MCQs in Mechanical Ventilation

A Case-based Approach

(With Explanatory Answers)

Sanjith Saseedharan

Foreword
Dilip R Karnad

JAYPEE

Contents

1. Physiology of Mechanical Ventilation....................1
2. Modes of Mechanical Ventilation..........................25
3. Advanced Modes of Mechanical Ventilation........53
4. Weaning and Extubation 67
5. Troubleshooting.. 91
6. Ancillary Therapy.. 120
7. Ventilator-Associated Pneumonia....................... 143
8. Graphics in Mechanical Ventilation 165

3

Advanced Modes of Mechanical Ventilation

1. A 52-year-old male was admitted to the intensive care unit in severe respiratory distress with a primary diagnosis of ARDS as a result of Swine flu (H1N1). Patient was intubated on admission and ventilated with the ARDSnet protocol (low volume) for lung protective ventilation strategy. However even with high peep (16 cm of H_2O) the FiO_2 kept climbing up. The plateau pressure was 40 cm of H_2O. The clinician decides to place the patient on Airway pressure release ventilation. While setting up the ventilator one of the following is wrong:

a. The P-high should be set at 25–30 cm of H_2O
b. The P-low can be set at 0 cm of H_2O
c. The APRV can be set up by measuring the transalveolar pressure
d. The periodic release is aimed at maintaining oxygenation

ANSWERS

a. Right answer

Airway pressure release ventilation is a time triggered, pressure targeted, time cycled mode of ventilation which allows spontaneous breathing throughout the breath cycle. This type of ventilation is a partial ventilatory support which is based on the open lung concept.[1] Various methods have been described in setting up the P-high on the APRV. Physiologically the best method would be to study the pressure volume curve and place the P-high just below the upper inflection point. This will ensure that there is no ventilator induced lung injury. However, getting a smooth pressure volume curve is cumbersome and difficult as patient has to be extremely passive and hence heavily sedated or paralyzed.[2] Some authors have also suggested using the plateau pressure (or desired pressure) as the value of P-high (lower the P/F, higher the P-high). A good starting point is 28 cm of H_2O. However the general suggestion is not to exceed P-high beyond 30–35 cm of H_2O. This may be higher in cases of morbid obesity, ascites or decreased intrathoracic compliance. It is important to set the high pressure alarm beyond the set pressure.

References

1. Lachmann B. Open up the lung and keep the lung open. Intensive Care Med. 1992;18(6):319-21.
2. Daoud EG. Airway pressure release ventilation. Ann Thorac Med. 2007;2(4):176-79.

b, c. Right answers

As mentioned above there are no clear cut guidelines based on solid data to guide clinicians on this. However in theory it seems very physiological to use the inspiratory pressure volume curve to determine the lower inflection point and thus place the P-low just above the lower inflection point. Many papers have recommended this. However, there has to be a passive breath to get a smooth curve (this means that patient will have to be deeply sedated or paralyzed). However, there is controversy on this technique even for assessing optimal peep.[1] Hence, whether this technique (use of pressure volume curve) can be used for setting P-high or P-low is a dilemma. Another suggestion is to set the P-low at 75% of the original peep.[2]

Some authors have recommended keeping P-low at 0 cm with a short T low. This will lead to a large pressure ramp from P-high to P-low which will allow tidal ventilation at very short times. The short T-low will lead to intentional gas trapping leading to the development of Auto-PEEP which will help in maintaining end expiratory lung volume.[3,4] Another method would be to adjust the pressure as per the transalveolar pressure measured via an esophageal balloon (transalveolar pressure = airway pressure–esophageal pressure).

References

1. Hickling KG. The pressure-volume curve is greatly modified by recruitment: a mathematical model of ARDS lungs. Am J Respir Crit Care Med. 1998;158(1):194-202.

