Invasive Mechanical Ventilation (PL≥6)

Clinical Indications:

Patient with a pulse requiring airway management by an advance airway and mechanical ventilation.

Contraindications:

Cardiac arrest or unresolved pneumothorax.

Notes:

A BVM is to be used to confirm advanced airway placement.

A BVM with mask are to always be within reach of provider responsible for continuous monitoring of the airway and mechanical ventilation.

The ≥PL6 is provider responsible for continuous monitoring of the airway, $ETCO_2$, and mechanical ventilation.

All mechanical ventilation parameters need to be documented in ePCR.

Follow manufacturer guideline for disinfecting and cleaning after every use.

Procedure:

1. Set up the ventilator and circuit, then input initial ventilator settings, then place patient onto ventilator:
   a. Interfacility Transports with Mechanical Ventilation Already Applied: Converse with the patient's Provider (MD/DO or PA/NP) or Respiratory Therapist at the sending facility regarding current ventilator settings. Modifications from the prescribed ventilator settings should only be made based on changes in patient condition and response to ongoing mechanical ventilation. Consult OLMC as needed.

	Volume Control Settings (Pt Wt > 10 kg)
1.	Set mode to Assist Control (AC)
2.	Target Minute Ventilation (Ve): Adult *without* acidosis: 6 - 8 mL/kg/min Adult *with* acidosis: 9.0 L/min Pediatrics: 4.0 – 5.0 L/min Infants: 1.5 – 3.0 L/min
3.	Set Tidal Volume (Vt): Adults - See Table 1; based on height & IBW. Pediatrics – See Table 4; use actual weight
4.	Set Initial Rate: 12 – 20 based etiology Adjust Vt & Rate to target $ETCO_2$
5.	Set I time for I:E Ratio of 1:2
6.	Set FiO_2 at 1.0 Then titrate down to achieve SpO2 ≥ 94%
7.	Set PEEP to 5 cmH_20 Then adjust to achieve SpO2 ≥ 94%

	Pressure Control Settings (Pt Wt ≤ 10kg)
1.	Set mode to Assist Control (AC)
2.	Set PC: 15 – 20 cmH_2O Adjust PC to target a patient appropriate tidal volume based on patient IBW.
3.	Set Initial Rate: Peds: 20 – 30 Infants: 30 – 40 Adjust PC & rate to target $ETCO_2$
4.	Set I time for I:E Ratio of 1:2
5.	Set FiO_2 at 1.0 Then titrate down to achieve SpO2 ≥ 94%
6.	Set PEEP to 5 cmH_20 Then adjust to achieve SpO2 ≥ 94%

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Table 1. Male and Female Adult IBW in Kg for Vt

Adult Male Patients							
		Lung-Protective		Resuscitative		Metabolic	
		6 ml/kg		10 ml/kg		8 ml/kg	
Height	IBW kg	Vt	Initial f	Vt	Initial f	Vt	Initial f
5'0"	50	300	12	500	12	400	20
5'1"	52	314	12	523	12	418	20
5'2"	55	328	12	546	12	437	20
5'3"	57	341	12	569	12	455	20
5'4"	59	355	12	592	12	474	20
5'5"	62	369	12	615	12	492	20
5'6"	64	383	12	638	12	510	20
5'7"	66	397	12	661	12	529	20
5'8"	68	410	12	684	12	547	20
5'9"	71	424	12	707	12	566	20
5'10"	73	438	12	730	12	584	20
5'11"	75	452	12	753	12	602	20
6'0"	78	466	12	776	12	621	20
6'1"	80	479	12	799	12	639	20
6'2"	82	493	12	822	12	658	20
6'3"	85	507	12	845	12	676	20
6'4"	87	521	12	868	12	694	20
6'5"	89	535	12	891	12	713	20
6'6"	91	548	12	914	12	731	20

Adult Male IBW kg = [2.3 x (Ht - 5ft) + 50]

