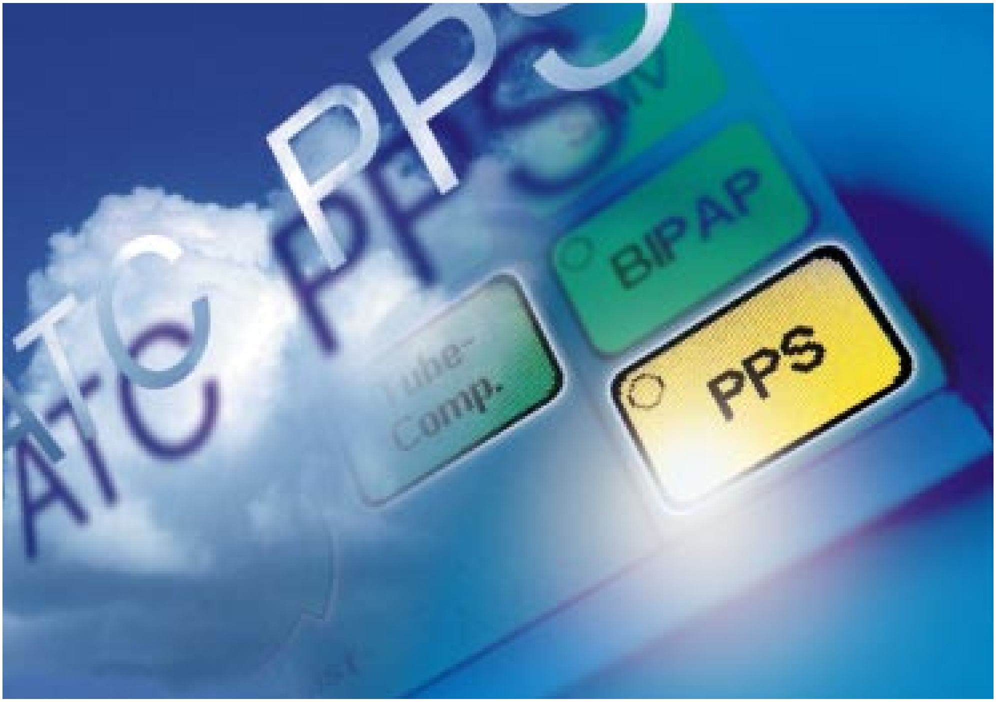

ATC and PPS Breathing Support with Optimum Patient Comfort

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ATC and PPS
Breathing Support with Optimum Patient Comfort

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Preface

Today most users emphasize the need for spontaneous breathing ability during mechanical ventilation. This all began with triggered ventilation where the goal was to synchronise the beginning of inspiration. Ventilation forms like pressure support (ASB), for the first time, also permitted synchronisation with the end of inspiration. Today proportional pressure support (PPS) offers the results of even further innovation, where at every point the breath delivered by the ventilator is proportional to the breathing effort of the patient. Essentially, the result is a reduction in resistive and elastic work of breathing. One example of reduction in resistance is compensation of artificial airway resistance created by the tube.

Contents

Automatic Tube Compensation: ATC

By creating artificial airway resistance, the tube makes it considerably harder for patients to breathe spontaneously. Automatic Tube Compensation (ATC) is a new addition for all existing ventilation modes. ATC is easy to set and precisely compensates for this artificial airway resistance. The objective is to give the patient the feeling that, in terms of work of breathing, he is not intubated, and hence ATC can also be described as “electronic extubation”.

The basic principles and setting of ATC are described in more detail below.

Principles of tube compensation

Virtually all ventilated patients in intensive care are intubated, and the tube constitutes a major constriction within the airways.

So long as a patient is being given controlled ventilation, this artificial airway resistance is no great problem, since it can be overcome fully by the ventilator. However, as soon as the patient is supposed to breathe on his own, for the purposes of weaning for example, the artificial resistance caused by the tube makes breathing more difficult as compared with non-intubated patients.

The flow of gas through the tube results in a difference in pressure (ΔP_{tube}) between the two ends of the tube. The respiratory muscles have to compensate for this pressure difference by creating a powerful negative pressure in the lung.

This greater work of breathing can be cancelled out by increasing the pressure at the top end of the tube by exactly the same amount as the difference in pressure.

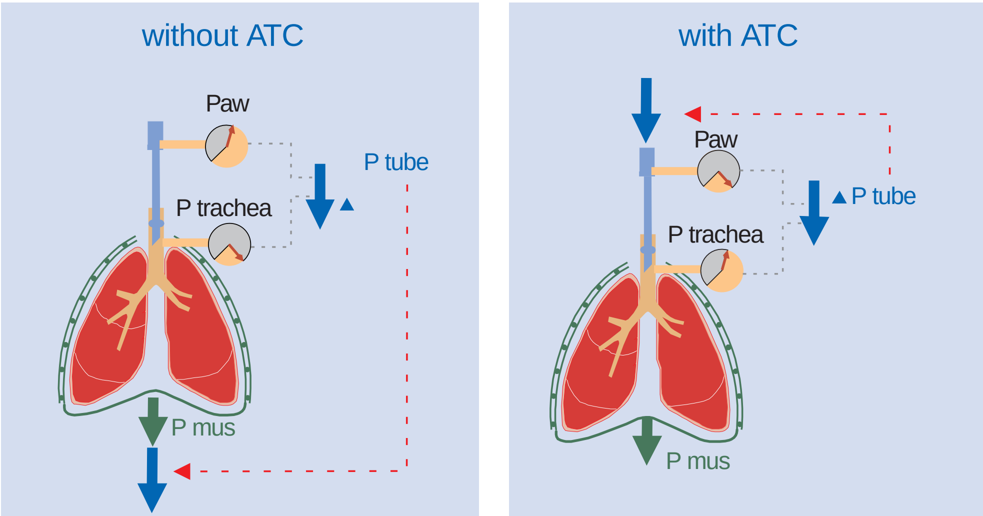


Fig. 1
Without ATC (left), the patient has to generate ΔP_{tube}. With ATC (right), the ventilator produces exactly this ΔP_{tube} and relieves the patient of the extra work.