2. Paulmarikbook, Evidence based critical care. Chapter 19 mechanical ventilation.
3. Rose L, Hawkins M. Airway pressure release ventilation and biphasic positive airway pressure: a systemic review of definitional criteria. Intensive Care Med. 2008;34(10):1766-73.
4. Kaplan LJ, Bailey H, Formosa V. Airway pressure release ventilation increases cardiac performance in patients with acute lung injury/ adult respiratory distress syndrome. Crit Care. 2001;5(4):221-6.

d. Wrong answer

There are two ways of setting up the APRV T-low or the periodic release. One way is to keep the T-low (usually set at 50 to 75% of the PEFR, by observing the graphs) very short with a zero P-low (in order to ensure good pressure gradient to ensure adequate ventilation of the lung in very short time from P-high to P-low) in order to increase the inflation : deflation ratio and thus create AutoPEEP. The other is to use a longer T-low to eliminate AutoPEEP and keep a P-low in order to prevent alveolar collapse. However, the periodic release can be aimed at the removal of CO_2 or the exhaled tidal volume.

2. This patient was started on a P-high of 26 cm of H_2O, A P-low of zero. A T-high of 5 sec and a T-low of 0.5 at an FiO_2 of 100%. However the saturation was found to be 87%. In order to improve the saturation:

a. Increase the P-high
b. Increase the T-low
c. Reduce the T-low
d. Increase the T-high

ANSWERS

a, c, d. Right answers

APRV is nothing but CPAP at a high level with intermittent releases to remove pent up gases. The high level CPAP, low airway pressures, low gas flow rates, forms a sort of recruitment among alveoli with different time constants and thus improves oxygenation. In order to improve oxygenation it is important to increase P-high by small amount (approx 2-3 cm) every

30 minutes keeping a close watch on the hemodynamics. However, it is important that the P-high not be exceedingly high (>35) as this may result into lung injury. Another way to do this is by increasing the T-high (by 0.5 to 2 secs) which will offer more recruitment and thus contribute to the improvement of oxygenation. This again would cause changes in hemodynamics and hence close watch on the hemodynamics is essential. The minimum T-high duration is generally 4 seconds. As the compliance of the lung improves the T-high is lengthened in 0.4 to 0.6 sec intervals up to 12–15 seconds thus optimizing oxygenation and lung mechanics. This will also reduce repeated opening and closing of the alveoli which is implicated in the causation of VILI.[1,2] Similarly reducing T-low in 0.1 sec decrements toward expiratory flow limitation at 75% can also improve the oxygenation by improving the end expiratory volume thus increasing AutoPEEP effectively.[3] However by this there can be an increase of CO_2 due to reduced time of release of pent up gas.

References

1. Frawley PM, Habashi NM. Airway pressure release ventilation: theory and practice. AACN Clin Issues. 2001;12(2):234-46;quiz 328-9.
2. Dreyfuss D, Saumon G. Ventilator-induced lung injury: lessons from experimental studies. Am J Respir Crit Care Med. 1998;157(1): 294-323.
3. Stock MC, Downs JB. Airway pressure release ventilation: a new approach to ventilatory support during acute lung injury. Respir Care Clin N Am. 1987;32:517–24.

b. Wrong answer

Increasing T-low will effect in more time for the lungs to empty and, hence is effective to reduce the respiratory acidosis. This can also be done only if the expiratory flow of the release does not drop below 25% of the PEFR (this allows us to keep the P-low at 0 cm of H_2O in order to affect emptying of the lung without derecruitment).

3. Subsequently, the P-high was increased by 2 cm every 15 minutes. At a P-high of 34 the oxygenation parameters started improving. The SpO_2 was found to be 96% at an FiO_2 of 40%. Meanwhile the $EtCO_2$ showed a value of 90. A blood

gas revealed a pH of 7.1 pCO_2 of 96. At this point the right maneuver would be:

a. Increase sedation as the patient is not synchronizing well with the ventilator causing the $EtCO_2$ to go up
b. Reduce the T-low by 1 with close watch on Auto-PEEP and $EtCO_2$
c. Reduce the P-high
d. Increase the T-low by 0.05 every 5–10 minutes with close watch on the SpO_2 and $EtCO_2$.

ANSWERS

a. Wrong answer

One of the advantages of APRV is the avoidance of patient sedation. The patients breathes spontaneously on both the levels of respiration. Spontaneous breaths tend to improve ventilation-perfusion matching by preferentially aerating well-perfused, dependent lung regions thus improving regional gas exchange, opening more alveoli and reducing atelectasis.[1]

Hence, by increasing the sedation, the problem will not be solved.

