POCKET GUIDE

# MODES OF VENTILATION
# SERVO-i
# INVASIVE AND NON INVASIVE

MAQUET

CRITICAL CARE

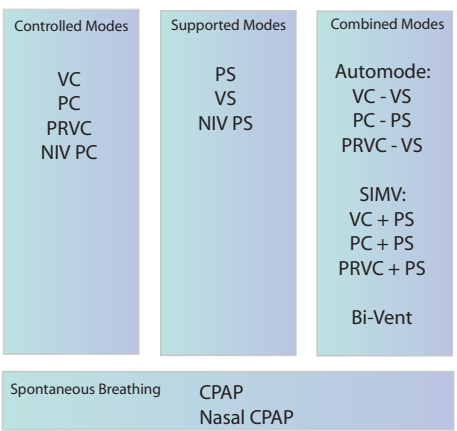
## Table of contents

## INTRODUCTION

Mechanical ventilation is required when a patient is unable to achieve adequate ventilation and thereby gas exchange. The ventilation pattern must be adapted to suit the patient's need for oxygenation and $CO_2$ elimination. The Servo-i Ventilator system provides ventilation modes, which clinicians can tailor to the patient's need.

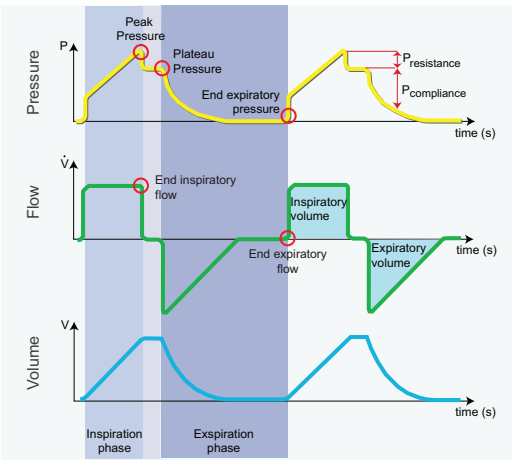
**Note:** This Pocket Guide only covers selected topics and cannot replace the User's manual and the Service manual. For detailed information please always refer to the latest corresponding User's manual and/or instructions for use. More detailed information concerning modes of ventilation can be found in the SERVO Education Study Guide and the SERVO Education Tutorial.

### Summary of ventilation modes



## Flow Pattern Volume Control ventilation

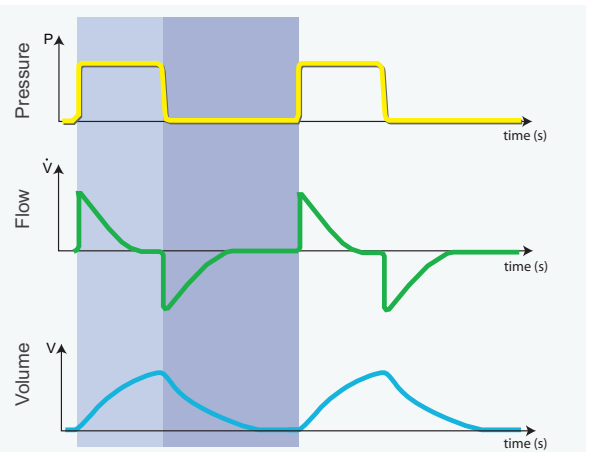
The Flow Pattern in Volume Control and SIMV (VC) is constant during inspiration. During the pause time the flow is zero. At the beginning of expiration, flow is large. It gets smaller and smaller and reaches zero by the end of expiration.



## INTRODUCTION

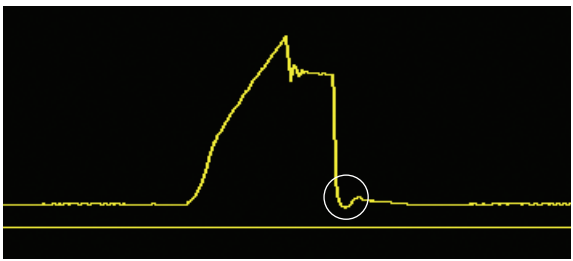
### Flow Pattern - Pressure Control ventilation

In Pressure Control, Pressure Regulated Volume Control (PRVC), Pressure Support, Volume Support, SIMV (PRVC) with Pressure Support and SIMV (PC) with Pressure Support the flow is decelerating and the pressure is constant.



## Time Constant Valve Controller™

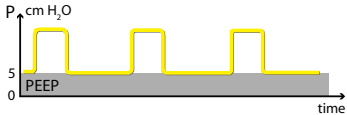
To reduce the resistance in the beginning of expiration the expiratory valve has a controlling algorithm, the Time Constant Valve Controller™, which continuously calculates the elastic and resistive forces of the respiratory system. The initial opening of the expiratory valve is adapted to keep resistance as low as possible while strictly maintaining the set PEEP in the airway.



# IMPORTANT VENTILATORY SETTINGS - INVASIVE VENTILATION

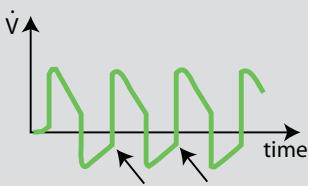
## PEEP

Positive End Expiratory Pressure (PEEP) can be set in the range of 0 - 50 cm$H_2O$. A Positive End Expiratory Pressure is maintained in the alveoli and may prevent collapse of the airways.




