CRITICAL CARE AIR TRANSPORT CLINICAL PRACTICE GUIDELINE (CCATT CPG)

Mechanical Ventilation during Critical Care Air Transport

This CPG provides guidance for the management of mechanical ventilation in the aeromedical environment.

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BACKGROUND & INTRODUCTION

a. Mechanical ventilation can injure the lung. Appropriate ventilator strategies help minimize ventilator induced lung injury.

b. Lung protective ventilation is appropriate for most CCAT patients, even if they do not have Acute Respiratory Distress Syndrome (ARDS).

   i. While many patients transported by CCATT who are mechanically ventilated may not meet diagnostic for ARDS, similar pathophysiologic processes such as alveolar overdistention (volutrauma), barotrauma, atelectrauma, and inflammation are likely at work.

   ii. In patients at risk for ARDS, a lung protective ventilation strategy reduces the risk of developing ARDS

c. This document closely follows the ventilation strategy from the ARDS Network ARMA trial.

   i. This is the least harmful strategy formally studied and validated in a large trial.

   ii. Some experts may choose to deviate from the strategy in an individual patient.

   iii. The strategy has been modified in some respects to simplify its use.

DETERMINING STABILITY FOR FLIGHT

a. Stability for flight is a multi-factorial decision based on the patient, sending facility, CCAT team, and flight characteristics.

b. Patient characteristics

   i. PEEP and FIO2

      1. PEEP / FiO2 greater than 14 cm H2O / 70% should prompt careful consideration of risks and benefits. Such patients have little room to increase FiO2 or mean airway pressure if their condition worsens during flight. However, it is still possible to transport these patients safely.

      2. All patients, including those on mechanical ventilation, will experience a decrease in PO2 as the partial pressure of oxygen in the air decreases as you increase in altitude.

         a. Patients with marginal gas exchange will require additional support during flight.

         b. A cabin altitude restriction will lessen the impact on oxygenation.

   ii. Patients on aggressive support that has been stable over time are better candidates for transport than those with increasing support leading up to flight time.

   iii. Concurrent hemodynamic compromise, severe metabolic acidosis, or traumatic brain injury will complicate ventilator management and should be considered in assessing stability for flight.

c. Sending facility characteristics
   i. Type of ventilators available
   ii. Availability of rescue therapies (proning, inhaled nitric oxide/prostacyclin, advanced mechanical ventilation techniques, etc.)
   iii. Personnel experience and expertise
   iv. Current beds available and anticipated casualties
d. Expertise of CCAT team members with advanced mechanical ventilation strategies
e. Flight characteristics
   i. Flight duration
   ii. Aircraft type
   iii. Patient load and complexity
   iv. Altitude restriction
f. If in doubt about the patient's respiratory stability for transport consult the ECMO team
   i. Extracorporeal Membrane Oxygenation (ECMO) is available 24/7 by calling commercial 210-916-ECMO (3266). The Brooke Army Medical Center ECMO team is a joint endeavor with the 59th Medical Wing and the US Army Institute for Surgical Research.
   ii. ECMO team's transport capabilities include ECMO for cardiopulmonary support and continuous renal replacement therapy. Early consultation is encouraged to facilitate planning.
   iii. ECMO team can provide expert management guidance even if they do not transport the patient.

PRE-FLIGHT PREPARATION

a. Ventilator

   i. Most patients can be safely transported using the Impact 731 ventilator.
      1. Allows for volume control or pressure control ventilation.
      2. Altitude compensated.
      3. Rated for patients 5 kg and above.
         a. For patients 5-30 Kg a 731 infant/pediatric circuit with 4.2ml of dead space should be utilized

b. Patients less than 5 Kg are usually transported by a Neonatal Transport Team.

4. Inverse ratio limited to I:E of 2:1

b. Oxygen

i. Oxygen requirements should be calculated for all patients.

1. Refer to Appendix A. ****Appendix A refers to the LTV 1000 ventilator and may no longer be applicable****

a. There is no safety factor in the calculations.

b. Additional oxygen beyond calculated requirement should be determined by each team on a case-by-case basis based on patient and transport characteristics.

ii. Each mechanically ventilated patient should ideally have a dedicated PTLOX.

iii. Aeromedical Evacuation AFIs support 2 patients on high-flow and recommend that 3rd patient should be on low-flow.

iv. The Aeromedical Evacuation team is responsible for allocating oxygen and will make that determination. CCATT, AE, and front-end Aircrew must work together to balance medical, logistic, and tactical challenges.

c. Patient Preparation

i. Patients with respiratory disease should be placed on the transport ventilator as soon as feasible by CCATT to ensure that the patient can be safely maintained on transport ventilator and allow time for an ABG to be drawn.

ii. Medical Teams that are preparing patients with respiratory dysfunction for transport within the next 24hrs should practice conservatively in managing these patients before flight.

