Ventilation Modes in the OR

An Overview
I. Controlled Ventilation

The patient’s ability to perform the work of breathing will determine the required work of respiratory support and therefore the mode of ventilation.

- Pressure Controlled Ventilation
- Volume Controlled Ventilation / Intermittent Positive Pressure Ventilation
- (Synchronised) Intermittent Mandatory Ventilation

Pressure Controlled Ventilation (PCV)

In pressure-controlled ventilation the breathing gas flows under constant pressure into the lungs during the selected inspiratory time, i.e. the preselected inspiratory pressure $P_{\text{max}}$ [Notice: $P_{\text{max}}$ (old term) = $P_{\text{insp}}$ (new term)] is upheld for the total duration of inspiration. The flow is highest at the beginning of inspiration (i.e. when the volume is lowest in the lungs). As the pressure is constant the flow is initially high and then decreases quickly with increasing filling of the lungs (“decelerating flow”).

Where there is a change in compliance or resistance the tidal volume changes, e.g. if there is a sudden increase in bronchial resistance the patient will hypoventilate as in this type of ventilation the tidal volume is the degree of freedom. This type of ventilation must be monitored closely with set alarms.

Another example: If the compliance decreases, the volume decreases and if the compliance increases, the volume increases.

Pressure-controlled ventilation is especially suited for ventilation in leakage losses (fistula, paediatrics, uncuffed ventilation tubes) as an increased flow to maintain the pre-selected pressure can automatically compensate these losses to a certain degree.

Other possible leakage losses: masks

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1 Oczenski, Wolfgang. 1987, S. 82
2 Oczenski, W. 1987, S.92
3 Oczenski, W. 1987, S.92
The effective tidal volume results from the product of compliance and $P_{\text{max}}$. Pressure-controlled ventilation may be the ventilation method of choice in cases of severe ARDS.

The inspiratory pressure level and the steepness of the pressure increase is set in PCV such that on the one hand the selected tidal volume is administered, on the other hand the initial inspiratory flow is not too high (< 2 l/sec).

The necessary inspiratory pressure level depends on the compliance of the lungs. Pressures exceeding 35 cm H$_2$O should generally be avoided$^4$.

**Advantages of PCV:**

- Reduction of the peak pressure and therefore of the risk of barotrauma and tracheal injury
- Effective ventilation in cases of distribution disorders. The decelerating inspiratory flow associated with pressure limitation reduces over-inflation of well ventilated "faster" alveoli (= compartments with low resistance) and reduces the following flow of "pendelluft" from the slow obstructive lung areas.
- Improved gas exchange by application of decelerating flow$^5$.

**Disadvantages of PCV:**

- Can cause volutrauma$^6$

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$^4$ Oczenski, W. 1987, S. 92-93
$^5$ Oczenski, W. 1987, S. 92
$^6$ Arthur Jones. (http://www.respiratorycare-online.com/venttopics_handout.PDF)
Volume Controlled Ventilation / Intermittent Positive Pressure Ventilation (VCV / IPPV)

The simplest model of a volume controlled ventilator is a plunger. A *pre-selected tidal volume is delivered with a constant flow* (*flow-controlled ventilation*) *without regard to airway pressure*, i.e. the ventilatory pressure is directly proportional to the airway resistance and indirectly proportional to the compliance. 

[...]

**Ventilation with Low Inspiratory Flow**

The *inspiratory flow* is a measure for the velocity with which the breathing gas is applied. If ventilation occurs with a *high inspiratory flow* the pre-selected tidal volume is applied before the inspiratory time is over (respirators are time controlled). The inspiratory time can be divided into a flow and no-flow phase. In the pressure-time diagram an inspiratory pressure plateau (=inflation hold) develops.

**In volume controlled ventilation the inspiratory flow levels should therefore be set as low as possible:**
- to keep ventilation as homogeneous as possible
- to keep the ventilatory pressure in the lungs as low as possible
- to keep the inspiratory pause (=inflation hold or no-flow phase) as short as possible

[...]

In volume-controlled ventilation the selected volume cannot be administered in the selected time if the inspiratory flow is set too low. The ventilation is *limited by time*, i.e., it no longer involves constant volumes.

Volume-controlled (flow constant ventilation) is the preferred type of ventilation for the healthy lung. It is therefore administered mainly in anaesthesia. A further *absolute indication is craniocerebral trauma* as flow constant ventilation guarantees safe administration of the selected tidal volume and therefore exact adjustment of the Pa CO$_2$.

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7 Oczenski, W. 1987, S.87-90
Advantages of VCV:

- Guaranteed tidal volume – $V_T$ is constant even with variable compliance and resistance.
- Less atelectasis compared to pressure control.
- $V_T$ increase is associated with a linear increase in minute ventilation\(^8\).

Disadvantages of VCV:

- **Over-inflation** of healthy lung compartments (=lung compartments with small time constant) and impaired breathing mechanics, while compartments with large time constant are insufficiently ventilated.
- The inhomogeneous ventilation leads to **an impaired ventilation/perfusion ratio** and an increased intrapulmonary right-to-left shunt.
- “**Pendelluft**” arises from pressure differences between the individual lung compartments in the inspiratory pause. This represents an intrapulmonary redistribution of the breathing gas, which has already taken part in gas exchange in the lung compartments with a large time constant. This breathing gas is therefore low in oxygen content\(^9\).
- The limited flow available may not meet the patient’s desired inspiratory flow rate. [...] 
- Can cause excessive airway pressure leading to **barotrauma, and adverse hemodynamic effects**\(^10\)