### *Auto PEEP*

*If the respiratory rate is set high or the expiratory time is not long enough there is a risk for auto PEEP. The patient does not have enough time to exhale and it is evident on the flow curve that flow will not return to zero before the next breath starts.*

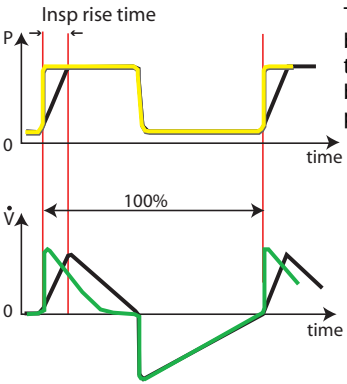



*There are different ways to check on the SERVO-i if the patient has an auto PEEP:*

- *The Exp. flow will not go back to zero before next inspiration starts.*
- *V̈ee is not zero, see 2nd page of Additional values on the User Interface.*
- *Total PEEP = set PEEP + Auto PEEP. Press "Exp. Hold" for a few seconds to see total PEEP on 3rd page of Additional values on the User Interface.*

## Inspiratory rise time

Inspiratory rise time is the time taken to reach peak inspiratory flow or pressure at the start of each breath, expressed either as a percentage of the respiratory cycle time or in seconds. The flow and pressure rise time can be adapted in accordance with the patient.




The Inspiratory rise time has to be set to a comfortable value for the patient and can be evaluated by the shape of the flow and pressure curves.

**Note:**
The Inspiratory rise time is shown in seconds if:

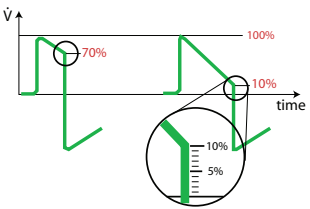
- the ventilator is configured for Insp. time in seconds.
- if ventilating in Pressure Support/CPAP or Volume Support.

The Inspiratory rise time is shown in %:

- in all controlled modes of ventilation if the ventilator is configured for the I:E ratio.

## Inspiratory cycle off

Inspiratory cycle off is the point at which inspiration changes to expiration in spontaneous and supported modes of ventilation.




**Important:** Set the Inspiratory cycle off setting correctly to avoid hyperinflation of the lungs and increased work of breathing. It is possible to set the Inspiratory cycle off from 1% to 70% of inspiratory peak flow for both adults and infants (default values are 30% for adults and 30% for infants).

If the Inspiratory cycle off cuts off inspiration too early, the patient will not get enough Tidal Volume.

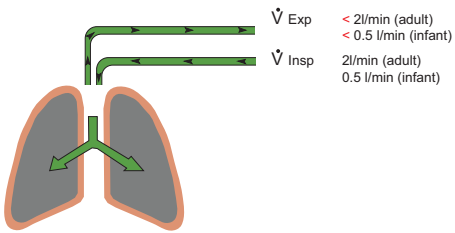
If the pressure increases 3 $cmH_2O$ above the set Pressure Support level above PEEP, the ventilator changes from inspiration to expiration.

## Trigger Sensitivity

Trigger sensitivity determines the level of patient effort needed to trigger the ventilator to inspiration.

Trigger sensitivity can be set as either flow triggering ("*Trigg. Flow*") or pressure triggering ("*Trigg. Pressure*"). However, flow triggering is preferable as this enables the patient to breathe with less effort.

**Important:** The trigger level should be set as sensitively as possible without activating self-triggering.




The ventilator continuously delivers a flow during expiration, which is measured in the expiratory channel.

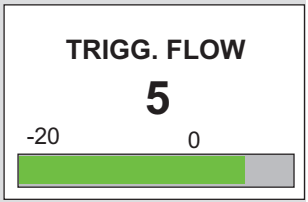
- Adult flow: 2 l/min (~33 ml/s)
- Infant flow: 0.5 l/min (~8 ml/s)

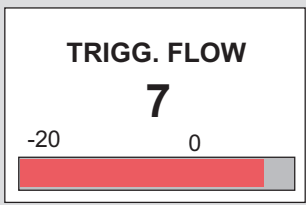
When the difference between the inspiratory and the expiratory flow equals the preset flow trigger level, the SERVO-i will start a new inspiration.

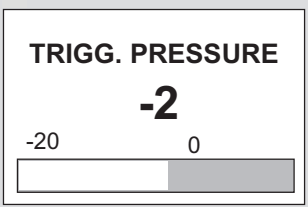
# IMPORTANT VENTILATORY SETTINGS - INVASIVE VENTILATION

*The flow Trigger sensitivity setting is divided into steps of 10%; with each step increasing the Trigger sensitivity.*

*In the red area the patient only has to inhale a very small part of the trigger flow to trigger a breath – hence there is a risk for self triggering.*




*The pressure Trigger sensitivity can be set within the range 0-(-20) cm$H_2O$. To initiate a breath the patient has to create the negative pressure that is set as Trigger sensitivity.*

*The higher the negative Trigger pressure is set on the ventilator, the more work of breathing the patient must perform. The Trigger sensitivity should be set as sensitive as possible without causing self triggering – auto triggering.*

