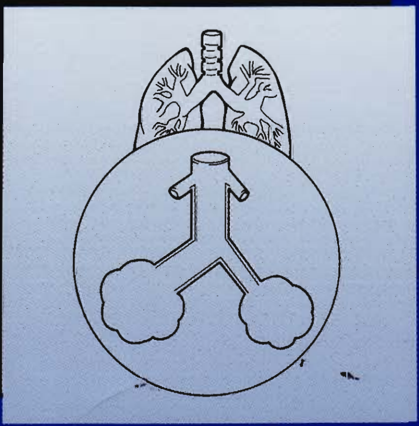
PRESSURE CONTROL VENTILATION REVIEW



PRESSURE CONTROL VENTILATION REVIEW

From the late 1950s and into the 1990s, positive pressure ventilation (as opposed to negative pressure ventilation) has been the basic approach to mechanical ventilation. With the introduction of the MA-1 in 1967, volume-cycled ventilation has been the method of choice throughout the 1970s and 1980s. Recently, third-generation ventilators have offered technological innovations such as pressure support, flow triggering, and pressure control ventilation. Clinicians can now choose from a wider variety of modes.

Regardless of the method by which positive pressure ventilation is achieved, increased pressure at the mouth and flow or volume entering the lungs are linked together. As pressure rises, volume increases or vice versa. Gas delivery from the pneumatic system varies as a result of which parameters are preset and which ones are allowed to change according to the patient's condition.

For reasons that are not well understood, the popularity of positive pressure ventilation modes seems to vary. For various reasons, a modality may fall into a period of disuse for certain categories of patients. When a modality returns to popular use, it is often refined by improved technology. Pressure control ventilation (PCV) is an example of a "reborn" modality. Different types of pressure-based ventilation have included intermittent positive pressure breathing (IPPB), pressure support (inspiratory assist), time-cycled pressure-limited ventilation (TCPV), and PCV. Although all pressure ventilation is similar in that pressure is the primary or controlled, preset parameter, the level of ventilatory support and the ventilator's response to the patient's condition can vary according to the "type" of pressure-based ventilation.

This paper is intended as a review of the current literature concerning PCV. Many investigators and specific articles are referenced throughout this review. Although there are a variety of opinions concerning the application of PCV, as well as controversy over the efficacy of its use, all parties seem to agree that more research and investigation are necessary. This paper in no way attempts to suggest when or how PCV should be used. However, it should serve as a tool for those who would like to obtain a more comprehensive understanding of the theory and current application of PCV. With these points in mind, the objectives of this review include:

- A comparison between volume ventilation and PCV.
- A comparison between pressure support and PCV.
- The theory and comparison of conventional ratio and inverse ratio PCV.
- Some guidelines for selecting patients who may benefit from PCV.
- Some guidelines for assessing the efficacy of PCV, using the patient as his own control.

COMPARISON TO VOLUME VENTILATION

Beginning in the 1960s, there have been two basic types of adult ventilators: volume-cycled and pressure-cycled. With a volume ventilator, the operator sets a specific volume to be delivered, and pressure rises as volume fills both circuit and lungs. Distribution of delivered volume depends on the relative compliance levels of the circuit and the lungs. Generally, the flow rate of the breath delivery is also preset in volume ventilation and because the tidal volume and flow rate are preset, the inspiratory time is determined by these two values. For example, a tidal volume of 1 liter delivered at a flow rate of 60 Lpm (1 liter per second), results in an inspiratory time of 1 second.

Figure 1 shows the pressure and flow curves for volume ventilation with a square waveform:

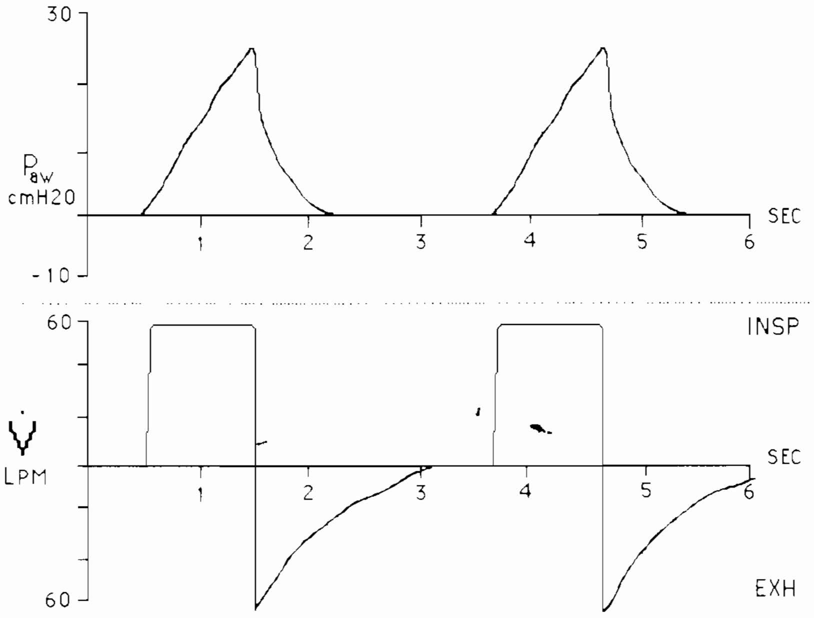


Figure 1. Typical Pressure and Flow Curves (Volume Ventilation)

On a pressure-cycled ventilator, the operator sets a specific pressure, and the machine delivers flow until that pressure is reached. Once the preset pressure is reached, inspiration ends and exhalation begins. There is no guaranteed tidal volume with pressure-cycled ventilation, and the inspiratory time depends on how quickly the pressure builds. Figure 2 is an example of the pressure and flow curves for pressure-cycled ventilation.

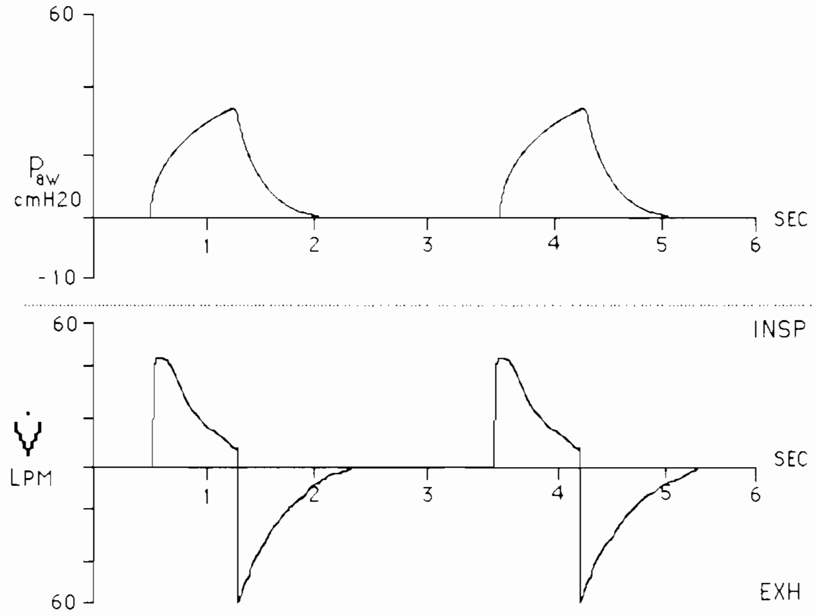


Figure 2. Typical Pressure and Flow Curves (Pressure-Cycled Ventilation)

If the patient splints or fights the breath delivery, the inspiration can end prematurely, resulting in erratic or insufficient tidal volumes, as shown in Figure 3.

