MECHANICAL VENTILATION DURING CRITICAL CARE AIR TRANSPORT (CCAT) CLINICAL PRACTICE GUIDELINE

Publication date: 12 Oct 2013

Certified current by the U.S. Air Force Mobility Command as of 14 Dec 2021

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Background & Introduction

1. Mechanical ventilation can injure the lung. Appropriate ventilator strategies will minimize ventilator induced lung injury.
2. Lung protective ventilation is appropriate for most CCAT patients, even if they do not have Acute Respiratory Distress Syndrome (ARDS).
   a. The same pathophysiologic processes are likely at work, even if they have not reached a level that meets the formal ARDS definition.
   b. There is evidence that lung protective ventilation decreases ARDS development in patients at risk, which describes most CCAT patients.
3. This document closely follows the ventilation strategy from the ARDS Network ARMA trial.
   a. This is the least harmful strategy formally studied and validated in a large trial.
   b. Some experts may choose to deviate from the strategy in an individual patient.
   c. The strategy has been modified in some respects to simplify its use.

Determining Stability for Flight

1. Stability for flight is a multi-factorial decision based on the patient, sending facility, CCAT team, and flight characteristics.
2. Patient characteristics
   a. PEEP and FIO2
      i. PEEP / F_IO_2 greater than 14/70% (See Appendix B.) should prompt careful consideration of risks and benefits. Such patients have little room to increase F^IO_2 or mean airway pressure if their condition worsens during flight. This does not mean patients on these settings cannot be transported safely.
      ii. All patients, including those on mechanical ventilation, will experience a decrease in PO2as ambient pressure decreases.
         - Patients with marginal gas exchange will require additional support during flight.
         - Cabin altitude restriction will lessen the impact on gas exchange.
   b. 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.
   c. Concurrent hemodynamic compromise or traumatic brain injury will complicate ventilator management and should be considered in assessing stability for flight.
3. Sending facility characteristics
   a. Type of ventilators available
   b. Availability of rescue therapies (proning, inhaled nitric oxide/prostacyclin, advanced mechanical ventilation techniques, etc.)
   c. Personnel experience and expertise

   d. Current beds available and anticipated casualties

4. Expertise of CCAT team members with advanced mechanical ventilation strategies
5. Flight characteristics
   a. Flight duration
   b. Aircraft type
   c. Patient load and complexity
   d. Altitude restriction

Pre-flight Preparation

Ventilator

1. Most patients can be safely transported using the Impact 731 ventilator.
   a. Allows for volume control or pressure control ventilation.
   b. Altitude compensated.
   c. Rated for patients 5kg and above.
   d. Cannot do inverse ratio.
2. The LTV 1000 ventilator offers additional capability needed in some patients but also has limitations.
   a. Inverse ratio ventilation.
   b. Better choice for pediatric transports.
   c. Unable to compensate for altitude.
   d. Unable to achieve 100% Fi02 due to turbine (93-94% highest $Fi0_2$ attainable).

Oxygen

1. Oxygen requirements should be calculated for all patients.
   a. The LTV 1000 with high F_IO_2 and minute ventilation can exhaust a full Portable Therapeutic Liquid Oxygen System (PTLOX) during along mission. Never forego the oxygen calculation.
   b. Refer to Appendix A.
      - There is no safety factor in the calculations.
      - Additional oxygen beyond calculated requirement should be determined by each team on a case by case basis based on patient and transport characteristics.
2. Each mechanically ventilated patient should ideally have a dedicated PTLOX.
3. It is possible to have two patients on one PTLOX; Aeromedical Evacuation will make that determination if necessary.

Patient Preparation

1. Note endotracheal (ET) tube depth at the teeth that correlates to appropriate placement by CXR.
2. Secure ET tube using a dedicated securing device.
   a. If burns or facial trauma preclude this, consider securing tube to upper central incisor using silk suture or wire.
   b. Be certain that lips and tongue are not injured by device.
3. Avoid exposing airway to atmospheric pressure during ventilator changeover if PEEP is ≥ 10cm H_2O.
   a. Lung de-recruitment occurs rapidly with exposure to atmospheric pressure.
   b. Gently clamp ET tube using a Kelly clamp while the circuit is broken for ventilator changeover.
   c. Pad the Kelly clamp with tape or short pieces of rubber tubing to avoid damage to the ET tube.
   d. Do not clamp wire reinforced tubes as they will kink permanently.
4. All ventilated patients should have a heat-moisture exchanger in place.
5. Check ET tube cuff pressure prior to departure.
   a. 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).
   b. Palpating ET tube cuff is inaccurate and should not be relied upon to estimate cuff pressure. ***Use a cuff manometer***.
   c. Goal is 20 – 30 cm H_2O (15-22 mm Hg).
   d. ET tube cuffs should be filled with air. Do not use saline.
6. All ventilated patients should have the head of bed elevated at least 30° unless there is a contraindication.
   a. Most patients will not have a contraindication. Ask the sending physician or neurosurgeon for clarification if necessary.
   b. The backrest designed for the NATO litter is the most appropriate way to elevate the head of bed.
7. All ventilated patients should have continuous $ETCO_2$ monitoring.
   a. Use caution interpreting the absolute value as it may not accurately reflect $PaCO_2$.
      - The difference between $PaCO_2$ and $ETCO_2$ reflects dead space, which can change rapidly in critically ill patients.
      - There is also likely to be some measurement error.
   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 CO_2 that may prompt arterial blood gas measurement.
   c. Providers skilled with $ETCO_2$ monitoring may infer hemodynamic data from $ETCO_2$ data.
8. All ventilated patients require gastric decompression prior to flight. Oro-gastric tube preferred to naso-gastric tube to prevention sinusitis.

