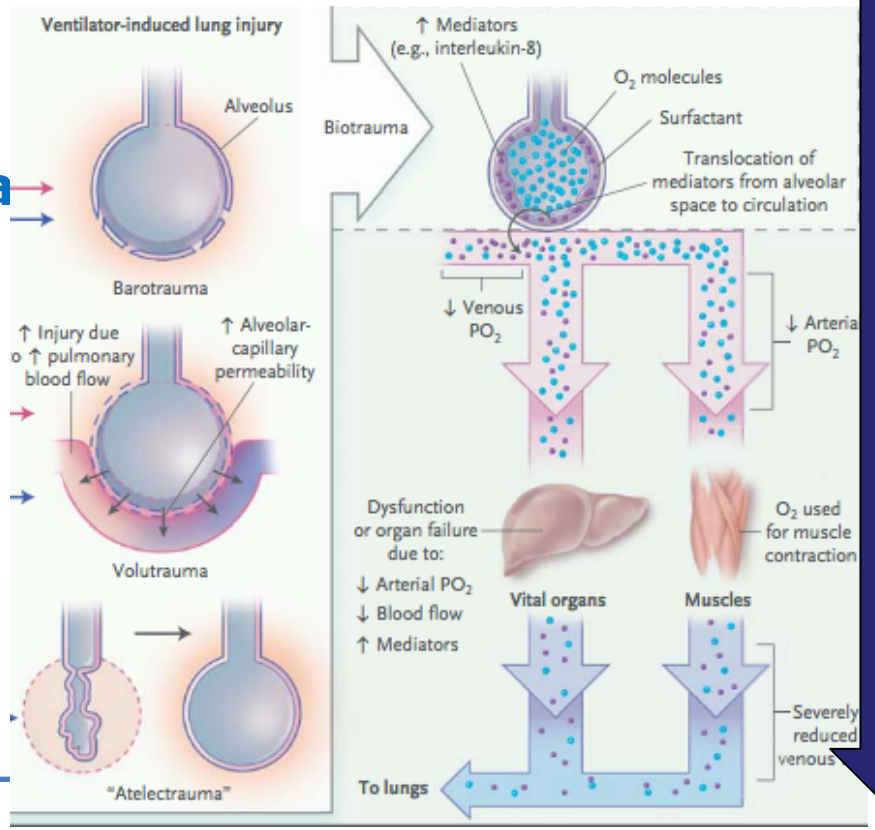
Methods of delivery:

- Endotracheal tube (preferred)
- Nasotracheal tube
- Laryngeal mask (short-term, emergency)
- Tracheostomy (emergency airway, or long-term ventilation)

Requires sedation, appropriate equipment and trained staff

LPV reduces ventilator-induced lung injury

- **LPV reduces ventilator-induced lung injury**
  - **Reduces barotrauma (e.g pmeumothorax)**
  - **Reduces volutrauma**
    - **Excessive strain**
  - **Reduces atelectrauma**



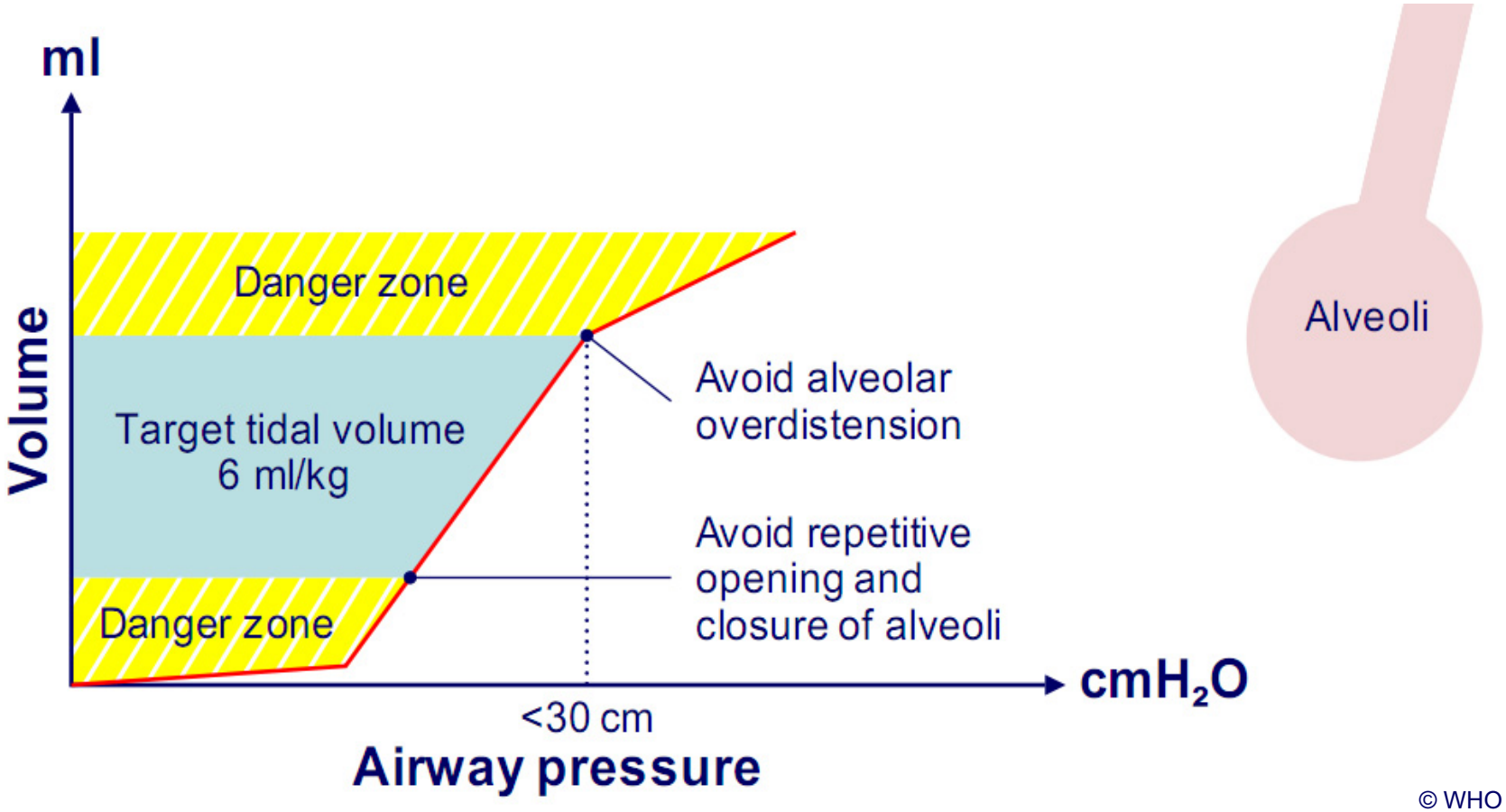
- **- Barotrauma**
  - **e.g. pneumothorax**
- **- Volutrauma**
  - **alveolar overdistension causes alveolar capillary permeability**
- **- Atelectrauma**
  - **sheer injury from repetitive closing and opening of alveoli**
- **- Biotrauma**
  - **inflammatory mediators, organ dysfunction**
- **- Oxygen toxicity.**