Pressure Monitoring is recommended

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\(^8\) Lawson, W., MS. (http://www.uthscsa.edu/respiratorycare/vent-handout.PDF)

\(^9\) Oczenski, W. 1987, S.87-90

\(^10\) Lawson, W., MS. (http://www.uthscsa.edu/respiratorycare/vent-handout.PDF)
(Synchronised) Intermittent Mandatory ventilation “(S)IMV”

SIMV ventilation is a mixture between spontaneous breathing and mechanical ventilation. The mandatory breaths ensure a certain minimum ventilation of the patient. This minimum minute volume is determined by setting tidal volume and IMV frequency. […]

SIMV differs from IMV because mandatory breaths are synchronised with the breathing of the patient. In order to prevent the mechanical breath being applied in the expiratory spontaneous breathing phase, a finely adjusted trigger window, the mandatory breath can be activated by the patient and is therefore synchronous with spontaneous breathing. The expectation window is 5 seconds long*. At higher IMV frequencies it can span the whole spontaneous breathing cycle. The mechanical breath is therefore triggered when the patient initiates an inspiratory effort after the end of the spontaneous breathing phase and within the expectation window.

*The duration (5 seconds, ...) of the expectation window (= trigger window) depends on the anaesthesia machine and the frequency.

Apart from the number of mandatory breaths, with modern ventilators the ventilatory pattern of the mandatory breath can also be varied via the adjustable variables** VT, IPPV frequency, inspiratory flow and I/E ratio, where by IPPV frequency and I/E ratio determine the duration of the mandatory breath. **Notice: “the adjustable variables in volume-controlled SIMV”

The SIMV breaths can be volume- or pressure-controlled […]11.

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11 Oczenski, W. 1987, S. 110-111
Advantages of SIMV:

- Synchronization of the mandatory breaths with any attempts at spontaneous breathing undertaken by the patient
- All other postulated and proven benefits are attributable solely to the patient’s intermittent spontaneous breaths.
- SIMV mode as primary ventilation pattern is advantageous as compared to controlled ventilation or other assisted modes\(^\text{12}\).

Disadvantages of SIMV:

- Fatigue at low SIMV rates - high WOB via circuit, demand valve in SIMV\(^\text{13}\)

\(^{12}\) Kuhlen, Guttmann, Rossaint. 2001, S. 24
\(^{13}\) Hronek I., Sladen R. (http://www.columbia.edu/~mh22/deptwww/divs/icu/ventmodes.html)
II. Pressure Support Ventilation (PSV)

Syn: Assisted Spontaneous Breathing (ASB)

[...] **PSV is currently an optional mode on all modern ventilators and is without doubt the most popular mode of partial ventilatory support, [...]**.

In this mode, each breath is triggered by an inspiratory effort of the patient and is provided with a preset level of pressure support. After a valve opens, a mechanical inspiratory gas flow is provided, so that the proximal airway pressure can be quickly raised to the preset level and kept constant throughout the inspiratory phase. This mode therefore results in a decelerating gas flow.

**During PSV, the breathing pattern is predominantly determined by the patient himself.** The assisted breath is not only triggered but also terminated by the patient. Depending on the type of the ventilator, the drop in inspiratory peak flow to a preset or freely selectable threshold value is generally used as an indication that the respiratory muscles are beginning to relax. This is followed by passive expiration to a preset end-expiratory pressure level (PEEP).
During pressure support ventilation the patient determines the frequency and cycle length, while the degree of pressure support is preset. The tidal volume in PSV depends on the mechanics of the respiratory system (compliance of lung and thorax, airway resistance), the time allowed for the respiratory cycle and the extent of patient-ventilator synchronization \(^\text{14}\).

**Spontaneous breathing:**
Spontaneous breathing is the favourite ventilation mode in 60% of LMA-uses in Great-Britain. After correct positioning of the LMA, the respiration will be supported at first with soft manual ventilation as long as the patient starts to breathe gradually by himself.

Even if there is a decision for spontaneous breathing, at the beginning, there should be a manual controlled ventilation, to guarantee ventilation and to reduce risks for atelectasis.

Having compared Assisted Spontaneous Breathing (ASB) with CPAP-Ventilation (CPAP), patients had significant deeper end-expiratory CO2-Values with ASB, higher stroke volume and better oxygen saturation.

The more an anaesthetist is experienced in using the LMA, the fewer narcotics will be used.

**Advantages of PSV:**
- Better synchrony between patient and ventilator
- Increased patient comfort [...]  
- Decrease in work of breathing [...]  
- Deepening of weak shallow spontaneous breathing\(^\text{15}\)

**Disadvantages of PSV:**
- PSV does not take into account the flow-dependence of the tube resistance\(^\text{16}\). [...]

\(^{14}\) Kuhlen, Guttmann, Rossaint. 2001, S. 25-26  
\(^{15}\) Rozé, Krüger.  
(http://www.draeger.com/com/MT/Library/CriticalCare/Literature/E_Pressure_Support_Vent_9097499.PDF)
III. Articles and abstracts about Pressure Support Ventilation

A. Articles and abstracts about Pressure Support Ventilation in anesthesia

Pressure Support Ventilation: Technology Transfer From the Intensive Care Unit to the Operating Room

Department of Anesthesia, Medicine, and Surgery, Stanford University Medical Center, Stanford California

Mechanical ventilation has traditionally been used in two very different settings, namely in the operating room for anesthetized patients with otherwise adequate respiratory function and in the intensive care unit (ICU) for patients with respiratory failure. An improved understanding of pulmonary pathophysiology and recent technological advances have significantly altered our current approach to mechanical ventilation in the ICU. The article in this issue of Anesthesia & Analgesia by Christie and Smith on pressure support ventilation (PSV) for anesthetized patients is an attempt to define the value of these new approaches in the operating room setting.

