



**Pressure Support Ventilation –  
A New Triggered Ventilation Mode for Neonates**

Jean Christophe Rozé  
Thomas Krüger

**Important Notice:**

Medical knowledge changes constantly as a result of new research and clinical experience. The authors of this introductory guide has made every effort to ensure that the information given is completely up to date, particularly as regards applications and mode of operation. However, responsibility for all clinical measures must remain with the reader.

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## 1.0 Introduction

Pressure Support Ventilation (PSV), a well known and widely accepted mode of respiratory support in adults has numerous publications, which describe application and benefits in this field of ventilation.

Pressure Support Ventilation although available in a few neonatal/pediatric ventilators is seldom used due to technical limitations despite the wide use of triggered ventilation modes such as SIMV or A/C in neonatology.

A specifically adapted neonatal Pressure Support Ventilation is now available with the Babylog 8000plus. This booklet sets out recommendations and descriptions, which refer to the Babylog 8000plus with software 5.0. The offered unique benefits for the use of PSV in neonates facilitate the application and improve the effectiveness of this new respiratory support. Nevertheless the first part of this booklet discusses theory of triggered ventilation in general and describes all the different ventilation modes. As well, an overview of the numerous publications in the field of triggered ventilation is given. The second part of this booklet focuses then on Pressure Support Ventilation as a further step in the evolution of neonatal triggered ventilation modes. PSV can be used during the acute phase of respiratory distress syndrome as well as during weaning, preferably in neonates who show high oxygen cost of breathing. The benefits, indications, limitations, ventilation strategies and control are described to help clinicians better understand and apply this new respiratory support. Moreover, the use of Pressure Support Ventilation in combination with the new mode Volume Guarantee is discussed.

The outlined strategies are based on publications and the first hand personal experience gained with this new mode. Nevertheless, due to the constant change in medical knowledge some of the descriptions may require revision in the future.

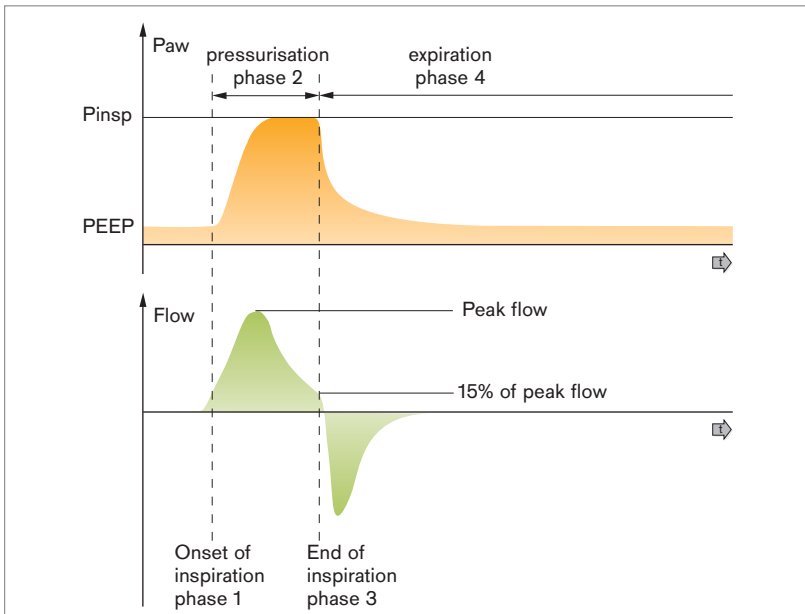
We hope that this booklet will help promote the use of Pressure Support Ventilation, based on the evidence so far there is the potential for many promising advances in the management of respiratory support of the critically ill neonate.

## 2.0 Pressure Support Ventilation

### 2.1 DEFINITION

Pressure Support Ventilation is a pressure limited ventilatory mode in which each breath is patient-triggered and supported. [1] It provides breath-by-breath ventilatory support by means of a positive pressure wave synchronized with the inspiratory effort of the patient, both patient-initiated and patient-terminated. Thus, during a cycle of Pressure Support Ventilation four phases can be distinguished which constitute the working principles of PSV [1]:

- Recognition of the beginning of inspiration
- Pressurization
- Recognition of the end of inspiration
- Expiration



**Figure 1:**

Pressure and airway flow signals during a PSV breath, showing the four phases: Recognition of the beginning of inspiration, pressurisation, recognition of the end of inspiration and expiration.

## **2.2 ADVANTAGES OF PRESSURE SUPPORT VENTILATION IN ADULTS [1]**

In adult ventilation Pressure Support Ventilation is world wide the mostly used ventilation mode for weaning patients off the ventilator. Many studies have been performed to evaluate Pressure Support Ventilation in adult critical care. The main advantages [1] observed during these studies were:

- Better synchrony between patient and ventilator
- Increased patient comfort
- Reduced need for sedation
- Decrease in work of breathing
- Decrease in oxygen cost of breathing
- Shorter duration of weaning process (observed only in few studies) [2]
- Endurance oriented training of respiratory muscles [47]
- Deepening of weak shallow spontaneous breathing

## **2.3 PRESSURE SUPPORT VENTILATION IN NEONATES**

During conventional ventilation neonates are ventilated with continuous flow, pressure limited, time cycled ventilators. The introduction of triggered

ventilation has been a marked improvement in neonatal ventilation. Various triggered ventilation modes have been developed for neonates: Synchronous Intermittent Mandatory Ventilation (SIMV), Assist/Control Ventilation (A/C), and more recently Pressure Support Ventilation (PSV). Among these, PSV gives the patient optimum liberty during ventilation. The patient decides over start of inspiration and start of expiration and therefore controls inspiration time, breathing frequency and minute volume. Pressure Support Ventilation supports spontaneous breathing in a unique and harmonious way and is thus predestined to become the ventilation mode best suited to weaning patients off the ventilator also in neonatal respiratory care.

Before focusing on PSV, we first have to look at all the other triggered ventilation modes and their characteristics.

## 3.0 Triggered Ventilation in Neonates

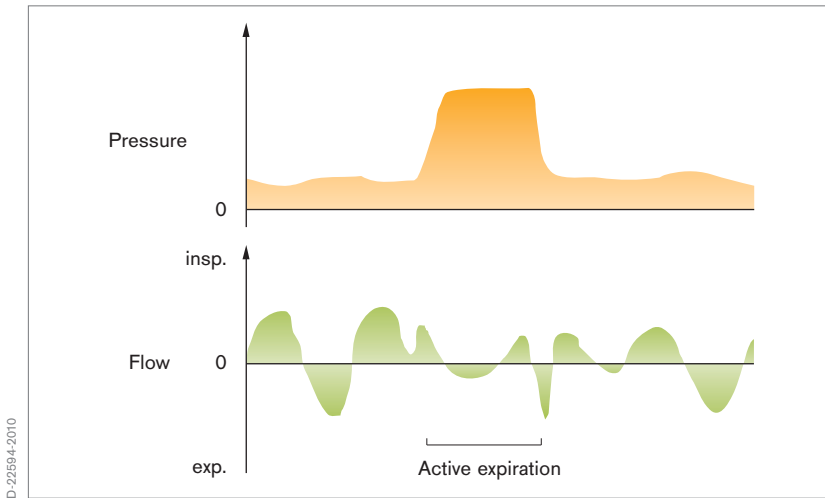
### 3.1 CONSEQUENCES OF ASYNCHRONY

Asynchrony between spontaneous ventilation and mechanical breaths can be problematic. [3] Asynchrony causing active expiration against ventilator inflation may occur irregularly or continuously, depending on the ventilator setting. [4,5] Consequences of active expiration may be a decrease in tidal volume and minute volume, an increase in oxygen consumption, an increase in intrathoracic pressure, a decrease in cardiac output and an increase in venous pressure. [3] Therefore during asynchrony, agitation of patient, inadequate gas exchange, increased risk of pneumothorax [6], and intraventricular hemorrhage [7] have been observed. However, when positive pressure inflation and spontaneous inspiration coincided, oxygenation improvement was found. [8] In babies paralysed by Pancuronium to avoid asynchrony, the risk of pneumothorax<sup>6</sup> and intraventricular hemorrhage [9] was reduced.

### 3.2 PREVENTING ASYNCHRONY

Asynchrony may be prevented by adapting ventilator settings to the spontaneous breathing pattern, by using triggered ventilation modes, or by using heavy sedation or paralysis.

Most neonatologists do not adapt the practice of regular paralysis in infants with active expiration, because paralysis has some disadvantages: in small infants, it has been associated with increases in oxygen requirements [10] as well as failure of skeletal muscle growth<sup>11</sup> and delay in weaning process. [12] Sedation is more often used but also shows some disadvantages such as hypotension and modification of EEG.



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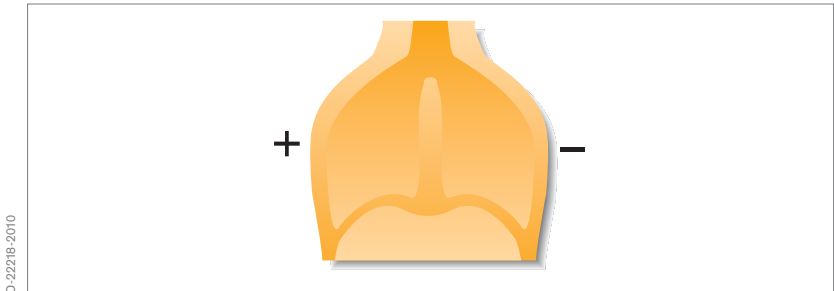
Figure 2: Tracing of pressure and flow during active expiration

Synchrony can sometimes be achieved by shortening inspiration time and/or increasing ventilator rate so as to match ventilator settings with the spontaneous respiratory rate of the infant. [8,13] But these modifications are not always successful and are not widely accepted in clinical practice because of the high intermittent mandatory rates required. [14]

An alternative approach is to detect the infant's inspiratory effort and use it to trigger positive pressure inflation (triggered ventilation).

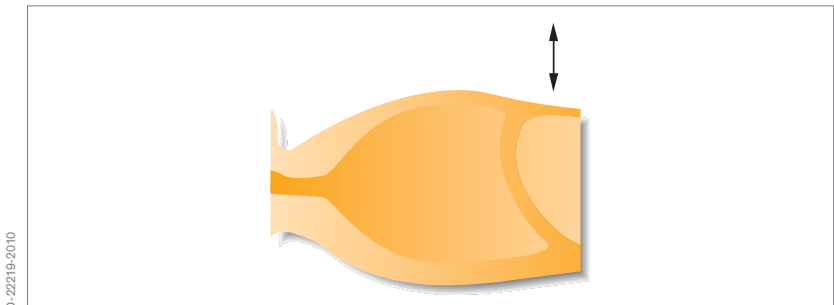
## 4.0 Trigger Signals

### 4.1 PRINCIPLES OF TRIGGERING



#### 4.1.1 THORACIC IMPEDANCE

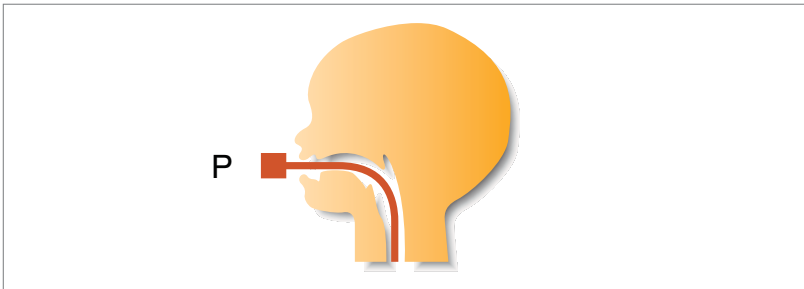
The signal is obtained by a cardiorespiratory monitor. [15] Detecting the changes in transthoracic impedance that occur with inspiration and expiration as a result of fluctuations in the ratio of air to fluid in the thorax. This signal can be affected by cardiac artefacts, lead placement, and change in position of the infant.