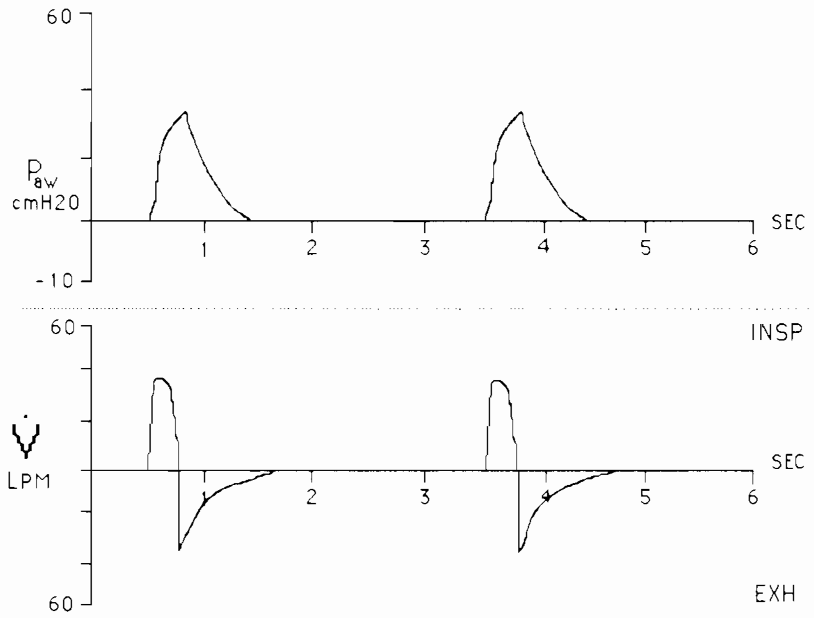


Figure 3. Pressure and Flow Curves (Patient Fights the Ventilator)

Not only can a patient's splinting reduce volume delivery in pressure-cycled ventilation, but decreased lung compliance or increased airway resistance can also reduce the tidal volume. Because delivered tidal volumes are not guaranteed in pressure-cycled ventilation, intensive care ventilators have usually been volume delivery devices.

Volume ventilators that deliver a preset flow or a programmed flow over a prescribed inspiratory time are called *flow generators*. Flow generators are independent of patient demands while pushing gas into the lungs. If the patient's demand for flow exceeds the preset flow rate, most ventilators are unable to respond with an increase in delivered flow, and the patient's work of breathing increases as he experiences "flow starvation."[1] Such pressure and flow waveforms would look something like those illustrated in Figure 4.

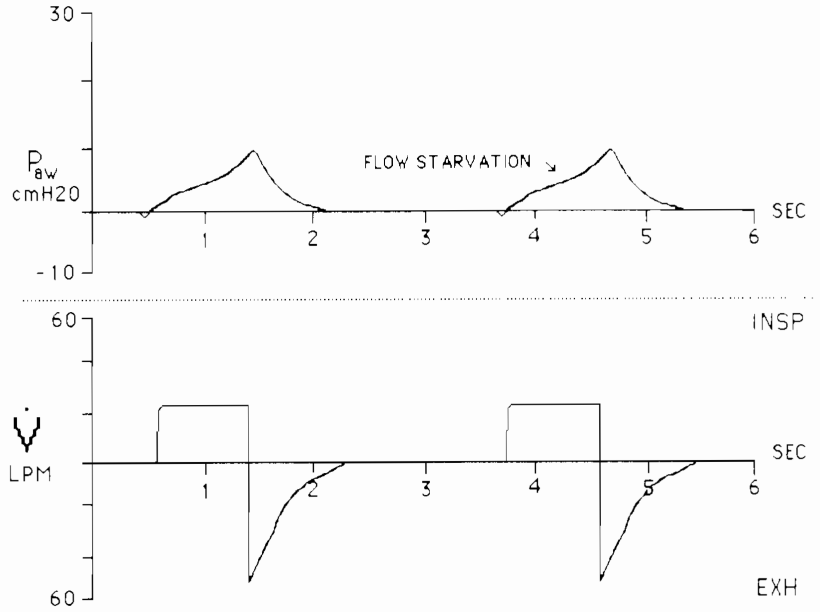


Figure 4. Pressure and Flow Waveforms During Flow Starvation in Volume Ventilation

In pressure-cycled ventilation, flow is the controlled parameter and pressure is the signal that ends inspiration. In PCV, pressure is the controlled parameter and time is the signal that ends inspiration. With PCV, the ventilator achieves a preset pressure level very quickly, and maintains that pressure level throughout the prescribed inspiratory time. Typical pressure and flow curves are shown in Figure 5.

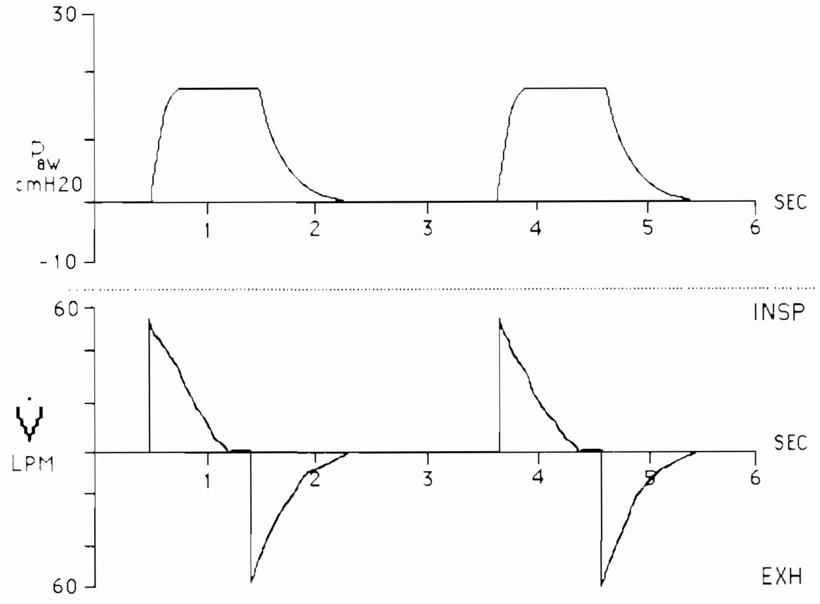


Figure 5. Pressure and Flow Curves in PCV

In PCV, the ventilator delivers whatever flow is necessary (within the limits of the flow control algorithm) to achieve and maintain the preset pressure level. This type of ventilator is called a *pressure generator*. Any factor that influences the pressure difference between the patient wye and the ventilator also influences the rate and pattern of flow. Changes in resistance or compliance, as well as spontaneous efforts from the patient, influence flow delivery. Figure 6, for example, shows that when patient effort is less, flow rate decreases — and when patient effort is more aggressive, flow delivery increases.