Before the mid-1960s, volume-controlled ventilation in an assist/control mode was standard practice, and weaning from mechanical ventilation was primarily an all-or-none phenomenon with T-tube trials. Maintenance of functional residual capacity (FRC) was subsequently recognized as a major factor in allowing adequate oxygenation, decreased work of breathing (WOB), and prevention of atelectasis in the tracheally intubated patient. The use of positive end-expiratory pressure (PEEP) became increasingly popular as a means to maintain FRC and prevent atelectasis. In the early 1970s, intermittent mandatory ventilation was introduced to allow weaning from mechanical ventilation without the development of excessive WOB and resultant neuromuscular fatigue. Ventilatory support of the patient with

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16 Kuhlen, Guttmann, Rossaint. 2001, S. 29-30
acute respiratory failure primarily relied on large tidal volume breaths for alveolar ventilation and PEEP for maintenance of oxygenation and FRC.

The available intermittent mandatory ventilation circuits were often designed with demand valves requiring varying degrees of patient effort during spontaneous ventilation. Similar circuits became commonplace for the routine use of continuous positive airway pressure as a means of maintaining FRC in the presence of an endotracheal or tracheostomy tube.

The value of maintaining FRC in reducing atelectasis, improving compliance, and reducing pulmonary vascular resistance was balanced by a potentially detrimental increase in WOB with use of such circuits. Although continuous-flow circuits as an alternative to demand valves were shown by Viale et al. to reduce WOB, the majority of equipment available in the operating room and ICU used demand valve circuits.

The past decade has seen the development of multiple new ventilatory modes, such as high-frequency ventilation, high-frequency oscillation, airway pressure release ventilation, and inverse ratio ventilation. Each of these techniques improves oxygenation by maintaining a high mean airway pressure but prevents barotrauma by reducing peak airway pressure. These techniques are applicable primarily to the patient with poor pulmonary compliance and increased physiologic shunting caused by adult respiratory distress syndrome.

In contrast to these techniques that primarily address oxygenation, **PSV is designed to maintain adequate alveolar ventilation without excessive WOB during spontaneous ventilation.** Pressure support ventilation is used in two different ways. First, **PSV may be used at low levels (5-10 cm H$_2$O) to decrease the increased WOB related to resistance of the endo-tracheal tube,** work due to limited flow rates, and work due to demand valves. In this application, PSV results in an increased airway pressure during inspiration and reduces WOB to those values that would occur in the absence of exogenous factors.

A second application of PSV is its use as a method to increase alveolar ventilation and maintain adequate tidal volumes. **Patients with respiratory failure**
frequently have decreased pulmonary (lung-thorax) compliance and increased minute ventilatory requirements, a combination that results in rapid, shallow breathing and markedly increased WOB. Pressure support ventilation may be used to decrease WOB to an acceptable level. During inspiration, the force producing lung expansion is the difference between airway pressure and pleural pressure.

By increasing airway pressure during inspiration, PSV increases this pressure differential, resulting in an augmented tidal volume without increased WOB. Because inspiration during PSV is terminated when air flow decreases below a set value, tidal volumes and minute ventilation are partially dependent on patient effort. In general, PSV is used at levels of 5-50 cm H₂O to increase tidal volume and decrease WOB.

Intensive care units were organized in the 1950s to provide optimal therapy for patients with respiratory failure, commonly a result of poliomyelitis. Anesthesiologists became the principal caregivers, transferring knowledge and techniques accrued through decades of experience in the operating room. The use of large tidal volume (12-15 mL/kg) mechanical ventilatory support arose from studies demonstrating benefit in reducing atelectasis and maintaining FRC. In the majority of ICU units, the standard approach to mechanical ventilation of patients with normal lungs now includes intermittent mandatory ventilation with large (12-15 mL/kg) tidal volumes, low levels (approximately 5 cm H₂O) of PEEP, and low levels (5-8 cm H₂O) of pressure support. This approach is designed to maintain normal FRC and normal WOB. With the recognition of decreased FRC as principal sequela of general anesthesia and the major role that this pathophysiologic occurrence plays in the development of postoperative complications, it is surprising that the previously mentioned therapeutic approaches have not been routinely utilized in the operating room. In contrast, ventilation of such patients in the operating room typically uses full mechanical ventilation with low tidal volumes, no PEEP, and no pressure support. Spontaneous ventilation is frequently not allowed, owing to concerns with regard to FRC, WOB, and alveolar ventilation. The article by Christie and Smith in this issue of Anesthesia & Analgesia addresses some of these concerns.
By monitoring airway pressure, esophageal (pleural) pressure, and air flow, Christie and Smith measured WOB in nine patients during general endotracheal anesthesia and spontaneous ventilation. Each patient was studied under three different ventilatory conditions: a standard anesthesia circle system, a servocontrolled ventilator with demand flow ventilation, and a servocontrolled ventilator with 5 cm H2O PSV. In anesthetized patients breathing through circle or demand flow systems, WOB was two- to threefold higher than normal. The addition of 5 cm H2O PSV reduced WOB to normal. There were no differences in hemodynamics or respiratory variables during the three modes of ventilation.

The increased inspiratory WOB during general endotracheal anesthesia can be considered the sum of three components: mechanical ventilatory work needed to overcome the elastic and flow-resistance properties of the lungs and thorax; work required owing to the resistance of the endotracheal tube; and work required owing to the resistance of the ventilator system.