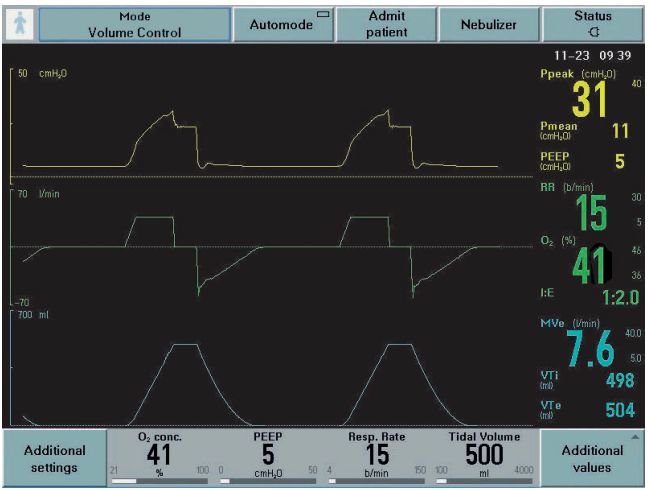

*When the patient triggers a breath a purple "T" appears between the text message and the alarm message areas. The initial part of the pressure or flow curves changes to purple to indicate that the patient is triggering the breath.*

***Notes:***

1. *If the breath is flow-triggered, then the purple color indication appears on the flow curve.*
2. *If the breath is pressure-triggered, then the purple color indication appears on the pressure curve.*

## VOLUME CONTROL (VC)

### Volume Control




In this controlled mode of ventilation the ventilator delivers the preset Tidal Volume with a constant flow during the preset Inspiratory time with the preset Pause time and at the preset Respiratory rate.

The Peak pressure can vary from breath to breath if the patients compliance and resistance changes.

In a tight system the inspired Tidal Volume should be the same as the expired Tidal Volume. The time for inspiration and expiration can be configured to be set in I:E ratio or Inspiration time in seconds.

*Example*

*In SERVO-i you can select if you want to set the Tidal Volume or the Minute Volume. The flow during Volume Control ventilation is constant. The Insp. time in % is seen in the information area in the menu "Set ventilation mode". Inspiratory rise time: Time to peak inspiratory flow at start of each breath as a percentage of the respiratory cycle time.*

*How to calculate the flow*

*Example:*
*Preset Insp. Min. Volume = 6 l/min*
*Insp.time = 25%*

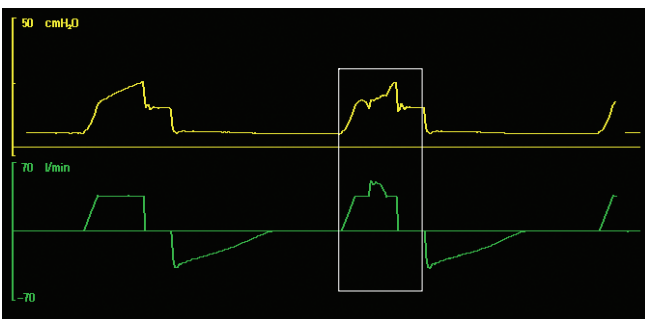
*Gives inspiratory flow* $\frac{6x100}{25} = 24$ *l/min*

## VOLUME CONTROL (VC)

It is very important to set a sensitive triggering level to give the patient the possibility to breathe spontaneously as soon as possible. If the patient is making an inspiratory effort during the expiratory phase, an assisted breath is delivered with the same tidal volume as set on the ventilator. Immediate sensing of inspiratory effort from the patient is mandatory in achieving synchronicity.

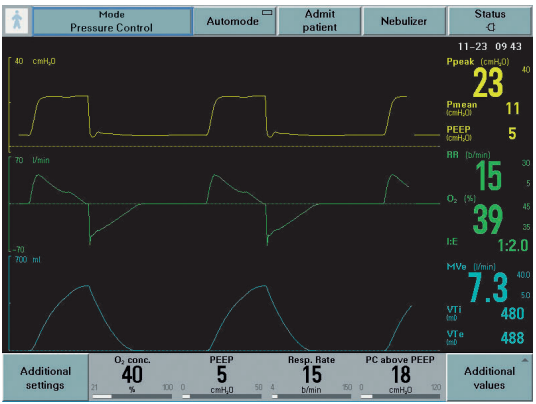
Sometimes the patient may demand a higher Tidal Volume/flow than that set on the ventilator. For example, this may be the case if the patient is in pain, has an increased temperature or their respiratory drive changes.

The Flow-adapted Volume Controller™ will always work with the patient and deliver the extra volume requested. If the patient decreases airway pressure by 3 $cmH_2O$ during the inspiratory phase then the ventilator delivers a flow profile adapted to the patient's immediate needs.



## Pressure Control

In this controlled mode of ventilation the ventilator delivers a flow that maintains the preset pressure at a preset respiratory rate during a preset inspiratory time.




During inspiratory time the pressure is constant and the flow is decelerating. If for any reason pressure decreases during inspiration, the flow from the ventilator will immediately increase to maintain the set inspiratory pressure.

The maximum available flow is 200 l/min (3.3 l/s) for an adult and 33 l/min (0.55 l/s) for an infant. The volume can vary from breath to breath if the patient's compliance and resistance changes.

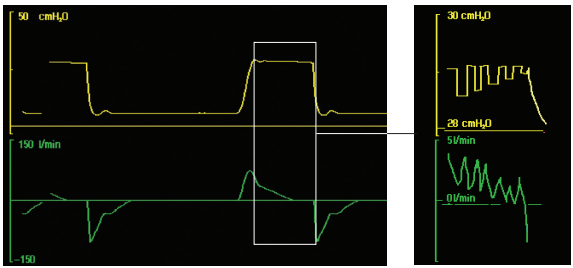
**Important:** Always set the alarm limits for Exp. Minute Volume to adequate levels.

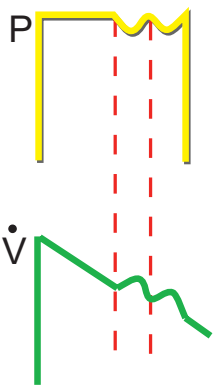
## PRESSURE CONTROL (PC)

Inspiratory rise time in PC is the time taken to reach the Peak inspiratory pressure of each breath. Settings can be in the range 0–20% of the respiratory cycle time - from an extremely fast response to a low initial inspiratory flow.