1. Chest tubes should be left in place, particularly for patients on positive pressure ventilation. As patients climb in altitude, any residual pneumothorax may re-expand. Additionally, patients may require increasing ventilatory pressures to achieve oxygenation goals at altitude, putting the patient at risk for recurrent/worsening pneumothorax.

2. Patients on a ventilator typically should not be extubated immediately prior to transport. The decreased partial pressure of oxygen at altitude may not be easily overcome with non-invasive oxygenation. Additionally, transport can be painful and may require higher doses of pain medication. Both factors put a recently extubated patient at risk for respiratory insufficiency and reintubation.

iii. Review CXR

1. Note ETT depth and ensure correlation with CXR
2. Note invasive line positioning
3. Consider repeating CXR if more than 12 hrs. old or if clinical conditions have changed.

iv. Secure ET tube using a dedicated securing device.

1. If burns or facial trauma preclude this, consider securing tube to upper lateral incisor and adjoining canine tooth using silk suture or wire. Umbilical tape is also acceptable.
2. Be certain that lips and tongue are not injured by device.

v. Avoid exposing airway to atmospheric pressure during ventilator changeover if PEEP is ≥ 10cm H_2O.

1. Lung de-recruitment occurs rapidly with exposure to atmospheric pressure.
2. Gently clamp ET tube using a Kelly clamp while the circuit is broken for ventilator changeover.
3. Pad the Kelly clamp with tape or short pieces of rubber tubing to avoid damage to the ET tube.
4. Do not clamp wire reinforced tubes as they will kink permanently.

vi. All ventilated patients should have a heat and moisture exchanger (HME) in place.

vii. Check ET tube cuff pressure prior to departure.

1. Proper ET tube cuff inflation is mandatory to avoid aspiration, de-recruitment and ventilator malfunction (pressure too low) or damage to tracheal mucosa (pressure too high).
2. Palpating ET tube cuff is inaccurate and should not be relied upon to estimate cuff pressure. Use a cuff manometer.
3. Goal Cuff Pressure is typically 20 – 30 cm H_2O (15-22 mm Hg). Alternatively, the Minimal Leak Test should be used in pediatric patients and can be used safely in adults.
4. ET tube cuffs should be filled with air. Do not use saline.

viii. All ventilated patients should have the head of bed elevated at least 30° unless there is a contraindication.

1. Most patients will not have a contraindication. Ask the sending physician or neurosurgeon for clarification if necessary.
2. The backrest designed for the NATO litter is the most appropriate way to elevate the head of bed.

ix. All ventilated patients should have continuous $ETCO_2$ monitoring.

1. Use caution interpreting the absolute value of the ETCO2 as it may not accurately reflect PaCO2.
    a. The difference between PaCO2 and ETCO2 reflects dead space. A difference of 3-5 mmHg is normal in healthy patients. In critically ill patients this number can vary significantly and change rapidly with various disease processes.
    b. The true value is the ability to immediately detect circuit disconnections and ventilator failures by observing changes in the waveform and to identify trends in CO2 that may prompt arterial blood gas measurement.
2. Should CPR be necessary, ETCO2 monitoring may be used to evaluate the adequacy of chest compressions, the goal is greater than 10 mmHg at a minimum and 20 mmHg ideally.
3. Additionally, ETCO2 waveforms may offer insight into a variety of respiratory dynamics.

x. All ventilated patients require gastric decompression at take-off and landing.
1. Large bore oro-gastric tubes are preferred to large bore naso-gastric tubes for decompression to reduce the risk of sinusitis.
2. For babies and others at risk of hypoglycemia, weigh the risks and benefits of discontinuing enteral feeds. If gastric feeds must be terminated, monitor patient for hypoglycemia and/or have a plan to mitigate this with dextrose containing fluids.
3. Patients with post pyloric feeding tubes and secured airways (ETT or Trach with cuff inflated) have a very low risk of aspiration and may continue enteral feeding.