Both general anesthesia and endotracheal intubation without PEEP result in decreases in FRC that decrease pulmonary compliance and increase airways resistance. The resistance of an endotracheal tube is related to tube diameter and length. A 7-mm endotracheal tube will increase WOB by approximately 30mJ/L. The increased work required owing to the breathing system varies with the specific demand valves, flow rates, and inspiratory trigger level. In the study by Christie and Smith, WOB was not divided into its three components. Brochard et al. Recently reported data that does provide such a division in patients with respiratory failure. During spontaneous ventilation with a Siemens Servo 900C ventilator, WOB decreased to approximately 900mJ/L; after tracheal extubation, WOB further decreased to 810 mJ/L. The level of support required to balance the additional WOB due to the endotracheal tube and ventilator varied from 3.4 to 14.4 cm H2O. In that study, one patient had a 7.5-mm endotracheal tube and different ventilator systems in the operating room may result in the need for significantly high levels of pressure support.

In the study by Christie and Smith, 5-cm H2O pressure support decreased WOB but did not affect tidal volumes and respiratory rates. Similar results have been reported by Slee et al. in which increased airway impedance increased WOB but did not affect tidal volumes and respiratory rate during general
anesthesia. In both studies, inspiratory time varied to maintain a constant tidal volume; however, other studies indicate that increased airway impedance may result in decreased tidal volumes and minute ventilation. Anesthetized patients frequently breathe at low tidal volumes and minute ventilation owing to the combined effects of decreased pulmonary compliance, increased inspiratory resistance, and the effects of the anesthetic agent. In such situations, the anesthesiologist usually relies on mechanical ventilation to prevent atelectasis and hypercarbia. **Pressure support ventilation provides a rational alternative method to achieve adequate tidal volume and alveolar ventilation during spontaneous ventilation.** As the current versions of servocontrolled ventilators become more widely available in the operating room, additional studies will be required to define the benefits of such an approach.
Assisted spontaneous breathing during anaesthesia with the laryngeal mask airway

Association Low Flow Anaesthesia
- GENT 1998 -
Dr. Nigel Harper
Manchester Royal Infirmary
http://www.alfanaes.freeserve.co.uk/Session982.htm

It has long been known that dose-dependent respiratory depression is an invariable accompaniment to general anaesthesia (Eger 1981) but it was not until capnography came into routine use that anaesthetists realised the extent of the marked hypercapnoea that is commonly associated with spontaneous ventilation. This and other factors encouraged a move towards the widespread use of endotracheal intubation and mechanical ventilation a phenomenon that was already well established in paediatric anaesthesia and in the USA.

The more recent introduction of the laryngeal mask airway has partially reversed this trend, especially in Europe, and a higher proportion of patients are breathing spontaneously throughout their surgical procedure.[...]

Within minutes of inducing anaesthesia in the supine position the FRC falls by approximately 20% towards the residual volume. This occurs even if the patient is mechanically ventilated and irrespective of the presence of nitrous oxide. The cause of this reduction in the resting volume of the lung is not clear but there are deleterious effects on the patency of the airways, compliance and gas exchange.

During mechanical ventilation with large tidal volumes the physiological deadspace is increased during anaesthesia, possibly as a result of over ventilation of under perfused alveoli. This phenomenon attenuates the expected fall in arterial carbon dioxide tension. Conversely, at the small tidal volumes associated with depressed spontaneous breathing, the physiological deadspace may be markedly reduced. This can be thought of as a compensatory mechanism. In addition, carbon dioxide production is reduced by approximately 15% compared with the awake individual.
Without these mechanisms, patients breathing with the small tidal volumes we observe during anaesthesia would be even more hypercarbic. All breathing circuits are associated with an increase in the work of breathing. Only the work associated with inspiration is important: expiration is largely the result of elastic recoil of the lung and chest wall and requires very little work. The phasic contraction of the abdominal muscles during anaesthesia contribute very little to expiration.

The use of pressure support ventilation to decrease the work of breathing is well established in the Intensive Care Unit where it is employed to assist the process of weaning from full mechanical ventilation. These patients are often disadvantaged by severe respiratory muscle weakness, poor pulmonary compliance and high metabolic rate. Increasing levels of pressure support progressively reduce the respiratory rate and progressively increase the tidal volume (by approximately 25%) and minute ventilation of sedated ICU patients. These changes are associated with a reduction in the work of breathing which is reduced by approximately 50% by increasing the pressure support level from zero to 12 cm H2O. The reduction in pressure support is only as great as the increase in work of breathing associated with inserting an endotracheal tube (Brochard 1991). Pressure support ventilation is an important modality in the ICU and there is no doubt that the duration of the weaning process is reduced. It is clear that the benefits of pressure support in this group of patients are not solely the direct result of a decrease in the work of breathing but are the consequence of an increase in the efficiency of ventilation. [...]
The Controversy

In 1992 Christie and Smith working in Tampa, Florida published the effects of pressure support on various respiratory parameters during enflurane anaesthesia in 9 patients. Their primary aim was to investigate the effect of 5 cm H2O pressure support on the work of breathing. Respiratory rate, tidal volume, PaCO2, and end-tidal CO2 were unchanged but the work of breathing was reduced from 532 mJ/L breathing from a circle system to 171 mJ/L during 5 cm H2O pressure support ventilation. They did not observe any irregular breathing patterns.