*Example:*
*Respiratory rate 15, the time for 1 breath is 60/15 = 4 sec*

$$\text{Inspiratory rise time 10\%} = \frac{4 \times 10}{100} = 0.4 \text{ sec}$$



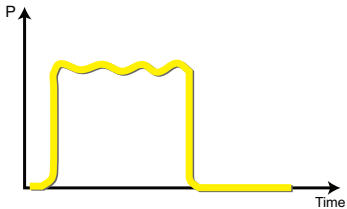

The SERVO-i immediately senses the smallest deviations in pressure during inspiration, and compensate with an increase in flow during the breath.

A decrease in pressure will occur when there is a leakage in the breathing system, at the endotracheal tube, or in the lungs e.g. pneumothorax or fistula.
When previously collapsed airways are starting to open the pressure decreases and the alveoli are opened by a precise increase in flow.

## PRESSURE CONTROL (PC)

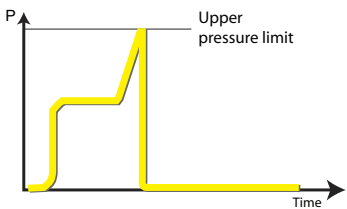
### Active expiratory valve

If a patient tries to exhale during inspiration then pressure increases. When the pressure increases to 3 $cmH_2O$ above the set inspiratory pressure level, then the expiratory valve opens and regulates the pressure down to the set inspiratory pressure level.




### Upper pressure limit

If the pressure increases to the set Upper pressure limit e.g. the patient is coughing, then the expiratory valve opens and the ventilator switches to expiration.

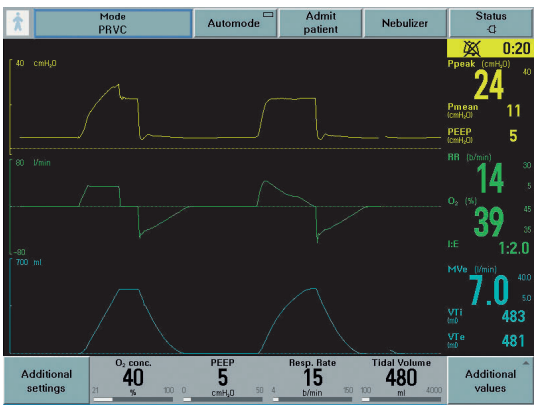


## PRESSURE REGULATED VOLUME CONTROL (PRVC)

### Pressure Regulated Volume Control

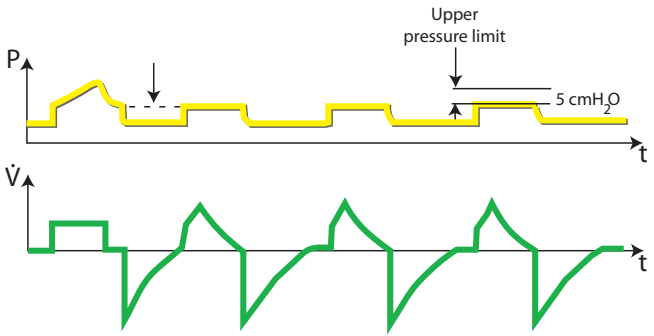
**Important:** PRVC is not recommended when there is a leakage in the patient´s breathing circuit

PRVC is a controlled mode of ventilation which combines the advantages of Volume Controlled and Pressure Controlled ventilation. The SERVO-i delivers the preset Tidal Volume with the lowest possible pressure.



## PRESSURE REGULATED VOLUME CONTROL (PRVC)

The first breath delivered to the patient is a Volume Controlled breath. The measured plateau pressure is used as the pressure level for the next breath. For the following breath, this pressure is constant during the set inspiratory time and the flow is decelerating.




The set Tidal Volume is achieved by automatic, breath-by-breath regulation. The ventilator adjusts the inspiratory Pressure Control level to the lowest possible level to guarantee the preset Tidal Volume, in accordance with the mechanical properties of the airways/lung/thorax.

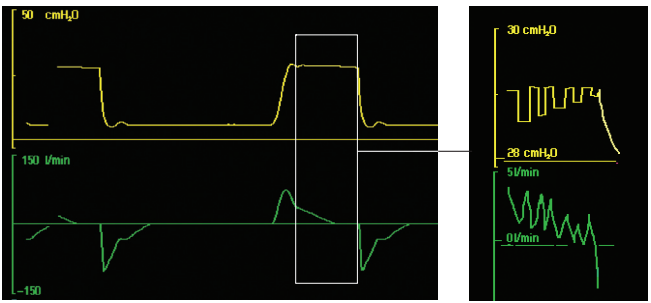
## PRESSURE REGULATED VOLUME CONTROL (PRVC)

If the measured Tidal Volume increases/decreases above/below the preset Tidal Volume, then the pressure level decreases/increases between consecutive breaths (in steps of a maximum 3 $cmH_2O$) until the preset Tidal Volume is delivered.


The maximum available pressure level is 5 $cmH_2O$ below the preset Upper pressure limit. If the pressure reaches 5 $cmH_2O$ below the preset Upper Pressure limit, the ventilator will deliver as much volume as possible with this pressure. At the same time, the alarm message *"Regulation Pressure Limited"* will be displayed in the alarm message area to inform the user that the set volume cannot be delivered. The alarm limit for expired Minute Volume will also alert the user if properly set.