Reference

1. Froese AB, Bryan AC. Effects of anesthesia and paralysis on diaphragmatic mechanics in man. Anesthesiology. 1974;41:242–55.

b. Wrong answer

Reducing the T-low (or the release) will allow lesser time for the ventilation (release of gas) to take place. In fact this may cause a pent up of gases in the alveoli causing an increase in $EtCO_2$ and a deterioration of hemodynamics.

c. Wrong answer

Reducing the P-high may be counterproductive as this may further worsen the oxygenation parameters and lead to other problems like a drop in SpO_2 and an increase in pCO_2. In fact an elevated P-high is generally used to improve the oxygenation and ventilation in patients whose respiratory system compliance is an issue (as in stiff chest, raised intra-abdominal pressure, obesity, etc.). So, in this case, increasing the P-high may help in ventilation (removal of CO_2).

d. Right answer

In this case, reducing the T-low may be inappropriate. This may lead to an reduction in time spent in the release of gases which may increase the CO_2 retention, causing the blood pressure to deteriorate and lead to increase in dead space ventilation.[1]

Hence increasing the T-low by 0.05 seconds every 10–15 minutes (generally up to 1) would help to increase the time spent in the exhalation phase and allow the lungs to ventilate and remove oxygen. Practically while setting the T-low, one of the methods is to look at the expiratory gas flow waveform. So when the expiratory gas flow reaches to 50–75% of the peak expiratory gas flow the clinician stops the release and the patient moves to P-high[2] Excessively prolonged T-low (causing termination beyond 25% of the peak expiratory flow) can be counterproductive as this may lead to all the alveoli (including the one with slower time constants) to empty out which would thus cause the intrinsic peep to be lost. This would then defeat the purpose of APRV which is a form of "continuous recruitment". Theoretically the T-low would depend on the expiratory time constant and that in turn is a product of the compliance in the respiratory system and the resistance in the airway. Hence ARDS patient (with low compliance) will have shorter time constants and patients like asthma will have longer time constants.[1]

References

1. Martin LD, Wetzel RC. Optimal release time during airway pressure release ventilation in neonatal sheep. Crit Care Med. 1994;22: 486–93.
2. Frawley PM, Habashi NM. Airway pressure release ventilation: theory and practice. AACN Clin Issues. 2001;12(2):234-46; quiz 328-9.

4. A 36-year-old male was admitted in respiratory distress in the ICU with primary diagnosis of leptospirosis with pulmonary involvement. The baseline PaO_2/FiO_2 ratio was less than 200. The patient was barely saturating to 88% on a non rebreathing mask. Addition of an NIV at an FiO_2 of 100%

with IPAP setting of 12 and EPAP of 8 was not helping. The respiratory rate kept climbing and oxygenation kept falling. The patient was intubated and ventilated. The attending consultant decides to put this patient on a PRVC mode owing to the severe ARDS and poor lung compliance in order to avoid "injurious ventilation". With respect to PRVC:

a. PRVC is a support mode of ventilation
b. The ventilator adjusts the pressure during the breath and thus "regulates" the pressure
c. In PRVC the patient cannot initiate a breath
d. PRVC allows a set tidal volume to be delivered at a minimum set pressure.

ANSWERS

a. Wrong answer

PRVC is a controlled mode of ventilation. The ventilator delivers a preset tidal volume at a preset rate at a preset inspiratory time.[1] PRVC is a pressure limited, time cycled mode of ventilation.

Reference

1. Siemens. (2006). Siemens Servo 300 Clinical Reference Manual. Manufacturer's Literature.

b. Wrong answer

In the PRVC mode the ventilator adjusts the pressure on a breath by breath basis and does not adjust pressure "during" the breath. In PRVC the ventilator first gives a test breath in-order to test the characteristics of the respiratory system. An upper pressure limit is set by the clinician. The ventilator then gives a breath and measures the tidal volume in such a way that it does not reach more than 5 cm below the upper pressure limit. If the measured tidal volume is low then the pressure is increased in 1–3 cm increments till the prescribed tidal volume is reached. If the peak pressure reaches 5 cm below the upper pressure limit the ventilator delivers the breath but the measured breath will be lesser than the desired breath. In this scenario the ventilator would give a "limited pressure alarm". If the upper pressure limit is reached the ventilator would not deliver a breath. Hence the ventilator assesses the previous breath and makes changes in the next breath.