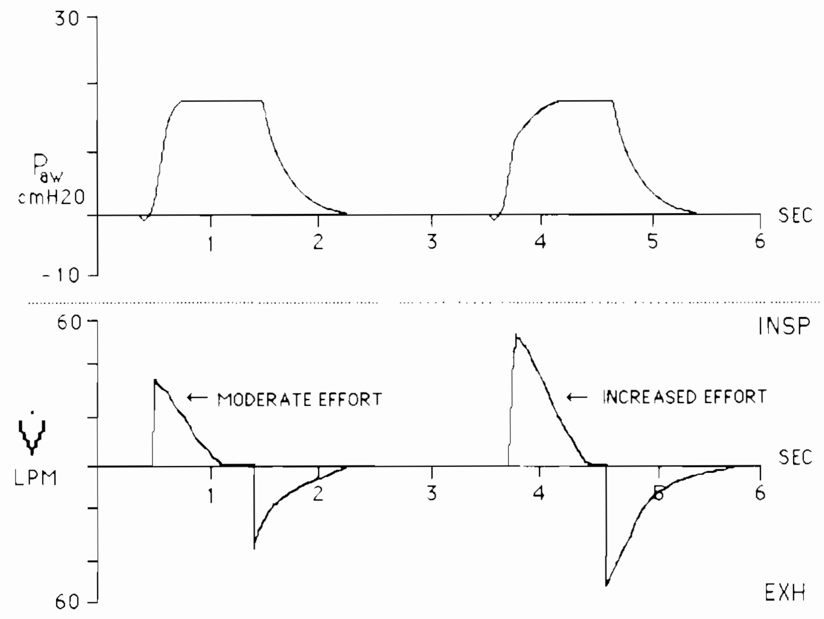


Figure 6. Pressure Ventilation: Flow Follows Patient Demand

The most significant difference between volume ventilation and pressure-based ventilation is how flow is delivered. The square waveform is most often seen in volume ventilation. Although most third-generation ventilators offer other waveform choices, the rate of flow and shape of the waveform are predetermined and not influenced by the patient. In contrast, the flow waveform in PCV is not predetermined and generally takes on a decelerating, or ramp-type shape. (It is important to distinguish PCV from the most frequently used type of neonatal ventilation, in which pressure and inspiratory time are preset, but gas delivery is limited by a preset flow rate.)

Comparison to Pressure Support Ventilation

In this section, pressure and flow waveforms are compared for pressure support and PCV. Pressure support is designed to give the patient more control over his or her breathing pattern. Inspiratory time is determined partially by patient effort and physiology, and partially by the particular ventilator's strategy to signal exhalation. The typical algorithm ends inspiration when flow declines to some percentage of peak inspiratory flow or some absolute value. However, an actively exhaling patient can drive airway pressure above the target level by some pressure level (usually 1.5 or 3.0 cmH_2O), and end inspiration. In any case, pressure support requires spontaneous effort to trigger inspiration, and the ventilator performs a variable portion of the work for the patient. Figure 7 illustrates some of the major differences between pressure support and PCV.

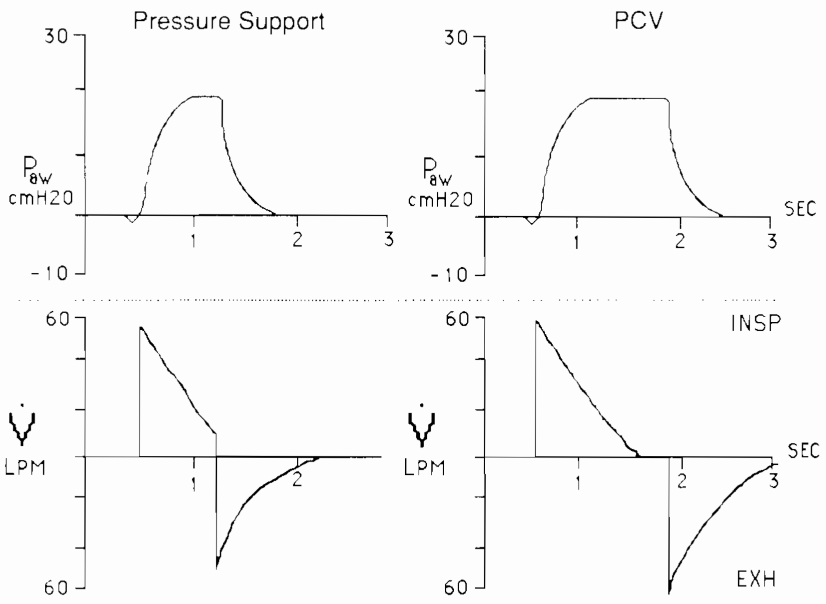


Figure 7. Pressure and Flow Waveforms (Pressure Support vs. PCV)

Pressure support requires a consistent, spontaneous respiratory drive, because all breaths must be patient-initiated. The patient has primary control of respiratory rate, inspiratory time, inspiratory flow rate, and tidal volume. The tidal volume depends on the level of pressure support, the degree of patient effort, and the resistance and compliance of the system[2], as well as the algorithmic design.

Unlike pressure support, which depends on a sustained respiratory drive, PCV is designed for the patient who may or may not be assisting the ventilator. Whether using PCV in CMV or SIMV, the practitioner sets a respiratory rate. In CMV, any spontaneous efforts result in a patient-initiated mandatory breath. The ventilator delivers a preset inspiratory pressure instead of a set tidal volume. Like pressure support, the flow rate which accompanies the breath is not preset, but changes as conditions change. Because the inspiratory time and breath rate are preset, PCV may offer more stability in delivered tidal volumes at moderate SIMV respiratory rates. The general appearance of patient-initiated, pressure-controlled, mandatory breaths is illustrated in Figure 8.

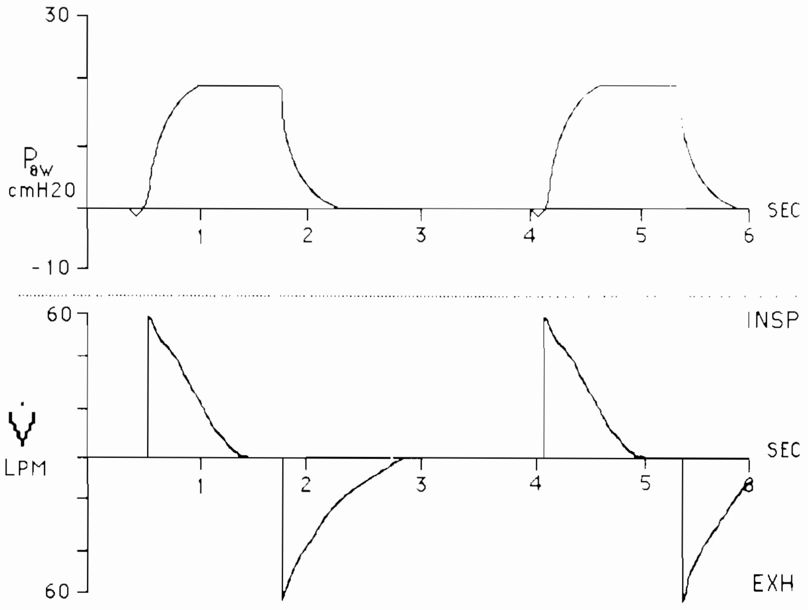


Figure 8. Patient-Initiated Mandatory Breaths in PCV

If the ventilator is in SIMV, the patient's spontaneous efforts result in either a patient-initiated mandatory or a spontaneous breath (see Figure 9).