#### 4.1.2 ABDOMINAL MOVEMENT

The signal is either a pneumatic signal generated by the deformation of a foam filled flexible capsule taped to the abdominal wall, or the induction signal generated by movement of a coil in a magnetic field. [16]

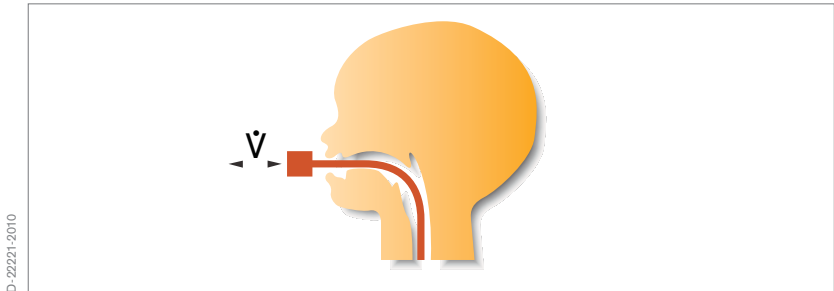
In all cases, the spontaneous breathing is derived from the outward abdominal movement. This signal requires paradoxical chest/abdominal movements.



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#### 4.1.3 AIRWAY PRESSURE CHANGES

The signal is obtained by a pressure sensor placed in the inspiratory or expiratory limb of the ventilatory circuit or Y-piece. Spontaneous breathing is detected by changes in airway pressure greater or equal to 0.5 cm H<sub>2</sub>O. [16] The signal can be affected by movement of condensed water in the patient circuit.

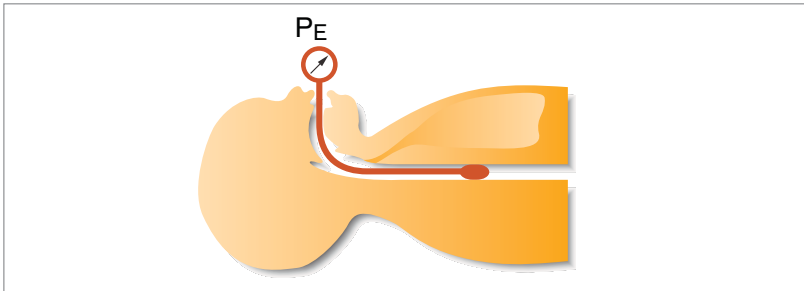


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#### 4.1.4 AIRWAY FLOW CHANGES

The signal is obtained from a flow sensor, pneumotachograph or hot wire anemometer placed between the endotracheal tube connector and the ventilatory circuit. The flow signal or the volume signal, obtained by mathematical integration, is used to detect spontaneous breathing.

This signal can also be affected by movement of condensed water in the patient circuit or in the Y-piece (in case of pneumotachograph). [8]



#### 4.1.5 ESOPHAGEAL PRESSURE CHANGES

Spontaneous breathing is detected by changes in esophageal pressure.

A negative deflection of 0.5 cm H<sub>2</sub>O triggers the ventilator. But this signal is hard to obtain in clinical practice, because the catheter is difficult to place and cannot be kept in proper position over longer periods of time. [3]

## **4.2 SPECIFIC PROBLEMS WITH DIFFERENT TRIGGER SIGNALS**

The possible problems with triggered ventilation in general are lack of response, autotriggering, artefacts, delayed response, and handling difficulties during clinical use, such as correct placement of sensors. [14,18]

### **4.2.1 LACK OF RESPONSE**

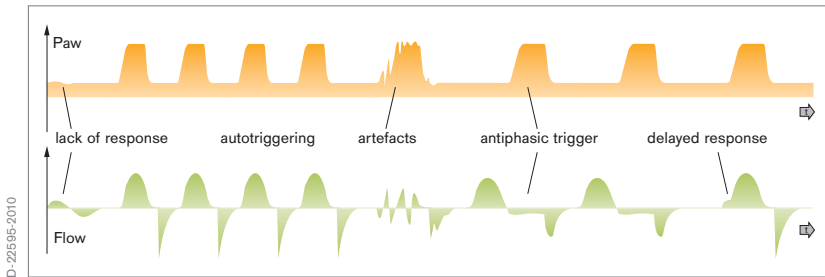
Sometimes the spontaneous breathing is not detected by the trigger device. Then the trigger threshold may be too high, or the sensitivity of the trigger device too low. As a result, triggering may fail altogether or require unnecessarily high efforts (high work of breathing).

### **4.2.2 AUTOTRIGGERING**

The ventilator is automatically triggered even without spontaneous breathing. Moving artefacts or an ET-tube leakage can cause autotriggering. Sometimes it is difficult to decide whether the patient is triggering the ventilator or the ventilator is autotriggering.

### **4.2.3 ARTEFACT**

In general any type of artefact can disturb the detection of spontaneous breathing. Examples are abdominal movement in case of abdominal capsule sensor, peristalsis in case of esophageal pressure sensor (hiccup) or movement of water in the circuit in case of airway pressure sensor.



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Figure 3: Different problems during triggered ventilation

#### 4.2.4 ANTIPHASIC TRIGGER

In case of wrong placement of the abdominal sensor capsule, a trigger signal can be generated during the expiratory phase. The result is antiphasic ventilation.

#### 4.2.5 DELAYED RESPONSE TIME

The effective response time of a ventilator system is sum of trigger delay and system delay. [14] The trigger delay is the time necessary to recognise an inspiratory effort and send a trigger signal to the ventilator. The trigger delay depends on the sensitivity of the sensor itself and the data processing rate of the ventilator. The trigger delay varies between 5 and 100 ms depending on the trigger sensors used and the set trigger threshold. The system delay is defined as the time for internal data processing and time for pressurisation of the patient circuit. The system delay is usually about 25 ms or less.

If the total response time is too long the ventilator may support the patient too late, coinciding with the spontaneous expiratory phase. An ineffective ventilatory support with high work of triggering and breathing is the result.

### 4.3 TECHNICAL COMPARISON OF DIFFERENT TRIGGER SIGNALS

Each triggering mechanism has its advantages and disadvantages. The main characteristics of the different trigger signals and sensors are listed in table 1.

Signal	Sensor	Response time	Advantages/Disadvantages
Abdominal movement	Graseby capsule	53 + 13 ms	Reliability depends on correct placement Need of paradoxical thorax/abdominal movement Fixed sensitivity setting only
Thoracic impedance	Chest leads	70 - 200 ms	Reliability depends on correct placement Drying of contact gel Long trigger delay
Airway pressure	Pressure transducer	40 -100 ms	Easy to use Autotriggering, increased work of breathing Sensitivity depends on patient circuit compliance No measurement of tidal volume.
Airway flow	Differential pressure transducer (pneumotach)	25 - 50 ms	Easy to use Measurement of tidal volume, monitoring of leaks Autotriggering, difficulties in case of secretions and water condensation
Airway flow	Hot wire anemometer	40 ms	Easy to use Measurement of tidal volume, monitoring of leaks Autotriggering, difficulties in case of secretions

**Table 1:** Main characteristics of different trigger signals (adapted from references 14,18,48)

#### 4.4 CLINICAL COMPARISON OF DIFFERENT TRIGGER SIGNALS

Various studies have been performed to compare different trigger signals. Table 2 shows the results of 8 studies. In 5 of them airway flow was compared with other trigger signals. Airway flow trigger is one of the signals combining ease of use with an acceptable response time and the possibility of monitoring tidal volume, minute volume and leaks.

Compared trigger signals	Type and number of subjects	End point	Conclusion of the study	Ref.	Year
Airway pressure vs thoracic impedance	10 rabbits and 10 premature infants	Tidal volume delivered, trigger delay	Superior performance of airway pressure	19	1991
Airway pressure vs thoracic impedance	10 premature infants	Blood gases	Superior performance of airway pressure trigger	20	1992
Airway flow vs Abdominal movement	10 newborn infants	Rate of asynchrony	No significant differences in asynchrony rates	21	1993
Airway flow vs airway pressure	6 adult rabbits	Inspiratory work of breathing	Superior performance of airway flow trigger	22	1994
Airway flow vs airway pressure	5 adult rabbits	Trigger delay work of breathing diaphragmatic activity	Superior performance of airway flow trigger	23	1995
Airway flow vs abdominal movement and thoracic impedance	10 very preterm infants	Trigger delay, autotriggering,, trigger failure	Superior performance of airway flow trigger	24	1996
Airway flow vs thoracic impedance	10 preterm infants	Trigger delay, autotriggering, trigger failure	Superior performance of airway flow trigger	25	1996
Airway flow vs abdominal movement	12 preterm infants	Triggering rate, trigger delay, sensitivity	Superior performance of abdominal movement	26	1996

Table 2: Clinical comparison of different trigger signals

## 5. Different Ventilation Modes

### 5.1 UNTRIGGERED MODES

During untriggered ventilation a ventilatory cycle occurs periodically at fixed intervals. It is strictly time cycled. There are two pressure controlled untriggered ventilation modes: CMV and IMV. The difference between Continuous Mandatory Ventilation (CMV = IPPV) and Intermittent Mandatory Ventilation (IMV) is only the difference in the set respiration rate of the ventilator:

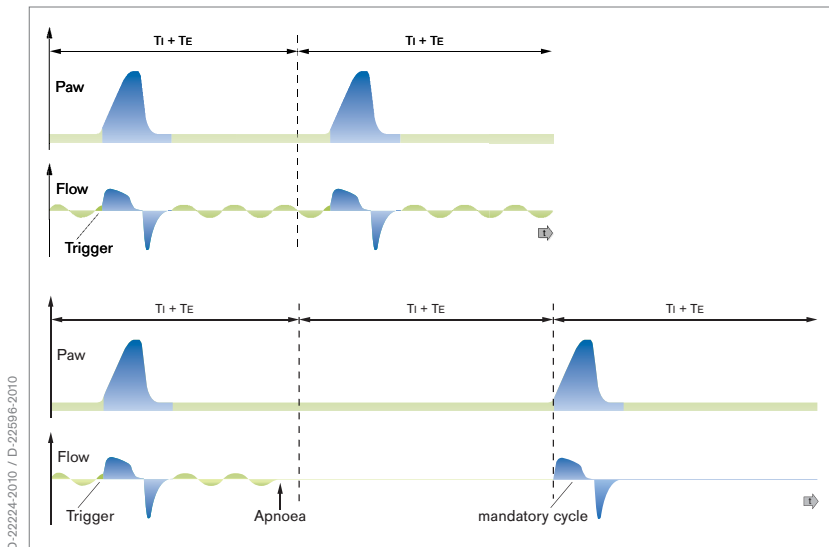
- During CMV the respiration rate of the ventilator is set faster than the spontaneous respiratory rate (usually between 50 and 80 breaths per minute).
- During IMV the respiration rate of the ventilator is lower (less than 30 breaths per minute), thus between two controlled breaths, the baby can breathe spontaneously.