Adult Female Patients							
		Lung-Protective		Resuscitative		Metabolic	
		6 ml/kg		10 ml/kg		8 ml/kg	
Height	IBW kg	Vt	Initial f	Vt	Initial f	Vt	Initial f
5'0"	46	273	12	455	12	364	20
5'1"	48	287	12	478	12	382	20
5'2"	50	301	12	501	12	401	20
5'3"	52	314	12	524	12	419	20
5'4"	55	328	12	547	12	438	20
5'5"	57	342	12	570	12	456	20
5'6"	59	356	12	593	12	474	20
5'7"	62	370	12	616	12	493	20
5'8"	64	383	12	639	12	511	20
5'9"	66	397	12	662	12	530	20
5'10"	69	411	12	685	12	548	20
5'11"	71	425	12	708	12	566	20
6'0"	73	439	12	731	12	585	20
6'1"	75	452	12	754	12	603	20
6'2"	78	466	12	777	12	622	20
6'3"	80	480	12	800	12	640	20
6'4"	82	494	12	823	12	658	20
6'5"	85	508	12	846	12	677	20
6'6"	87	521	12	869	12	695	20

Adult Female IBW kg = [2.3 x (Ht - 5ft) + 45.5]

2. Titrate settings and provide continuous patient monitoring based on changes to ongoing physiological data and assessment.

If the patient has an acute change resulting in progressive clinical decline, then disconnect the patient from the mechanical ventilator and provide manual bag-valve ventilations.

Table 2. Response to Changes in Parameters

Parameter	Level	Corrective Action			
		FiO2	Rate	PEEP	Other
$ETCO_2$	High		↑	↑	
	Low		↓		Check BP
SpO_2	Low	↑		↑	
Peak Inspiratory Pressure	High	1. Assess for plateau pressure 2. Rule out **DOPES**: **D**islodgement or misplaced ETT **O**bstruction or secretions in tube/circuit **P**neumothorax **E**quipment, check connections **S**edation, consider additional sedation, and analgesics if indicated			
	Low	1. Reassess all connections of the entire circuit. 2. Increase Vt or PC			
BP	Low	1. Fluid or pressure therapy 2. Consider tension pneumothorax 3. Check for over breathing 4. Consider Resuscitation Mode			
Rate	High	Consider sedation if patient is over breathing the set ventilator rate.			
Exhaled Vt	Low	1. Rule out air trapping, AutoPEEP of 0 to confirm no air trapping. 2. Rule out small leaks, check pilot bulb 3. Assume dead space problem, ↑ Vt while maintaining a PIP < 35 cmH_2O			
Plateau Pressure	High	*Inspiratory Hold Maneuver*: High PIP/High Plateau Pressure = Lung Compliance Problem, change to PC.			
AutoPEEP	High	*Expiratory Hold Maneuver*: If AutoPEEP is >0, then the patient is air trapping – provide a longer E time by adjusting I:E ratio from 1:2 to 1:4, 1:5, or 1:6. Also consider a bronchodilator to allow for increased exhalation.			

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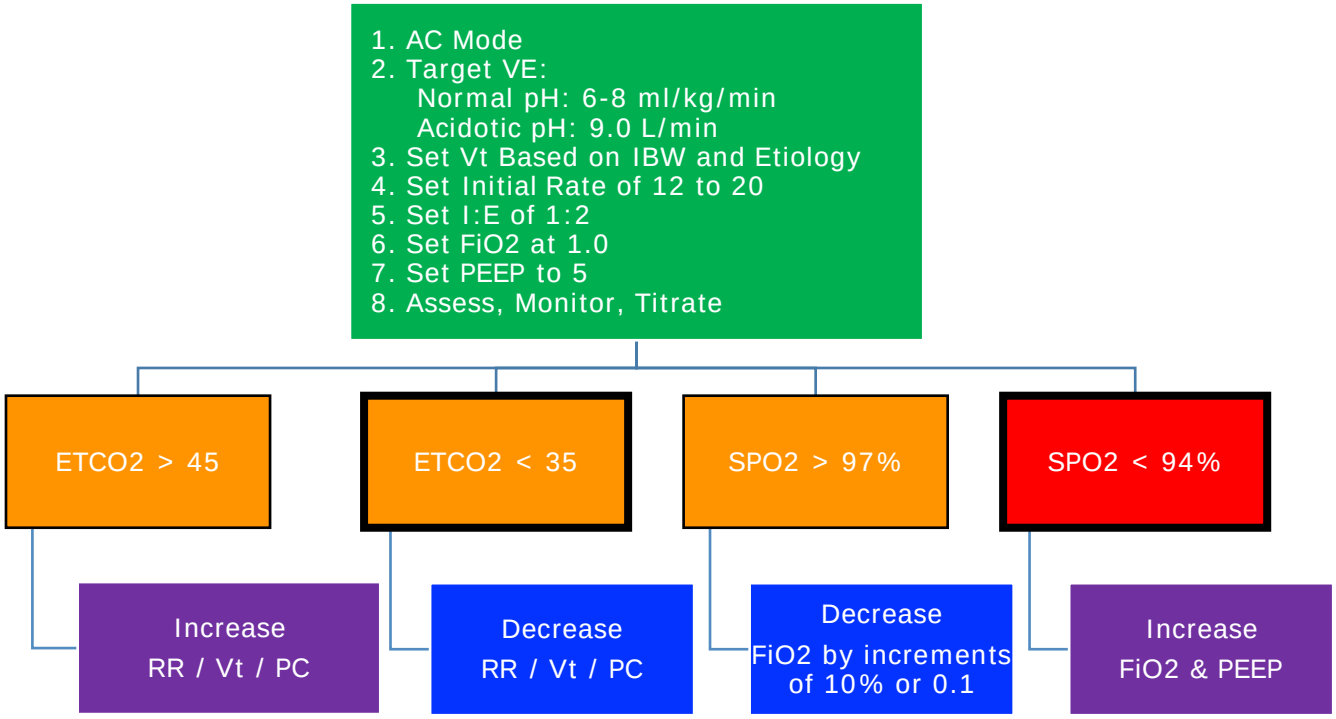
Figure 1. Summary of Main Approach for AC VC (>10kg) Patients