BASIC VENTILATOR MANAGEMENT

a. Mode of Ventilation

i. Avoiding injurious ventilator settings is far more important than the mode of ventilation.

ii. There is no outcome-based evidence favoring one mode of ventilation over another.

iii. Patients in the landmark ARDSNet ARMA trial were all ventilated in volume assist-control ventilation and many clinicians choose to use this mode primarily.
1. However, pressure control has some theoretical advantages.
    a. A decelerating flow waveform is more comfortable for the patient and may improve gas mixing. This is only available in PC mode on the 731 ventilator. VC mode on the 731 ventilator only allows square wave flow, unlike most ICU ventilators.
    b. Inverting I:E ratio is an option for increasing the mean airway pressure (and thus

improving oxygenation). This is easier to manage in PC than VC.

c. Setting a Peak Inspiratory Pressure (PIP) ensures that the Plateau Pressure (Pplat) will remain below PIP.

2. A theoretical drawback to Pressure Control is that close attention must be paid to tidal volumes delivered as they can change over time due to changes in the patient's physiology.

b. Ventilator Settings

i. Initial approach and assessment

1. For patients on a ventilator, start by trying to match prior vent settings
2. Place patients with respiratory dysfunction on the transport vent early to verify stability
3. The presence of any of the below potentially harmful vent settings or patient characteristics should prompt consultation with the ECMO transport team. Consider consultation even if ECMO transport is not possible as they can offer additional management suggestions.
   a. Pplat > 32
   b. PIP > 40
   c. FiO2 > 60% on appropriate PEEP
   d. PEEP > 14
   e. pH < 7.25 despite attempts to increase MV
   f. P/F Ratio < 150 despite on appropriate PEEP and FiO2
4. Patients will likely require increased PEEP or FiO2, and possibly MV at altitude. Ensure that there is room to safely titrate up all vent settings by approximately 20% at altitude.
5. See below for guidance for newly intubated patients or patients not tolerating current vent settings.

ii. Tidal Volume (VT)

1. Tidal volume should be based on predicted body weight (PBW) according to: PBW = 50+2.3 (height in inches – 60) for males. Refer to Appendix B. (May use "wingspan" instead of height).
   a. Goal VT is 4-8 cc/kg based on predicted body weight.
   b. Patients with lung injury or concern for potential lung injury should have a target VT 6 ml/kg PBW
   c. Other patients may find a VT of 8cc/kg more comfortable than lower volumes. This

target may be appropriate as long as PIP ≤ 40 cmH2O and Pplat ≤ 30 cmH2O.

d. If a patient is not tolerating the target VT consider additional sedation and paralytic.

e. While VT can be manipulated to control pCO2, the best way to manage pCO2 is to alter the respiratory rate. If adjusting tidal volume, do not increase VT above 8 cc/kg to control pCO2

iii. Respiratory Rate

1. Respiratory rate should be 12-32
2. Adjust the respiratory rate to achieve a pH between 7.35 and 7.45. If this goal cannot be reached, permissive hypercapnia is appropriate for ARDS patients without TBI. Tolerance of pH as low as 7.25 may be appropriate for transport and allow for avoidance of injurious vent settings. See section on "Permissive Hypercapnia" below. If in doubt, consult the ECMO team.
3. The pH is more important that the actual pCO2 ***Not applicable to TBI patients***
4. Patients with baseline CO2 retention will have a normal pH at elevated pCO2, this is normal.

iv. Volume Control (VC)

1. Start at 6-8 ml/kg PBW for patients with minimal lung disease
2. Start at 6 ml/kg PBW for patients with respiratory dysfunction
3. Adjust Respiratory Rate (RR) for a Minute Ventilation (MV) that achieves the goal pH and PaCO2.
4. Check Pplat, if >30, VT can be titrated down to 4ml/kg to reach a safe Pplat. A VT of 4 ml/kg PBW is usually uncomfortable for the patient and may require increased sedation.
5. If PIP is elevated, consider increasing inspiratory time. Other measures to increase airway diameter including suctioning or bronchodilators may be considered in the appropriate clinical circumstances.

v. Pressure Control (VC)

1. Switching to PC mode allows the respiratory provider to target a safe upper limit for Peak Inspiratory Pressure (PIP) and Plateau Pressure (Pplat).
    a. PIP is greater than or equal to Pplat in PC mode. If flow equals zero at the end of inspiration, PIP = Pplat, otherwise Pplat < PIP.
2. Plateau pressures equal to or less than 30 cmH2O are thought to be safe
3. Driving Pressure (ΔP) = Pplat – PEEP

a. Driving Pressures less than 15 mmHg correlate with better outcomes
b. Driving Pressure can be titrated up or down to change VT; this is the most direct way to change VT.
c. The Zoll 731 ventilator is not PEEP compensated. Increasing PEEP without changing the PIP will decrease Driving Pressure and VT.