### 5.2 TRIGGERED MODES

Synchronized Intermittent Mandatory Ventilation (SIMV), Assist/Control (A/C) and Pressure Support Ventilation (PSV) are the three triggered ventilation modes used in neonatal ventilation. Assist/Control (A/C), Patient Triggered Ventilation (PTV) and Synchronized Intermittent Positive Pressure Ventilation (SIPPV) are different names for the same ventilatory mode. In the following sections of this booklet the term Assist/Control (A/C) is used. At least SIMV and A/C are available with modern neonatal ventilators.

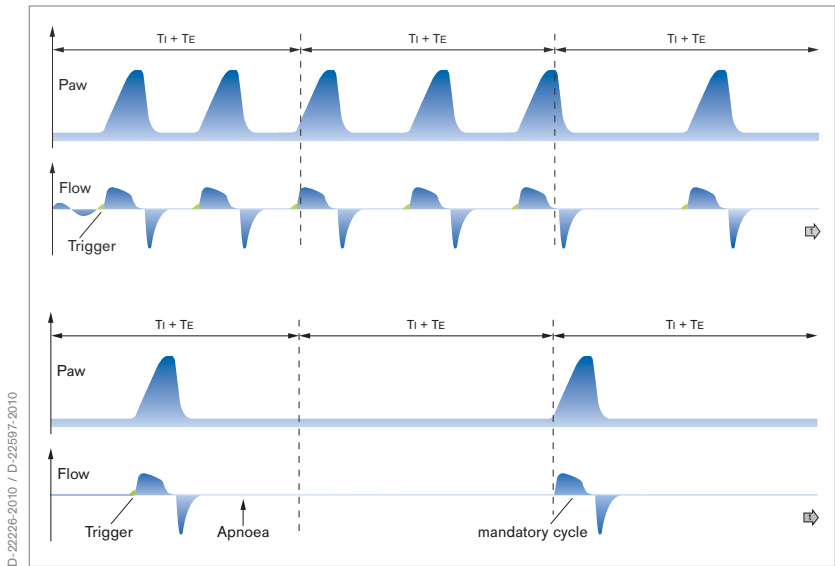
**SIMV:** The respiration rate of the ventilator is fixed to the set rate. Between the ventilator inflations the baby can breathe spontaneously on the positive end-expiratory pressure level. The set ventilator inflations per minute are synchronized with the spontaneous respiration of the baby. The duration of

the inspiration (inspiratory time) is fixed and determined by ventilator setting. In case of an apnoea most of the available ventilators are time cycled and ventilate the patient with the set rate determined by set  $T_I$  and  $T_E$ . (figure 4)



**Figure 4:** Upper part: SIMV during spontaneous breathing  
 Lower part: SIMV Backup-ventilation in case of apnoea

A/C: Each breath is assisted by the ventilator with a predefined level of pressure. The duration of the inspiration (inspiratory time) is fixed and determined by ventilator setting. The respiration rate can be controlled by the patient. In case of an apnoea most of the ventilators are time cycled and ventilate the patient with the set rate. (figure 5)



**Figure 5:** Upper part: A/C during spontaneous breathing  
Lower part: A/C Backup ventilation in case of apnoea

PSV: Each breath is assisted by the ventilator with a predefined level of pressure. The duration of the inspiration (inspiratory time) is automatically adjusted to the patient's inspiratory time. Therefore the patient can control the respiration rate and the inspiratory time. (see also next chapter)

PSV + Volume Guarantee: This combination of Pressure Support Ventilation and Volume Guarantee (VG) allows the patient to control the rate and inspiratory time; at the same time a set target tidal volume is delivered by automatic adaptation of the pressure support level. The option Volume Guarantee is new type of volume controlled ventilation in neonates and is available with the Babylog 8000plus (for more details a separate booklet about Volume Guarantee is available).

Thus, during SIMV and A/C, inspiratory time is fixed and determined by ventilator setting. Despite an inspiratory trigger active expiration may occur in case of inadequately set inspiratory time  $T_i$ .

Untriggered Modes	Triggered Modes
CMV (IPPV)	A/C (SIPPV, PTV)
IMV	SIMV
	PSV
	PSV-VG

## 5.3 PRESSURE SUPPORT VENTILATION

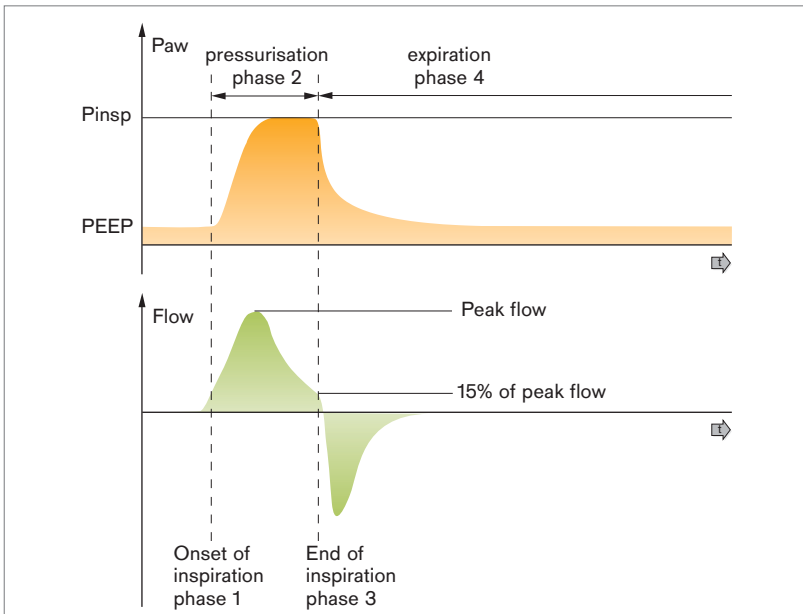
### 5.3.1 DEFINITION

A ventilatory cycle during Pressure Support Ventilation consists of 4 phases.

1. phase: Recognition of the beginning of inspiration (trigger)
2. phase: Pressurisation for the time of spontaneous inspiration
3. phase: Recognition of the end of inspiration  
(expiratory trigger or termination) and start of expiration
4. phase: Expiration

In the Babylog 8000plus the end of inspiration is determined by the diminution of inspiratory flow below 15 % of the peak inspiratory flow of the same cycle (figure 6). It is not necessary to adjust the termination criteria manually for adaptation to leak flow since the Babylog 8000plus is doing this automatically depending on the measured leakage (see also 5.3.2 Automatic Leak Adaptation).

During Pressure Support Ventilation each spontaneous breath is supported by the ventilator. Therefore respiration rate and duration of inspiration are controlled by the patient.



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**Figure 6:** Pressure and airway flow signals during a PSV breath, showing the 4 phases: Recognition of the beginning of inspiration, pressurisation, recognition of the end of inspiration and expiration.

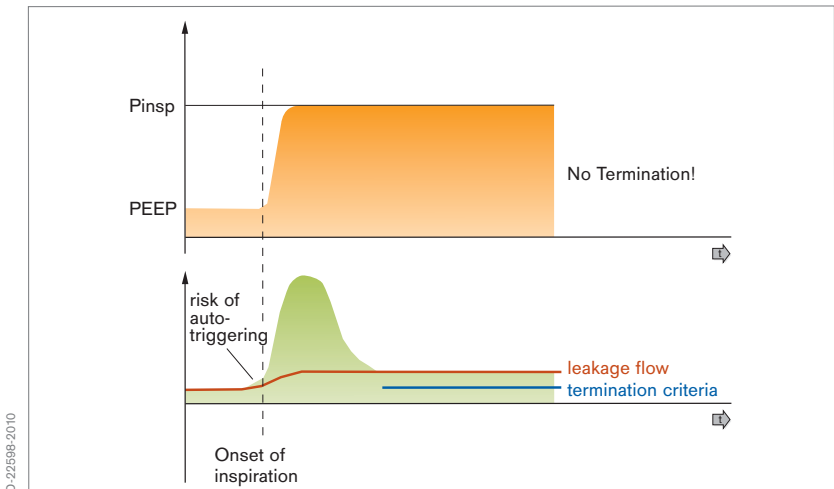
Ventilatory mode	Inspiratory trigger	Assistance of each breath	Ventilator respiration rate	Inspiratory time	PIP
IMV	No	No	Fixed	Fixed	Fixed
SIMV	Yes	No	Fixed	Fixed	Fixed
A/C	Yes	Yes	Variable	Fixed	Fixed
PSV	Yes	Yes	Variable	Variable	Fixed
PSV + VG	Yes	Yes	Variable	Variable	Variable

**Table 3:** Overview of different ventilation modes and their characteristics

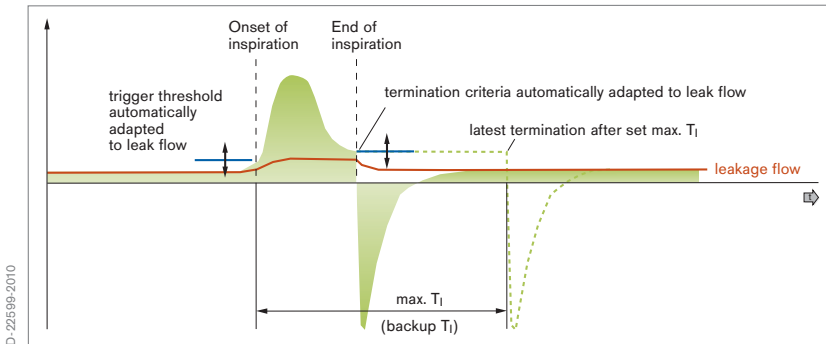
### 5.3.2 AUTOMATIC LEAK ADAPTATION

In the past a limitation for use of PSV in neonates was the commonly present ETT leakage. In case of a leak around uncuffed tracheal tubes one can observe an ongoing inspiratory flow at the end of spontaneous inspiration, which escapes through the ETT leak (leak flow). If this leak flow exceeds the termination criteria (expiratory trigger level) the system cannot determine the end of the inspiration (figure 7).

As well one can observe an ongoing inspiratory flow (leak flow) at the end of expiration, which can lead to autotriggering (autocycling) in the case that the leak flow exceeds the trigger threshold and therefore triggers a breath without spontaneous activity. To prevent autotriggering the trigger threshold has to be increased manually each time the leak increases. And the trigger threshold has to be decreased as soon as the leakage is reduced to prevent an inadequately high trigger level, which leads to prolonged trigger delay, high work of breathing and a low trigger success rate.



**Figure 7:** Possible failure of termination criteria in case of major leaks (without leak adaptation and upper limit of inspiratory time).



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**Figure 8:** Two safety systems in the Babylog 8000plus prevent inadequate long inspiratory times: automatic leak flow adapted termination criteria and upper limit of inspiratory time (backup T<sub>I</sub>)

In the Babylog 8000plus, a compensatory system, involving leak modelling, automatically adapts the trigger sensitivity level (trigger threshold) and termination criteria (expiratory trigger level) to the present leak flow. Due to this automatic leak adaptation autotriggering (autocycling) and inadequate long inspiratory times can be prevented.

PSV with the Babylog 8000plus works up to leaks of 60% and more. Therefore, Pressure Support Ventilation can now also be used in neonates.