## PRESSURE REGULATED VOLUME CONTROL (PRVC)

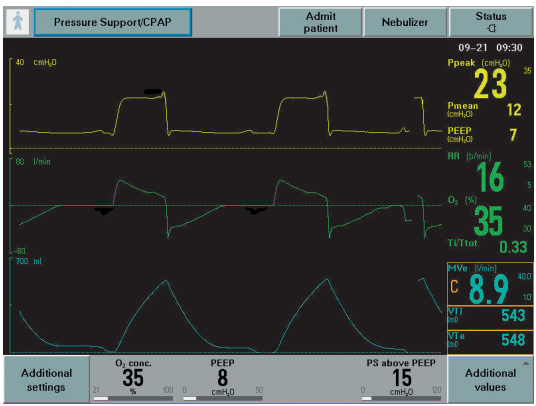
The SERVO-i will sense the smallest deviations in pressure. If it appears that previously collapsed units of the lung are starting to open in the late phase of inspiration then the pressure tends to decrease. This is compensated by a precise increase in flow.




Terminal airway resistance decreases in discrete steps as pressure is applied. By immediately sensing the pressure drop that could be induced by an opening avalanche, SERVO-i provides adequate flow to balance and further enhance the opening process.

## Pressure Support

Pressure Support is a spontaneous mode of ventilation. The patient initiates the breath and the ventilator delivers support with the preset pressure level. With support from the ventilator, the patient also regulates the Respiratory Rate and the Tidal Volume.




In Pressure Support the patient triggers all breaths, the preset inspiratory Pressure Support level is kept constant and there is a decelerating flow. Set PEEP and set Pressure Support above PEEP result in $P_{peak}$ (peak pressure).

## PRESSURE SUPPORT (PS)

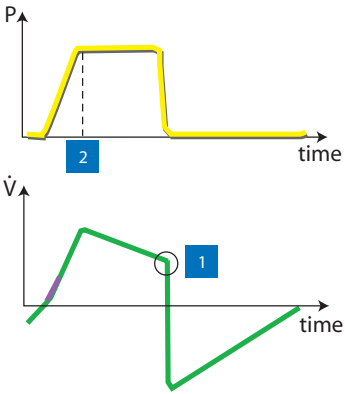
If the mechanical properties of the lung/thorax and patient effort change, then delivered Tidal Volume will be affected. In this case the Pressure Support level must be adjusted to obtain the desired ventilation.

The higher the preset inspiratory pressure level from the ventilator the more gas flows into the patient. As the patient becomes more active the Pressure Support level may be gradually reduced.

If the patient fails weaning it may be due to delayed termination of the inspiratory support. If the inspiratory part of the breath is prolonged, the patient will recruit his expiratory muscles and cycle the ventilator to expiration by an increase in pressure. This process utilizes patient energy and may shorten the time for expiration. This may induce Auto PEEP, increase work of breathing and cause lost trigger efforts by an increased internal threshold to triggering. In this case the Inspiratory cycle off should be increased. It is important to monitor the corresponding Tidal Volume levels.

## Pressure and flow curves

Inspiration starts when the patient triggers a breath and gas flows into the patient's lungs at a constant pressure. Since the pressure provided by the ventilator is constant, the flow will decrease until the Inspiratory cycle off (1) is reached and then the expiration starts.
Depending on how the Inspiratory rise time (2) is set, the pressure will either rise very quickly or slowly at the beginning of the breath.




**Expiration starts:**

- when the inspiratory flow decreases to the preset Inspiratory cycle off level.
- if the Upper pressure limit is exceeded.
- if the inspiration exceeds 2.5 s in Adult range and 1.5 s in Infant.
- if the flow drops to a flow range between 25% of the peak flow and lower limit for Inspiratory cycle off fraction level and the time spent within this range exceeds 50% of the time spent in between the start of the inspiration and the entering this range.
- if the pressure increases 3 $cmH_2O$ or 10% above the Pressure Support level (highest value applicable).

## PRESSURE SUPPORT (PS)

**Important:**

1. The Trigger Sensitivity should be set optimally for the patient without increasing the work of breathing and ensuring that the patient can inhale freely.
2. The Inspiratory rise time should be increased from the default settings to a value comfortable for the patient.
3. Inspiration and expiration must be adapted to the patient. For example, if the Inspiratory cycle off value is set too high, then the ventilator may cycle off prematurely resulting in inadequate Tidal Volume.
4. It is important to monitor the Tidal Volume levels and the Respiratory Rate.
5. The apnea alarm should always be set to suit the situation of the individual patient.
6. Ensure that the alarm limits for the expiratory Minute Volume alarm and for the Respiratory Rate are appropriately set.

## Continuous Positive Airway Pressure (CPAP)

CPAP works in exactly the same way as Pressure Support, except the Pressure Support level is set to zero. Continuous positive pressure is maintained in the airways, and if properly set, airway collapse can be prevented.

Inspiration starts upon patient effort, and expiration starts as for Pressure Support.

## Backup Pressure Support

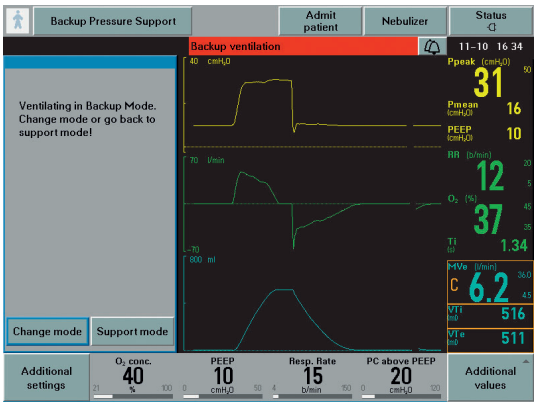
If the apnea alarm limit is reached the ventilator automatically switches to Backup Pressure Support. The ventilator starts ventilating in Pressure Control with the preset Pressure Control level above PEEP and the default settings for I:E ratio, Respiratory Rate and Insp. rise time.