Three years later, Bhatt and colleagues (1995) working in Hong Kong published a study (9 patients, isoflurane anaesthesia) in which a level of pressure support of 10 cm H2O was studied in addition to 5 cm H2O. In contrast to the Christie’s work, the respiratory rate was reduced and the tidal volume was increased by 5 cm H2O. These effects were more marked at 10 cm H2O support. The mean PaCO2 was unaffected but in at least half of the patients their breathing became irregular at both levels of support. When pressure support was first applied in this group of patients there was a progressive fall in end-tidal CO2 and a progressive increase in the duration of each respiratory cycle. After a period of 2 - 3 minutes the expiratory phase was greater than 10 seconds; i.e. the patient was apnoeic. They concluded that pressure support ventilation produces a fall in arterial CO2 sufficient to cause apnoea in some patients.

Under experimental conditions it is difficult to induce apnoea in healthy volunteers by deliberate hyperventilation. However, when arterial CO2 is deliberately reduced in anaesthetised patients, it is possible to induce apnoea more easily. The level of arterial CO2 at which apnoea occurs, the apnoeic threshold, is approximately 0.7 - 1.2 kPa (5.3 - 9.0 mm Hg) below the normal value (Hanks et al. 1961). Bhatt and colleagues concluded that ‘it would be difficult to justify the use of pressure support ventilation during anaesthesia in a healthy population.

In February 1996 the Florida group (Bosek et al. 1996) published a larger series (20 patients) in which they investigated the effects of a) 5 cm H2O pressure support; or b) sufficient pressure support to result in a measured tidal volume of 8 ml/kg. Anaesthesia on this occasion was with desflurane. Their results confirmed their earlier work in which 5 cm H2O pressure support did not alter the respiratory rate, tidal volume, PaCO2, or end-tidal CO2. Approximately 17 cm H2O support was needed to produce a tidal volume of 8 ml/kg. At this high level of support the mean tidal volume was increased (from 237 to 518 ml) but a marked reduction in respiratory rate (from 26 to 11) resulted in an overall small reduction in the minute volume. The arterial CO2 was actually reduced from 6.8 to 6.0 kPa (51 to 45 mmHg). They were able to demonstrate (using the modified Bohr equation) that the reduction in PaCO2 was the result of a pressure support-mediated reduction in physiological deadspace. In common with their earlier study
and in contrast to the work of Hanks, no patient experienced an apnoeic episode of greater than 10 seconds. They concluded that 'Pressure support of spontaneous breathing appears to be a reliable alternative to controlled mechanical ventilation ...' A recent study of assisted breathing in conscious volunteers demonstrated an increase in tidal volume with no change in respiratory frequency and preservation of the regular pattern of breathing although the inspiratory time was shortened (Mecklenburgh and Mapleson 1998).

**Work in progress**

It is difficult to reconcile the apparently conflicting literature on pressure support ventilation during anaesthesia. All three studies used the Siemens 900 series ventilator. **Different inhalational agents were used but enflurane, which normally produces greater respiratory depression than isoflurane or desflurane, was not associated with irregular breathing or apnoea.** The Hong Kong group performed their study in the absence of surgical stimulation. The Florida group minimised the influence of surgical stimulation by performing regional blocks.

Studies currently being undertaken by the author may cast some light on the mechanisms which produce apnoea during pressure support ventilation. In a preliminary study we have demonstrated that pressure support via a laryngeal mask airway can reduce PaCO2 towards normal levels in some patients but not others. In some patients irregular breathing and apnoea can be induced before there is any reduction in end-tidal CO2. The rapidity with which this phenomenon occurs after a step-increase in pressure support suggests that either muscle-spindle or proprioceptive afferents lead to rapid inhibition of the motor neurone pool in the anterior horn of the spinal cord. It appears that it may be possible to over-ride the irregularities in the breathing pattern in some patients.

Further work in progress may be able to identify modes of assisted breathing which may be used to restore PaCO2 to normal levels during inhalational anaesthesia without suffering the penalty of an irregular breathing pattern.
Pressure support ventilation decreases inspiratory work of breathing during general anesthesia and spontaneous ventilation

Joan M. Christie, MD, and Robert A. Smith, MS
Department of Anesthesiology, University of South Florida College of Medicine, Tampa, Florida

- Abstract -
Spontaneous ventilation may offer advantages over controlled mechanical ventilation (CMV), but increase in work of breathing may diminish its usefulness. During general anesthesia, respiratory depression and increased work of breathing often preclude spontaneous ventilation, and patients then receive CMV. We compared the inspiratory work of breathing of anesthetized patients who breathed with pressure support ventilation (PSV) with that associated with a demand gas flow and a standard anesthesia circle system. We studied nine consenting patients who underwent general inhaled anesthesia with or without regional supplementation. An anesthesia/ventilator system (Siemens 900D, Solna, Sweden) provided PSV (5 cm H2O) or demand gas flow during spontaneous inspiration. Gas flow during demand breathing and PSV was initiated when inspiration produced a 2-cm H2O reduction in airway pressure. An anesthesia machine (Dräger Narkomed 3, Telford, Pa.) provided a gas flow rate of 6 L/min through a standard semiclosed circle system. Airway pressure, airway gas flow rate, and esophageal pressure were continuously transduced, and data or signals were conveyed to a computer. Tidal volume and respiratory rate were computed from the flow curve. The inspiratory work of breathing was calculated as the integral of the area subserved by a plot of esophageal pressure and tidal volume during inspiration. Heart rate and mean arterial blood pressure were recorded, and arterial blood was sampled for gas tension and pH analysis. No differences were found in pHa, Paco2, Pao2, tidal volume, respiratory rate, heart rate, or mean arterial blood pressure among the three modes of ventilation. Inspiratory work of breathing was less when patients received PSV (171 ± 65 mJ/L) (mean ± SD) compared with breathing with a demand valve (690 ± 231 mJ/L) or circle system (532 ± 160 mJ/L) (P < .05). Mean airway pressure was more with PSV (5.4 ± 1.0 cm H2O) than with the demand flow (0.1 ± 1.4 cm H2O) or with the circle system (0.4 ± 1.0 cm H2O) (P < 0.05); FIO2 remained constant at 0.4 ± 0.05.