As an additional safety feature an upper limit of inspiratory time (backup T<sub>I</sub>) can be set by the user, preventing excessively long inspiratory times in case of failure of breath termination (figure 8).

### 5.3.3 BACKUP VENTILATION

To provide sufficient ventilation in case of an apnoea a Backup Ventilation can be set also in PSV. As in A/C ventilation, a minimum respiration rate (Backup Rate) is set with the TE control (see also 7.1.6 Setting the Backup Rate). When the patient ceases to trigger the Babylog 8000plus will simply revert to CMV, delivering cycles at the set rate, TE and Pinsp. The active inspiratory time is the time necessary to completely fill the patient's lung at the given inspiratory pressure. This time is normally shorter than the set maximum inspiratory time under PSV. The rest of set maximum TI and the set TE are used as expiratory time. (figure 9)

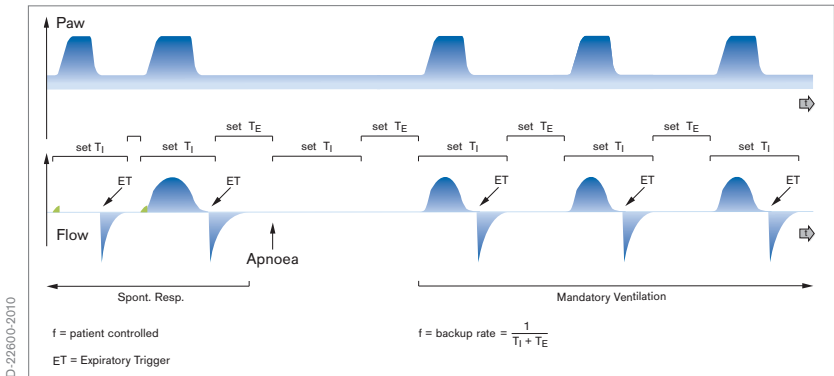


Figure 9: Backup Ventilation in case of apnoea under PSV

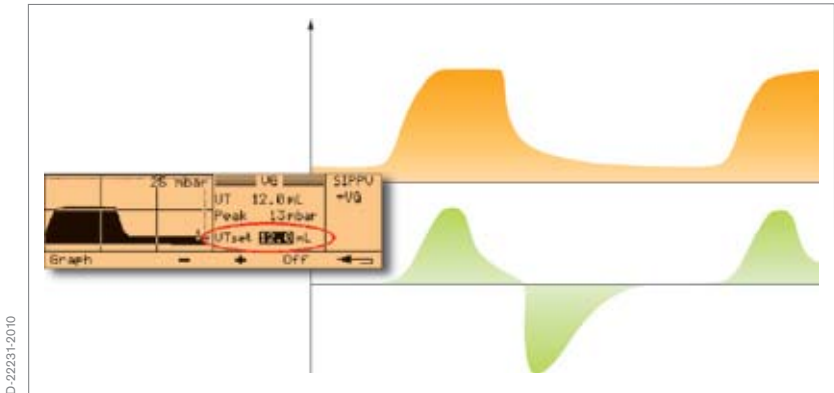
#### 5.3.4 LIMITATIONS AND CONTRA-INDICATIONS

Each individual patient requires his/her own optimal ventilation mode and parameters. Also Pressure Support Ventilation has its limitations and contra-indications. Bronchospasm and lack of spontaneous respiratory drive are two contra-indications for PSV.

In patients with low respiratory drive, Pressure Support Ventilation only has the advantage of automatic TI compared with Controlled Mandatory Ventilation (CMV) (see also 5.3.3 Backup Ventilation).

In case of bronchospasm, peak flow is decreased and inspiratory flow comes back to baseline very fast. Thus, spontaneous inspiration time is very short and the pressure support very brief while the newborn needs a higher level of support. This is a limitation for all ventilatory modes, that use the flow signal to adapt the ventilatory support (i.e. Proportional Assist Ventilation). [49]

Volume Guarantee is a useful option for such cases. In case of bronchospasm Volume Guarantee will automatically increase the pressure support level in order to deliver the set target tidal volume. Thus peak flow is not decreased, and pressure support level is maintained during the whole spontaneous inspiration (for more information a separate booklet about Volume Guarantee is available).



**Figure 10:** Working principle of Volume Guarantee. According to a set tidal volume inspiratory pressure is automatically regulated by the ventilator.

#### 5.4 CLINICAL STUDIES COMPARING VENTILATION MODES

Many studies have been performed to compare different ventilatory modes. The layout and results of the main studies are represented in table 4.

Compared ventilatory modes	Type and number of subjects	End point	Conclusion of the study	Ref.	Year
IMV vs CV	neonates	Duration of mechanical ventilation	IMV > CV	27	1977
SIMV vs CV	7 neonates	Oxygenation, Tidal volume, Work of breathing	SIMV > CV	28	1994
SIMV vs IMV	30 neonates	Consistency of tidal volume	SIMV > IMV	29	1994
SIMV vs IMV	neonates	Oxygenation	SIMV > IMV	30	1995
SIMV vs IMV	327 neonates	Duration of mechanical ventilation	SIMV > IMV in birth weight specific groups	31	1996
SIMV vs IMV	77 neonates	Duration of mechanical ventilation, BPD	SIMV > IMV in premature neonates	32	1997
A/C vs CV	14 neonates	Oxygenation and blood pressure variations	A/C>CV	33	1993
A/C vs IMV	6 preterm infants	Work of breathing	A/C > IMV	34	1996
A/C vs IMV/CV	30 neonates	30 neonates Adrenaline concentration	A/C > IMV	57	1998
A/C vs IMV	40 preterm infants	Duration of mechanical ventilation	A/C > IMV	35	1993
A/C vs SIMV	40 preterm infants	Duration of weaning, Failure of weaning	A/C = SIMV	36	1994
A/C vs SIMV	2x40 preterm infants	Duration of weaning	A/C > SIMV at low rate (5/min), but not at 30/min	51	1995
A/C vs SIMV	16 neonates	Oxygen cost of breathing	A/C > SIMV	37	1997
PSV vs CV	15 neonates	Cardiac output	PSV > CV	38	1996
PSV vs CV+IMV	30 preterm infants	Duration of mechanical ventilation	PSV>CV+IMV	39	1994
PSV vs IMV	rabbit model of neonate	Diaphragmatic activity	PSV > IMV	40	1994

">" means "superior to"

Table 4: Main clinical studies comparing different ventilatory modes in neonates.

## 6.0 Benefits of Pressure Support Ventilation

In adult ventilation the following benefits were observed when a patient is on PSV [1]:

- Better synchrony between patient and ventilator
- Increased patient comfort
- Reduced need for sedation
- Decrease in work of breathing and oxygen cost of breathing
- Shorter duration of weaning process (observed only in few studies) [2]
- Endurance oriented training of respiratory muscles
- Deepening of weak shallow spontaneous breathing

During Pressure Support Ventilation start of inspiration, start of expiration, inspiration time, breathing frequency and minute volume are controlled by the patient and not by the ventilator. Therefore Pressure Support Ventilation is predestined to become the ventilation mode best suited to weaning patients off the ventilator also in neonatal respiratory care.

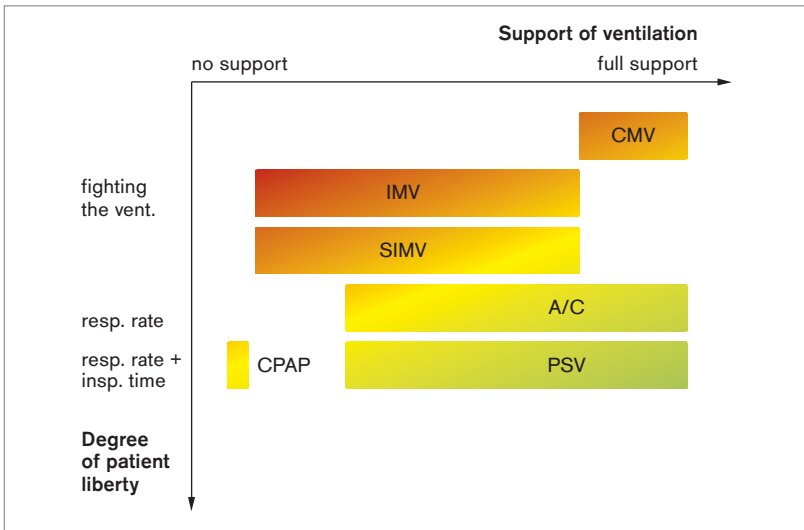
### 6.1 WEANING NEWBORN INFANTS FROM THE VENTILATOR

#### 6.1.1 EASY WEANING

Duration of mechanical ventilation must be as short as possible. For most newborns, weaning from the ventilator is not difficult. However, for some patients, weaning is a major clinical challenge. The problem is not mainly apnoea, for which different therapies are available (e.g. drugs, nasal ventilation or nasal CPAP). But failure of the respiratory muscle pump, which can result from decreased neuromuscular capacity, increased respiratory pump load, or a combination of both factors can lead to a difficult and prolonged weaning process.

#### 6.1.2 DIFFICULT WEANING

Patients with a higher respiratory pump load show increased work of breathing and increased oxygen cost of breathing [41], defined as the oxygen



**Figure 11:** Schematic representation of the degree of patient liberty (Y axis) and ventilatory support (x axis) in different ventilatory modes.

consumption ( $\dot{V}O_2$ ) difference between spontaneous and controlled ventilation. Most measurements of energy expenditure performed in infants with BPD have shown an increase in  $\dot{V}O_2$ . We have observed a higher  $\dot{V}O_2$  in newborns with BPD than in control infants at the time of weaning. [42] This increase was secondary to a higher oxygen cost of breathing (OCB). Higher OCB was probably related to higher work of breathing as has been observed in adults. We observed the highest OCB mainly in newborns with more severe BPD. [42] These observations are consistent with previous reports showing a correlation between  $\dot{V}O_2$  and the degree of respiratory illness in premature newborns [43] and in newborns with BPD. [44]

Thus, to wean newborns with high cost of breathing, we have to use ventilatory modes that optimally reduce work of breathing.

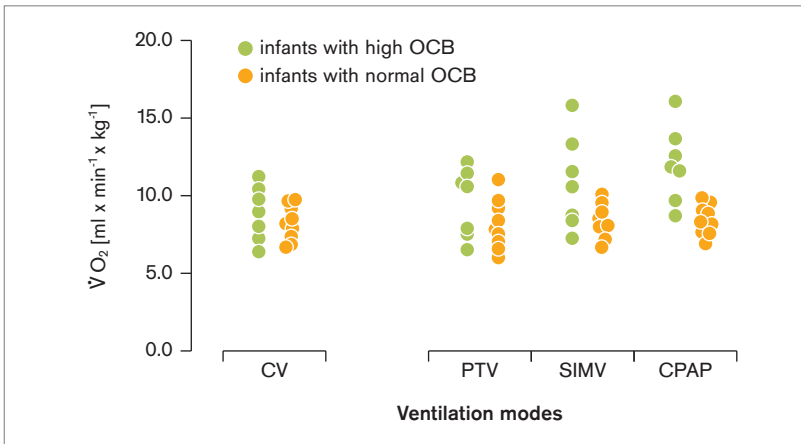
## 6.2 WEANING STRATEGIES

### 6.2.1 SELECTION OF WEANING TYPE

There are two different types of weaning modes: Using IMV or SIMV the ventilatory respiration rate and the inspiratory pressure are reduced during the weaning process. Using A/C or PSV only the inspiratory pressure is reduced during weaning process. Some physiological and clinical studies can help to choose the right weaning strategy.