The pressure difference across the tube changes proportionately to the gas flow (see Fig. 3). This means that the compensation pressure at the top of the tube also has to be continuously adjusted to the current flow.

Direct measurement of the pressure at the carinal end of the tube is highly prone to error in clinical routine on account of moisture and mucus etc. As the dimensions and physical properties of the tube are known, the pressure difference across the tube can also be continuously calculated [1][2]. Using the flow measured by the ventilator, the difference in pressure at any given time can be calculated on the basis of the following equation:

Pressure = R_{tube} Coef. x $Flow^2$, where tube resistance R is itself dependent on the flow.

By increasing the pressure at the top of the tube, the patient is deliberately relieved of the artificially increased work of breathing. This can be illustrated using a simple example: a person pulling a car will have to work less hard the more the person at the back pushes.

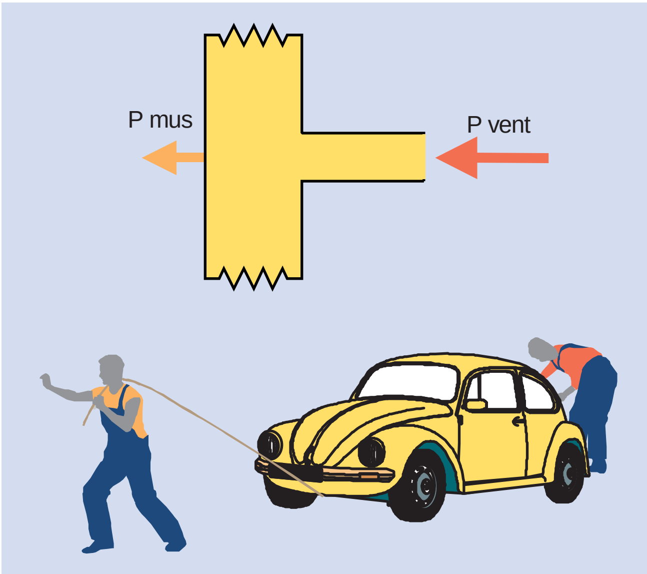


Fig. 2
In ventilation, the higher the pressure support (P_{vent}), the less the work of breathing required of the patient to receive the same level of ventilation.

In clinical practice nowadays, pressure support is also used to compensate for the tube. In conventional pressure support (ASB), the ventilation pressure (P_{aw}) is increased to a fixed preset level as soon as the ventilator detects an inspiratory effort on the part of the patient. Once therapy and weaning have been successfully completed, a small support pressure ASB is generally used to compensate for the tube until the patient is finally extubated. As can be seen in Figure 3, however, in the case of a 7.5 mm tube with an ASB of 5 mbar this pressure level only provides optimal compensation for the actual drop in pressure at the tube when the flow is 45 L/min.

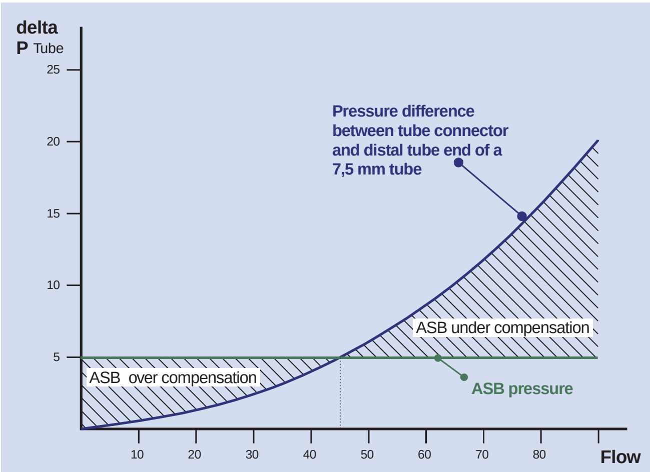


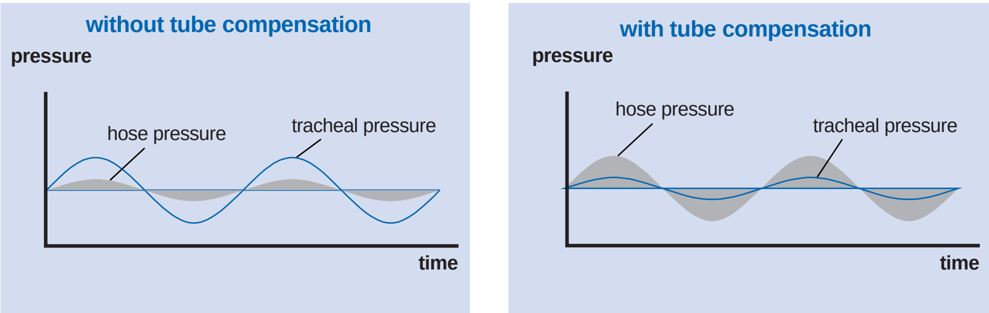
Fig. 3
Fixed pressure support (ASB) as compared with the pressure support (blue line) usually required to compensate for the tube.