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Lung protective ventilation (LPV)



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Endotracheal intubation



- Inform the patient and family.
- **Use airborne precautions.**
- Anticipation and preparation are key:
  - **but do not** delay procedure
  - patients with ARDS can desaturate quickly when oxygen is removed
  - monitor-respond to haemodynamic instability
  - properly titrate induction anaesthetics
  - have a plan if difficulties encountered.
- Ensure experienced clinician performs procedure.
- Checklist for rapid sequence induction.

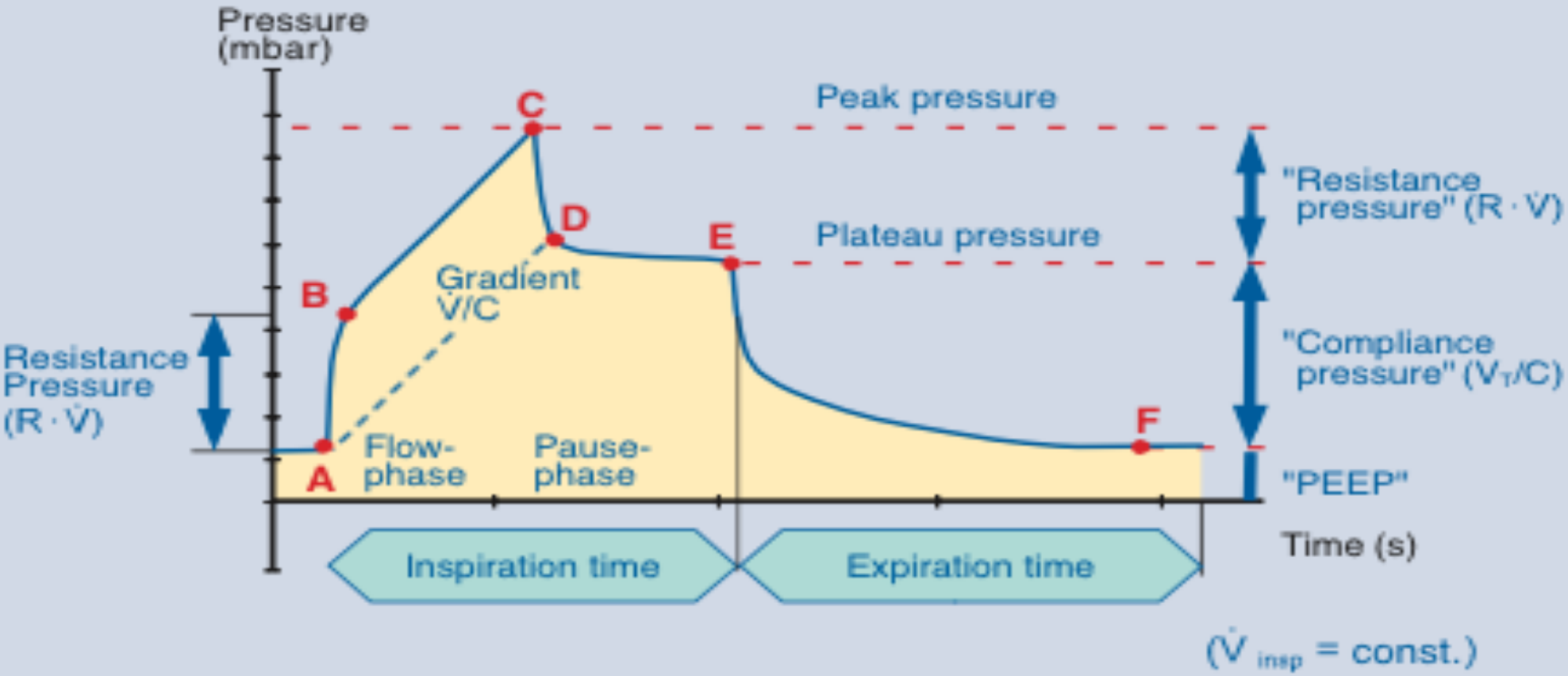
Pre-oxygenate with 100% FiO_2 for 5 minutes, via a bag valve mask, NIV or high-flow system.