9. Consider repeat CXR if > 12 hours has elapsed since most recent one or clinical condition has changed significantly.
10. Tube feeds not administered through a small bowel feeding tube should be discontinued prior to flight.

Basic Ventilator Management

Mode of Ventilation

1. Avoiding injurious ventilator settings is far more important than the mode of ventilation.
2. There is no outcome based evidence favoring one mode of ventilation over another.
3. Patients in the landmark ARDSNet ARMA trial were all ventilated in volume control ventilation.
4. Pressure control has some theoretical advantages:
   - Decelerating flow waveform is more comfortable and may improve gas mixing.
   - Inverting I:E ratio is an option for increasing the mean airway pressure that is not available on the Impact 731.

Ventilator Settings

1. Tidal Volume (V_T)
   a. If using volume control:
      i. Start with V_T at 6 cc/kg
      ii. Decrease V_T as needed to achieve peak inspiratory pressure (PIP) ≤ 35 (preferably ≤30)
      iii. Do not go below V_T = 4 cc/kg.
   b. If using pressure control:
      i. Start with PIP 30-35 cm H_2O.
         - The difference between PEEP and PIP will determine V_T and is known as driving pressure or ΔP.
         - Changes in PEEP or PIP without concomitant changes in the other will change ΔP, thereby changing V_T.
      ii. Incrementally decrease ΔP (by decreasing PIP and/or increasing PEEP) as needed to achieve V_T = 6 cc/kg.
      iii. It is acceptable to target a V_T as low as 4 cc/kg if required to maintain PIP ≤ 30 - 35cm H_2O.
   c. 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.
   d. V_T = 8 cc/kg is acceptable in spontaneously breathing patients who are fighting the ventilator as long as the PIP or set pressure remains ≤35 (preferably ≤ 30).
   e. Do not increase tidal volume to control pCO_2.

2. Respiratory Rate
    a. Respiratory rate should be 6 – 35
    b. Adjust to achieve pH ≥ 7.3
    c. The actual pCO_2 is not important, only the pH. ******Not applicable to TBI patients******
        - Respiratory acidosis is typically very well tolerated.
        - Trying to normalize pCO_2 will worsen ventilator induced lung injury.
3. PEEP and FIO2
    a. Set initial PEEP and F_IO_2 based on MTF settings or your best estimate of what the patient needs. Minimum PEEP is 5 cm H_2O.
    b. Titrate PEEP and F_IO_2 to achieve SaO_2 92 – 96% according to the ARDSNet ARMA table in Appendix B.
    c. Recheck PIP and V_T after any change in PEEP. Adjust V_T or ΔP as needed.
        i. Increasing PEEP may increase PIP and necessitate decreasing V_T in volume control ventilation.
        ii. The LTV 1000 and 731 ventilators are not PEEP compensated.
            - Increasing PEEP without a concomitant increase in PIP will decrease ΔP and V_T.
            - Decreasing PEEP without a concomitant decrease in PIP will increase ΔP and V_T.

Alarms

1. 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.
2. Suggested initial settings
    a. High pressure alarm should be set 50% above the baseline PIP (1.5 X current PIP).
    b. Low pressure alarm should be set 50% below the baseline PIP (0.5 X current PIP).
    c. High respiratory rate alarm (731 only) should be set 10 above the patient's respiratory rate.
    d. Low respiratory rate alarm (731 only) should be set 10 below the set rate.
    e. Minute ventilation alarm (LTV 1000 only) should be set 50 % below the baseline minute ventilation (0.5 X current minute ventilation)

Ongoing Management

Airway Suctioning

1. Suctioning every 4 hours is appropriate without copious secretions or mucous plugging.
2. Frequent suctioning may lead to lung de-recruitment and worsen gas exchange in patients with ARDS.

ET Tube Cuff Pressure

1. Significant changes may occur on ascent and descent (pressure increases with ascent, decreases with descent).
2. Pressure should be checked and documented with manometer before departure, at cruise altitude, during descent and after landing.

Mouth Care

1. Regular mouth care decreases the ventilator associated pneumonia risk.
2. Chlorhexidine is the preferred agent.
3. Recommended frequency is every 4 hours, workload permitting. Document on 3899.