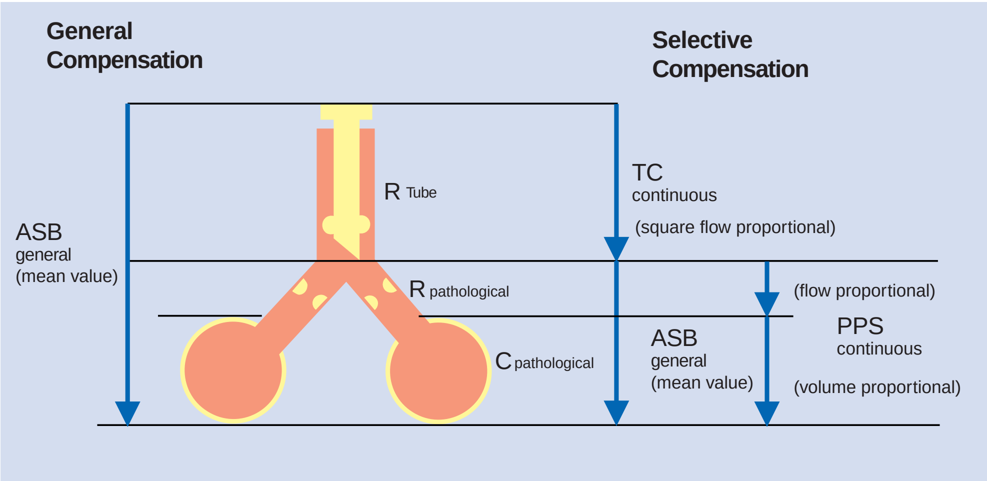
If a patient generates a high flow with a strong inspiratory effort, therefore, the pressure difference across the tube can be considerably greater than the set ASB pressure. The tube will then not be fully compensated. The ASB pressure which is set to compensate for the tube can therefore only be selected correctly if an average value is chosen. As the patient's spontaneous breathing improves, the proportion of ASB needed for tube compensation would thus have to be constantly adjusted manually.

In such cases, automatic tube compensation offers optimized automatic adjustment, the pressure at the top of the tube being increased proportionately to the flow by the ventilator. Hence the ventilator continually calculates the pressure difference over the tube and increases the pressure in the hose system by precisely this amount. (Fig. 1).

If a smaller tube is used, the pressure difference will be greater for the same flow. Hence the narrower the tube's diameter, the greater the work of breathing required of the patient [3]. The internal diameter of the tube is thus an important parameter in ATC which is set just once at the start of ventilation.

Fig. 4
Normal behaviour of pressure in the ventilation hoses (shaded curve) and the pressure in the trachea (single line) in an intubated patient with and without ATC.





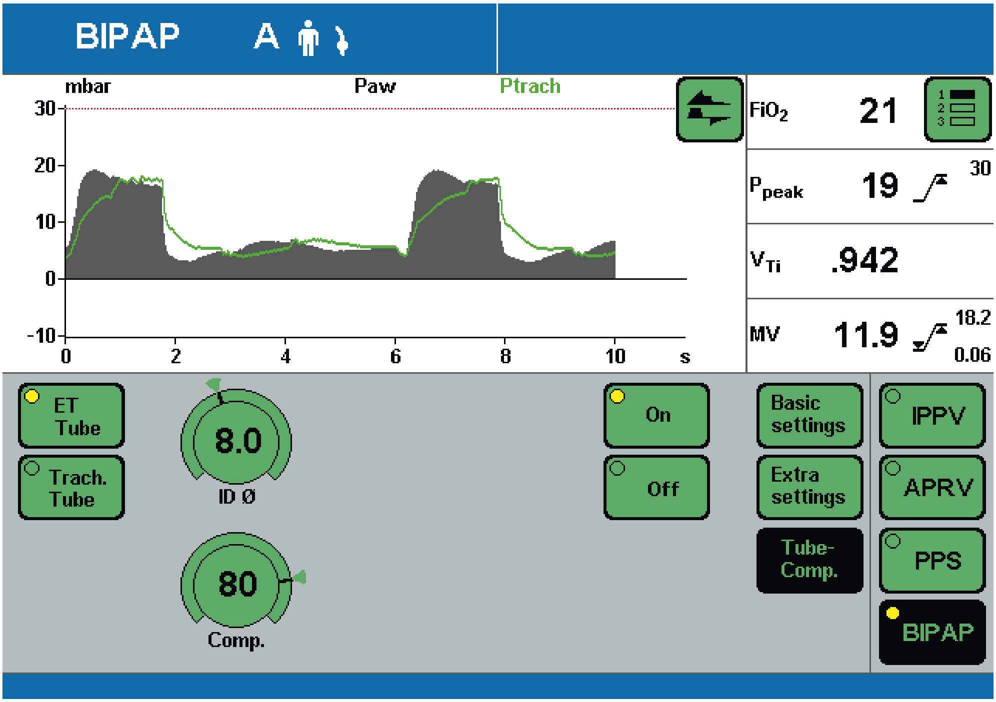
When ATC is activated, the ventilator regulates compensation on the basis of the current tracheal pressure (calculated continuously). The tracheal pressure curve (in addition to the pressure in the hose system) is shown as a coloured line on the ventilator screen which makes it easy for the user to follow the effect of the automatic tube compensation.

Fig. 5
With the aid of tube compensation and proportional pressure support (PPS) as described below, the various airway resistances and compliance can be compensated selectively.