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Initial Mechanical Ventilation Checklist

- ☐ Ensure an adequate BP (SBP > 90 & MAP > 60) capable of producing a distal pulse
  Treat BP if SBP < 90 or MAP < 60
- ☐ Identify Minute Ventilation (Ve) needs of the patient
  Normal VE: 100 mL/kg/min;
  If YES to any of the following, then VE = 9.0L/min Adults | 4-5 L/min Peds | 1.5-3 L/min Infants
  - pH lower than 7.25?
  - Presence of Kussmaul breathing?
    - Adults: > 30 breaths per minute
    - Pediatrics: > 40 breaths per minute
    - Infants: > 50 breaths per minute
  - Abnormal $ETCO_2$?
    - High = potentially respiratory & mixed disturbance
    - Low = potentially metabolic acidosis or hypoperfusion
- ☐ Obtain Tidal Volume (Vt)
  Adults - based on Ideal Body Weight (IBW) using Table 1
  Peds – Use actual weight and Table 4
- ☐ Set Mode to Assist Control (AC) and Choose Appropriate Settings: VC or PC
  Volume Control Ventilation (VC) > 10kg
  Acceptable for most patients. Provides tightest control of minute ventilation (Ve). Indicated for any patient with compliant lungs. Non-compliant lungs are indicated by a Pplat > 30 cmH_2O
  Pressure Control Ventilation (PC); ***mandatory* for patients < 10kg**
  Indicated for all patient types. Avoids barotrauma. This mode is ideal for patients with non-compliant lungs Pplat > 30.
- ☐ Set I:E Ratio
  1:2 for non-air trapping patients
  1:4 – 1:6 for patients with bronchoconstriction, **asthma**, COPD, ***and pediatric patients <15 years old*** that have reduced ability to exhale inspired gas out of their lungs – see section for **Modifications to Standard Settings.**
- ☐ Set FiO_2 to 1.0 (100%) then titrate down to maintain $SpO_2 \geq 94\%$
- ☐ Set PEEP to 5 cmH_2O
- ☐ Input all settings ***then*** connect the set ventilator to your patient.

Ongoing Mechanical Ventilation & Problem-Solving Checklist

- ☐ Evaluate measured minute ventilation (Ve) and if it does not closely match to targeted Ve, then proceed to evaluate frequency/rate (f) and exhaled tidal volume (Vte) to identify cause of missed Ve target.
- ☐ Evaluate frequency/rate (f), which is the number of times the patient's lungs are ventilated. CAN differ from the respiratory rate, but should closely match the set RR rate within 1 breath
  If f > RR then rule out vibration trigger and increase sensitivity – OR – rule out under sedation
- ☐ Evaluate Vte, which should closely match the set Vt.
  If there is a discrepancy, then rule out circuit/cuff leak – OR – assume dead space problem
- ☐ Evaluate the Peak Inspiratory Pressure (PIP), which should remain < 35 cmH_2O
  If PIP > 35 cmH2O, then complete DOPE to identify quick solutions
- ☐ Evaluate Plateau Pressure (Pplat), which should < 30 cmH_20
  If PPlat > 30 cmH2O, then consider lung injury and switch from VC to PC ventilation
- ☐ Evaluate AutoPEEP, which should be 0
  If > 0, indicates the patient is rebreathing
  Could be from a respiratory disease, a RR too high, or I:E > 1:2 (eg. 2:1 or 1:1) – Correct by reducing RR or reducing I:E to 1:4 – 1:6
- ☐ Adjust settings based on $ETCO_2$ (35 – 45 mmHg) and SpO_2 (97 – 94%)