We conclude that PSV with 5 cm H2O can be used to decrease inspiratory work in spontaneously breathing patients during general anesthesia compared with spontaneous breathing with a standard circle system or demand gas flow and that the reduction is not associated with deleterious hemodynamic effects.

Pressure Support Ventilation versus Continuous Positive Airway Pressure with the Laryngeal Mask Airway

- A Randomized Crossover Study of Anesthetized Adult Patients

Background: The authors tested the hypothesis that pressure support ventilation (PSV) provides more effective gas exchange than does unassisted ventilation with continuous positive airway pressure (CPAP) in anesthetized adult patients treated using the laryngeal mask airway. [...] Results: In both groups, PSV showed lower end tidal carbon dioxide (P < 0.001), higher oxygen saturation (P < 0.001) and higher expired tidal volume (P < 0.001) compared with CPAP. [...] Conclusion: The authors concluded that PSV provides more effective gas exchange than does unassisted ventilation with CPAP during LMA anesthesia while preserving leak fraction and hemodynamic homeostasis. [...] SPONTANEOUS breathing is the most popular mode of ventilation with the laryngeal mask airway (LMA), but provides less effective gas exchange than does positive pressure ventilation (PPV). Pressure Support Ventilation (PSV) is a form of partial ventilatory support in which each spontaneous breath is assisted to an extent that depends on the level of a constant pressure applied during inspiration. Bosec et al. Showed that PSV improves gas exchange in anesthetized intubated patients; but, there is only one anecdotal report of PSV usage with the LMA. [...] 

19 Brimacombe, Keller, Hörmann. Anesthesiology 2000, 92:1621-3
Articles and abstracts about Pressure Support Ventilation in general

Patient Work of Breathing during Pressure Support and Volume-cycled Mechanical Ventilation

John W. Kreit, Mark W. Capper and William L. Eschenbacher
Division of Pulmonary, Allergy and Critical Care Medicine, University of Pittsburgh Medical Center, Pittsburgh, Pennsylvania

- Abstract -

A computer-assisted technique based on the equation of motion of the respiratory system was used to measure inspiratory work of breathing in 11 patients during pressure support ventilation (PSV) and assisted, volume-cycled mechanical ventilation (AMV). During both modes of ventilation, patient work of breathing was calculated as the difference between the total work performed on the respiratory system (as predicted by the equation of motion) and the work performed by the ventilator. Patient work of breathing during AMV was also calculated as the difference between ventilator work measured during assisted and controlled mechanical breaths. By either method of work calculation, patient work of breathing during AMV was less than previously reported. In addition, when equal tidal volumes were delivered, there was no significant difference between the work performed by the patient during AMV and PSV. Patient work of breathing during PSV was found, however, to vary inversely with the level of pressure support. We conclude that: patient work of breathing during AMV and PSV can be calculated using a computer-assisted technique based on the equation of motion of the respiratory system, and depending on the amount of pressure support provided, patient work of breathing during PSV may be greater than, less than, or equal to the work performed during AMV.

20 Kreit, Capper, Eschenbacher. Am J Respir Care Med 1994;149: 1085-1091
Effect Pressure Support Ventilation on breathing patterns and respiratory work

H. Tokioka, S. Saito and F. Kosaka
Department of Anesthesiology and Resuscitology, Okayama University Medical School, 2-5-1 Shikata-cho, Okayama 700, Japan

- Abstract -
We assessed the effect of pressure support ventilation (PSV) on breathing patterns and the work of breathing in 10 postoperative patients. Minute ventilation (VE) increased by 8% with 5 cm H2O PSV and 10% with 10 cm H2O PSV compared to 0 cm H2O PSV. The increase in VE was achieved by increased mean inspiratory flow (24% with 5 cm H2O PSV and 67% with 10 cm H2O PSV) and a decrease in duty cycle (13% with 5 cm H2O PSV and 39% with 10 cm H2O PSV). The decrease in duty cycle along with a decrease in respiratory frequency allowed a greater expiratory time including a rest period for the respiratory muscles, which might minimize the risk of muscle fatigue. Furthermore, the inspiratory work added by the ventilator was near zero with 5 cm H2O PSV and 10 cm H2O PSV. Oxygen consumption also decreased significantly with 5 cm H2O PSV. We conclude that PSV improves the breathing patterns and minimizes the work of breathing spontaneously via ventilator.

Comparison of Pressure Support Ventilation and assist control ventilation in patients with acute respiratory failure

H. Tokioka, S. Saito and F. Kosaka

Department of Anesthesiology and Resuscitology, Okayama University Medical School, Okayama, Japan

- Abstract -

We compared the effects of pressure support ventilation (PSV) with those of assist control ventilation (ACV) on the breathing pattern, work of breathing and blood gas exchange in 8 patients with acute respiratory failure. During ACV, the tidal volume was set at 10ml/kg, and the inspiratory flow was set at 50 to 70l/min. During PSV, the pressure support level selected was 27 ± 5 cm H2O to make the breathing pattern regular. Tidal volume was significantly higher (908 ± 179 ml vs. 633 ± 96 ml) during PSV than during ACV and a lower peak airway pressure. Respiratory frequency was lower (15 ± 4 breaths/min vs. 24 ± 5 breaths/min) during PSV than during ACV, associated with a lower duty cycle, which improved synchrony between the patient and the ventilator. The oxygen cost of breathing, an estimate based on the inspiratory work added by a ventilator and the oxygen consumption, did not change significantly. PaO2 was significantly higher during PSV than during ACV. We conclude that PSV using high levels of pressure support can improve the breathing pattern and oxygenation and fully sustain the patient’s ventilation while matching his inspiratory efforts.