4. Setting the PIP
   a. Start by setting the vent PIP to 10 cmH2O above PEEP (Driving pressure of 10 cmH2O)
   b. Quickly titrate the PIP up or down for a target VT of 4-8 ml/kg.
   c. 8 ml/kg PBW VT may be appropriate for patients without respiratory dysfunction
   d. Otherwise, for patients with any concern for lung injury, titrate PIP to achieve VT of 6ml/kg PBW
   e. Changes of 2-4 cmH2O can be made every few breaths.
5. VT can change quickly in critically ill patients leading to changes in MV/pH/PaCO2.
   a. Providers must be attentive for changes in VT and MV.
   b. Decreases in Pulmonary Compliance will decrease VT
   c. Increases in Pulmonary Resistance may decrease VT
6. Inspiratory Time can be increased or decreased to change VT
   a. Increases in inspiratory time will increase VT
   b. Decreases in inspiratory time will decrease VT
   c. Changes in Respiratory Rate may change inspiratory time which may change VT

vi. Permissive Hypercapnia – Patients with hypercarbic respiratory failure (ex. ARDS or COPD) may require permissive hypercapnia to remain in safe pressure ranges on the ventilator.

1. Respiratory acidosis is well tolerated, to an extent. Titrating up ventilator pressures can be more harmful than tolerating moderate hypercarbia.
2. Prioritize lung protective ventilation with Pplat < 30 cmH2O.
3. Manipulate respiratory rate to maintain a minimum pH of 7.25.
4. Investigate non-respiratory causes of acidosis and treat appropriately
5. Bicarbonate administration may help in the treatment of non-anion gap acidosis. It may also be utilized as a temporizing measure for severe acidosis (pH < 7.15) with concern for high risk of cardiovascular collapse. However, note that bicarbonate will be rapidly converted to CO2 requiring increased minute ventilation for clearance, and thus may

ultimately worsen respiratory acidosis for patients unable to ventilate.

vii. Oxygenation

1. Oxygen saturation goals should, in general, be between 93-99%.
    a. While literature supports allowing for oxygen saturation as low as 90%, in the transport environment targeting a saturation of 93% or above allows for an increased degree of safety due to the number of patient handoffs and equipment challenges that can be encountered.
    b. Oxygen saturation of 100% indicates a PaO2 of 100 mmHg or more and could indicate harmful hyperoxia. Targeting normoxia of 93-99% reduces the possibility of harm from hyperoxia and preserves a finite resource in flight.
2. FiO2
    a. Start at 60% for patients with minimal lung disease
    b. Start at 100% for patients with respiratory dysfunction
    c. Titrate FiO2 in coordination with PEEP (see below)
    d. FiO2 changes can be made rapidly and are best titrated to pulse oximetry, not PaO2 on ABG.
    e. Consider increasing FiO2 by 20% immediately prior to take off in patients with marginal oxygenation
3. PEEP
    a. Start PEEP of 5 mm Hg for patients with minimal lung disease
    b. Start at a PEEP of 10-15 mm Hg for patients with hypoxic respiratory failure
    c. Attempt to match PEEP and FiO2 per ARDSNet ARMA table in Appendix B
    d. Increases in PEEP take 30-60 min to have an effect.
    e. Decreases in PEEP take effect immediately. If PEEP is decreased too rapidly, it may take 30-60 min to re-recruit areas of atelectasis
    f. Recruitment Maneuvers may speed response to changes increases in PEEP (see below)
    g. Consider low PEEP and High FiO2 for patients with pneumothorax, air leaks from the chest tube, or recent lung surgery.
    h. Recheck PIP and Pplat after titrating PEEP and ensure appropriate VT and MV
    i. High PEEP can decrease cardiac output and may cause hypotension in hypovolemic patients. Additional volume loading may be necessary to maintain hemodynamics.

c. Alarms

i. Alarms should be set to alert the team to malfunctions or changes in physiology without causing frequent false alarms. The following guidance is a starting point, but each team will determine appropriate alarm settings for each mission.

ii. Suggested initial settings

1. High pressure alarm should be set 50% above the baseline PIP (1.5 X current PIP).
2. Low pressure alarm should be set 50% below the baseline PIP (0.5 X current PIP).
3. High respiratory rate alarm (731 only) should be set 10 above the patient's respiratory rate.
4. Low respiratory rate alarm (731 only) should be set 10 below the set rate.