LPV targets

- Target tidal volume 6 mL/kg in adult and children
  - ideal body weight
- Target plateau airway pressure (Pplat) ≤ 30 cmH_2O
- Target SpO_2 88–93%

• Reaching LPV targets reduces mortality in patients with ARDS.
• Lung Safe (JAMA 2016) study observed only < 2/3 patients with ARDS received TV < 8 mL/kg, Pplat measured in just 40% patients and PEEP < 12 cm H_2O in 82%. Finding indicate potential for improvement.
• Implementation remains a challenge worldwide.

Pplat: target ≤ 30 cm H_2O



Measure the plateau airway pressure at the end of passive inflation, during an inspiratory pause (> 0.5 sec). PEEP is the pressure at the end of expiration.

Initiation of LPV



- Set TV 6–8/kg **predicted body weight.**
- Set RR to approximate minute ventilation (MV):
  - do not set > 35/min
  - remember MV = VT × RR.
- Set I:E ratio so inspiration time less than expiration:
  - requires higher flow rates
  - monitor for intrinsic PEEP.
- Set inspiratory flow rate above patient demand:
  - commonly > 60 L/min.
- Set FiO_2 at 1.00, titrate down.
- Set PEEP 5–10 cm H_20 or higher for severe ARDS.

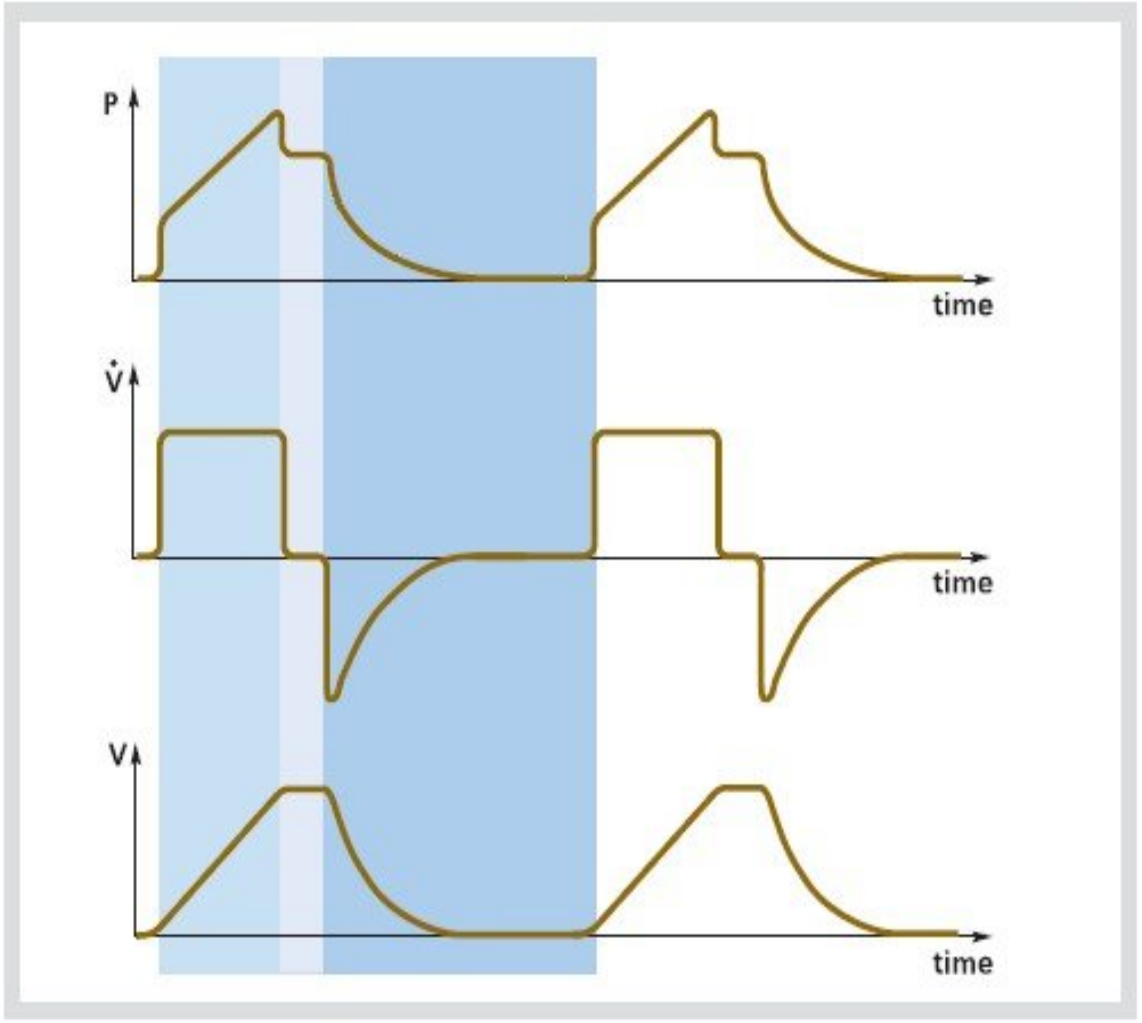
Monitor ventilator and gas exchange parameters frequently to reach targets

- Monitor SpO_2 continuously.
- Monitor pH, PaO_2, $PaCO_2$ as needed using blood gas analyser:
  - should be available in all ICUs.
- Monitor ventilator parameters regularly:
  - Pplat and compliance at least every 4 hours, and after changes in PEEP or TV
  - intrinsic PEEP and I:E ratio after changes in respiratory rate
  - ventilator waveforms for asynchrony.