The default inspiratory pressure is:

- adult 20 $cmH_2O$
- infant 10 $cmH_2O$

## PRESSURE SUPPORT (PS)

Alarms will alert staff of the change and the message "*Ventilating in Backup Mode. Change mode or go back to support mode!*" is displayed on the User Interface.

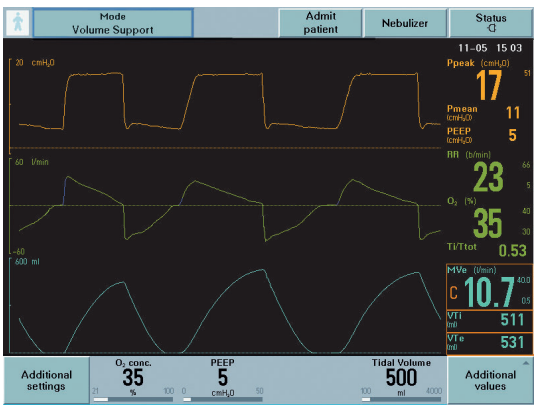



The user must decide whether or not the Support mode is suitable.

## Volume Support

Volume Support is a spontaneous breathing mode. The patient initiates the breath and the ventilator delivers support in proportion to the inspiratory effort and the target volume. The inspiratory flow will be decelerating.

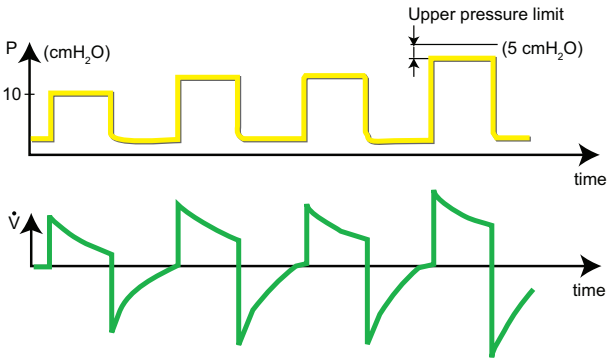
This mode of ventilation avoids ventilator-induced hyperinflation, but compensates and adapts to changes in respiratory load. The set Tidal Volume is delivered to the patient with different support from the ventilator depending on the patient´s activity.




If the patient´s activity increases then the inspiratory Pressure Support will decrease, provided the set Tidal Volume is maintained. However, if the patient breathes below the set Tidal Volume, then the inspiratory Pressure Support will increase.

## VOLUME SUPPORT (VS)

The start-up sequence is 4 breaths. The first breath is given with a support of 10 $cmH_2O$. From that breath the ventilator continually calculates and regulates the pressure needed to deliver the preset Tidal Volume. During the remaining 3 test breaths, the maximum pressure increase is 20 $cmH_2O$ for each breath.




If, after the start-up sequence, the delivered Tidal Volume falls/rises below/above the set Tidal Volume then the Pressure Support level increases/decreases in steps of a maximum of 3 $cmH_2O$ breath by breath until the preset Tidal Volume is delivered.

The maximum available pressure level is 5 $cmH_2O$ below the preset Upper pressure limit. Should the pressure reach this level, then the alarm message "*Regulation Pressure Limited*" will be displayed in the alarm message area to inform the user that the set volume cannot be delivered.

The inspiratory Pressure Support level automatically adapts to changes in the mechanical properties of the lung/thorax and patient effort.

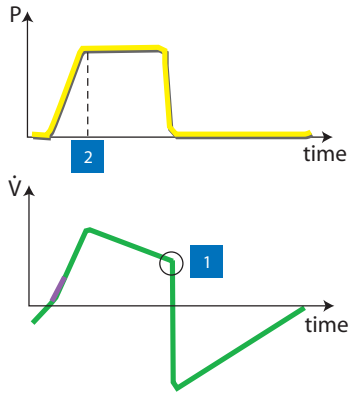
To evaluate the patient´s own work of breathing it is easy to go into the *"Trend graphs"* window and look at the airway pressure. A declining airway pressure indicates that the patient is taking over more of the respiratory work.

If the patient fails weaning it may be due to delayed termination of the inspiratory support. If the inspiratory part of the breath is prolonged, the patient will recruit his expiratory muscles and cycle the ventilator to expiration by an increase in pressure. This process utilizes patient energy and may shorten the time for expiration. This may induce Auto PEEP, increase work of breathing and cause lost trigger efforts by an increased internal threshold to triggering. In this case the Inspiratory cycle off should be increased. It is important to monitor the corresponding Tidal Volume levels.

## VOLUME SUPPORT (VS)

### Pressure and flow curves

Inspiration starts when the patient triggers a breath and gas flows into the patient's lungs at a constant pressure. Since the pressure provided by the ventilator is constant, the flow will decrease until the Inspiratory cycle off (1) is reached and then the expiration starts. Depending on how the Inspiratory rise time (2) is set, the pressure will either rise very quickly or slowly at the beginning of the breath.