ONGOING MANAGEMENT

a. Airway Suctioning

i. Suctioning every 4 hours is appropriate without copious secretions or mucous plugging.

ii. Frequent suctioning may lead to lung de-recruitment and worsen gas exchange in patients with ARDS.

b. ETT Cuff Pressure

i. Significant changes may occur on ascent and descent. Cuff pressure increases with ascent and decreases with descent.

ii. Cuff pressure should be checked and documented with manometer before departure, at cruise altitude, during descent and after landing.

c. Management of Oxygen Desaturation

i. Increase FiO2 to 100% if patient is desaturating quickly while you work through evaluation.

1. FiO2 can be quickly weaned based on SpO2 once the patient is stable
2. Rule out equipment malfunction, loss of O2 supply, or circuit disconnect and ensure that the desired FiO2 is being delivered to the patient

ii. Confirm ET tube placement is in trachea using ETCO2 and note location at teeth/lip

iii. If desaturation is severe switch immediately to manual bag ventilation with high flow oxygen and PEEP valve.

1. Suction the airway (consider simultaneous bag ventilation) to verify patency and clear mucous plugs.

2. Consider the need for ETT exchange if it is difficult to pass a suction catheter through the ETT.
3. When attempting to clear thick adherent mucous secretions make sure that the Zoll 330 suction machine is pulling -120 cm H2O. It is often necessary to TEMPORARILY clamp all other devices attached to suction, particularly the pleurevac.
4. Be aware that aggressive suctioning can lead to de-recruitment and mucosal injury, worsening hypoxia

iv. If the patient is dyssynchronous with the ventilator:
1. Consider changing the ventilatory mode.
2. Rule out pneumothorax/hemothorax.
3. Review peak pressure trend if using volume cycled ventilation.
4. Review VT trend if using pressure control ventilation. VT will decrease if significant pneumothorax develops and ΔP is not changed.
5. Evaluate existing chest tubes for proper function.
6. Consider increasing sedation or adding paralytic.
7. Evaluate lungs with ultrasound.
8. Needle decompression of the chest and placement of a chest tube may be necessary if there is suspicion of pneumothorax and concurrent hemodynamic compromise.
9. Consider needle decompression of the contralateral lung. Trauma patients are at high risk of bilateral pneumothorax even if only one side of the thorax shows signs of trauma.

v. Consider increasing PEEP. Raising PEEP may take 30 min to improve SpO2.

vi. Consider recruitment maneuvers after increasing PEEP to next level on titration table.
1. Additional lung can sometimes be recruited using sustained inflations (recruitment maneuvers) of the lung, particularly in patients with an increased risk of atelectasis.
2. Current data does not support wide-spread use of recruitment maneuvers for hypoxia. The risks of barotrauma outweigh the minimal benefit seen in most cases and so recruitment maneuvers are largely avoided in routine ICU care.
3. Patients with ARDS, recent lung surgery, ongoing air-leak from pneumothorax, or under-resuscitation are at high risk for further injury.
4. A typical recruitment maneuver consists of inflation to 30-40 cm H2O for 30-40 seconds, which is difficult to do on transport ventilators.
5. Recruitment maneuvers increase intrathoracic pressure (by design) which can result in

decreased cardiac output and hypotension. Monitor blood pressure closely and terminate any of the below recruitment maneuvers if hypotension develops.

6. Pragmatic recruitment maneuvers on the 731 may be performed by:
   a. Volume control setting:
      i. Increase peep first to match anticipated final FiO_2 setting per ARDSNet
      ii. Increase tidal volume to 10ml/kg for 1 minute then reduce to prior volume
   b. Pressure control setting:
      i. Increase peep first to match anticipated final FiO_2 setting per ARDSNet
      ii. Set PIP to 30 cm H20
      iii. Manual breath hold for 20sec on two consecutive breaths as tolerated by patient
7. Recruitment maneuver can be performed with bag-valve manual ventilation.
   a. Set PEEP valve on bag-valve unit to 20 cm H_2O.
   b. Deliver five sequential breaths, each held for 5-8 seconds.
   c. Clamp endotracheal tube while switching between ventilator and bag. Exposure to atmospheric pressure will quickly result in lung de-recruitment, hypoxemia and increased ventilator induced lung injury.

d. Monitoring Oxygen Utilization

i. When using PTLOX, periodically check amount of oxygen consumed.
ii. Oxygen consumption may vary between ventilators, even with the same settings.
iii. Leaks in system may cause excessive oxygen consumption.
iv. Comparing actual to predicted oxygen consumption will allow early detection of excess utilization that may necessitate troubleshooting, changes in management or diverting aircraft in extreme cases.