Pressure support ventilation and the critically ill patient with muscle weakness

J. W. H. Watt
Spinal Injuries Unit
Southport and Ormskirk Hospital NHS Trust
Town Lane
Southport PR8 6PN
UK

The case reports by Kannan and colleagues in this issue of British Journal of Anaesthesia serve to highlight that we should remain alert for inspiratory triggering failure during pressure support ventilation (PSV) in patients with severe muscle weakness. Despite improvements in the ability of ventilators to respond to the patient’s own breathing pattern, inspiratory triggering failure may also be encountered in patients with chronic obstructive airways disease (COAD) or acute lung injury, who have high intrinsic positive end-expiratory pressure (PEEPi) in addition to possible muscle fatigue. There is also the potential for expiratory triggering failure and mismatches in tidal exchange in PSV.

[..] The flow ‘sensitivity’ setting of 2 litre min⁻¹ may be considered to be equivalent to a pressure ‘sensitivity’ setting of cm H₂O. Whether at a flow sensitivity of 1 cm H₂O, cardiogenic oscillations can result in spurious autotriggering in nearly one in five patients, and even in the brain dead. In contrast, when the trigger setting is less sensitive, triggering may fail in the presence of muscle weakness or impaired central drive. This could also occur when tracheobronchial secretions episodically increase the inspiratory resistance. Inspiratory triggering may fail in patients with a rapid respiratory rate and short expiratory time, and in patients with significant intrinsic PEEP and a corresponding delay in the fall in airway pressure on expiration. Deviation from the one to one response which is a ventilatory response following each breathing effort, increases at higher ventilatory frequencies and higher levels of pressure support and lower levels of patients effort.

[..]

Being simple to set up, PSV has become widely used for the patient with an adequate ventilatory drive who is not so ill as to require muscular paralysis and controlled ventilation, especially as it probably prevents or helps restore deconditioned respiratory muscles, and the patient does not appear to ‘fight’ the
ventilator in the same way as with synchronized intermittent mandatory ventilation (SIMV). [...] Another reason for mandatory back-up rate is that peripheral muscle fatigue in acute tetraplegia is associated with adaptive central fatigue, which may manifest as periodic breathing or sleep apnoea. The tetraplegic patient who has lost all intercostal breathing has also lost the ability to share the work of breathing between the diaphragm and intercostal muscles, a pattern known as respiratory alternans, which predisposes to fatigue. A raised carbon dioxide blood gas tension in neurological patients breathing with CPAP or PSV is always indicative of muscle weakness or fatigue. [...]
Spontaneous versus positive pressure ventilation with the laryngeal mask airway: a review

Abstract:
Over the last 10 years, the Laryngeal Mask Airway (LMA) has gained widespread acceptance as a general purpose airway for routine anaesthesia. Published data from large studies and reports have confirmed the safety and efficacy of the device for spontaneous and controlled ventilation during routine use. The initial experience with the LMA should ideally be confined to short cases requiring the patient to remain spontaneously ventilating. With experience, it will be found that less anaesthetic agent is required during anaesthesia with the LMA and patient recovery should be improved as a result. Spontaneous breathing is the chosen mode of ventilation in approximately 60% of LMA uses in the UK. During spontaneous breathing a minimal inspiratory pressure support will help with higher end-tidal carbon dioxide levels. The anaesthetist should be experienced with using the LMA in spontaneously ventilating patients before using it with positive pressure ventilation. Several large scale studies have failed to show any link between positive pressure ventilation and pulmonary aspiration or gastric insufflation. The main disadvantage of the LMA is that it does not protect against aspiration. From a practical point of view, most fasted patients with normal lung compliance may be mechanically ventilated through the LMA to airway pressures of approximately 20 cmH₂O. The low pressure seal implies that tidal volumes should be approximately 6-8 ml*kg⁻¹ and the inspiratory flow rates should be reduced to achieve adequate and safe ventilation.

IV. Dräger & Pressure Support

In the Critical Care we have a lot of know-how in Pressure Support (PS) thanks to our long lasting experience. Supplementary, our anaesthesia workstation will provide Pressure Support from now on too. We observe that there is a strong trend in the market to let patients breathe spontaneously during anesthesia.

For an intubated or LMA’ed (Laryngeal Mask) spontaneously breathing patient, PS will clearly reduce the work of breathing. In the interest of the patient and his wellness, Pressure Support is the ideal choice, if the patient is able to breathe spontaneously. Already today PS is a popular ventilation mode and will continue to be even more popular.

What does Pressure Support mean for you & your spontaneously breathing patient?

- Less invasive ventilation
- Prevent ventilatory muscle fatigue & failure
- Reduction of sedation
- Reduction of risk of atelectasis
- Improved gas exchange in anesthetized patients

From this it follows:

- Less risk & more comfort for a spontaneously breathing patient
- Improved quality of patient care

How can Dräger support you?

Based on its outstanding experience and excellence in the fields of Anaesthesia & Intensive Care Unit (ICU) ventilation and its sophisticated, highly reliable, piston ventilator technology …

… Dräger now offers an automatic Pressure Support Ventilation mode!
Allowing you to increase your personal dedication towards your patients, for the sake of a higher quality of patient care and an even improved patient outcome, while reducing your stress level.