c. Wrong answer

In the PRVC mode the patient can trigger the ventilator. This depends on the trigger sensitivity and hence should be set accordingly. If the patient does not trigger the ventilator then a mandatory breath is given at the designated time.

d. Right answer

Conventional volume controlled ventilation has been the work horse for decades. However the problem with volume control ventilation is the inability to regulate the pressure and this potentially excessive airway pressure can lead to barotrauma, volutrauma and hemodynamic disturbances. The purpose of PRVC is to avoid this and hence in PRVC a set tidal volume is delivered within the limits of the set pressure.

5. Tidal volume was set at 420 mL and the upper pressure limit was set at 35, FiO_2 was 60% with a peep of 14 and the patient was paralyzed for the first day in view of gross respiratory insufficiency and high peep requirements. Three days later the patient seemed to have improved. The requirements of FiO_2 had reduced to 45% and the peep reduced to 8. The patient's paralytic agents were stopped and the patient was allowed to initiate breaths. Two hours into this the patient's tidal volume kept increasing and patient started having an increase in the pulse rate. A repeat blood gas showed metabolic acidosis and review of lactates showed the lactates to increase. There was no sign of secondary infections and the mean arterial pressure showed a 10% increase. The urine output was normal. At this stage:

a. Reduce the tidal volume set as measured tidal volume is increasing
b. This may be a tube block and hence adequate suctioning is required
c. Reduce the upper pressure limit
d. This reflects a drop in pressure support and an increase in patient demand.

ANSWERS

a. Wrong answer

The measured tidal volume is increasing. The ventilator thus reduces the pressure support. This is what the ventilator does!!!

Unfortunately the work of breathing is increasing as seen by the: (a) metabolic acidosis, (b) increase in the lactates, and (c) increased sympathetic drive. The reduction in support coupled with increased patient demand (resulting in increased work of breathing) would be detrimental. Hence, it is important to address the problem that has resulted in the increase of work of breathing. On the ventilator front it is important to increase (rather than decrease) the set tidal volume to increase the pressure support.

b. Wrong answer
A tube block would result in the upper pressure alarm reaching rapidly and thus the ventilator would not deliver a breath.

c. Wrong answer
Reduction in the upper pressure limit would not help in anyway. In fact, this may reduce the tidal volume in effect resulting in inefficient ventilation.

d. Right answer

6. **The cause of the demand of the patient increasing (reflected by an increase in the volumes and lactates) was found to be a fluid overload. The patient was diuresed. An echo was repeated which did not reveal any fresh signs of myocardial infarction or changes in heart functions. Subsequently it was decided to wean off this patient and the patient was placed on a "volume support"mode. With respect to the volume support mode the following is wrong:**
   a. A volume support mode is designed for patients with an intact respiratory drive
   b. In volume support mode the patient triggers every breath
   c. In volume support the patient determines the inspiratory rate and inspiratory time
   d. In volume support if the patient does not require any more support the ventilator switches off and may cause rebreathing.

ANSWERS

a Right answer
The volume support mode is a form of partial ventilator support best used for weaning the patient off the ventilator.

b. Right answer

In the volume support mode the ventilator delivers the pressure support and volume based on the trigger. Hence, it is important to set a right trigger so that the patient can trigger the ventilator. The general backup mode for volume support mode is PRVC and hence if the patient does not trigger the ventilator beyond the set apnea time the ventilator delivers a breath as per the set PRVC settings.

c. Right answer

Since this is a pure support mode the patient determines the respiratory rate and the inspiratory time. The clinician sets the desired minute ventilation. If desired minute ventilation is not achieved in view of lower respiratory rate the next tidal volumes are increased by virtue of an increase pressure support (however below the set pressure limit) time.

d. Wrong answer

If the patient does not require any more support the ventilator will not provide support but will keep monitoring the spontaneous tidal volumes and rate and thus help in monitoring the patient during the weaning procedure.