APPENDIX A: OXYGEN REQUIREMENTS

Oxygen Consumption Tables for LTV 1000 Ventilator

Liters of Gaseous Oxygen Consumed Per Hour

FiO2 \ Minute Ventilation	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
0.3	96	103	109	116	123	130	137	144	150	157	164	171	178	185	191	198	205
0.4	202	216	231	245	260	274	289	303	317	332	346	361	375	390	404	418	433
0.5	308	330	352	374	396	418	441	463	485	507	529	551	573	595	617	639	661
0.6	415	444	474	504	533	563	592	622	652	681	711	741	770	800	829	859	889
0.7	521	558	595	633	670	707	744	782	819	856	893	930	968	1005	1042	1079	1116
0.8	627	672	717	762	807	851	896	941	986	1031	1075	1120	1165	1210	1255	1299	1344
0.9	734	786	838	891	943	996	1048	1101	1153	1205	1258	1310	1363	1415	1467	1520	1572
1	840	900	960	1020	1080	1140	1200	1260	1320	1380	1440	1500	1560	1620	1680	1740	1800

Find the correct minute ventilation column then go down to the correct FiO2 row. The number where these intersect is the liters of gaseous oxygen consumed per hour. There is no safety factor in this calculation. The amount of safety factor needed should be determined by the team on a case-by-case basis.

Liters of Liquid Oxygen Consumed Per Hour

FiO2 \ Minute Ventilation	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
0.3	0.12	0.13	0.14	0.15	0.15	0.16	0.17	0.18	0.19	0.20	0.21	0.21	0.22	0.23	0.24	0.25	0.26
0.4	0.25	0.27	0.29	0.31	0.32	0.34	0.36	0.38	0.40	0.41	0.43	0.45	0.47	0.49	0.51	0.52	0.54
0.5	0.39	0.41	0.44	0.47	0.50	0.52	0.55	0.58	0.61	0.63	0.66	0.69	0.72	0.74	0.77	0.80	0.83
0.6	0.52	0.56	0.59	0.63	0.67	0.70	0.74	0.78	0.81	0.85	0.89	0.93	0.96	1.00	1.04	1.07	1.11
0.7	0.65	0.70	0.74	0.79	0.84	0.88	0.93	0.98	1.02	1.07	1.12	1.16	1.21	1.26	1.30	1.35	1.40
0.8	0.78	0.84	0.90	0.95	1.01	1.06	1.12	1.18	1.23	1.29	1.34	1.40	1.46	1.51	1.57	1.62	1.68
0.9	0.92	0.98	1.05	1.11	1.18	1.24	1.31	1.38	1.44	1.51	1.57	1.64	1.70	1.77	1.83	1.90	1.97
1	1.05	1.13	1.20	1.28	1.35	1.43	1.50	1.58	1.65	1.73	1.80	1.88	1.95	2.03	2.10	2.18	2.25

Find the correct minute ventilation column then go down to the correct FiO2 row. The number where these intersect is the liters of liquid oxygen consumed per hour. 1 L liquid oxygen = 800 L gaseous oxygen. There is no safety factor in this calculation. The amount of safety factor needed should be determined by the team on a case-by-case basis.

Hours of Use Per Liter of Liquid Oxygen

FiO2 \ Minute Ventilation	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
0.3	8.36	7.80	7.31	6.88	6.50	6.16	5.85	5.57	5.32	5.09	4.88	4.68	4.50	4.33	4.18	4.04	3.90
0.4	3.96	3.70	3.46	3.26	3.08	2.92	2.77	2.64	2.52	2.41	2.31	2.22	2.13	2.05	1.98	1.91	1.85
0.5	2.59	2.42	2.27	2.14	2.02	1.91	1.82	1.73	1.65	1.58	1.51	1.45	1.40	1.35	1.30	1.25	1.21
0.6	1.93	1.80	1.69	1.59	1.50	1.42	1.35	1.29	1.23	1.17	1.13	1.08	1.04	1.00	0.96	0.93	0.90
0.7	1.54	1.43	1.34	1.26	1.19	1.13	1.07	1.02	0.98	0.93	0.90	0.86	0.83	0.80	0.77	0.74	0.72
0.8	1.28	1.19	1.12	1.05	0.99	0.94	0.89	0.85	0.81	0.78	0.74	0.71	0.69	0.66	0.64	0.62	0.60
0.9	1.09	1.02	0.95	0.90	0.85	0.80	0.76	0.73	0.69	0.66	0.64	0.61	0.59	0.57	0.55	0.53	0.51
1	0.95	0.89	0.83	0.78	0.74	0.70	0.67	0.63	0.61	0.58	0.56	0.53	0.51	0.49	0.48	0.46	0.44

Find the correct minute ventilation column then go down to the correct FiO2 row. The number where these intersect is the number of hours that a 1 L of liquid oxygen will operate the ventilator. 1 L liquid oxygen = 800 L gaseous oxygen. There is no safety factor in this calculation. The amount of safety factor needed should be determined by the team on a case-by-case basis.