### 6.2.2 PHYSIOLOGICAL STUDIES

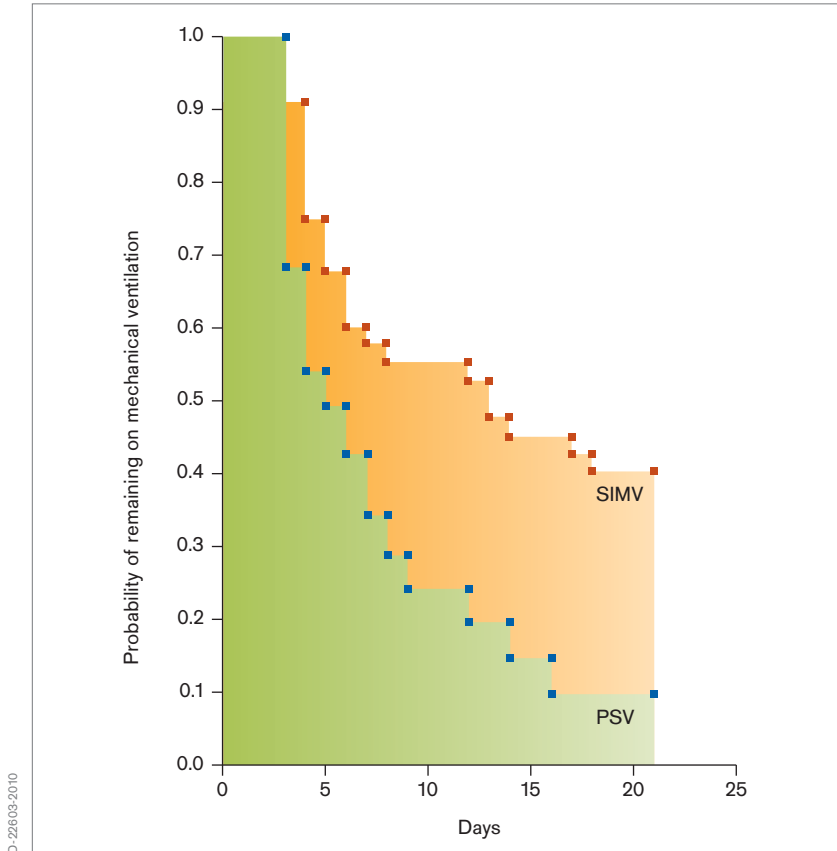
At the time of weaning,  $\dot{V}O_2$  can be reduced by using ventilation modes which minimise the work of breathing and consequently the oxygen cost of breathing. In a recent study, we found that we could reduce  $\dot{V}O_2$  in neonates with high OCB at the time of weaning by using Assist/Control as compared to CPAP or SIMV. We studied 16 infants requiring assisted ventilation for acute respiratory distress or chronic lung disease. Three weaning ventilation modes were studied in each newborn in random order: A/C, SIMV and CPAP. These three modes were compared with Controlled Ventilation (CV). OCB was high in 7 infants ( $23.0\% \pm 4.7\%$ ) and normal in the other 9 ( $< 10\%$  of total  $\dot{V}O_2$ ). In the high OCB group, the increase in  $\dot{V}O_2$  compared to CV was significantly lower with A/C ( $10\% \pm 11\%$ ) than with CPAP ( $38\% \pm 13\%$ ,  $p < 0.05$ ), and tended to be lower than with SIMV ( $28\% \pm 17\%$ , NS). The  $\dot{V}O_2$  increase was correlated with the increase in spontaneous ventilation ( $R^2 = 0.19$ ;  $F [1,26] = 5.94$ ;  $p < 0.03$ ). The percentage of spontaneous breaths without any assistance increased from 2% during A/C to 75% during SIMV and 100% during CPAP ( $p < 0.001$ ). In the normal OCB group, no significant variation in  $\dot{V}O_2$  was observed in the different ventilatory modes.



**Figure 12:** Oxygen consumption for infants with high and normal oxygen cost of breathing in different ventilation modes. [37]

In this study, we showed that the A/C mode can significantly reduce the increase in  $\dot{V}O_2$  observed in some infants at the time of weaning as compared to SIMV or CPAP. A/C significantly reduced  $\dot{V}O_2$  by 20 % in newborn infants with high OCB. [37] This decrease is probably related in part to reduced work of breathing as observed in adults [45] or children [46,50] during Pressure Support Ventilation. Besides, Jarreau et al showed that A/C reduces the work of breathing in premature infants. [34] Gullberg et al found PSV to increase cardiac output in neonates and infants in comparison to controlled ventilation. [38]

Thus, A/C or rather PSV effect an endurance training of respiratory muscles (low pressure/ high volume work of breathing, consistent tidal volume). [47]

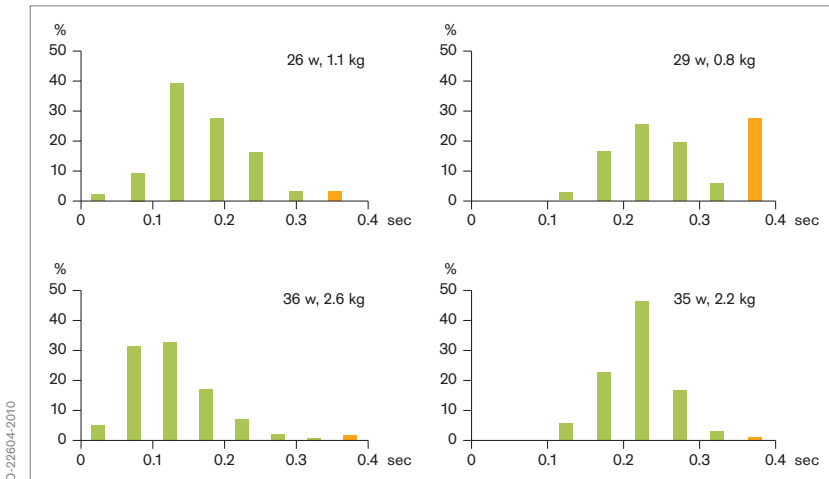


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**Figure 13:** Schematic representation of the effect of weaning by pressure reduction alone (PSV) or pressure and ventilation rate reduction (SIMV) on duration of the weaning. Adapted from Brochard: *Am J Respir Crit Care Med* 1994; 150: 896-903

### 6.2.3 CLINICAL STUDIES

Clinical studies indicate that weaning solely by reduction of pressure is better than reduction of pressure and ventilatory rate. Chan and Greenough



**Bild 14:** Häufigkeitsverteilung der Inspirationszeit bei 4 Frühgeborenen, die im PSV-Modus beatmet wurden. Der orangefarbene Balken zeigt die maximale Inspirationszeit, vorgegeben durch die Einstellung am Beatmungsgerät.

showed a reduction in weaning time using PTV instead of IMV. [35] Dimitriou et al found a shorter time of weaning using A/C in comparison to SIMV at low rates. [51] Jarreau et al demonstrated that PTV modifies the pattern of breathing by reduction of respiratory rate and decreases the WOB. [34] Donn et al compared IMV to PSV in a study of 30 preterm newborns (weight  $1280 \pm 100$  g, gest. age  $29.5 \pm 1$  wk.). They showed that patients treated with PSV were weaned more rapidly and had a significantly shorter mean time to extubation than those treated with conventional IMV. [39]

#### 6.2.4 PSV IS BETTER THAN A/C!

Assist/Control is not Pressure Support Ventilation (PSV). During A/C, pressure is controlled, and each respiratory effort is assisted as in PSV. However, during A/C, inspiratory time is fixed by ventilator setting. During PSV, inspiratory time is adapted to the spontaneous inspiration of the patient. This prevents air trapping and inversion of the inspiratory /

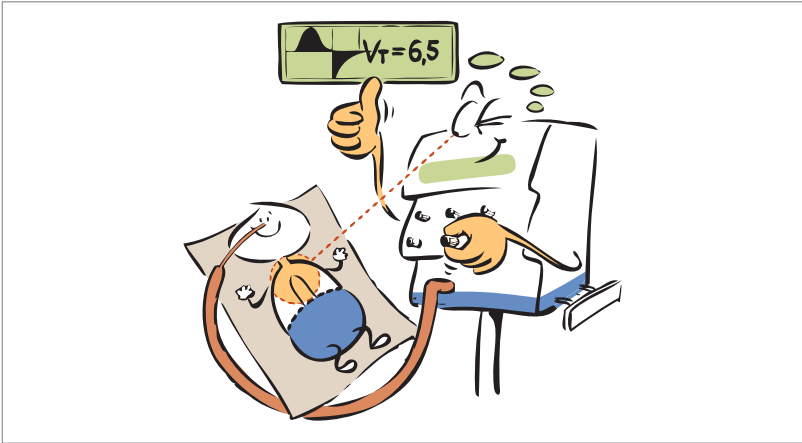
expiratory ratio when infants are breathing rapidly. We have observed a large variability (standard deviation x 100/mean) in the spontaneous inspiratory time of some newborns during PSV at the time of weaning, ranging from 19.3 to 24.2 % in 4 newborns during PSV (see figure 13). Thus PSV mode is probably more accurate than A/C because it adapts the pressure support to the patient's spontaneous inspiratory time.

Due to technical limitations PSV for neonates was not available in the past. Now, a leak adapted PSV is available as an option for Babylog 8000plus.

#### **6.2.5 PSV WITH VOLUME GUARANTEE**

PSV with Volume Guarantee is an option available with the Babylog 8000plus. To wean patients with PSV, pressure support must be reduced, for example, from 20 to 4 mbar in 3-5 mbar steps. If PSV is used with Volume Guarantee, pressure will be regulated to deliver a target tidal volume defined by the ventilator setting. If we reduce target tidal volume, for example by 10 %, to begin the weaning process, there are two possibilities:

either the patient is ready to be weaned and will make an effort himself to maintain the delivered tidal volume at the initial value while the respirator gradually and automatically decreases the pressure support; or the patient is not yet ready to wean.



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In the latter case, the infant tires, makes no effort, and receives the decreased target tidal volume. In this case, the weaning process is interrupted, and we return to the previous target tidal volume. To validate this hypothesis of »automatic« weaning, we studied 4 newborn infants and observed a progressive decrease in pressure support. These infants were extubated successfully at the end of this process. However, this result must be confirmed by further clinical studies.

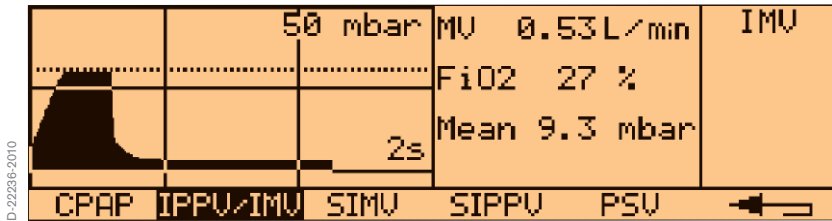
Note: For more information concerning Volume Guarantee, a separate booklet is available.