Monitor ventilator waveforms

- **Scalar waveforms**

- **Plot pressure against time.**
- **Plot flow against time.**
- **Plot volume against time.**



Target TV 6 mL/kg and Pplat ≤ 30 cm H_2O

- Reduce TV to reach target of 6 mL/kg over couple of hours.

- If TV is at 6 mL/kg and Pplat remains > 30 cm H_2O then reduce TV by 1 mL/kg each hour, to a minimum 4 mL/kg:
  - at the same time, increase RR to maintain MV
  - allow for permissive hypercapnea
  - monitor and treat asynchrony.

Considerations when interpreting Pplat measurement

- Pplat is most accurate when measured during passive inflation.
- Patients who are actively breathing have higher transpulmonary pressures for given Pplat.
- Patients with stiff chest wall or abdominal compartment may have lower transpulmonary pressures for given Pplat.
- Goal is to avoid high Pplat and high TV in ARDS patients.

Allow permissive hypercapnea

- **Mortality benefits of LPV outweigh risk of moderate respiratory acidosis:**
  - no benefit to normalizing pH and $PaCO_2$
  - contraindications to hypercapnea are high intracranial pressure and sickle cell crisis.

- If pH 7.15–7.30:
  - increase RR until pH > 7.30 or $PaCO_2$ < 25 (maximum 35)
  - decrease dead space by:
    - **decreasing I:E ratio to limit gas-trapping**
    - **changing heat and moisture exchanger to a heated humidifier**
    - **remove the dead space (flex tube) from the ventilator circuit.**

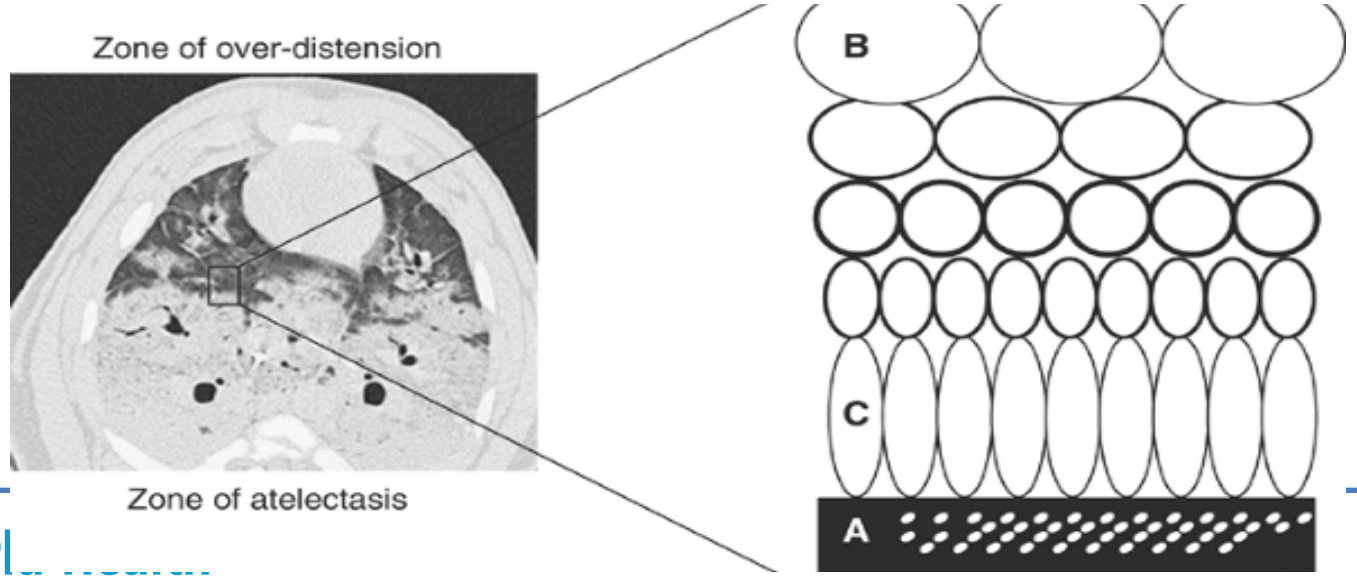


- If pH < 7.15 after above:
  - give buffer therapy intravenously (e.g. sodium bicarbonate)
  - TV may be increased in 1 mL/kg steps until pH > 7.15
  - if necessary, Pplat target of 30 may be temporarily exceeded.

Benefits of PEEP

- PEEP is the airway pressure at the end of expiration:
  - recruits atelectatic lung to prevent atelectrauma.

- Challenge is in determining "how much PEEP" for the heterogenous ARDS lung.



- Zone B are open units ("baby lung")
- Zone C are at risk units that can participate in gas exchange
- Zone A are lung units that are collapsed

Use the ARDS-net PEEP-FiO_2 grid to guide PEEP

- Set PEEP corresponding to severity of oxygen impairment:
  - titrate the FiO_2 to the lowest value that maintains target SpO_2 88–93%.
  - set corresponding PEEP, based on individual:
    - higher PEEP for moderate-severe ARDS.