Minutes of Use Per Full D Cylinder

FiO2 \ Minute Ventilation	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
0.3	171	159	149	140	133	126	119	114	109	104	99	96	92	88	85	82	80
0.4	81	75	71	67	63	60	57	54	51	49	47	45	43	42	40	39	38
0.5	53	49	46	44	41	39	37	35	34	32	31	30	28	27	26	26	25
0.6	39	37	34	32	31	29	28	26	25	24	23	22	21	20	20	19	18
0.7	31	29	27	26	24	23	22	21	20	19	18	18	17	16	16	15	15
0.8	26	24	23	21	20	19	18	17	17	16	15	15	14	13	13	13	12
0.9	22	21	19	18	17	16	16	15	14	14	13	12	12	12	11	11	10
1	19	18	17	16	15	14	14	13	12	12	11	11	10	10	10	9	9

Find the correct minute ventilation column then go down to the correct FiO2 row. The number where these intersect is the number of minutes that a full D cylinder will operate the ventilator. Assumes full D cylinder contains 1800 psi, is empty at 100 psi and tank factor 0.16. There is no safety factor in this calculation. The amount of safety factor needed should be determined by the team on a case-by-case basis.

APPENDIX B: PEEP, TV, AND FiO2 VENTILATION OF PATIENTS WITH ARDS

Male Patients – mls per Kg

Height				4	5	6	7	8	9	10
ft in	in	cm	Pre Wt (Kg)							
5'6"	66	168	64	255	320	385	445	510	575	640
5'8"	68	173	68	275	340	410	480	545	615	685
5'10"	70	178	73	290	365	440	510	585	655	730
6'	72	183	78	310	390	465	545	620	700	775
6'2"	74	188	82	330	410	495	575	660	740	820
6'4"	76	193	87	345	435	520	610	695	780	870
6'6"	78	198	91	365	455	550	640	730	825	915

Female Patients – mls per Kg

Height				4	5	6	7	8	9	10
ft in	in	cm	Pre Wt (Kg)							
5'	60	152	46	180	230	275	320	365	410	455
5'2"	62	157	50	200	250	300	350	400	450	500
5'4"	64	163	55	220	275	330	385	440	490	545
5'6"	66	168	59	235	295	355	415	475	535	595
5'8"	68	173	64	255	320	385	445	510	575	640
5'10"	70	178	69	275	345	410	480	550	615	685
6'	72	183	73	290	365	440	510	585	660	730

PEEP to FiO_2

PEEP Titration Table - ARDSNet ARMA Trial

PEEP	5	5	8	8	10	10	10	12	14	14	14	16	18	18	20	22	24
FiO2	0.3	0.4	0.4	0.5	0.5	0.6	0.7	0.7	0.7	0.8	0.9	0.9	0.9	1	1	1	1

<------Move across table to keep SaO_2 92 – 96 %------->

Patients falling in shaded area are not necessarily too sick for flight but risks and benefits should be considered as described in the CPG.