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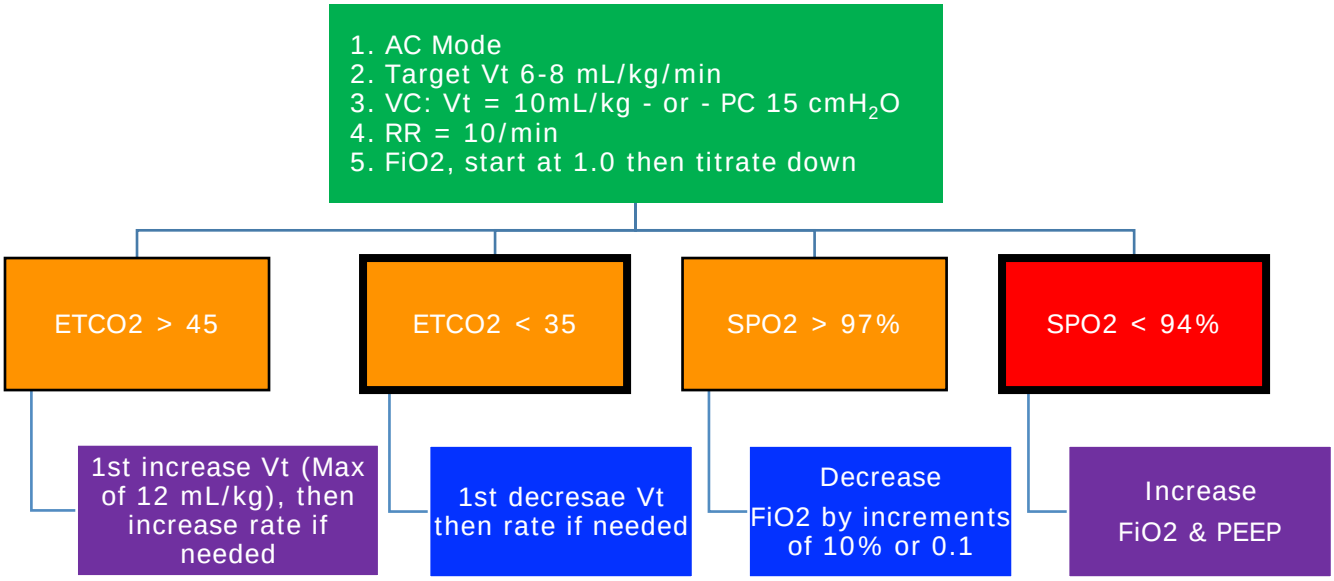
Modifications to Standard Settings:

1. **Cellular / Metabolic Acidosis (eg. DKA)**
   a. These patients typically need higher minute ventilation (Ve) in excess 10 L/min.
   b. Best practices include:
      i. If available, target a minute ventilation (Ve) to achieve the patient's pre-intubation $ETCO_2$
      ii. Administer a minute ventilation (Ve) to achieve an $ETCO_2$ of 25 mmHg
      iii. Special Note: Increasing Vt, PEEP, and ultimately PIP can cause hypoperfusion and hypotension. Aggressive monitoring of the patient's BP is required, and corrective actions should immediately occur with any hypotension (MAP < 60).