## 7.0 Pressure Support Ventilation in Practice

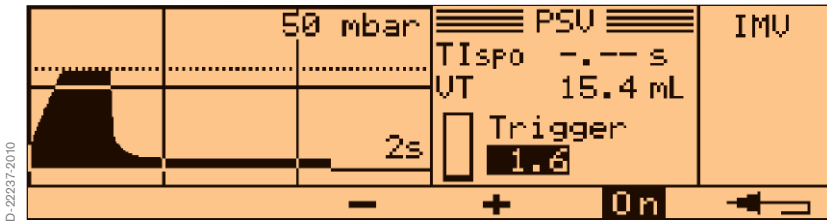
### 7.1 VENTILATOR SETTINGS IN PSV

#### 7.1.1 SELECTING THE PSV MODE

Press  key at the front panel of the Babylog. The following screen will be displayed.



Select the PSV mode by pressing the corresponding menu key. The following screen displays the settings for the inspiratory trigger threshold.

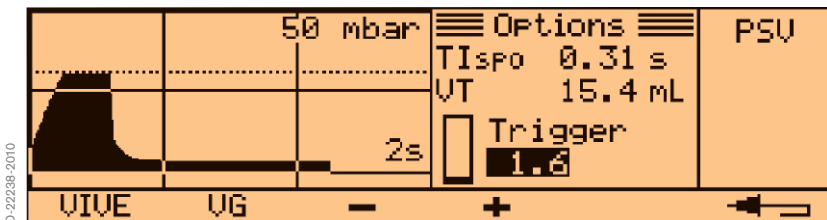


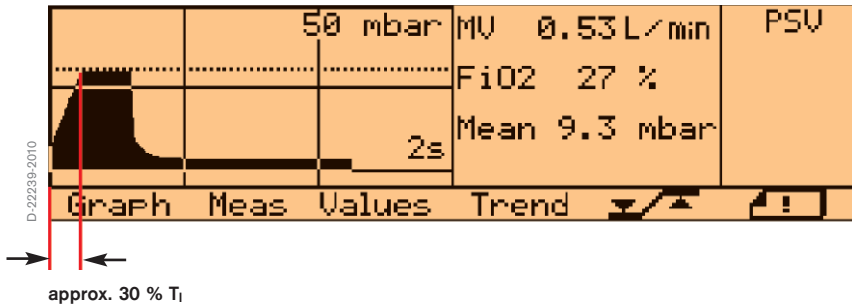
### 7.1.2 ADJUSTING TRIGGER THRESHOLD

After setting the trigger threshold (start at the lowest level) switch PSV on by pressing the >On< menu key.

The following screen displays the measured spontaneous inspiration time as well as the measured tidal volume. The trigger threshold can be adjusted by >+< and >-< menukeys if necessary. In case of autotriggering stepwise increase trigger threshold until autotriggering disappears.

Additionally the ventilation options VIVE or Volume Guarantee (VG) can be selected.





### 7.1.3 ADJUSTING INSPIRATORY FLOW

Adjust the inspiratory flow in the way that the pressure plateau is reached within the first third of inspiratory time. A too low flow would not meet the spontaneous peak flow demand of the patient and therefore would prevent a decelerating flow pattern, which is essential for the function of PSV. A too high flow would lead to artificially increased peak flows at the start of inspiration and would therefore lead to an early termination of inspiration.

### 7.1.4 ADJUSTING INSPIRATORY TIME (BACKUP T<sub>I</sub>)

Press  and the following screen displays the measured spontaneous inspiration time.

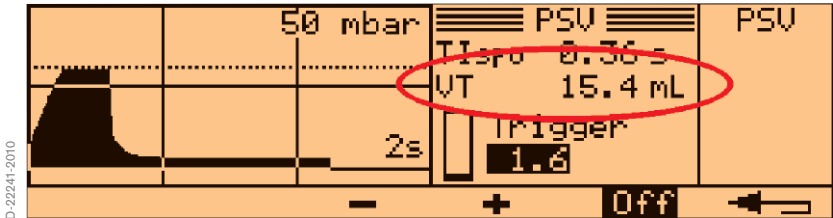


Adjust upper limit of inspiratory time with the T<sub>I</sub> rotary knob. In PSV the set T<sub>I</sub> limits inspiration time. If T<sub>I</sub> is set shorter than the actual spontaneous inspiration time, the breath will be terminated prematurely. Then the green LED next to the T<sub>I</sub> rotary knob will flash. In this case increase set T<sub>I</sub> until flashing stops.

The set T<sub>I</sub> should be adjusted at least 50% higher than the mean observed T<sub>I</sub> allowing the baby to sigh.

**7.1.5 ADJUSTING INITIAL PRESSURE SUPPORT LEVEL**

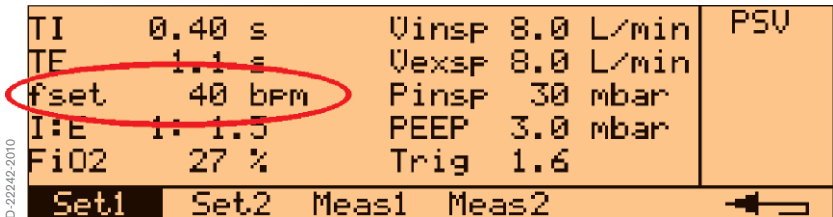
The pressure support level is adjusted by the Pinsp rotary knob. The initial pressure support level should be set to ensure a tidal volume of 4-6 ml/kg body weight.



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**7.1.6 SETTING THE BACKUP RATE**

Starting at the main menu press the menu key >Values<. The following screen displays all the settings including frequency (rate). With the TE knob this Backup Rate can be set. In case of an apnoea controlled ventilation with the set Backup Rate starts (see also chapter 5.3.3).



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## 7.2 WEANING BY PRESSURE SUPPORT VENTILATION

During weaning by Pressure Support Ventilation the pressure support level has to be reduced progressively over time.

After initializing the weaning process by PSV the patient needs a certain amount of pressure support because the ventilator has to take over the bigger part of the work of breathing (WOB). Figure 15 illustrates this situation. On the left side of figure 15 the total WOB (equals coloured areas) is shown in the combination of two PV-loops. The orange area corresponds to the WOB done by the patient, the blue area corresponds to the WOB done by the ventilator. The patient is able to trigger the ventilator but covers only the smaller part of the total WOB. So, both partners are sharing the total WOB necessary to generate the tidal volume.

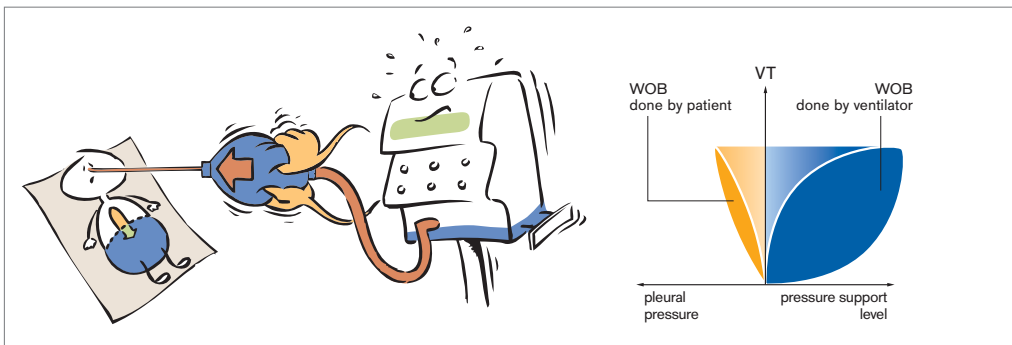
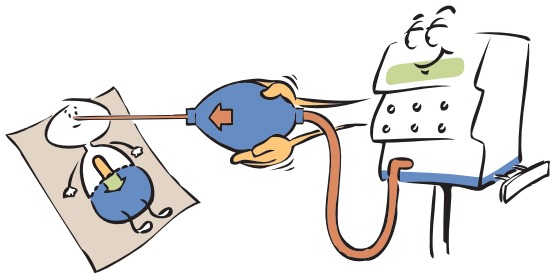
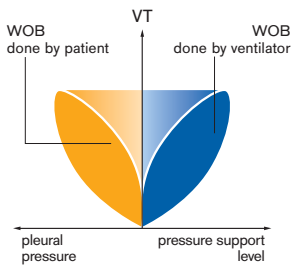


Figure 15

After some time the patient recovers, indicated by reduction of frequency and /or increase in tidal volume (or reduction in RVR). At that time the patient is able to take over a bigger part of total WOB. Therefore the pressure

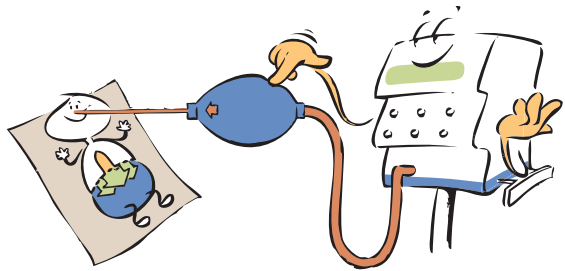
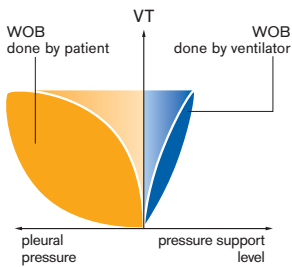
support level can be reduced gradually. The WOB is being shifted from the ventilator to the patient. (see figure 16)



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Figure 16

At the end of the weaning process the patient is able to cover the biggest part of total WOB. The ventilator is hardly supporting the baby, taking over just enough WOB to compensate for additional WOB due to ETT resistance. (see figure 17). At that time the extubation can be considered.



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Figure 17

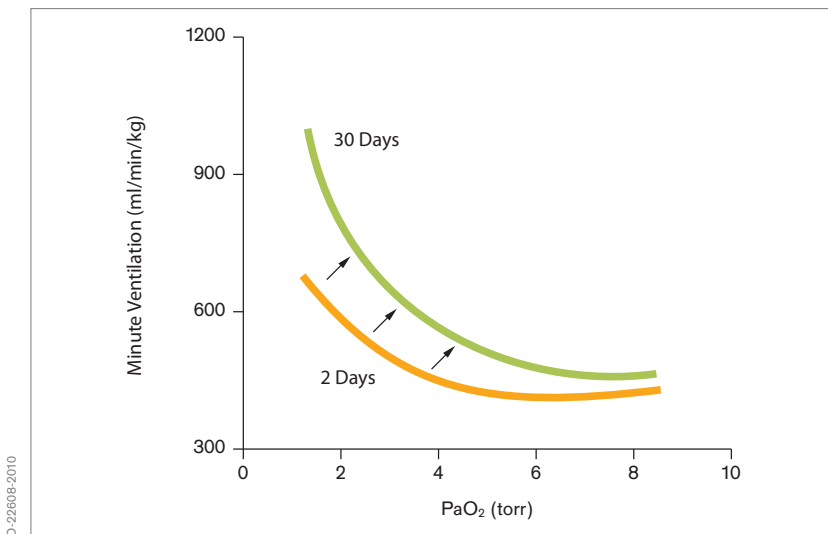
### 7.3 MONITORING PRESSURE SUPPORT VENTILATION

Before we consider monitoring of Pressure Support Ventilation, we first have to remember the physiological background of respiratory control of the neonate.