7. The patient was placed on volume support with an FiO_2 of 45%. The preset tidal volume was 450 and respiratory rate was 10. Patient was slightly anxious and thus placed on a small dose of dexmedetomedine along with the small dose of fentanyl that was already on. In a couple of minutes the tidal volume was found to be 600. At this stage:

a. Reduce the respiratory rate to 6 as the minute ventilation is increasing
b. Stop the sedation
c. Increase the set tidal volume to 600 mL
d. Increase the respiratory rate to 16

ANSWERS

a, c, d. Wrong answers

b. Right answer

In a volume support ventilation the respiratory rate is an important parameter that needs to be set. When the inspiratory time exceeds 80% of the total respiratory cycle time the ventilator stops the inspiration. In ventilators like the Servo 300 the main criteria is the inspiratory flow reducing to 5% of the peak flow, whereas the respiratory cycle related cycling is secondary mechanism. However this has not much bearing in the tidal volumes. In volume support ventilation the minute ventilation is set based on the tidal volume and respiratory rate dialed in by the clinician. If for any reason the patient drops the respiratory rate the minute ventilation is not reached then the ventilator computes a new target (which can be up to 150% of the set tidal volume). The applied pressure is gradually increased till the new tidal volume is reached. Hence in our case most probably the addition of dexmedetomidine has caused the patient to hypoventilate owing to which the minute ventilation was lower than the set minute ventilation. The ventilator thus computed the new tidal volume to meet the set minute ventilation.[1]

Reference

1. Jaber S, Delay JM, Matecki S, et al. Volume-guaranteed pressure-support ventilation facing acute changes in ventilatory demand. Intensive Care Med. 2005;31(9):1181-8. Epub 2005 Jul 20.

8. A young male was admitted to the intensive care unit after a road traffic accident with multiple rib fractures and flail chest with underlying chest contusion. This patient subsequently went into ARDS and required lung protective ventilation strategy. He was slowly weaned off to an SIMV combined with pressure support ventilation. However there seemed to be excessive ventilator dyssynchrony and the fellow decided to place the patient on proportional assist ventilation. What is true about proportional assist ventilation?

a. In this mode of ventilation the ventilator provides proportional assistance (initation and volume is machine controlled) till a target volume is reached
b. PAV is a spontaneous mode of ventilation which is patient triggered
c. There is no advantage of PAV over pressure support.
d. Hiccups and cardiac activity may cause over ventilation as these would trigger the ventilator excessively.

ANSWERS

a. Wrong answer

Unlike other modes the patient determines the initiation of breath, determination of volume, and the length of the breath. In short the patient is fully in control of his/her respiration.

b. Right answer

PAV is a spontaneous mode of ventilation where the ventilation is patient triggered and cycled by the patient where the ventilator simply amplifies patient instantaneous effort throughout inspiration while leaving the patient with complete control over all aspects of breathing pattern. However it is important to note that this form of ventilation should not be used in heavily sedated individuals. Changes in $PaCO_2$, PH and PaO_2 should elicit a response from the respiratory muscles, on the basis of which the ventilator would provide assistance in the PAV mode. However this response would be reduced in heavily sedated patients and hence such patients may not be right candidates for the PAV mode.

c. Wrong answer

With pressure support the clinician sets a specific pressure support to be delivered. Hence the pressure rises once the patient triggers the ventilator. The cycling off criteria is based on the flow (mostly when the flow reaches 25% of the inspiratory flow). The rise in the pressure would wholly depend on the patients respiratory mechanics. So, the flow decay would also depend on the resistance and compliance of the respiratory system. This means that it is highly possible that the ventilator keeps on in the inspiratory phase till much beyond the inspiratory effort. In PAV, the inspirations would stop the moment the inspiratory flow would stop enhancing patient ventilator synchrony. In a high demand setting the patient has to increase his own efforts to meet the requirement in pressure support modes. However, in PAV mode, the patient as well as the machine would proportionally share the increased work as a result of the increased demand of the patient.[1,2] However whether these physiological benefits would improve clinical outcomes or translate to actual patient benefits is not known and the evidence is conflicting in this regards.