**Expiration starts:**

- when the inspiratory flow decreases to the preset Inspiratory cycle off level.
- if the Upper pressure limit is exceeded.
- if the inspiration exceeds 2.5 s in Adult range and 1.5 s in Infant.
- if the flow drops to a flow range between 25% of the peak flow and lower limit for Inspiratory cycle off fraction level and the time spent within this range exceeds 50% of the time spent in between the start of the inspiration and the entering this range.
- if the pressure increases 3 $cmH_2O$ or 10% above the Pressure Support level (highest value applicable).

**Important:**

1. VS is not recommended when there is a leakage in the patient´s breathing circuit - usually occurring around the endotracheal tube or in the lungs (e.g. pneumothorax or fistula).
2. The Trigger Sensitivity must be set optimally for the patient without increasing the work of breathing and ensuring that the patient can inhale freely.
3. In supported modes of ventilation the inspiratory rise time should be increased from the default settings to a value comfortable for the patient.
4. Inspiration and expiration must be adapted to the patient.
5. It is important to monitor the Pressure levels and the Respiratory Rate.
6. The apnea alarm should always be set to suit the situation of the individual patient.
7. Ensure that the alarm limits for the expiratory Minute Volume alarm and for the Respiratory Rate are appropriately set.

## VOLUME SUPPORT (VS)

### Backup Volume Support

If the apnea alarm limit is reached the ventilator automatically switches to "Backup Volume Support" ventilation. The ventilator starts ventilating in Volume Control with the same Tidal Volume as in Volume Support, and the default settings for I:E ratio, Respiratory Rate and Insp. rise time.

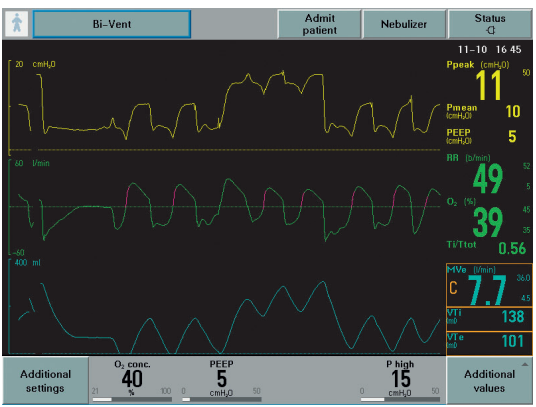
Alarms will alert staff of the change and the message "*Ventilating in Backup Mode. Change mode or go back to support mode!*" is displayed on the User Interface.


The user must decide whether or not the Support mode is suitable.

## Bi-Vent

Technically, Bi-vent is classified as a time-cycled, pressure-limited mode of ventilation that allows spontaneous breathing throughout the entire ventilatory cycle.

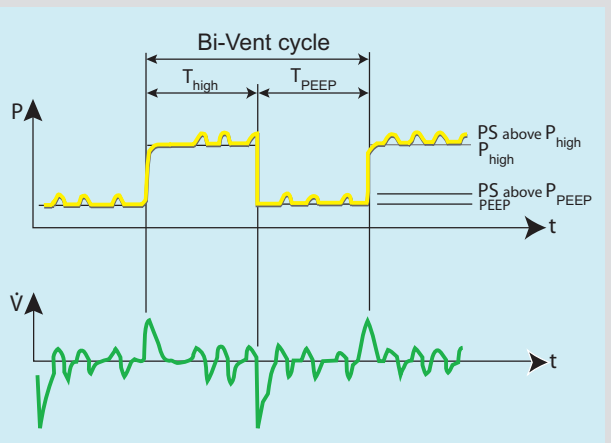
Bi-vent has two, time-cycled pressure levels and switches between these levels. In Bi-vent mode the patient can breathe spontaneously at both these levels, and it is possible to support the patient with Pressure Support at both pressure levels.



## BI-VENT

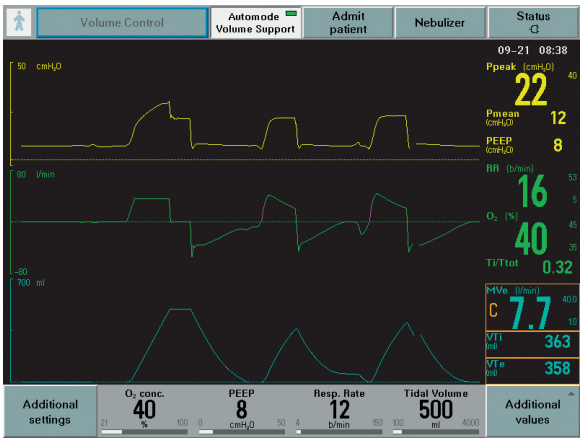
*Example:*

*Time for $P_{high}$ is set to 2 s and time for PEEP is set to 4 s and this will give you 6 s for the Bi-Vent cycle. The mandatory rate will be 60/6 = 10 breaths per minute. The Bi-Vent cycle may be shifted somewhat depending on the patient and the ventilator settings since the ventilator continuously synchronizes with the patient's breathing. Since Bi-Vent is a controlled mode of ventilation, backup ventilation is not available.*




*Every Bi-Vent cycle has a time for the $P_{high}$ and for the PEEP level. The time for $P_{high}$ can be set 0.2 – 10 s and the time for PEEP can be set 0.2 – 10 s. This means that you can set the mandatory rate from 3-150 breaths per minute.*

## Automode®




Automode is an interactive mode of ventilation. The combined control and support function of the ventilator adapts to the patient's breathing capacity. Automode allows the patient to go into a support mode automatically if they trigger the ventilator, thereby better adapting ventilation to patient effort. If the patient is not making any breathing effort the ventilator will deliver controlled breaths.