Tube compensation (ATC) settings

Tube compensation can be used in any mode of ventilation and is extremely easy to set. First of all the size of tube needs to be set, and then the user chooses whether the tube should be compensated completely (100 %) or only partially (1-99 %).
The tube compensation is then activated by pushing the ON button. The level of compensation setting may also be used as training for the respiratory muscles.

Fig. 6



The length of the tube has no significant bearing on the tube resistance even in the case of shortened tubes, and consequently does not need to be entered.

Tube compensation has an inspiratory and expiratory effect. For expiratory compensation the pressure in the hose system is reduced, if necessary, to no lower than the ambient pressure. The control ensures that the tracheal pressure (the pressure at the carinal end of the tube) does not fall below the set CPAP pressure.

For ease of comprehension, the calculated tracheal pressure and the pressure in the hose system are simultaneously displayed as pressure curves when the tube compensation is activated. The pressure in the hose system is shown as a shaded curve while the tracheal pressure appears as a single line.

In the case of obstructive patients it can sometimes be useful to deactivate the expiratory compensation. This results in the pressure at the end of the tube being maintained above the set CPAP pressure for a longer period. During the expiratory flow phase this may help to keep obstructed areas open for longer.

To this end the expiratory compensation can be deactivated in the configuration menu.

Proportional Pressure Support: PPS™

What is Proportional Pressure Support?

Proportional Pressure Support (PPS™) is a form of breathing support for patients whose spontaneous breathing efforts still require assistance or whose work of breathing is increased as a result of higher resistance and/or lower compliance [4]. Due to the fact that PPS could potentially be used for patients who today are being assisted with pressure support (ASB), the main similarities and differences of these methods will be described in greater detail below.

The principles on which Proportional Pressure Support is based are identical with those to be found in North American literature on Proportional Assist Ventilation (PAV).

The status of spontaneous breathing

In developing new modes of ventilation the goal has always been to make the “unphysiological” positive pressure ventilation as gentle and non-disruptive as possible. With the development of microprocessor technology it became possible for the first time to determine more or less freely the flow and pressure characteristics. Particular attention in this context was given to improving synchronization with the spontaneously breathing patient. The first step came with the triggering of the mechanical breath with IPPVassist. However, apart from the initiation of the ventilator breath, this still did not take the patient’s inspiratory efforts into account. The ventilator imposed a fixed flow and inspiration time, and the patient had no chance to participate. It was only later that intermittent spontaneous breathing became possible in the ventilation mode SIMV.

For the first time, pressure support (ASB) enabled more precise coordination with the spontaneously breathing patient. It was now finally possible for the patient to influence the flow delivered by the ventilator through his own respiratory efforts. Furthermore, the lung mechanics as well as the patient now largely determined the length of inspiration. However, it soon became apparent that defining the ASB pressure alone was not always enough to ensure that it was well-adjusted to the spontaneous breathing of the patient. There was clearly a need to adjust the initial flow of the inspiratory breaths too, and by using an adjustable pressure ramp it was possible to achieve greater patient comfort.

One of the limitations of pressure support (ASB) is that once the support has been set it remains constant. Changes in the patient’s spontaneous breathing do not affect the degree of support provided. Furthermore, the design of the ventilator means that it can only track the course of inspiration very roughly, with the result that the patient's breathing efforts are alternately over- and under-compensated. In Proportional Pressure Support, on the other hand, the pressure support is provided proportionately to the work of breathing throughout inspiration and the patient’s needs are directly and continuously met.

The lung mechanics of the spontaneously breathing patient

In a patient with healthy lungs, breathing gas flow and thus tidal volume are more or less proportional to the inspiratory effort. The greater the inspiratory effort, the greater the volume inhaled. In contrast, a patient with a lung disorder, increased resistance and/or reduced compliance may be faced with work of breathing per volume breathing gas which is increased to such an extent that the same inspiratory effort results in a much smaller volume being inhaled (Fig. 7).

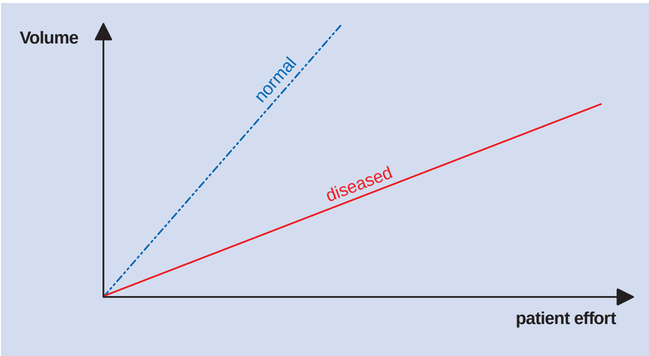


Fig. 7
A patient with diseased lungs receives a smaller volume for the same inspiratory effort as compared to a patient with healthy lungs.

However, as the patient will always attempt to get sufficient ventilation, there is a risk of muscle exhaustion. Using Proportional Pressure Support, however, the "comfort" for the spontaneously breathing patient can be increased significantly by deliberately reducing the work of breathing.

Figure 8 shows a simple model for the lung mechanics of a spontaneously breathing patient.