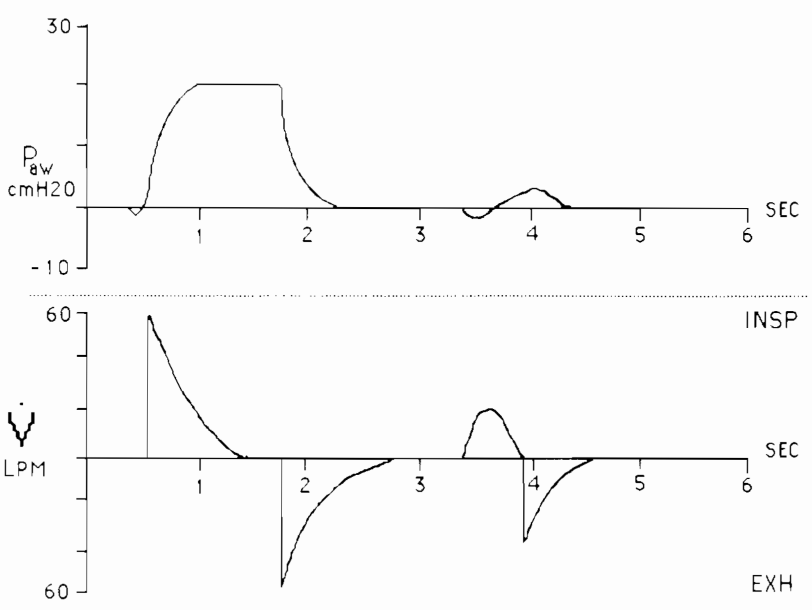


Figure 9. SIMV with Pressure Control Ventilation

By using pressure support with PCV in SIMV, the patient's spontaneous efforts can be amplified to deliver adequate tidal volumes. The pressure and flow waveforms may then look like those shown in Figure 10.

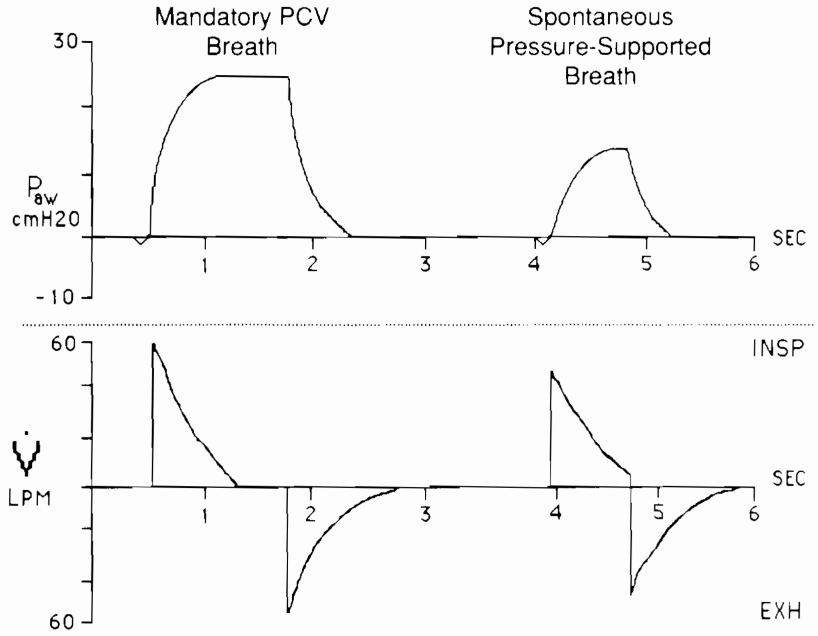


Figure 10. PCV: Patient-Initiated Mandatory Breath Followed by a Pressure-Supported Spontaneous Breath

Flow Triggering in PCV

Flow-by is also compatible with PCV in SIMV mode. This feature allows spontaneous and mandatory breaths to be flow-triggered, eliminating the extra work to initiate a breath typically experienced with pressure triggering. Figure 11 shows the pressure and flow curves for PCV with Flow-by.

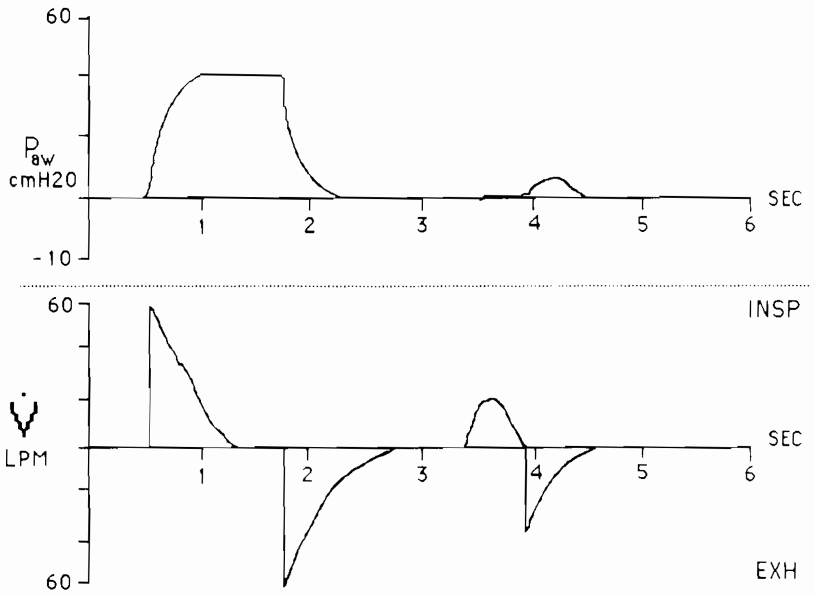


Figure 11. SIMV with Pressure Control Ventilation Using Flow-by

Clinical Advantages of PCV

Although there has been far too little published investigation on optimum flow curves during mechanical ventilation, research supports decelerating flow curves[3] and pressure ventilation as possible techniques for improving gas distribution. Data in the literature suggest that, when comparing pressure ventilation to volume ventilation, in some instances pressure ventilation may produce better arterial blood gases (ABGs) without cardiovascular deterioration.[4] In PCV (whether using normal or inverse I:E ratio), peak inspiratory pressure levels are usually lower than in volume ventilation, with similar mean airway pressures.[4,5,6] Patient comfort can be improved when flow delivery is sensitive to patient demand.[7] The following paragraphs discuss some of the potential reasons for these improvements.