See website: www.ardsnet.org

Table used for adults

Lower PEEP/higher FiO2

FiO_2	0.3	0.4	0.4	0.5	0.5	0.6	0.7	0.7
PEEP	5	5	8	8	10	10	10	12

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

Higher PEEP/lower FiO2

FiO_2	0.3	0.3	0.3	0.3	0.3	0.4	0.4	0.5
PEEP	5	8	10	12	14	14	16	16

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

Risks of high PEEP

- When high PEEP levels are used, be cautious:
  - earlier application of low tidal volume and the appropriate level of PEEP will minimize risk.
  - hypotension due to decreased venous return to right heart.
  - over-distension of normal alveoli and possible ventilator-induced lung injury and increase in dead space ventilation.
  - maximal PEEP levels:
    - maximal levels to be determined on individual basis, range between 10–15 cm H_20
    - use caution with higher PEEP levels in young children.

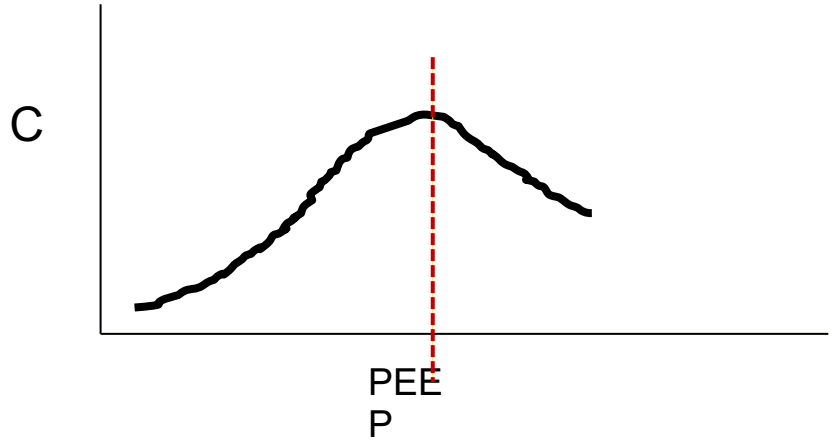
Driving pressure and PEEP

- An observational study found that ventilator changes associated with reduction of driving pressure (ΔP) was associated with improved outcome:
  - ΔP= TV/Compliance = Pplat - PEEP

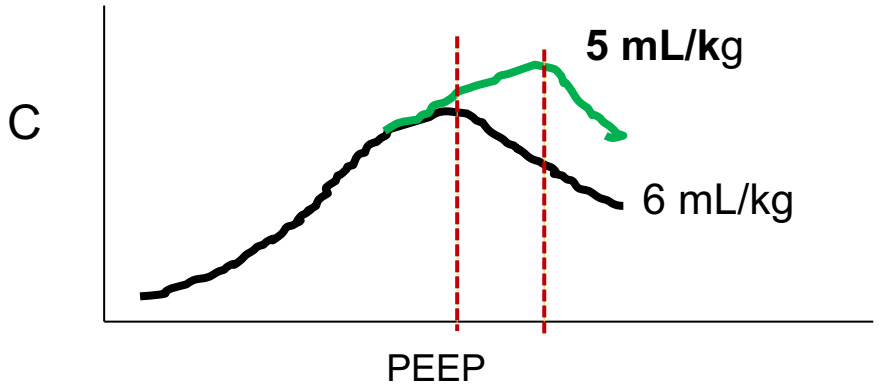
- Consider to also target ΔP= 12–15 cm H_2O:
  - can be achieved if an increase in PEEP leads to improved compliance from opening of lung units
  - helpful in patients with severely reduced chest wall compliance (i.e. severe ARDS) and high-PEEP requirements when ideal Pplat targets are not achieved.

Optimal PEEP for severe ARDS: maximal compliance vs tidal overdistension

- **1. TV = 6 mL/kg, PEEP titration trial assessing compliance**



- **2. Second trial to determine whether optimal PEEP shifts when a smaller TV is used**