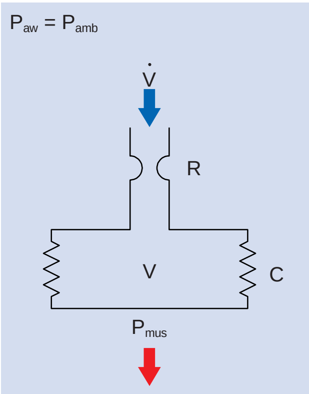


Fig. 8

P_{aw}: Airway pressure
P_{amb}: Atmospheric air pressure
P_{mus}: Muscle effort for spontaneous breathing
R: Resistance
C: Compliance
$\dot{V}$: Patient flow
Vt: Tidal volume

The lung, represented here by resistance and compliance, is filled with the tidal volume resulting from the effort of the respiratory muscles, and the tidal volume is then exhaled at the end of inspiration due to the elastic recoil forces of the thorax.
The airway pressure is equivalent to the ambient pressure. The development of flow and volume can be calculated from the equation of motion, where the sum of airway pressure and inspiratory effort creates the actual volume displacement.

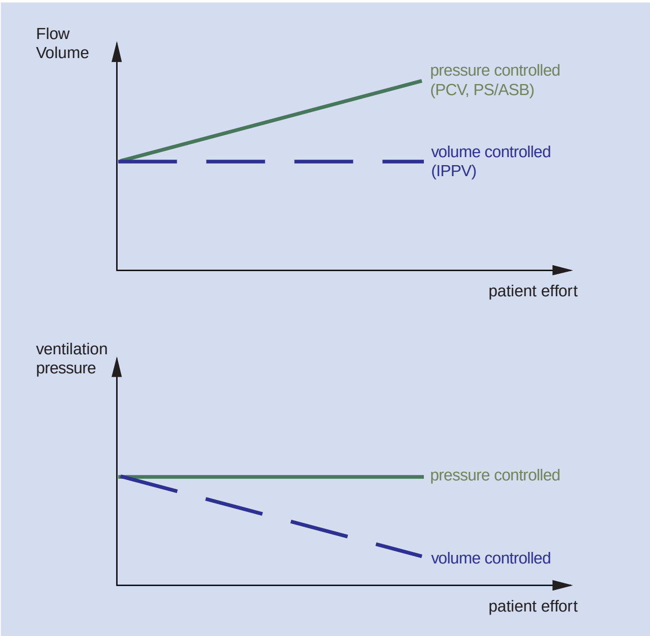
The spontaneously breathing, intubated patient

Figure 2 also applies for the spontaneously breathing, intubated patient, though in this case the airway pressure is controlled by the ventilator during inspiration. Hence from this point on the airway pressure will be referred to as Pvent.

$$P_{vent}+P_{mus} = R \times \dot{V} + 1/C \times V$$

Depending on the ventilation mode, the inspiratory effort of the patient can provoke different reactions from the ventilator with respect to flow, volume and ventilation pressure (Fig. 9).

Fig. 9
Reaction of ventilator to inspiratory efforts of patient in different modes of ventilation.



Whereas the classical volume-controlled modes do not show any reaction with regard to flow and volume, the pressure-controlled modes react by increasing flow and volume. Important in this context is only the basic correlation; the starting values shown in the diagrams for zero inspiratory effort are chosen at random and of course depend exclusively on the ventilator settings.

The spontaneously breathing patient with Pressure Support/ASB

Pressure Support (ASB) was the first form of breathing support able to give greater consideration to the individual needs of the spontaneously breathing patient. Figure 10 shows typical curves for the inspiratory effort and the resulting pressure changes in the ventilator, as well as flow and volume curves. The inspiratory effort is represented in this example by P_{mus} which can generally be measured using an oesophageal catheter.

The ventilator is triggered by the inspiratory effort of the patient and reacts by providing the preset inspiratory pressure. The volume of the resulting flow can be calculated as the sum of the “drive forces” $P_{mus} + P_{vent}$, or from the total resistance of the respiratory system including the tube. The “switch-off” criteria for the inspiration is based on the patient flow: if the patient flow falls below a predefined threshold, the ventilator switches to expiration. The moment when this happens is mainly determined by resistance and compliance.

Figure 11 clearly shows curves with constant spontaneous breathing volume and variation of resistance.

Figure 10 shows what happens when the inspiratory effort varies. For instance, the ventilator delivers more flow and volume when this is needed, yet this in turn demands increased work of breathing on the part of the patient.

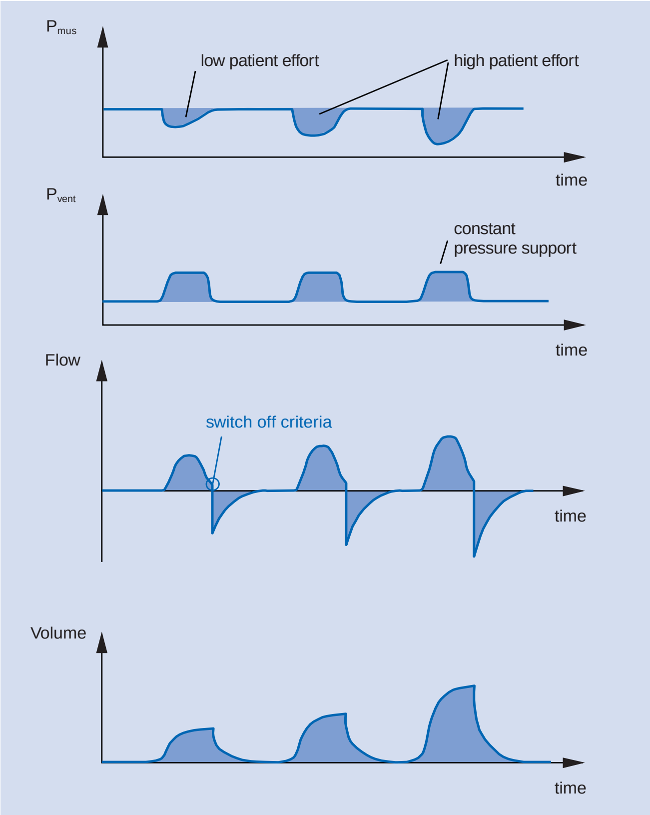


Fig. 10
Typical curves for the inspiratory effort, the resulting pressure changes in the ventilator and the flow and volume curves in PS/ASB.