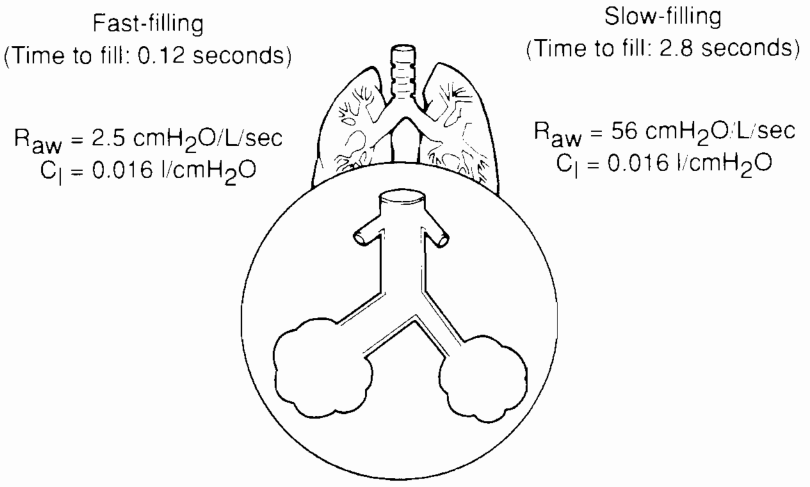
Reducing V/Q Mismatch

Some patients are difficult to ventilate due to ventilation/perfusion (V/Q) mismatch. There can be unequal distribution of the tidal volume if resistance and/or compliance differs from one lung region to another. Some airways are over-ventilated and alveoli over-distended, while others are under-ventilated in relation to pulmonary perfusion. Airways with higher airway resistance take longer to receive a given portion of the tidal volume.[4,8]

With PCV, gas flow is high early in the inspiratory phase as the ventilator attempts to "charge" the tubing and the upper airway with gas. Flow reaches the smaller airways earlier in the inspiratory phase, allowing more time for gas to be distributed according to local resistance and compliance.

As the pressure gradient begins to decline, flow decelerates as a function of the back pressure it meets. The decelerating waveform results in a more laminar flow at the end of inspiration, resulting in less turbulence when the gas is entering the smallest airways. If the inspiratory time is long enough, the slower-filling lung units are allowed to fill, constrained only by local time constants.[4] In patients who have markedly different resistance and compliance values from one lung region to another (such as COPD patients), a decelerating flow waveform may result in a more even distribution of ventilation.[3,6,9,10]

PCV and its associated ramp waveform, with high early flow rate and longer inspiratory time, fill much of the lung first, while the low flow at the last part of the breath involves redistribution and filling of areas limited by high time constants, as shown in Figure 12.[4,8]



Prolonged inspiratory time allows gas to reach the slow-filling areas, and ramp waveform provides laminar flow that reduces turbulence, allowing even gas distribution to all areas.

R_{aw} = Airway resistance
C_l = Lung unit compliance

Figure 12. Pressure Ventilation to Lungs with Varying Resistances[4]

Optimizing Inspiratory Time

By observing the flow waveform, the inspiratory time can be fine-tuned to accommodate the slower-filling lung units. If the inspiratory time is short and the flow is still positive at end inspiration, the inspiratory time can be increased to allow volume to fill those slower-filling units (see Figure 13).

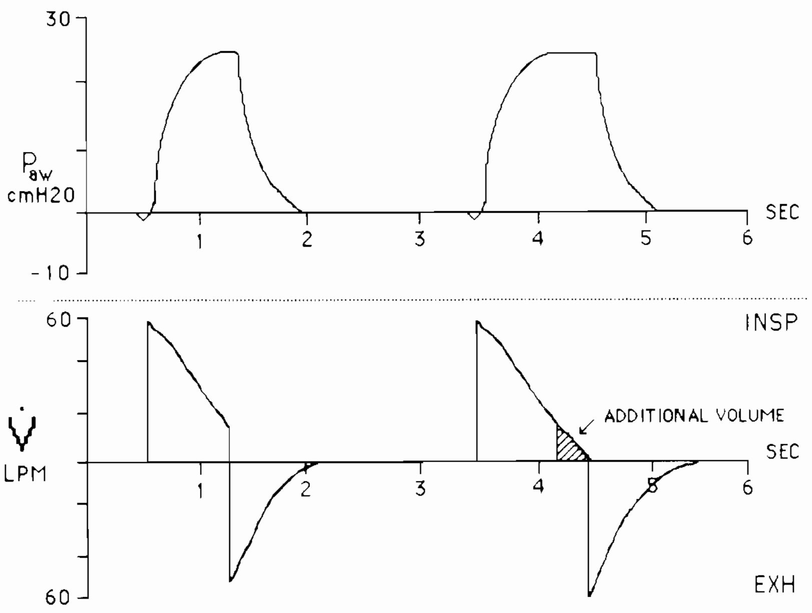


Figure 13. Adjusting Inspiratory Time in PCV to Ventilate Slower-Filling Lung Units

When respiratory rate changes are made in CMV or SIMV with normal I:E ratios, it may be desirable to hold the inspiratory time constant. The 7200®ae can be preset to maintain constant inspiratory times with changes in set respiratory rate. This feature maintains more consistency in delivered tidal volume.

Matching Ventilator Flow Delivery with Patient Demand

Investigations on work of breathing during patient-initiated mandatory breaths in CMV and SIMV indicate that the work of breathing can increase when the set flow rate does not match inspiratory demand.[1]

When using volume based ventilation, it can be difficult to match flow rate settings with patient demand. Clinical observation can usually detect the signs of a flow rate mismatch: patient/ventilator asynchrony is apparent; respiratory rate may be high; the patient may be using accessory muscles; and the patient appears uncomfortable. Using pressure support at the appropriate level can resolve the flow rate mismatch for some patients — but only for spontaneous breaths. A mismatch could still exist for mandatory breaths. Simply increasing the ventilator's preset flow rate beyond the patient's demand can result in turbulent flows and frequent pressure limiting, as shown in Figure 14.

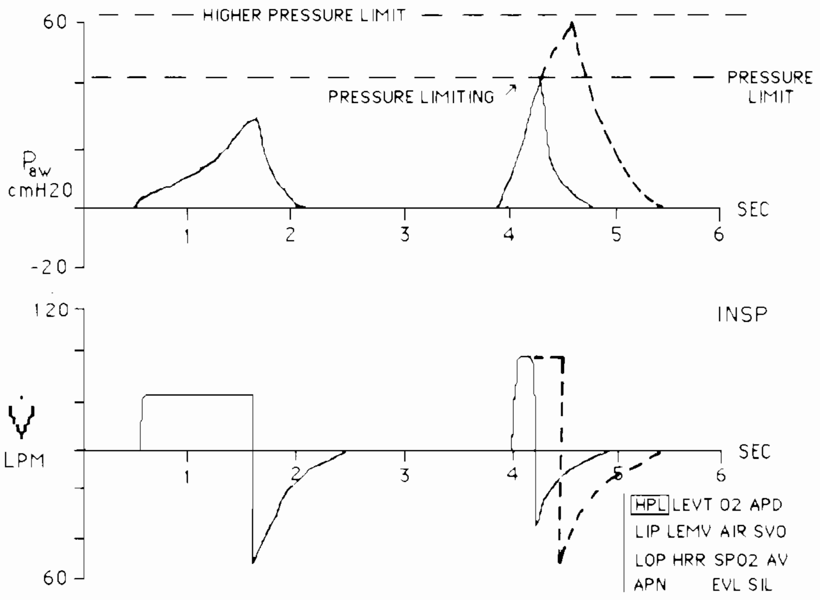


Figure 14. Attempting to Resolve Flow Rate Mismatch by Raising Flow Setting

Increasing the high pressure limit setting to accommodate higher peak flows may subject the lungs to high transient pressures, raising the risk of barotrauma.