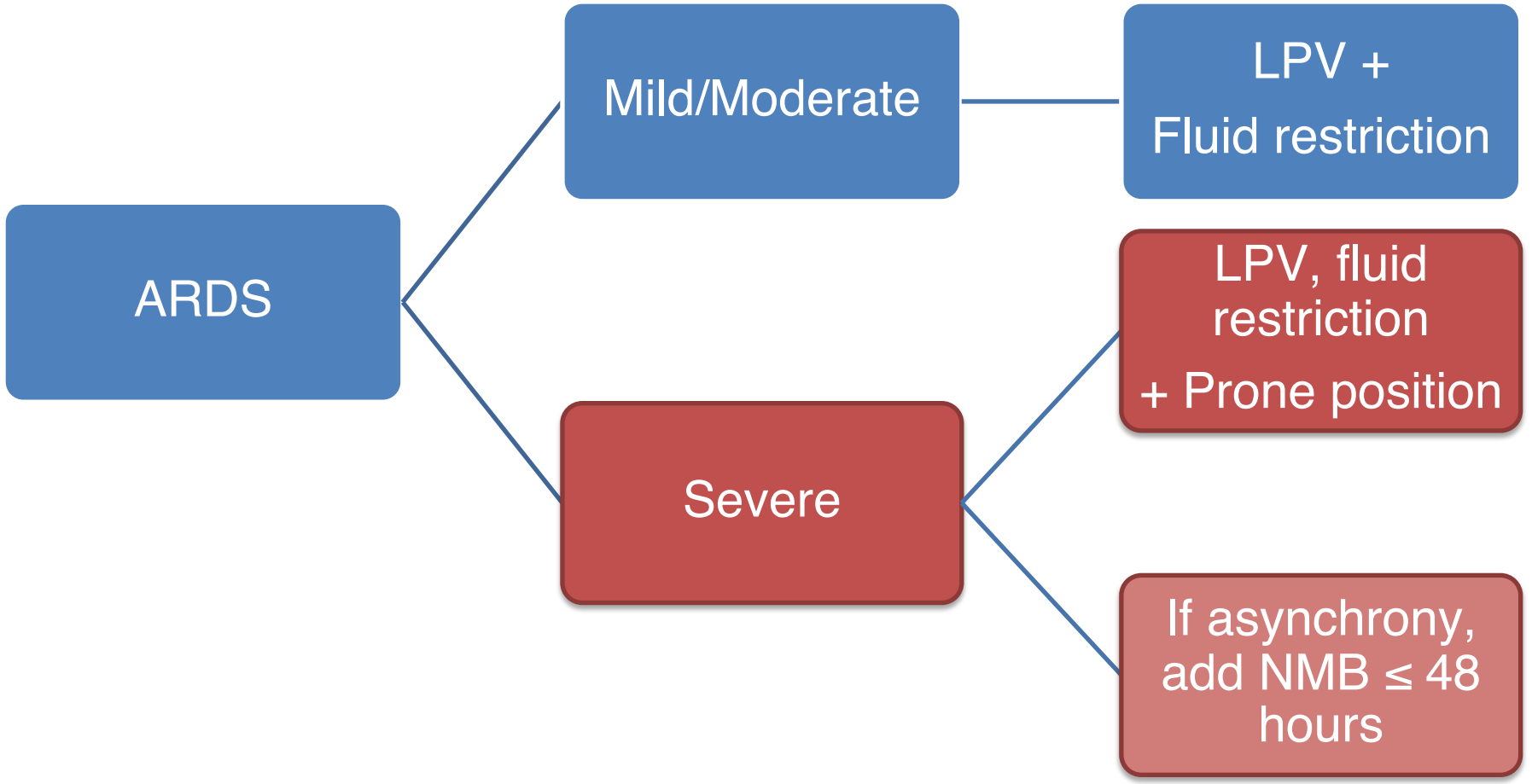
- Optimal PEEP is TV dependent. Measure compliance after PEEP and TV changes.
- It is the PEEP that provides the best oxygenation **and** compliance (TV/Pplat-PEEP).
- Consider to use as adjunct to PEEP/FiO_2 grid.
- Useful in situations when very high levels of PEEP are required, or when there is little recruitable lung tissue due to extensive consolidation/fibrosis.

Severe ARDS: PaO2/FiO2 ≤ 100 mmHg

- Patients with severe ARDS may be difficult to manage with just LPV strategy alone:
  - may develop refractory hypoxaemia, severe acidosis and unable to achieve LPV targets successfully.

- Recognize these patients **early**, using the Berlin definition, $PaO_2/FiO_2 \leq 100$ mmHg:
  - **earlier interventions** with additional therapeutic options reduces mortality from ARDS
  - key point is to avoid harmful ventilation.

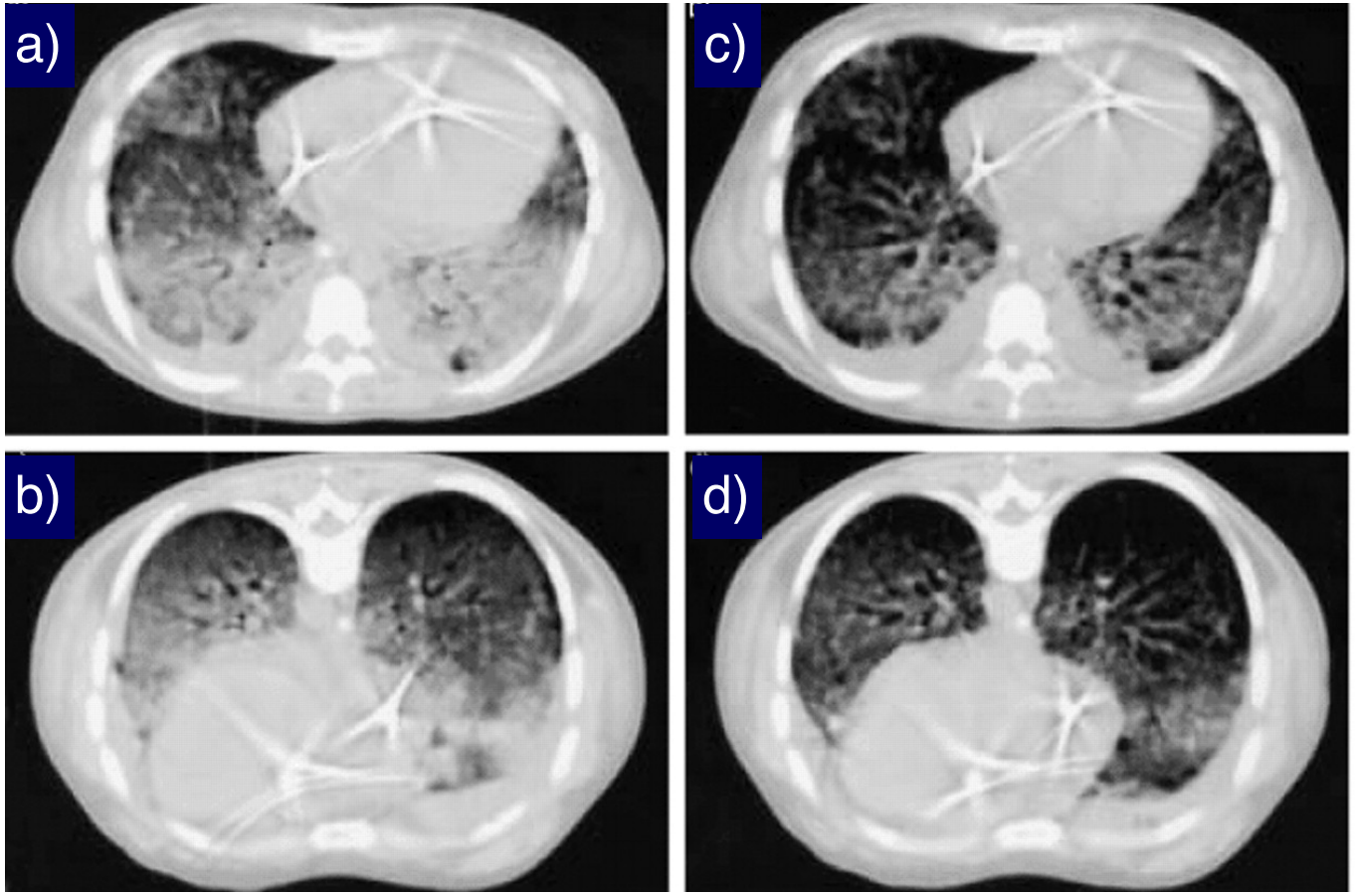
Severe ARDS: $PaO_2/FiO_2 \leq 100$ mmHg