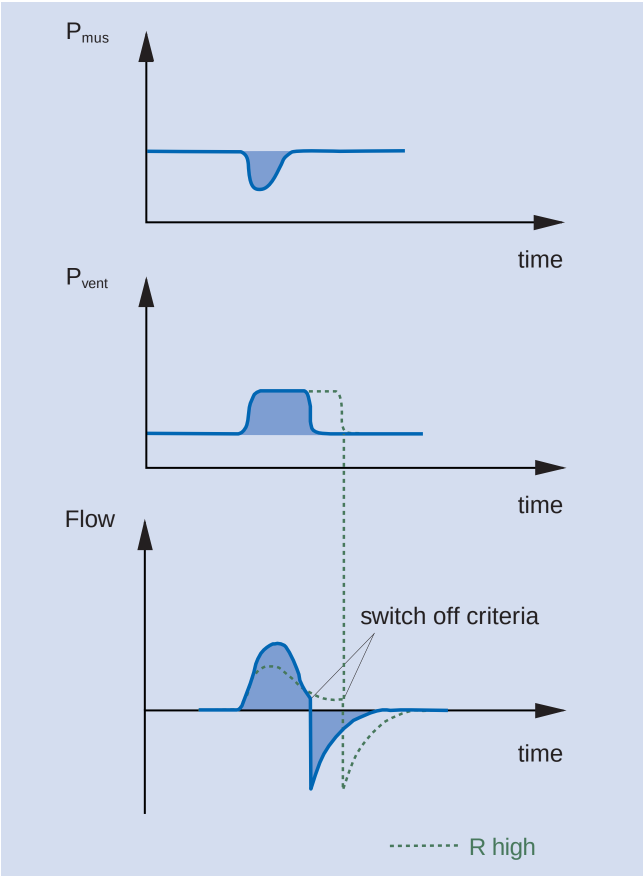


Fig. 11
In classical pressure support, the time when expiration starts is largely determined by the resistance and compliance of the lung.

In simplified terms, it can be said that the degree of support set in Pressure Support (ASB) is roughly correct only at the time of setting. If however the spontaneous breathing pattern changes, the ventilator does not sufficiently take this into account.

Basic principles of Proportional Pressure Support (PPS™)

There are several possible ways of explaining the properties of Proportional Pressure Support (PPS™) on the basis of existing knowledge. For example, PPS™ can be viewed as a further development of Pressure Support (ASB), even though there are several significant differences. Another possibility would be to regard PPS™ as a kind of CPAP in which two parameter settings, Flow Assist and Volume Assist, are used to reduce the work of breathing caused by resistance and compliance.

The principles of PPS™ are exactly the same as those of Proportional Assist Ventilation (PAV) as described in North American literature. A list of known publications is provided in the Appendix.

Using PPS™, the efficiency of spontaneous breathing can be increased in lung-diseased patients (Fig. 12). The principle which this is based on can be explained using the following equation of motion:

$$P_{AW} + P_{mus} = R \times \dot{V} + 1/C \times V$$

P_{AW}: airway pressure

In the case of the intubated patient, the airway pressure is replaced by the ventilation pressure provided by the machine. The following applies for the effort of the respiratory muscles

$$P_{mus} = R \times \dot{V} + 1/C \times V - P_{vent.}$$

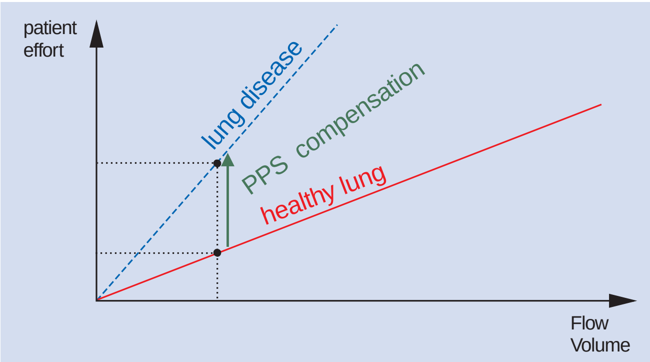


Fig. 12

If it is then possible to control the ventilator on the basis of the patient flow and the applied volume

$$P_{vent} = K1 \times \dot{V} + K2 \times V,$$

then obviously the "muscle work" required can be largely compensated depending on the constants K1 and K2 to be set:

$$P_{mus} = R \times \dot{V} + 1/C \times V - K1 \times \dot{V} - K2 \times V$$

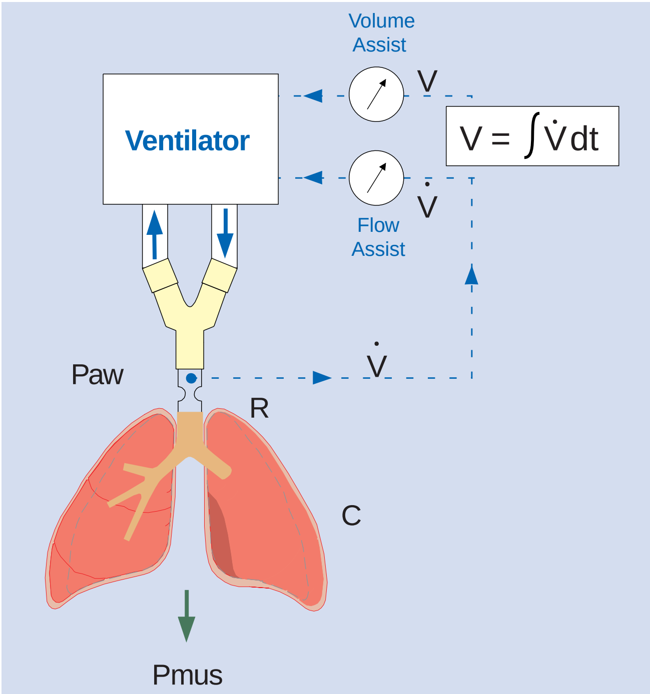
K1: Flow Assist
K2: Volume Assist.