Monitoring and Adjusting Ventilator Settings

1. Lung mechanics and gas exchange may change considerably during a long transport.
2. It is imperative to monitor for changes and adjust ventilator settings to meet mechanical ventilation goals.
3. Excessive V_T and inspiratory pressures are harmful and should be corrected when they are identified.
   - In volume control ventilation, incrementally change V_T by 50 cc's every 10 minutes until the desired values are achieved.
   - In pressure control ventilation, incrementally change PIP by 2 cm H_2O every 10 minutes until the desired values are achieved.
4. SaO_2 should be maintained 92 – 96% by titrating F_IO_2 and PEEP according to the ARDSNet ARMA table.
   a. F_IO_2 can be weaned up or down rapidly as any adverse effects can be quickly remedied by reversing the change.
   b. PEEP decreases
      - Rapid decreases may cause lung de-recruitment that is harmful and difficult to reverse.
      - Decrease by no more than 3 cm H_2O in a six-hour period.
   c. PEEP increases
      - Increasing PEEP can decrease cardiac output by decreasing venous return to the heart.
      - Volume loading may be needed as PEEP increases, especially when PEEP exceeds 10cm H_2O.

Management of Oxygen Desaturation

1. Confirm ET tube is in trachea using $ETCO_2$.
2. If desaturation is severe switch immediately to manual bag ventilation with high flow oxygen and PEEP valve.
3. Exclude equipment malfunction, loss of O2 supply, circuit disconnection.

4. Suction the airway (consider simultaneous bag ventilation) to verify patency and clear mucous plugs.
5. Consider increasing sedation or pharmacological paralysis if ventilator dysynchrony is present.
6. Consider pneumothorax/hemothorax.
    a. Review peak pressure trend if using volume ventilation.
    b. Review VT trend if using pressure control ventilation. V_T will decrease if significant pneumothorax develops and ΔP is not changed.
    c. Evaluate existing chest tubes for proper function.
    d. Needle decompress the chest and place a chest tube if there is suspicion of pneumothorax and concurrent hemodynamic compromise.
7. Consider recruitment maneuver and increasing PEEP to next level on titration table.
    a. Additional lung can often be recruited using sustained inflations of the lung.
    b. Classic recruitment maneuver consists of inflation to 30-40 cm H_2O for 30-40 seconds, which is difficult to do on transport ventilators.
    c. Recruitment maneuver can be performed with bag-valve manual ventilation.
        i. Set PEEP valve on bag-valve unit to 15-20 cm H_2O.
        ii. Deliver five sequential breaths, each held for 5-8 seconds.
        iii. Watch blood pressure closely and terminate maneuver immediately if hypotension develops.
        iv. Clamp endotracheal tube while switching between ventilator and bag. Exposure to atmospheric pressure will quickly result in lung derecruitment, hypoxemia and increased ventilator induced lung injury.

Monitoring Oxygen Utilization

1. When using PTLOX, periodically check amount of oxygen consumed.
2. Oxygen consumption may vary between ventilators, even with the same settings.
3. Leaks in system may cause excessive oxygen consumption.
4. 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: Mechanical Ventilation in ARDS

*******************************Not applicable to patients with TBI*************************************

Volume Control Ventilation

1. Set the I:E ratio at 1:2 to 1:4. The 731 ventilator defaults to a 1:2.5 I:E Ratio.
2. Set PEEP and FiO2 according to ARDSNet ARMA Trial PEEP table to achieve SaO_2 92-96%.[1] Note that the LTV 1000 is limited to PEEP 20 and the 731 limited to PEEP 25.
3. Set tidal volume at 6 cc/Kg and note peak inspiratory pressure (PIP).[2] If necessary, decrease tidal volume by 1 cc/Kgas needed to keep peak inspiratory pressure ≤ 35 cm H_2O (preferably ≤ 30). Do not go below 4 cc/Kg. Use table below as reference for appropriate tidal volume.[3]
4. Adjust respiratory rate to achieve pH ≥ 7.34. The actual PCO_2 is not important, only the pH.

Pressure Control Ventilation

1. Set I time to achieve I:E ratio of 1:2 to 1:4.
2. Set PEEP and FiO2 according to ARDSNet ARMA Trial PEEP table to achieve SaO_2 92-96%.[1] Note that the LTV 1000 is limited to PEEP 20 and the 731 limited to PEEP 25.
3. Set inspiratory pressure to achieve a tidal volume of 6 cc/kg. If this value is > 30 cm H_2O, then decrease until it is ≤30 cm H_2O or until tidal volume is 4 cc/kg. Use table below as reference for appropriate tidal volume.[3]
4. Adjust respiratory rate to achieve pH ≥ 7.34. The actual PCO_2 is not important, only the pH.

Tidal Volumes for Ventilation of Patients with ARDS – ARDSNET ARMA Trial

Male Patients – cc's 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 – cc's 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 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.

1. Increasing PEEP can decrease cardiac output and may cause significant hypotension in hypovolemic patients. Additional volume loading may be necessary to maintain hemodynamics.
2. This is a fairly accurate indicator of plateau pressure in our patient population. Plateau pressure is the correct parameter to follow but it cannot be easily measured with the Impact 731 ventilator.
3. Measuring the patient's "wingspan" should be used as an estimate of height. Sternum to fingertip multiplied x 2.
4. A pH of 7.2 may be an appropriate target if hemodynamics are relatively normal.