In cases of severe flow mismatch, a trial using PCV may be useful. PCV allows the patient to access more flow from the ventilator during a mandatory breath while inspiratory pressures are set to more acceptable levels. (See Figure 4, which illustrates flow starvation caused by an inappropriately low inspiratory flow setting.) Using a similar inspiratory time and an inspiratory pressure setting that results in a tidal volume similar to that used in volume ventilation, the patient can be observed for changes in ABGs, cardiac output, peak airway pressures, and patient comfort. Spontaneous breaths can be pressure supported while delivering an appropriate number of mandatory PCV breaths. While this approach offers a potential solution for managing flow starvation, the pressure assisted and controlled patient must be tightly monitored for minute ventilation.

PCV may be judged useful if tachypnea is reduced, patient/ventilator asynchrony is reduced, and the patient seems to be more comfortable. Of course, ABGs, cardiac output, and peak airway pressures should also improve or stay the same. If not, the patient's status may be telling you that his or her condition requires another approach.

PRESSURE CONTROL INVERSE RATIO VENTILATION (PCIRV)

Probably the best-known use of PCV is inverse ratio ventilation. PCIRV is used primarily for patients with adult respiratory distress syndrome (ARDS). Although ARDS is not fully understood, one central problem is decreased lung compliance. Because the lungs empty very quickly, the alveoli have a tendency to collapse. This, along with other problems such as pulmonary edema and atelectasis, causes V/Q mismatching and shunting.

PCIRV offers many of the benefits of conventional ratio PCV. In PCIRV (as in PCV), gas reaches the peripheral airways early in the inspiratory phase, resulting in less turbulent terminal flow which may help to open non- or under-ventilated alveoli. As alveoli are recruited, compliance may improve and lower peak inspiratory pressures may be used to deliver adequate tidal volume.[6,9]

The traditional treatment for ARDS is to pressurize the alveoli statically during exhalation with PEEP to keep them from collapsing.[11] The alveoli are then subjected to correspondingly higher peak inspiratory pressures and normal inspiratory times to reinflate the lungs. These high pressures can reduce cardiac output and increase the possibility of barotrauma.[12,13]

PCIRV is practiced using lower peak airway pressures during inspiration, but maintaining this airway pressure for an extended period of time.[6] Instead of using static PEEP to prevent alveolar collapse, expiratory time is shortened so there is enough time for CO_2 to exit the alveoli, but complete emptying does not occur.[9] Reversing the I:E ratio in this fashion causes "gas trapping" (also known as "auto-PEEP") in the lungs, keeping them open at the end of exhalation. Gas trapping can be seen by observing the expiratory flow waveform. Flow coming out of the lungs at the end of exhalation, just as the next inspiration is delivered, indicates auto-PEEP, but does not quantify it. As illustrated in Figure 15, relative values may be inferred by increasing or decreasing end expiratory flow.

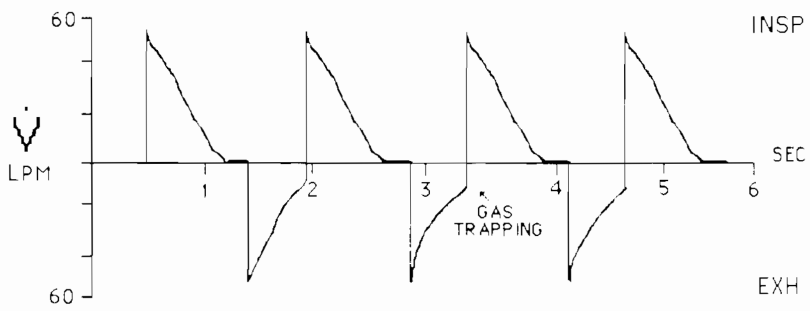


Figure 15. Gas Trapping in PCIRV

Candidates for PCIRV

Identifying the patient in the early stages of ARDS can be difficult. PCIRV is only one possible factor in a multifaceted management of a complex syndrome. True respiratory deaths, defined as dying of refractory hypoxemia or respiratory acidemia despite maximal attempts at oxygenation and ventilation, account for about 10% of all deaths in ARDS.[14] There is some hope that early identification and intervention may increase the success of treating the ARDS patient. Early treatment of ARDS includes correcting physiologic problems, suppressing alveolar inflammation, and preventing complications. PCIRV may help to correct physiologic problems, such as improving ABGs, while ventilating with lower peak airway pressures. To date, the most practical and successful way to intervene in ARDS is to identify a patient's clinical predisposition to ARDS.[15]

The first studies that sought to associate ARDS development with clinical predisposition were done in the early 1980s. Since then, the selection process has been refined to include a list of risk factors, including sepsis syndrome, aspiration of gastric contents, drug overdose requiring mechanical ventilation, pulmonary contusion, multiple major fractures, head trauma, and multiple transfusions for emergency resuscitation.

When only one risk factor is present, the patient is less likely to develop ARDS. The presence of multiple risks predicts a greater predisposition to ARDS. Figure 16 shows the incidence of ARDS in patients meeting predefined criteria.[15]