References

1. Giannouli E, Webster K, Roberts D, et al. Response of ventilator-dependent patients to different levels of pressure support and proportional assist. Am J Respir Crit Care Med. 1999;159(6):1716-25.
2. Jubran A, Van de Graaff WB, Tobin MJ. Variability of patient-ventilator interaction with pressure support ventilation in patients with chronic obstructive pulmonary disease. Am J Respir Crit Care Med. 1995;152(1):129-36.

d. Wrong answer

Here is where this form of ventilation would differ from the usual forms. For example in a pressure support of ventilation a hiccup, or a cardiac oscillation may cause the ventilator to trigger an inspiration which would cycle only after the cycling criteria (most often 25% of peak flow) is reached. However, in the PAV mode, the ventilator would trigger. However, no standard volume or pressure would be delivered as the ventilator would stop delivering the gas once the artifact (e.g. hiccup) or effort is over. With other modes, cardiac artifacts may continue to cause frequent triggering and delivery of large volumes even when efforts cease completely.[1]

Reference

1. Imanaka H, Nishimura M, Takeuchi M, et al. Autotriggering caused by cardiogenic oscillation during flow-triggered mechanical ventilation. Crit Care Med. 2000;28(2):402-7.

9. The commonly available closed loop systems are the proportional assist ventilation (PAV), adaptive support ventilation (ASV), knowledge-based systems and the neutrally adjusted ventilator assist (NAVA). Concerning the ASV the following is true regarding the mode:

a. The ASV can be used in all phases of mechanical ventilation from initiation to maintenance to weaning
b. The ASV does not adapt between different lung pathologies like COPD

ANSWER

a. Right answer

In this form of ventilation the doctor keys in the height of the patient (using which the ideal body weight and the dead space is calculated), a target percent of minute ventilation (% MV) to be given to the patient, PEEP, FiO_2 and maximum pressure alarm (P_{max}). Pressure controlled SIMV "test" breaths with pressure of more than 15 and RR (10–15) on basis of IBW are delivered with which the expiratory time constant, compliance, resistance, tidal volumes are measured. The expiratory time constant is also determined by the analysis of the flow-volume curve, using which ASV can this adjust I:E relation and the target rate in order to keep the target volume within a margin of safety. So if the patient has no spontaneous breaths the ASV will work as Pressure control, when the respiratory rate is not adequate as SIMV and Pressure support when respiratory rate is high. Cycling off will be based on time in controlled mode and flow in the support mode. The pressure limit (within P_{max}) is automatically adjusted to achieve an average delivered VT equal to the target. The ventilator continuously monitors the mechanics of the respiratory system and adjusts its settings accordingly.[1]

Reference

1. Arnal JM, Wysocki M, Novotni D, et al. Hamilton Manual, 2009. Available from: http://www. hamilton-medical. com.

b. Wrong answer

MCQs in Mechanical Ventilation
A Case-based Approach *(With Explanatory Answers)*

Salient Features

- Case-based
- Problem-based solving approach
- Multiple-choice questions
- All explanations provided (including explanations for the wrong answers)
- Relevant references provided
- Easy reading
- Day-to-day problems addressed

Sanjith Saseedharan has done his basic training in anesthesia from the prestigious Lokmanya Tilak Municipal General Hospital, Mumbai, Maharashtra, India, following which he has done his training in Critical Care Medicine from the Ruby Hall Clinic in Pune, Maharashtra. He developed a keen interest in Neurotrauma, Neurocritical Care and Nutrition in the said institutes and, hence, went on to complete a Fellowship in Neuroanesthesia and Neurocritical Care at the Hadassah University Teaching Hospital at Israel, where he trained under stalwarts like Charles Sprung and Charles Weissmann and probably is one of the few critical care physicians to have a substantial training fellowship in Neurocritical Care overseas. He also holds the European Diploma in Intensive Care. Dr Sanjith is a teacher for the Indian Diploma in Critical Care Medicine and Nursing Course and Fellowship Course in Critical Care Medicine from the Maharashtra University of Health Sciences, Nashik, Maharashtra. He has been an invited faculty for many conferences, national as well as international. He has received the award for the best innovation for his software application 'iNutriMon', a nutrition support software for hospitalized patients, and his keen interest in nutrition has put Raheja ICU among the top 15 in the field of nutrition as per the International Nutritional Survey. He has also presented papers in national and international conferences, and has many articles in peer-reviewed journals. His passion in the field of mechanical ventilation is the driver for the annual conference that he conducts in the city of Mumbai year after year. He presently heads the Department of Critical Care at the SL Raheja Hospital, Mumbai.

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