APPENDIX C: TROUBLESHOOTING – DOPE ALGORITHM

Alarm	DOPE	Possible Cause	Troubleshooting
High Pressure	D	Mainstem intubation	If the tube has advanced and unilateral ventilation is confirmed, retract the tube to proper depth using bougie technique to maintain placement.
High Pressure	D	Esophageal intubation	If the tube is advanced and unilateral ventilation is not present, rule out esophageal intubation. If breath sounds are present over abdomen, or gastric distention noted, remove the ET tube and secure airway by other means and place gastric tube for evacuation of gastric contents.
High Pressure	O	Obstruction of ET tube	Place patient on FiO_2 1.0 (100%) and prepare suction equipment. Suction airway using standard technique. If inhalation injury is suspected (burn, agent), saline may be used to facilitate suctioning.
High Pressure	O/E	Obstruction of ventilator circuit	Ensure circuit connections are attached and not kinked paying particular attention to connections and sharp bends.
High Pressure	P	Pulmonary circuit	Rule out/treat hemo/pneumothorax.
High Pressure	P	Pulmonary circuit	Consider Pulmonary Edema. Prolong Inspiratory time if appropriate (i.e. adjust from 1:3 to 1:2 to 1:1).
High Pressure	P	Pulmonary circuit	Consider airway swelling; may need to add or increase Pressure Support
High Pressure	P	Pulmonary circuit	Evaluate Tidal Volume. Consider lowering by 1cc/kg (min. 4cc/kg).
High Pressure	P	Patient arousal	Address analgesia/sedation needs.
High Pressure	P	Stacked breath/air trapping	Disconnect patient from the circuit and allow full exhale. Address cause (patient triggering, high rate, incomplete exhalation).
High Pressure	P	Chest tube malfunction	If hemo/pneumothorax are suspected, disconnect all attachments and troubleshoot chest tube and components.
High Pressure	P	Patient position	If laying supine, elevate head of bed (HOB) to reduce gravitational pressure on the chest.
High Pressure	E	Alarm setting	After ensuring patient optimization, adjust alarm settings.
Low Pressure	D	Extubation	If tube has been removed from the trachea, secure the airway using method within scope/skill of the provider.
Low Pressure	D	Esophageal intubation	If tube is advanced and unilateral ventilation is not present, rule out esophageal intubation. If breath sounds present over abdomen, or gastric distention noted, remove ET tube and secure airway by other means and place gastric tube for evacuation of gastric contents.
Low Pressure	E	ET tube balloon	Ensure ET Tube cuff is inflated (25-35 cmH_2O). If the cuff will not maintain inflation, exchange ET tube using bougie technique.
Low Pressure	E	Ventilator disconnect/leak	Ensure all connections are attached securely to the appropriate point. Run bare hand along circuit to feel any air escaping during inhalation paying special attention to valves and connections.
Low SpO2	DOPE	Assess patient	For acute desaturation, place FiO_2 at 1.0 (100%). Check chest rise and fall, $ETCO_2$, SpO2 probe placement. Check all conditions from high/low pressure chart to rule out other alarm failures.

Alarm	DOPE	Possible Cause	Troubleshooting
Low SpO2	x	Increase in altitude	Increase FiO2 to compensate for decrease in pressure.
Low SpO2	x	Patient deterioration	If desaturation is gradual and presumed to be caused by patient pathology, increase PEEP and FiO2 in a stepwise fashion according to ARDSNet table.
Low SpO2	x	Patient deterioration	Attempt alveolar recruitment maneuvers. Inflation to 30 - 40 cm H2O for 30 - 40 seconds (difficult with PMI). Recruitment maneuver can be performed with bag-valve manual ventilation. 1. Set PEEP valve on bag-valve unit to 15 - 20 cm H2O. 2. Deliver five sequential breaths, each held for 5 - 8 seconds. 3. Watch blood pressure closely. Terminate if hypotension develops. 4. Clamp endotracheal tube while switching between ventilator and bag. 5. Immediately assess for tension pneumothorax, if applicable.
Low SpO2	E	O2 supply	Check O2 PSI and condition of hose/connections.)
High ETCO2	E	Incorrect vent settings	VE may be too low (Adjust VT f/I:E for patients IWB).
High ETCO2	x	Hypermetabolic state	Address pain, shivering, hyperthermia / infection.
High ETCO2	x	Respiratory insufficiency	Increase rate (current EtCO2 x current rate/40).VE may be too high (Ensure proper VT/f/I:E for patients IWB).
Low ETCO2	E	Incorrect vent settings	VE may be too high (Ensure proper VT/f/I:E for patients IWB).
Low ETCO2		Ventilator dyssynchrony	If on AC and patient is not properly sedated, the patient may be breathing over the ventilator settings, increasing their VE. Consider sedation medications followed by paralytics, as needed.
Low ETCO2	x	Low perfusion state (hypovolemia or sepsis)	CHECK PATIENT'S PULSE FOLLOWING RAPID DROP. Continue to resuscitate patient within scope and skill.
Low ETCO2	x	Decrease in alveolar ventilation	Suction patient if suspected mucus/secretion plug. If associated with high pressure alarm, consider alveolar distention (air trapping/stacked breathing): remove patient from ventilator and allow full exhale.
Low ETCO2	x	Respiratory compensation (metabolic acidosis)	DO NOT ATTEMPT TO NORMALIZE patient's breathing without ABG and expert consultation.

Source: USASAM, Enroute Care Branch Ventilator Guide[16]