This illustrates clearly how the two parameters K1, Flow Assist, and K2, Volume Assist, can be used to reduce the amount of muscle work needed as a result of resistance and compliance. Theoretically, this method could bring down the amount of spontaneous breathing needed to zero, though in practice this is not possible due to technical stability limits.

Technical implementation

The technical principle on which PPS™ is based is shown in Fig. 13.

Fig. 13



In PPS™, the patient flow and volume are continually measured and calculated. Using the "amplification factors" Flow Assist and Volume Assist which are set by the user, the ventilator's microprocessor calculates continuously at each point of the breathing cycle the proportional pressure support for the patient.

Figure 14 shows what happens in PPS™ in the case of varying inspiratory efforts, and how this differs from Pressure Support (ASB).

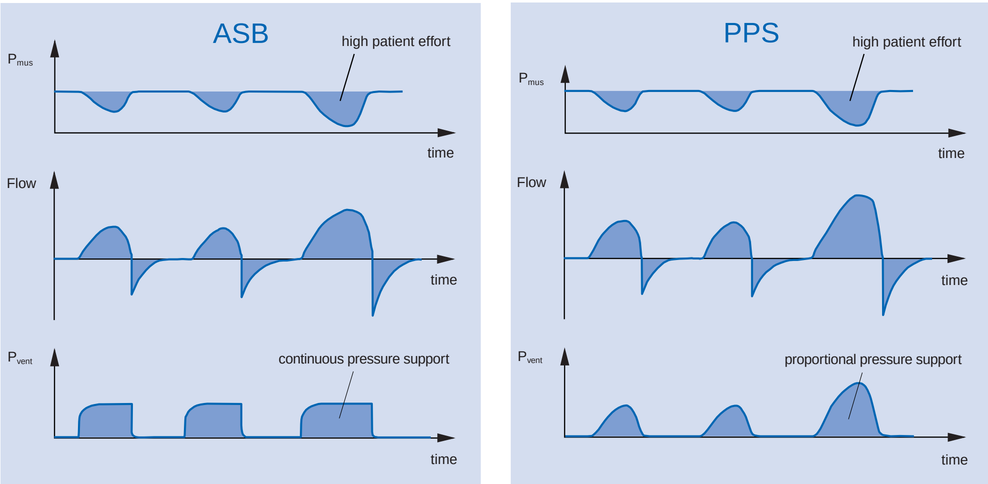


Fig. 14
Differences between PPS™ and classical PS with varying inspiratory efforts

The example shows a number of different inspiratory efforts which result in different levels of flow. A fundamental difference lies in the way the ventilator reacts to this variation. While support during Pressure Support (ASB) always remains constant, in PPS™ support is provided proportionally. This proportional delivery results in support being provided only when it is needed. For this reason it is advisable to provide apnoea ventilation for patients breathing in PPS™ as a safety net in case apnoea occurs.

Due to the fact that Proportional Pressure Support is a coupling method (see also Figure 13), there is always the danger of instability. This can occur whenever the "amplification factors" Flow Assist and Volume Assist are set at a higher level than the actual resistance or elastance ($E = 1/C$). Hence it is important to know at least roughly what the resistance and compliance values are, so as to be able to judge the degree of support needed. The next chapter will deal in more detail with possible setting strategies. The advantages and limitations of Proportional Pressure Support compared to conventional methods are listed opposite.

Advantages and limitations of PPS™

☺	☹
• Patient comfort • Patient needs are nearly completely met • No hyperventilation • Less sedation • Low airway pressures • Only two parameters need to be set in addition to PEEP and FiO_2	• Spontaneous breathing is essential for this procedure • No “minimum support” as ventilation guarantee • Setting requires knowledge of resistance and compliance • Instability possible if settings incorrect • Tube leakage may impair function

Differences between Pressure Support and Proportional Pressure Support

PS/ASB	PPS™
• Constant level of pressure support	• Pressure support varies with inspiratory effort
• Minimum support for as long as patient triggers the ventilator	• No minimum support as ventilation guarantee (though backup possible with apnoea ventilation)
	• Optimal adjustment to patient’s spontaneous breathing

Practical application of PPS™

Proportional Pressure Support (PPS) is based on the PAV (Proportional Assist Ventilation) method described in scientific articles. Prof. Dr. Magdy Younes first investigated the practical application of this type of breathing support [5].

Proportional Pressure Support (PPS) constitutes an extremely promising method of breathing support which in an almost optimal manner relieves the patient of the work of breathing which would normally be required in the face of pathologically changed lung mechanics.

In recent years, more and more studies have been published on the subject of proportional breathing support. If PPS is to be routinely used on patients in all kinds of different situations, as a next step it would be useful to gain a broad range of clinical experience and develop simple therapy recommendations.