**Which clinical benefits do you have?**
Pressure Support (PS) supports the intubated or LMA\'ed spontaneously breathing patient to easier overcome the resistance of the circuit, hence improving his comfort and the quality of patient care.

**PS is especially useful during:**
- **Patient wake-up period**
- **Settings where:**
  - a) No muscle relaxation is used, e.g. ENT-children, dental surgery, multiple peripheral indications …
  - b) Support for overcoming the risk of breathing depression is desired, e.g. caused by administered drugs, hypocapnia.
B. General Advantages of pressure support

✓ Decreases the patient's work of breathing (WOB) during anaesthesia
✓ Improved alveolar recruitment
✓ Improved venous return
✓ Lower shunt
✓ Reduction of invasivity of ventilation
✓ Prevention of ventilatory muscle fatigue & failure
✓ Reduction of sedation
✓ Reduction of risk of atelectasis
✓ Improved gas exchange in anesthetized patients
✓ Rapid wake-up, so quicker change over and shorter stays in recovery room with no need for post-ventilation
✓ Improved tidal volume ($V_T$)

With the Pressure Support you set a support level in cm H$_2$O (mbar) enough to overcome the resistance of the tube or LMA. Pressure Support is synchronized to the patient’s own spontaneous efforts.
C. Pressure Support & Fabius GS

Specialities of the pressure support in Fabius GS:

- Trigger sensitivity controlled via a Bias Flow
- Flow increased in Pressure Support up to 85 L/min
What is Bias-Flow?
In a word: Bias-Flow provides ‘a head start’ and reduces the work of breathing immediately.

The flow rate needed for trigger detection will be provided by moving the piston upward during the expiratory pause period. The maximum flow rate that is used will depend on the Trigger Sensitivity setting.

- **High Sensitivity**: means that a small patient effort is needed to trigger pressure support. With a high sensitivity setting the Fabius GS can use a low Bias-Flow rate.
- **Low Sensitivity**: means that a large patient effort is needed to trigger pressure support. With a low sensitivity setting the Fabius GS must deliver a high Bias-Flow rate.

Flow rates of two to twelve liters per minute will be used.
**How does it work?**

First, the patient’s **spontaneous inspiratory effort** is indicated by a **pressure drop** (A). Then the Fabius GS rapidly **increases flow** to reach the **desired Pressure Support Level** (B). Once the Pressure Support Level is **attained**, the ventilator delivered **flow** is **completely synchronized** with the patient’s demand to maintain the pressure plateau (C). The support level is **maintained until the inspiratory flow drops below 25%** of the maximum inspiratory flow delivered, then the ventilator **starts expiration** (D).

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**What’s about the trigger?**

In the Fabius GS you have a **flow triggered** (inspiration) and **flow cycled** (expiration) pressure support. During expiration the piston is moved back to the start position. The Fabius GS will monitor the flow going through the expiratory flow sensor to determine the piston speed needed.
Which settings can be adjusted?

(1) Pressure Support Level (over PEEP)
(2) Trigger Sensitivity [L/min]
(3) Inspiratory Flow [L/min]
(4) Positive End Expiratory Pressure [mbar]

<table>
<thead>
<tr>
<th>Parameter/Function</th>
<th>Minimum Value</th>
<th>Maximum Value</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>ΔPPS</td>
<td>3 (0 = CPAP available after 2.n)</td>
<td>20</td>
<td>hPa</td>
</tr>
<tr>
<td>PEEP</td>
<td>0</td>
<td>20</td>
<td>hPa</td>
</tr>
<tr>
<td>Insp Flow</td>
<td>10</td>
<td>85</td>
<td>L/min</td>
</tr>
<tr>
<td>Trigger Sensitivity</td>
<td>2</td>
<td>15</td>
<td>L/min</td>
</tr>
</tbody>
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## V. Abbreviations

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
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<tbody>
<tr>
<td>ACV</td>
<td>Assist Control Ventilation</td>
</tr>
<tr>
<td>AMV</td>
<td>Assisted (Volume-Cycled) Mechanical Ventilation</td>
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<tr>
<td>ASB</td>
<td>Assisted Spontaneous Breathing</td>
</tr>
<tr>
<td>CMV</td>
<td>Controlled Mechanical Ventilation</td>
</tr>
<tr>
<td>COAD</td>
<td>Chronic Obstructive Airway Disease</td>
</tr>
<tr>
<td>CPAP</td>
<td>Continuous Positive Airway Pressure</td>
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<tr>
<td>FRC</td>
<td>Functional Residual Capacity</td>
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<tr>
<td>ICU</td>
<td>Intensive Care Unit</td>
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<tr>
<td>IHS</td>
<td>Inspiratory Help System</td>
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<tr>
<td>IMV</td>
<td>Intermittent Mandatory Ventilation</td>
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<tr>
<td>IPPV</td>
<td>Intermittent Positive Pressure Ventilation</td>
</tr>
<tr>
<td>LMA</td>
<td>Laryngeal Mask Airway</td>
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<tr>
<td>PCV</td>
<td>Pressure Controlled Ventilation</td>
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<tr>
<td>PEEP</td>
<td>Positive End-Expiratory Pressure</td>
</tr>
<tr>
<td>PS(V)</td>
<td>Pressure Support (Ventilation)</td>
</tr>
<tr>
<td>SIMV</td>
<td>Synchronised Intermittent Mandatory Ventilation</td>
</tr>
<tr>
<td>VCV</td>
<td>Volume Controlled Ventilation</td>
</tr>
<tr>
<td>WOB</td>
<td>Work of breathing</td>
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</table>
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