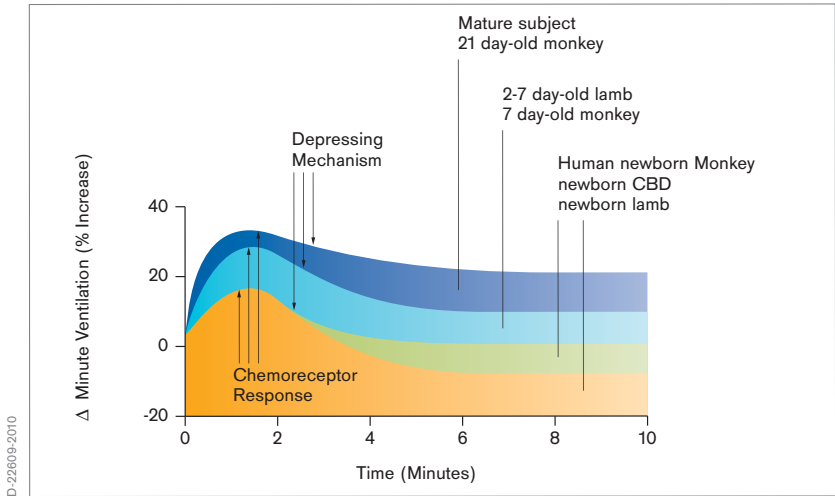
#### 7.3.1 PHYSIOLOGICAL BACKGROUND

##### 7.3.1.1 CHEMICAL CONTROL

Although the role of chemical stimulation in the transition from intermittent breathing of the fetus to continuous breathing is questioned, [52] the role of  $\text{PaCO}_2$  and  $\text{PaO}_2$  on the control of breathing is well established in the newborn after birth. Immediately after birth,  $\text{O}_2$  receptors are silent because of postnatal hyperoxia relative to fetal low  $\text{PaO}_2$  (25-28 mmHg). Later, in case



**Figure 18:** Change in ventilatory response to hypoxia in the lamb. Adapted from Bureau MA et al: J Appl Phys. 61:836-842, 1986



**Figure 19:** Schematic representation of the ventilatory response to steady-state hypoxia in the newborn. Adapted from Bureau MA, Lamarche J, Foulon P et al: *Resp. Phys.* 60:109-119, 1985

of steady-state hypoxia, the response of human newborn is biphasic [52,53]: an immediate hyperventilation (chemoreceptor response) is followed by a subsequent fall in ventilation towards or below baseline according to postnatal age. The decrease in minute volume (MV) is mainly due to a decrease in tidal volume. In case of hypercapnia, mammal and human newborns hyperventilate [52,53]: the minute volume/ $\text{PaCO}_2$  curve is linear but shifted to the right for the neonates: the threshold for this response is a  $\text{PaCO}_2$  of 50 to 55 mmHg in the newborn lamb. Moreover, the increase in minute ventilation is limited to 3 to 4 times baseline MV (in adults, the increase can be 10 to 20 fold baseline MV). In case of moderate hypercapnia, minute volume increases by increasing tidal volume and in case of higher

hypercapnia, tidal volume and frequency rate increase. However, increase of tidal volume can be limited by Hering Breuer reflex.

#### **7.3.1.2 THE RESPIRATORY PUMP**

The convection of gas into and out of the lung is secondary to the movement of rib cage and the excursion of the diaphragm with each contraction and relaxation phase. Chest wall muscles are critical for ventilation in the newborn with a pliable chest wall. Thus the main effector is the diaphragm. But neonatal diaphragm is different to adults by anatomical and histological aspects. Thus, the diaphragm of the neonate is prone to fatigue. [53,54]

#### **7.3.1.3 OXYGEN CONSUMPTION, CARBON DIOXIDE PRODUCTION AND WORK OF BREATHING**

Running the respiratory pump has an energy cost. In case of increased work of breathing, the cost of oxygen consumption and carbon dioxide production increases. The consequence of that is an increase in minute ventilation and increase in work of breathing. This vicious circle must be cut by medical intervention giving adequate respiratory support.

#### **7.3.1.4 PULMONARY REFLEXES**

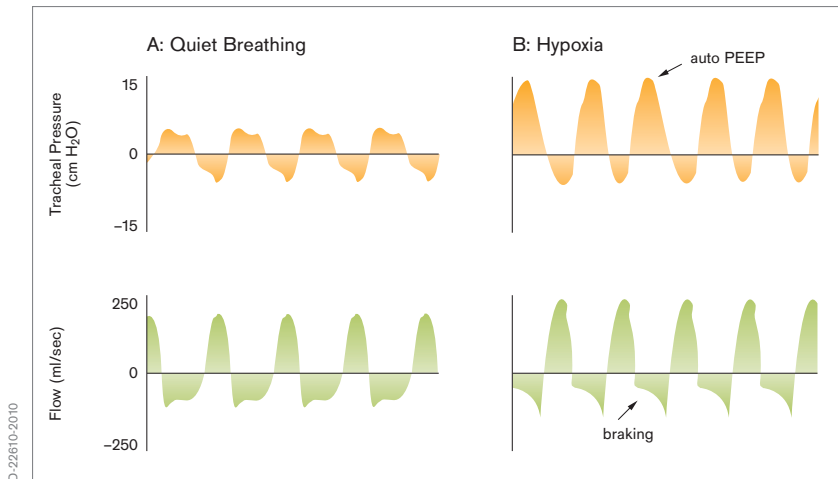
The most important reflex, particularly during neonatal period is the Hering-Breuer reflex. This reflex is initiated by lung distension and terminates inspiration and prolongs expiration time. Thus, increases in lung volume can cause apnoea. This reflex is much more pronounced in newborns, especially in newborn with low lung compliance. It is believed to be important as a protective mechanism against respiratory fatigue due to ineffective muscle work [53,55] and probably also against volutrauma.

### 7.3.1.5 PATTERN OF RESPIRATION IN NEONATES WITH RDS

The FRC is decreased in RDS, secondary to surfactant deficiency and collapse of small terminal airways. The newborn adopts a strategy to maintain FRC by using essentially three mechanisms:

- laryngeal narrowing during expiration,
- post inspiratory activity of inspiratory muscles and
- decrease in expiratory time (increase in respiration rate). [56] Moreover, in RDS compliance is low and resistance is normal, so time constant is low.

Thus, newborns are able to breath at high respiratory rates. In case of fatigue, the clinical signs are essentially shallow breathing with increase in respiratory rate and decrease in tidal volume. [53]

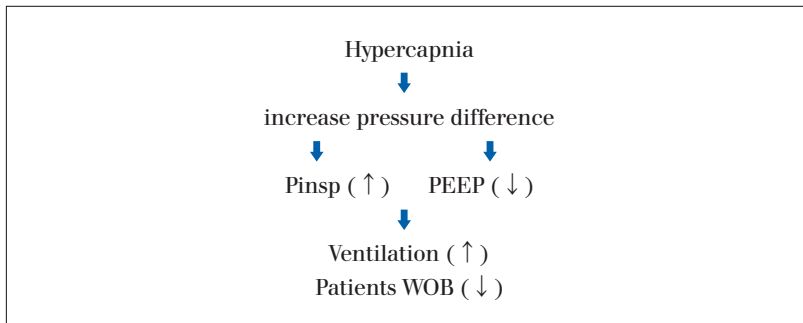


**Figure 20:** Expiratory laryngeal braking. A: Quiet breathing and B: in case of hypoxia. Laryngeal narrowing or braking can cause large auto-PEEP and increase FRC. Adapted from Davis GM, Bureau MA: Clinics in Perinatology, Vol.14, No.3, 1987

### 7.3.2 MONITORING IN PRACTICE

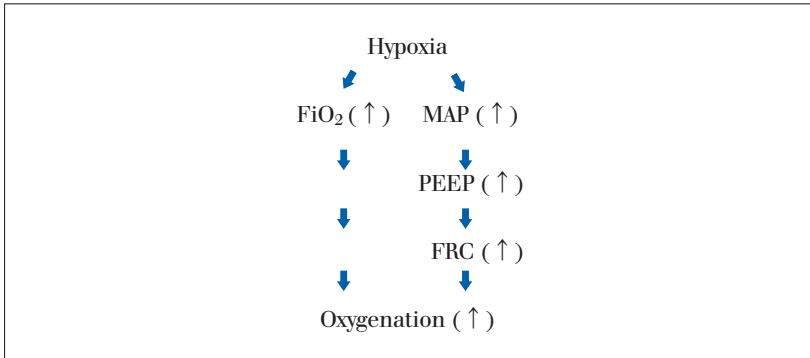
First, a clinical observation of the patient is mandatory. We have to observe a good adaptation of the ventilator to the neonate and harmony between these two partners.

Invasive or non-invasive blood gas monitoring help the clinician to adapt ventilation. Using Pressure Support Ventilation the settings for  $\text{FiO}_2$ ,  $\text{Pinsp}$  and PEEP have to be adjusted regularly. In case of hypercapnia, the pressure difference between  $\text{Pinsp}$  and PEEP must be increased to give more support and hereby take over a bigger part of the work of breathing.

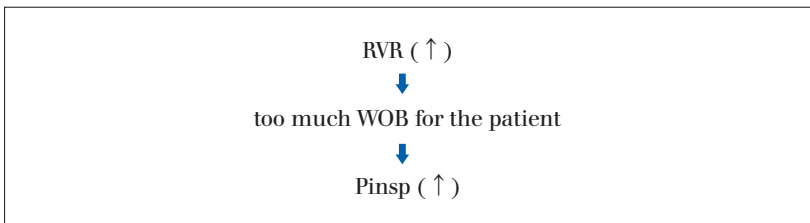


In case of hypoxia,  $\text{FiO}_2$  and/or mean airway pressure have to be increased according to clinical situation and the unit guidelines. Generally, mean airway pressure depends on  $T_I$ ,  $T_E$ ,  $\text{Pinsp}$  and PEEP. During PSV,  $T_I$  and  $T_E$  are controlled by the patient, thus to increase MAP you have to increase mainly PEEP.

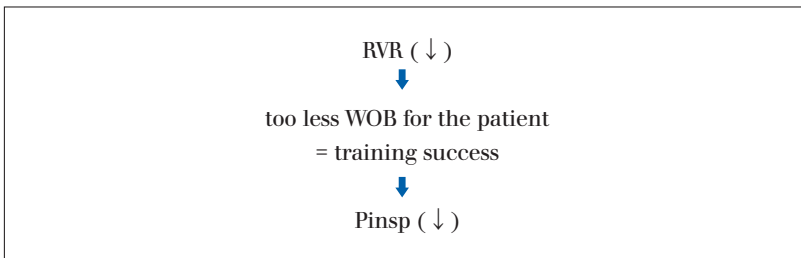
If the baby tends to hyperventilate despite normocapnia, probably FRC is low and MAP must be increased to increase FRC and improve oxygenation. (see also 'Pattern of respiration' of chapter 7.3.1.5).