The new Breathing Support Package option for Evita 4 now offers the possibility of clinical application. For the time being, use and setting of PPS will require a good knowledge of the physiology of the lungs and in some cases the user will have to “feel his way” carefully to find suitable settings, until empirical values are available as for the classical modes of ventilation. Some fundamental approaches from the relevant literature are described below.

The primary setting of PPS first requires a knowledge of the resistance and elastance (elastance = 1/compliance) of the lung. However, it has not been possible as yet to determine these values with sufficient accuracy for spontaneously breathing intubated patients. Varying amounts of inspiratory effort from the patient would considerably distort the results.

The most reliable values are obtained in volume-controlled ventilation with constant inspiratory flow and with the patient not breathing spontaneously. It is important to ensure that there is no intrinsic PEEP (the flow must return to zero in the expiratory phase). It may also be appropriate in this case to suppress the patient's spontaneous breathing with targeted hyperventilation [6].

In principle, the compliance can then be calculated manually on the basis of

$$C = P_{plat} - Peep / Vt$$

and the resistance from

$$R = P_{peak} - P_{plat} / \text{Insp. flow.}$$

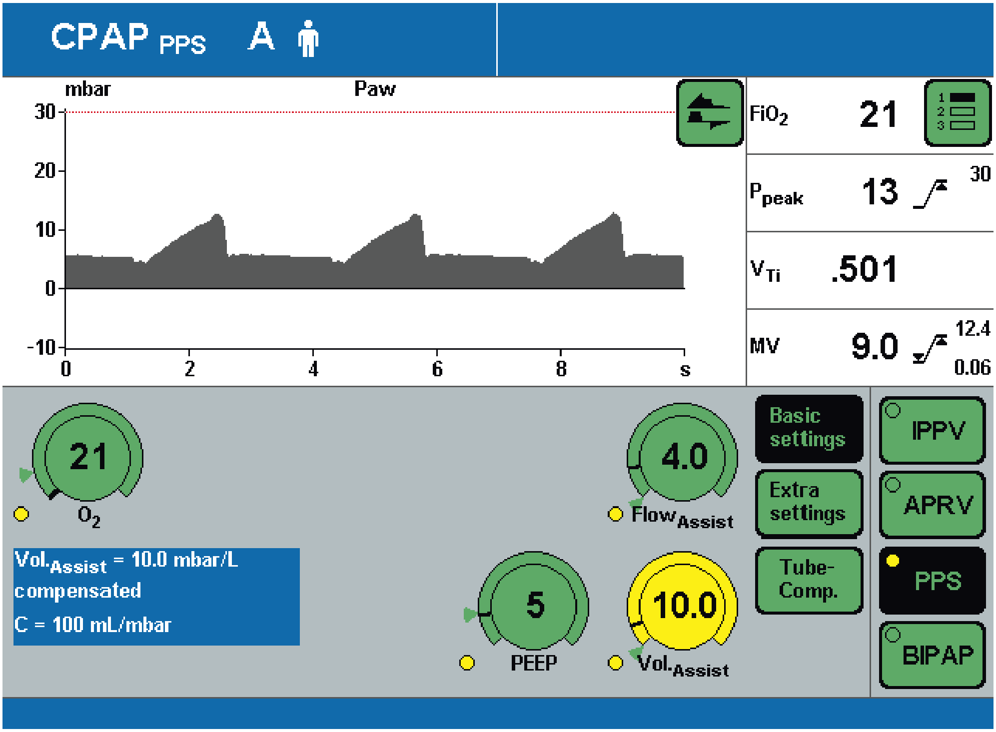
Using the resistance calculated as described, the tube resistance must also be established if PPS is to be combined with ATC [7].

The corrected formula would then be as follows:

$$R_{lung} = \frac{P_{peak} - P_{plat} - (Kx * \text{Insp. Flow}^2)}{\text{Insp. Flow}}$$

(For Kx see tube compensation factors from Instructions for Use of this option or relevant specialist literature).

In the relevant literature it is recommended that at most 80 % of the two established values be set when switching to proportional support [8].



Before switching to PPS, the volume and pressure limits must be set to a sufficient level to exclude the negative effects of possible overcompensation (“runaway”).

After switching modes, the first thing is to check that there are no signs of overcompensation ("runaway"). A sure sign of this problem is when a "Volume high" alarm is continuously activated, or when the patient is visibly using his expiratory muscles [8]. Another indication of "runaway" is a flow curve which rises quickly to a high level and then drops off abruptly [9].

If "runaway" does occur, the Volume Assist should be reduced until the problem is eliminated.

An overcompensation of resistance generally manifests itself in auto-triggering and cannot be corrected by setting the flow trigger. However, a clearly excessive Flow Assist can also cause "runaway", and the Flow Assist must then be reduced.

Following this initial setting, ventilation needs to be monitored regularly to check whether "runaway" conditions occur. If compliance improves (generally an increase) during therapy, this can likewise result in the set compensation for the elastance (elastance = 1/compliance) being higher than the actual elastance of the lung. In this context it is important to note that if for example a spontaneously breathing patient is repositioned, this can affect the compliance.

It may be that the only way to determine the elastance during PPS is to increase the Volume Assist to the point at which a "runaway" occurs [8]. This threshold should then be equivalent to the actual elastance of the lung and thorax, and the setting should then be reduced to 80 % of the value determined [8].

It is recommended that the original literature on proportional breathing support quoted in this booklet be studied before employing PPS (see Appendix).

On account of the extremely positive initial experience of PPS there are currently several studies underway which are likely to be published in the near future. For details of the literature which is currently available on this subject, please contact your local Dräger branch office.

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