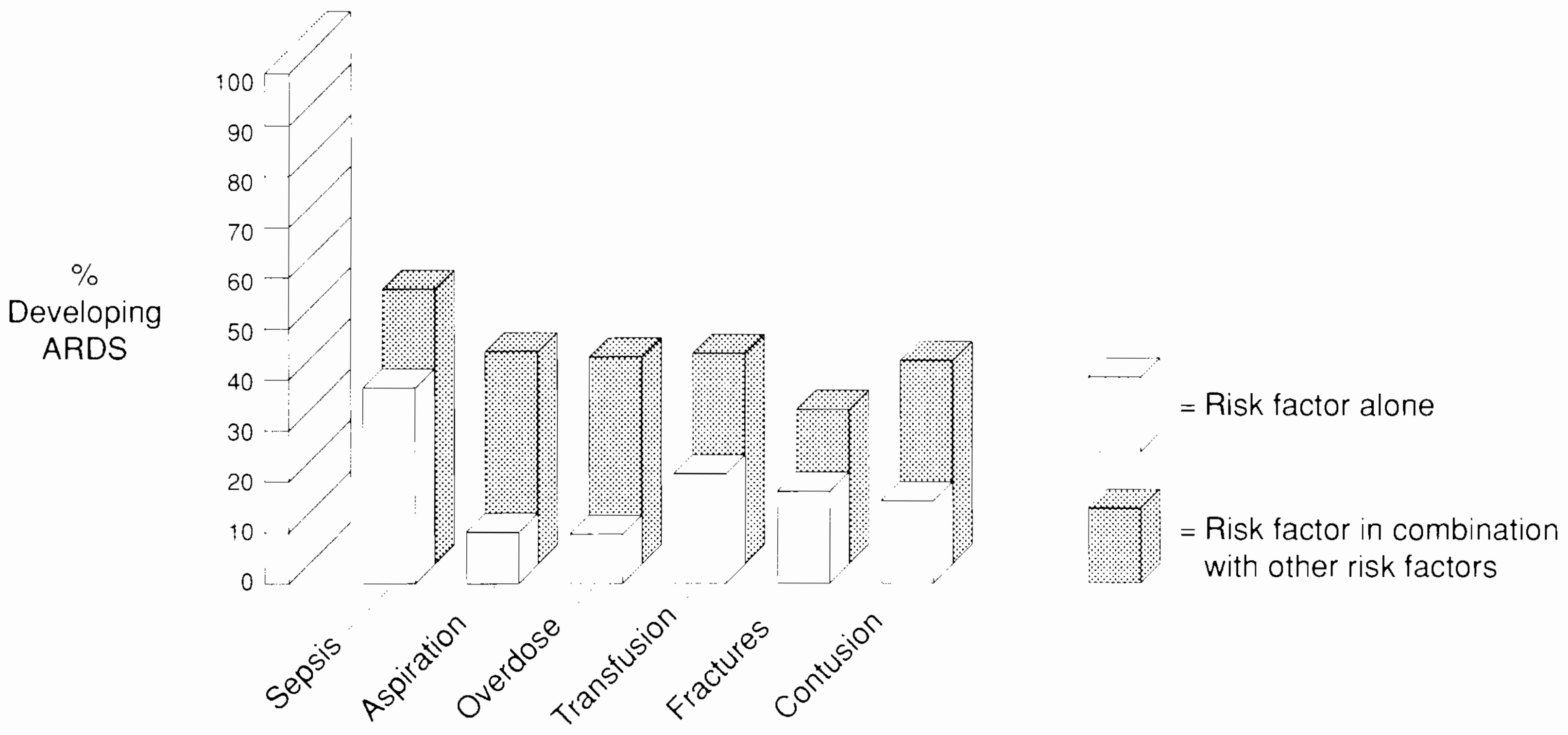


Figure 16. Risk Factors for ARDS[15]

Comparison of Inverse Ratio and Volume Ventilation

Table 1 summarizes some of the differences between PCIRV and volume ventilation.

Table 1. Differences Between Volume Ventilation and PCIRV

Volume Ventilation	PCIRV
Tidal volume is preset.	Volume delivery is a function of set inspiratory pressure, inspiratory time, and system compliance.
Flow rate is preset.	Flow rate is nonconstant.
Inspiratory time results from tidal volume, flow waveform, and either the I:E ratio or the flow settings.	Inspiratory time or I:E ratio are directly preset.
Flow waveform is preset.	Flow waveform not preset. Decelerating, ramp-type waveform results.
Peak airway pressure varies as a function of patient's resistance and compliance.	Peak airway pressure is constant. Peak airway pressure is reached and maintained until set inspiratory time is complete.
Pressure limit can declare exhalation.	If circuit pressure rises above set inspiratory pressure, the pressure limit setting terminates the breath.
Mean airway pressures vary depending on settings, mode, compliance, and resistance.	Mean airway pressures can vary with changes in respiratory rate, I time, I:E ratio, inspiratory pressure and set PEEP level, but are constant with patient compliance and resistance changes. Mean airway pressures are usually the same or higher than in volume ventilation.
Functional residual capacity (FRC) is maintained with set PEEP.	FRC is maintained through manipulation of expiratory time, which causes auto-PEEP.

PCIRV Criteria

PCIRV usually requires sedating and paralyzing the patient. Although paralysis with anesthesia has been shown to reduce oxygen consumption and improve chest wall compliance, it does not account for improvements seen when this unorthodox and unconventional mode of ventilation is used. A case example serves as evidence: a patient, being satisfactorily managed with PCIRV, was prematurely switched back to SIMV (volume-controlled, constant-ratio ventilation). Despite maintenance of the same FIO_2 and of paralysis, the patient's PaO_2 declined by 30 mmHg. If paralysis had been a significant factor in the maintenance of adequate arterial oxygenation (in PCIRV), the decline in PaO_2 should have been minimal.[9] The process of identifying patients who might benefit from PCIRV, establishing a policy and procedure for switching over from conventional forms of ventilation, and assessment criteria, varies according to institution.

The literature suggests that the clinician may consider switching from conventional ratio volume ventilation to PCIRV when a patient meets some or all of the criteria listed below; these criteria typically vary with physician preference and clinical presentation. While there are minor variations from one approach to another, the following have been cited in the literature as criteria for switching to PCIRV:[5,6,9,11]

- High peak inspiratory pressure (greater than 50 cmH_2O)
- FIO_2 setting greater than 0.60
- PaO_2 less than 60 mmHg
- High PEEP levels
- Minute ventilation greater than 10 Lpm
- Bilateral infiltrates on chest x-ray
- Shunt fraction greater than 15%
- Reduced static lung compliance (less than 40 ml/cmH_2O)

Assessing PCIRV

Switching to PCIRV is usually done once baseline values have been obtained for volume ventilation and minimum monitoring requirements have been established. These values have been used to evaluate the efficacy of PCIRV (some hospitals require more monitoring, some less): ABGs, mixed venous O_2 saturation, arterial saturation by oximetry, end tidal CO_2, minute ventilation, peak airway pressure, mean airway pressure, PEEP level, systemic blood pressure, static lung compliance, heart rate, urinary output, cardiac output, pulmonary artery pressure, pulmonary capillary wedge pressure, and pulmonary vascular resistance.

Many PCIRV protocols also require monitoring flow and pressure waveforms. The clinician can use the expiratory flow waveform to trend gas trapping. The more rapid the expiratory flow rate at the point of the next inspiration, the greater the degree of gas trapping. As in all methods of determining the presence of auto-PEEP, technology and measuring techniques present limitations to accuracy, especially at low levels of auto-PEEP.

Guidelines for PCIRV Settings

Ventilator settings are selected to minimize the possibility of barotrauma and oxygen toxicity, while maintaining adequate oxygen delivery and blood gas values. Each hospital uses a slightly different process to determine the appropriate settings for PCIRV. The following information was obtained from published research (cited at the end of this paper), and is intended as a review to give the clinician a perspective in approaching the various articles on PCIRV. Because the PCIRV patient's condition may change quickly, close monitoring and clinical surveillance are vital.

Inspiratory Pressure

- The plateau pressure observed in volume ventilation minus the set PEEP level is sometimes used as a starting point (since this approximates the pressure required to overcome the elasticity of the lungs). Other clinicians halve the peak pressure seen in volume ventilation as a starting point for PCIRV.[11]

- Watch the exhaled tidal volume closely; the goal is to achieve tidal volumes that are consistently similar to the tidal volumes found in volume ventilation. As alveoli open and compliance increases, the delivered tidal volume may begin to increase dramatically. Close, diligent observation of exhaled tidal volume must be maintained, and appropriate adjustments must be made as exhaled tidal volumes change.

- Some clinicians establish a minimum and maximum allowable inspiratory pressure level.

I:E Ratio

- The static compliance measured in volume ventilation is sometimes used as a starting point. Lower compliance values may require more inverse I:E ratios to achieve the desired effect.

- Some clinicians simply begin extending the inspiratory time in small increments, assess patient response, then extend I time further if oxygenation does not improve and hemodynamics are not compromised.

- Changes to the I:E ratio may be interspersed with incremental changes to the inspiratory pressure (approximately 2 or 3 cmH_2O at a time).[11] As compliance and/or resistance change, delivered volumes and auto-PEEP levels can change, and appropriate adjustments should be made to the I:E ratio, inspiratory pressure, or respiratory rate to regulate delivered tidal volume and auto-PEEP levels. Flow and pressure waveforms may be used to guide the clinician through this process.