If LPV targets not met, consider:

- Higher PEEP
- Recruitment manoeuvre
- ECMO

Prone position and lung recruitment



a) Supine, prior to proning

b) Prone - note aeration of posterior lung

c) Return to supine - posterior lung remains aerated

d) Repeat proning - further aeration of posterior lung

Intervention	Advantages	Disadvantages
Prone position	Recruits collapsed alveoli and improve VQ matching without high airway pressures. **Reduces mortality in patients with PaO_2/FiO_2 < 150 mmHg.** Start early and use > 16hrs/day.	Requires experienced team, risks of dislodgement of invasive catheters and ETT, ETT obstruction, pressure ulcers and brachial plexus injuries.
High PEEP	Easy, may recruit collapsed alveoli. **Reduces mortality in mod-severe ARDS (P/F ≤ 200).**	Slower onset, risks of ↓BP, ↓SpO_2, barotrauma, ↑dead space.
Recruitment manoeuvres + high PEEP	Faster onset, may recruit collapsed alveoli. Recommended for refractory hypoxaemia.	Risks of ↓BP, ↓SpO_2, barotrauma, ↑dead space.
Neuromuscular blockade*	Easy, fast acting, ↓asychrony, ↓VO_2. Use for 48 hours maximum. Conflicting evidence on benefit when compared to usual care.	Weakness during prolonged infusion. Though when used early for short course (< 48 hours) no increase in weakness.



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*Early neuromuscular blockade in the ARDS. N Engl J Med 2019;380:1997-2008

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LPV in young children and infants

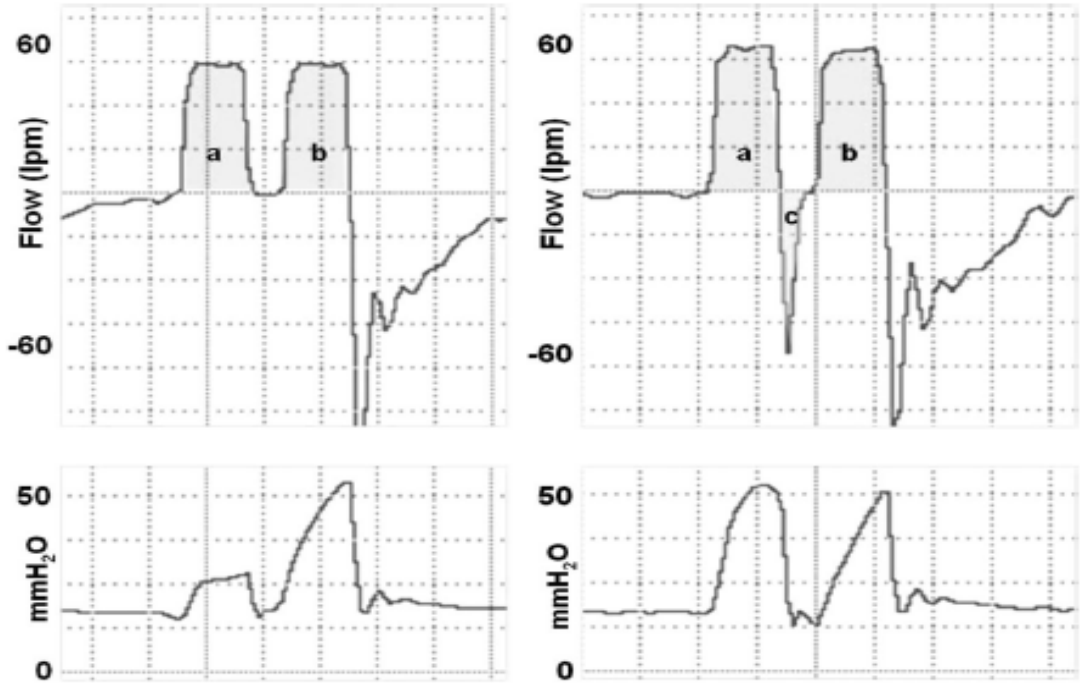
- Principles are similar for children with following considerations:
  - Most paediatric patients now have micro-cuffed or cuffed endotracheal tubes.
  - VC mode is preferred in children with cuffed endotracheal tube:
    - ensures primary control over TV.
  - PC mode is preferred if using uncuffed endotracheal tube in younger children:
    - ensures that adequate TV is delivered despite the leak of gas around the tube.