2. **Hypotension Approach**
   a. There are times where hemorrhagic / hypovolemic shock patients will have worsened cardiac output by positive pressure ventilation. You must appreciate how each positive pressure ventilation inhibits, to some extent, venous return to the thorax and heart causing decreased cardiac output.
   b. To prevent this, an approach has been developed to target lower set respiratory rates and higher tidal volumes. This approach limits the total amount of time the alveolar capillaries are tamponaded and helps to prevent a reduced blood pressure from positive pressure ventilation.
   c. Typical Vt settings are 8 – 12 mL/kg

Figure 2. Hypotension Approach



3. **ARDS Approach**
   a. Focus on lower volumes and higher rates to achieve an effective minute ventilation (Ve).
   b. Target 4 – 6 ml/kg of Vt then set respiratory rate to achieve an effective minute ventilation (Ve).
   c. Adjust by alternating PEEP and FiO_2 as below:

Table 3. Alternating PEEP & FiO_2 for ARDS Approach

Lower PEEP / Higher FiO_2								
FiO_2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0
PEEP	5	5 – 8	8 – 10	10	10 – 14	14	14 – 18	18 - 24

Higher PEEP / Lower FiO_2								
FiO_2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0
PEEP	5 – 14	14 – 16	16 – 18	20	20	20 – 22	22	22 – 24

4. Infants & Pediatric Ventilation

a. While patients > 10 kg can safely be ventilated via VC, you may want to still consider PC ventilation for larger pediatric patients.

b. Neonate patients < 5 kg should be ventilated by PC

i. Set PC setting between 15 – 20 cmH_2O

ii. Ensure the patient is producing exhaled tidal volume (Vte) that would be their tidal volume based on body weight.

1. If the patient's Vt should be 80 mL and their Vte is 160 mL, then reduce PC setting
2. If the patient's Vt should be 80 mL and their Vte is 30, then increase the PC setting

iii. Adjust the PC setting higher or lower to achieve desired $ETCO_2$

Table 4. Pediatric Tidal Volume Based on Patient Weight

	Pediatric Patients < 60"							
	Pt Weight		Lung-Protective		Resuscitative		Metabolic	
			6 ml/kg		10 ml/kg		8 ml/kg	
	Lbs	Kg	Vt	Initial f	Vt	Initial f	Vt	Initial f
Newborn	7	3	18	30	30	40	24	40
	9	4	24		40		32	
	11	5	30		50		40	
Infant	13	6	36	30	60	40	48	40
	15	7	42		70		56	
	18	8	48	30	80	40	64	40
	20	9	54	30	90		72	
Pediatric	22	10	60	20	100	30	80	30
	24	11	66		110		88	
	26	12	72	20	120	30	96	30
	29	13	78		130		104	
	31	14	84		140		112	
	33	15	90	20	150	30	120	30
	35	16	96		160		128	
	37	17	102		170		136	
	40	18	108		180		144	
	42	19	114	20	190	30	152	30
	44	20	120		200		160	
	46	21	126		210		168	
	48	22	132		220		176	
	51	23	138		230		184	
	53	24	144	20	240	30	192	30
	55	25	150		250		200	
	57	26	156		260		208	
	59	27	162		270		216	
	62	28	168		280		224	
	64	29	174		290		232	
	66	30	180	20	300	30	240	30
	68	31	186		310		248	
	70	32	192		320		256	
	73	33	198		330		264	
	75	34	204		340		272	
	77	35	210		350		280	
	79	36	216		360		288	

5. Asthmatic and Severe Bronchoconstriction

a. Permissive hypercarbia is appropriate for these patients in excess of $ETCO_2$.
b. Initial ventilator settings should be:
   PEEP: 0
   FIO_2: 1.0
   Vt: 5 mL/kg
   f: 10
   I:E: 1:4 – 1:6
c. Continuous monitoring to detect presence of breath stacking with immediate intervention with increasing I:E and increase sedation.
d. These patients should be heavily sedated, likely paralyzed, and closely monitored.
e. These patients are prone to mucous plugging and consider continuous inline nebulizers.
f. If the patient becomes hemodynamically unstable, then disconnect the patient from the ventilator, provide manual chest wall compression, and consider bilateral needle decompression.

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Specific Invasive Mechanical Ventilation Abbreviations:

Abbreviation	Long Form
AC	Assist Control
f	Frequency of Mechanical Ventilation
FiO_2	Fraction of Inspired Oxygen
I:E	Inspiratory: Expiratory Ratio
IBW	Ideal Body Weight
PC	Pressure Control
PEEP	Positive End Expiratory Pressure
PIP	Positive Inspiratory Pressure
Pplat	Plateau Pressure
RR	Respiratory Rate
VC	Volume Control
Ve	Minute Ventilation
Vt	Tidal Volume
Vte	Exhaled Tidal Volume