- The desired level of gas trapping is dictated by the lowest possible FIO_2 that provides adequate oxygenation with stable hemodynamics, and the lowest possible inspiratory pressure that results in adequate volume delivery.

- It is important to monitor mean airway pressure and cardiac output very carefully when changing I:E ratio, respiratory rate or inspiratory pressure; the objective is to increase oxygen delivery to the tissues, and not just to raise the SaO_2.

Respiratory Rate

- The rate is typically set based on its effect on the overall cycle time, and is used to fine-tune expiratory time and gas trapping with ventilators that do not allow for independent control over I time or small changes in I:E ratio setting. The effect on overall minute ventilation must also be considered.

- With the 7200ae, I:E ratio or inspiratory time can be held constant in the event of a respiratory rate change; a change as small as 0.1 second in I time is possible.

PEEP

- This setting depends on the level of PEEP that was used before switching to PCIRV.

- Some clinicians halve the PEEP setting if it was greater than 8 cmH_2O, or remove it completely if less than 8 cmH_2O.[11] Others reduce PEEP to one-half the initial value, and attempt to reduce PEEP even further while maintaining FRC with gas trapping.[6]

- The combination of set PEEP and auto-PEEP created by gas trapping is not fully understood. Many clinicians prefer to leave the PEEP setting the same as in volume ventilation. Others feel that set PEEP has no effect until it exceeds the level of auto-PEEP.

- Increased gas trapping decreases the pressure difference between end expiratory pressure in the alveoli and peak inspiratory pressure, and may result in decreased tidal volumes and increased $PaCO_2$. Excessive gas trapping can overdistend the alveoli to the point that pulmonary capillary blood flow is compromised; a widening of the $PaCO_2$-$PeCO_2$ gradient could signal compromised blood flow, as dead space ventilation increases.

- There are several ways to trend auto-PEEP or gas trapping, such as analysis of the expiratory phase of the flow waveform and respiratory inductive plethysmography. Although auto-PEEP cannot be quantified in absolute terms (cmH_2O pressure), these techniques can be employed to trend changes in lung volume on a given patient. These methods may be utilized on patients with or without spontaneous respiratory efforts.

Direct measurements of auto-PEEP can be made through an expiratory hold maneuver or use of an esophageal balloon which references pleural pressure. The esophageal balloon has much merit but is also time consuming and technique dependent. With an expiratory hold maneuver, an accurate measurement of auto-PEEP requires that the patient not initiate any spontaneous effort. Also, since gas volume must equilibrate in both lungs and ventilator circuit with the expiratory hold measurement, it will result in an underestimation of the actual auto-PEEP. The expiratory hold maneuver is probably best employed during PCIRV with a patient receiving medication to induce sedation or paralysis.

FIO_2

- If the patient is not already on 100% oxygen, many clinicians set the FIO_2 at 1.0 during the switch to PCIRV. Using ABGs and saturation from arterial and/or mixed venous oximetry, the FIO_2 is carefully decreased as oxygenation improves.

- Because a primary goal of PCIRV is to avoid oxygen toxicity, the practitioner should set FIO_2 at the lowest possible value that results in adequate oxygen delivery to the tissues.

As the patient's compliance improves and the FIO_2 requirement diminishes, the I:E ratio and expiratory time can be slowly returned to conventional levels, as tolerated by the patient. The I:E ratio and expiratory time can be adjusted in much the same way that

PEEP decreases as the disease process improves. Patients who have been on PCIRV often tolerate weaning better on PCV throughout the SIMV stage of weaning.

PCIRV *is* controversial. Although many favorable studies have been published, and many more hospitals have used it with favorable results, ongoing long-term studies are required to determine where PCIRV will be most useful. Some have criticized that mortality rates in most studies have not been significantly reduced, and that most ARDS patients die from causes other than primary pulmonary failure. Others argue that the patients who end up on PCIRV are the sickest patients who fail conventional ventilatory techniques, and are therefore a higher-risk population. The most important goal in treating ARDS patients is to provide appropriate respiratory support while inducing the least lung damage possible. Because research literature has implicated high peak pressures in barotrauma, the advantage of PCIRV may be in reducing morbidity rather than mortality.

Summary

PCV is a refined pressure ventilation mode in which assisted ventilation breaths are delivered by allowing flow to adjust itself to maintain constant inspiratory pressures. This results in a descending flow curve. The potential effects of this are a more even gas distribution and perfusion match, greater response to patient flow demand, and a decreased inspiratory pressure. This may be valuable in conventional ratio ventilation in either SIMV or CMV, or with inverse ratio ventilation in controlled ventilation. Although there are many articles published on this topic, and many more hospitals already using these techniques, much more experience is needed to fully understand the best application and patient selection.

References

1. Marini JJ. The inspiratory workload of patient-initiated mechanical ventilation. *Am Rev Respir Dis* 1986; 134:902-09

2. Kacmarek RM. The role of pressure support ventilation in reducing work of breathing. *Respir Care* 1988;33:99-120

3. Al-Sady N, Bennett ED. Decelerating inspiratory flow waveform improves lung mechanics and gas exchange in patients on intermittent positive-pressure ventilation. *Intensive Care Med* 1985; 11:68-75

4. Boysen PG, McGough E. Pressure-control and pressure-support ventilation: flow patterns, inspiratory time, and gas distribution. *Respir Care* 1988; 33:126-34

5. Abraham E, Yoshihara G. Cardiorespiratory effects of pressure controlled inverse ratio ventilation in severe respiratory failure. *Chest* 1989; 96:1356-59

6. Tharrat RS, Allen RP, Albertson TE. Pressure controlled inverse ratio ventilation in severe adult respiratory failure. *Chest* 1988; 94:7855-62

7. MacIntyre NR. Pressure support ventilation: potential clinical applications. *Probl Pulmon Dis* 1986; 2:1-7

8. Jansson L, Jonson B. A theoretical study on flow patterns of ventilators. *Scand J Respir Dis* 1972; 53:237-46

9. Gurevitch MJ, Van Dyke J, Young ES, Jackson K. Improved oxygenation and lower peak airway pressure in severe adult respiratory distress syndrome. *Chest* 1986; 89:211-13

10. Modell HI, Cheney FW. Effects of inspiratory flow pattern on gas exchange in normal and abnormal lungs. *J Appl Physiol* 1979; 46:1103-07

11. Lain DC, DiBenedetto R, Morris SL, Nguyen AV, Saulters R, Causey D. Pressure control inverse ratio ventilation as a method to reduce peak inspiratory pressure and provide adequate ventilation and oxygenation. *Chest* 1989; 95:1081-88

12. Kolobow T, Moretti MP, Fumagalli R, et al. Severe impairment in lung function induced by high peak airway pressure during mechanical ventilation. *Am Rev Respir Dis* 1987; 135:312-15

13. Haake R, Schlichtig R, Ulstad DR, Henschen RR. Barotrauma. *Chest* 1987; 91:608-13

14. Montgomery AB, Stager MA, Carrico CJ, Hudson LD. Causes of mortality in patients with adult respiratory distress syndrome. *Am Rev Respir Dis 1985*; 132:485-89

15. Hudson LD. The prediction and prevention of ARDS. *Respir Care* 1990; 35:161-73