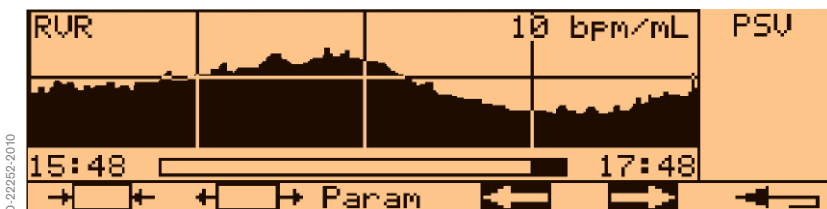
Moreover, during weaning, we can look at the respiratory rate / tidal volume ratio (Rate Volume Ratio = RVR). As with fatigue, newborns decrease tidal volume and increase respiratory rate and therefore increase the RVR. This ratio is a weaning criteria with high sensitivity and high specificity to predict successful extubation in adults (area under the ROC curve is 0.89). [41] As yet, there are no data for neonates available, but the rate volume ratio (RVR) can be used very well also for monitoring the weaning process in neonates. Based on the neonatal physiology, a gradual increase in RVR can indicate a beginning fatigue of the patient. In this case an increase of pressure support level (P<sub>insp</sub>) might be necessary.



Likewise, a decrease in RVR can indicate a success of weaning. Then we probably have to decrease the pressure support level in order to shift a further part of the WOB from the ventilator to the patient.



The Rate Volume Ratio is monitored by the Babylog 8000plus and can be displayed as value and graphical trend. Starting from the main menu, press >Trend< and >Param< repeatedly until the parameter RVR appears on screen.



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Up to now there are no studies available, which focus on this new parameter for use in neonatal Pressure Support Ventilation. Nevertheless the Rate Volume Ratio might be a powerful monitoring parameter for this purpose.

## 8.0 Conclusion

### **Demonstrated Advantages**

Pressure Support Ventilation is a pressure controlled ventilation mode now available for neonatology. This mode gives the patient optimum control during ventilation. The patient decides over start of inspiration and start of expiration and therefore controls inspiration time, breathing frequency and minute volume.

### **Technology behind**

Pressure Support Ventilation has been extensively studied in adults. Many advantages have been observed: better synchrony between patient and ventilator, increased comfort of the patient, endurance oriented training of respiratory muscles and shorter duration of weaning in some clinical studies. The neonatal Pressure Support Ventilation of the Babylog 8000plus was specially designed for use in neonates and covers the specific problems of this patient population.

### **Set up operation**

Pressure Support Ventilation is available at a fingertip and can be easily set up. After adjusting trigger sensitivity and maximum inspiration time an initial pressure support level can be set according to patient weight. Respiration rate, tidal volume and the Rate Volume Ratio (RVR) together with blood gases can be used to monitor PSV and further adapt ventilation parameters.

**Benefits for the neonate**

In newborns, physiological and clinical studies have shown the benefits of triggered ventilation, and the superiority of Assist/Control mode over Synchronous Intermittent Mandatory Ventilation during weaning. Pressure Support Ventilation supports spontaneous breathing in a unique and harmonious way and is thus predestined to become the ventilation mode best suited to weaning patients off the ventilator. During weaning, Pressure Support Ventilation shows promising advance in reducing work of breathing in patients with high oxygen cost of breathing.

The first clinical trials show encouraging results. Nevertheless further clinical studies have to confirm these first experiences, despite the difficulties and the great number of patients to be included.

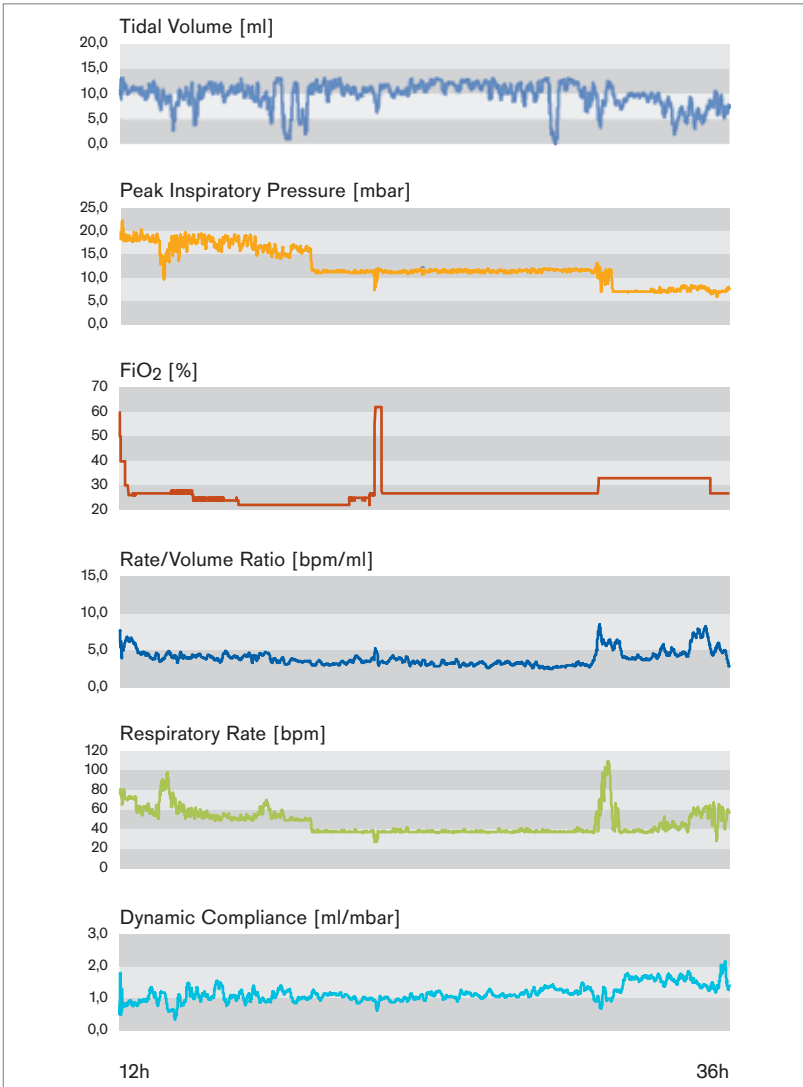
## 9.0 Appendix

### 9.1 CASE REPORTS

#### **Case 1:**

Infant female GA 36 weeks, Birthweight 2060 g, with moderate respiratory distress syndrome. Weaning process was performed by use of PSV mode and gradual reduction of the pressure support level only.

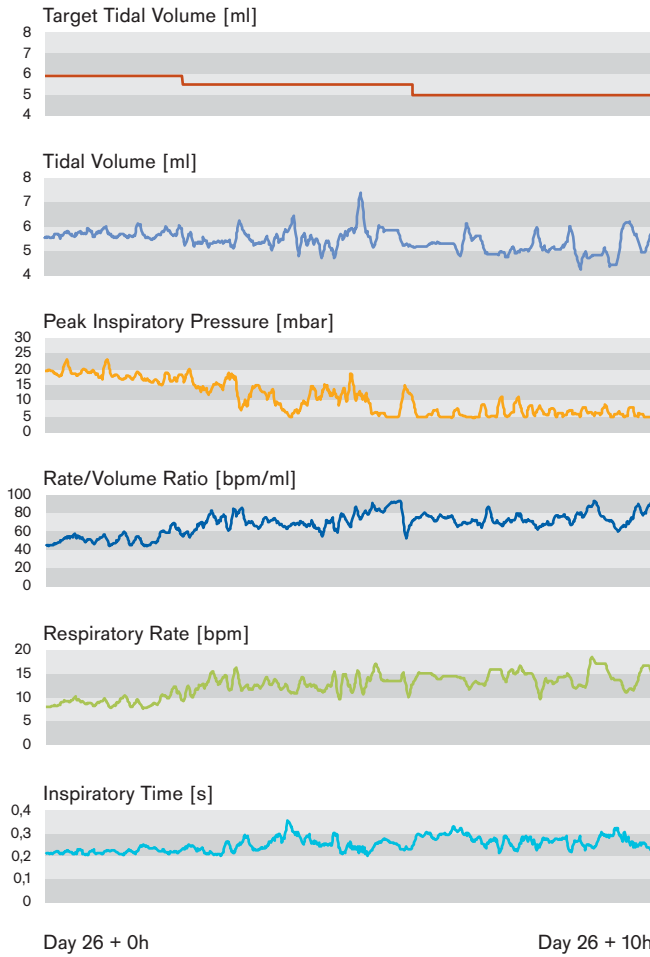
Low  $\text{FiO}_2$  and the Rate/Volume Ratio were stable during the whole weaning process. The baby was weaned off the ventilator with success at the end of this process. The duration of mechanical ventilation was 1 day. The figures show the trend of peak inspiratory pressure,  $\text{FiO}_2$ , RVR, tidal volume, respiratory rate and compliance during the last 24 hours.



**Case 2:**

Infant, male, GA 26 weeks, Birthweight 860 g with severe respiratory distress syndrome and later bronchopulmonary dysplasia. Weaning process was performed at day 26 in PSV mode with Volume Guarantee option. Target tidal volume was initially set to 6 ml and was later gradually decreased to 5 ml.

During the weaning period the peak inspiratory pressure was automatically reduced from 20 mbar to 5 mbar. Parallely inspiratory time as well as respiratory rate increased. Rate/Volume Ratio increased, probably initiated by reduction of pressure support level and therefore an increase in respiratory rate and in fatigue of this tiny baby. Nevertheless the RVR stabilised at a higher level. The tidal volume was relatively stable over the whole weaning period. As the baby could maintain a good minute ventilation at a very low pressure support level, we tried to extubate the baby after 10 hours of weaning. This trial was successful. The baby received supplementary oxygen for 5 days more.



## 9.2 ABBREVIATIONS

A/C	Assist Control Ventilation
BPD	Bronchopulmonary Dysplasia
C	Compliance
CDH	Congenital Diaphragmatic Hernia
CLD	Chronic Lung Disease
CMV	Controlled Mandatory Ventilation
CPAP	Continuous Positive Airway Pressure
CV	Controlled Ventilation
EEG	Electro Encephalogram
ETT	Endotracheal Tube
f	Ventilation Frequency
FiO <sub>2</sub>	Fraction of Inspiratory O <sub>2</sub> Concentration
FRC	Functional Residual Capacity
ICH	Intracranial Haemorrhage
I:E	Inspiratory-to-Expiratory Ratio
IMV	Intermittent Mandatory Ventilation
IPPV	Intermittent Positive Pressure Ventilation
kg	Kilogram bodyweight
LED	Light Emitting Diodes
MAP	Mean Airway Pressure
MV	Minute Volume
NS	Not Significant
OCB	Oxygen Cost of Breathing

PAV	Proportional Assist Ventilation
Paw	Airway Pressure
PEEP	Positive End-Expiratory Pressure
PIE	Pulmonary Interstitial Emphysema
Pinsp	Set maximum Pressure for Ventilation
PIP	Peak Inspiratory Pressure
PPHN	Persistent Pulmonary Hypertension of the Newborn
PSV	Pressure Supported Ventilation
PTV	Patient Triggered Ventilation
R	Resistance
RDS	Respiratory Distress Syndrome
RSV	Respiratory Syncytial Virus
RVR	Rate Volume Ratio
SIMV	Synchronised Intermittent Mandatory Ventilation
SIPPV	Synchronised Intermittent Positive Pressure Ventilation
T <sub>E</sub>	Expiratory Time
T <sub>I</sub>	Inspiratory Time
T <sub>Ispo</sub>	Spontaneous Inspiratory Time (active T <sub>I</sub> during PSV)
VG	Volume Guarantee
VIVE	Variable Inspiratory Flow, Variable Expiratory Flow
$\dot{V}O_2$	Oxygen Consumption
V <sub>T</sub>	Tidal Volume
V <sub>T set</sub>	Set Tidal Volume for Volume Guarantee
WOB	Work of Breathing

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