LPV in young children and infants

- For severe pARDS:
  - maximal PEEP levels:
    - maximal levels to be determined on individual basis, range between 10–15 cm H_20
    - use caution with higher PEEP levels in your children.
  - prone position can be considered, though trial data are lacking.
  - NMB can also be considered, though trial data are lacking.

Tip #1 (1/2)
Avoid patient ventilator asynchrony

- Identify and treat patient-ventilator asynchrony:
  - **Double-triggering** is the most common form of asynchrony:
    - patient takes two breaths without exhaling
    - usually because patient ventilatory demand higher than set TV.



Tip #1 (2/2)
Avoid patient ventilator asynchrony

- Potential harmful effects:
  - increased respiratory load, ventilator induced lung injury, worse gas exchange, worse lung mechanics, prolong days of IMV.

- Treatment:
  - increase flow (VC mode), prolong inspiratory time (PC mode)
  - suction trachea, eliminate water from ventilator tubing, eliminate circuit leaks
  - increase sedation if severe ARDS and unable to control TV.

Tip #2
Targeted sedation

- For patients with severe ARDS:
  - Target deep sedation if ventilatory asynchrony and unable to control TV and use NMB early.
- As the patient's ARDS improves:
  - Target lighter sedation targets to facilitate early mobility and SBT.
- Respiratory alkalosis may be a sign of untreated pain.

Tip #3
Reducing PEEP levels at the right time

- Patients may have prolonged course of IMV.
- The initial reduction of high levels of PEEP should be done gradually:
  - 2 cm H_2O, once or twice a day
  - too rapid reduction of PEEP may precipitate significant deterioration
  - increase in dead space (Vd/Vt) will rise before compliance or oxygenation decreases.
- Give lung protective ventilation strategy time to work (lungs need time to heal).

Tip #4 (1/2)
LPV using PCV

- PC ventilation may be used for LPV, when appropriate:
  - if patient ventilator asynchrony is difficult to manage on VC mode
  - preferred in young children when using uncuffed ETT (next slide).

- Set Pinsp (inspiratory pressure) to target desired TV:
  - because TV is variable, MV not controlled.
  - Pinsp needs to be changed as compliance of respiratory system changes
  - control I:E ratio with the i-time setting.

Tip #4 (2/2)
LPV using PCV

- Caution:
  - if patient has high ventilatory demand and is triggering vent the VT goal may be exceeded
  - when PC level is reduced to control VT the patient may experience increased work of breathing
  - PCV does not always improve asynchrony and WOB in ARDS.

Tips #5 & 6

- Avoid (or minimize) disconnecting the patient from the ventilator to prevent lung collapse and worse hypoxaemia:
  - use in-line catheters for airway suctioning
  - clamp tube when disconnection required
  - minimize unnecessary transport.

- Be systematic in your approach to troubleshooting problems encountered when delivering IMV:
  - see toolkit for checklists to guide troubleshooting.

Use a restrictive fluid strategy (1/2)

- Safe to use in patients with ARDS that are **not** in shock or with acute kidney injury:
  - at least 12 hours after vasopressor use.

- Leads to fewer days of IMV (quicker to extubate).

- Monitor urine output and CVP (when available), see Toolkit for details.

CVP	Urine output < 0.5 mL/kg/hr	Urine output ≥ 0.5 mL/kg/hr
> 8	Furosemide and reassess in 1 hr	Furosemide and reassess in 4hr
4–8	Fluid bolus and reassess in 1 hr	Furosemide and reassess in 4hr
< 4	Fluid bolus and reassess in 1hr	No intervention and reassess in 4hr

Use a restrictive fluid strategy (2/2)

- Minimize fluid infusions.
- Minimize positive fluid balance.
- Infants commonly present with elevated levels of antidiuretic hormone and hyponatraemia:
  - avoids hypotonic fluids
  - treat with fluid restriction.

Treat the underlying cause

- Identify and treat the cause of ARDS to control the inflammatory process:
  - e.g. patients with severe pneumonia or sepsis must be treated with antimicrobials as soon as possible

- If there is no obvious cause of ARDS, you must consider alternate aetiologies:
  - need objective assessment (e.g. echocardiogram) to exclude hydrostatic pulmonary oedema
  - see Diagnosis of pneumonia, ARDS and sepsis slideshow

Useful websites

- NEJM video on prone position:
  - https://www.youtube.com/watch?v=E_6jT9R7WJs
- http://www.ardsnet.org
- http://www.palisi.org/

Summary

- Intubation and invasive mechanical ventilation are indicated in most patients with ARDS and hypoxaemic respiratory failure.
- Lung protective ventilation (LPV) saves lives in patients with ARDS. LPV means:
  - delivering low tidal volumes (target 6 mL/kg ideal body weight or less)
  - achieving low plateau airway pressure (target Pplat ≤ 30 cm H_2O)
  - use of moderate-high PEEP levels to recruit lung.
- Restrictive fluid management when no shock or acute kidney injury
- For patients with severe ARDS, also consider early use of prone position and moderate-high PEEP levels; patients with asynchrony may benefit from NMB.

Acknowledgements

Contributors

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