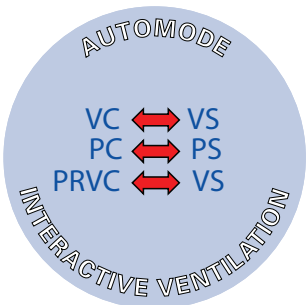
Automode provides both the patient and clinician with the best possible means of starting the weaning period when ventilator therapy is initiated.

## AUTOMODE®

Essentially the ventilator works in two modes: control or support. When the patient makes an inspiratory effort in control mode, then the ventilator reacts by supplying a supported breath.

Three different coupling modes combining control and support are available:

- Volume Control - Volume Support
- Pressure Control - Pressure Support
- PRVC - Volume Support




The start-up algorithm for Automode will protect against false triggering. The ventilator initially adapts with the adjustable Trigger Timeout. Trigger Timeout is the maximum allowed apnea time in Automode before controlled ventilation is activated. This means that for the spontaneously breathing patient the Trigger Timeout limit increases successively.

The patient has to breathe 10 breaths in a row before the ventilator will wait the whole Trigger Timeout period before switching to controlled ventilation. If the patient triggers fewer breaths the ventilator will decrease the time when it switches to controlled ventilation. The time before the ventilator switches from support to controlled ventilation will be shorter and shorter the fewer breaths the patient triggers. If the patient breathes more than 10 breaths in a row and then stops it will take the set Trigger Timeout, e.g. 7 seconds, before the ventilator initiates controlled ventilation.

Patient activity can be seen by looking at the trend, which will indicate the activity of the patient over 24 hours.

Early detection and adaptation to patient effort promotes spontaneous breathing and early weaning. At the first sensing of spontaneous effort, Automode delivers supported breaths adapted to patient's effort, instead of a controlled mechanically pre-programmed pattern.

# SYNCHRONIZED INTERMITTENT MANDATORY VENTILATION (SIMV)

## SIMV

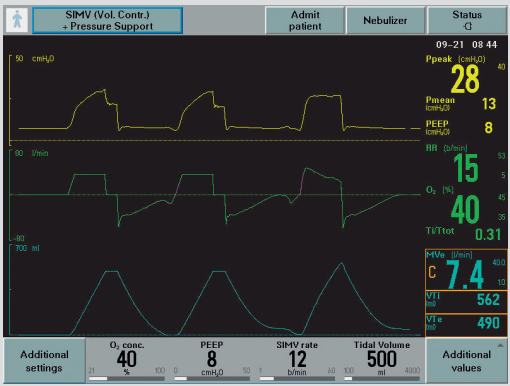
During SIMV the patient receives mandatory breaths that are controlled or assisted by the ventilator. These mandatory breaths are synchronized with the breathing efforts of the patient who can breathe spontaneously between the breaths.

The mandatory breath is defined by the basic settings (mode of ventilation, breath cycle time, respiratory pattern and volumes/pressures). The SIMV rate is the rate of the mandatory breaths per minute.

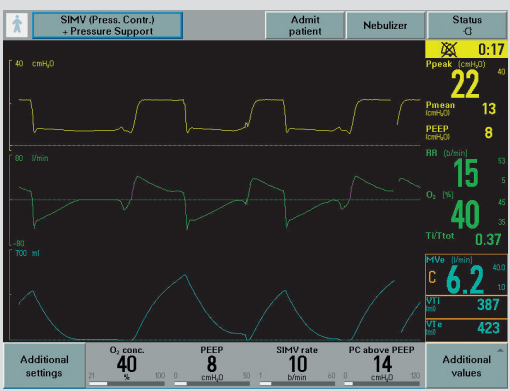
The spontaneous/Pressure-Supported breath is defined by setting the Pressure Support level above PEEP and the cycle off %. When the user gradually decreases the SIMV rate, the patient has more and more time for the spontaneous/Pressure-Supported breaths.

There are three different SIMV modes:

- SIMV (Volume Control) + Pressure Support
- SIMV (Pressure Control) + Pressure Support
- SIMV (PRVC) + Pressure Support

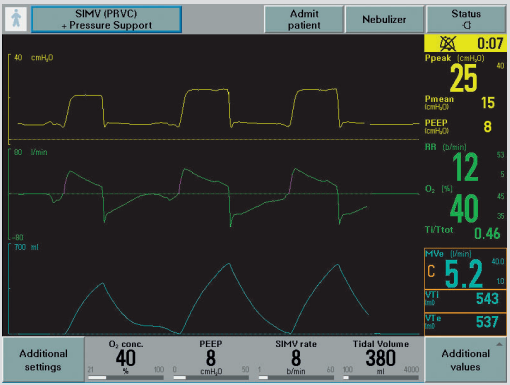



*SIMV (Volume Control) + Pressure Support*




*SIMV (Pressure Control) + Pressure Support*

# SYNCHRONIZED INTERMITTENT MANDATORY VENTILATION (SIMV)

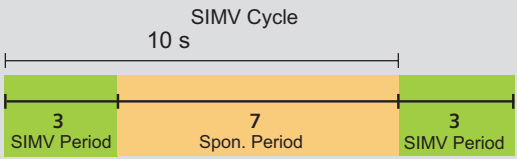



*SIMV (PRVC) + Pressure Support*

## Breath Cycle Time (Breath Cycle T)

This is the length of the total respiratory cycle of the mandatory breath. The total time for inspiration, pause and expiration.

**Note:** The Breath Cycle Time is only applicable if the SERVO-i is configured for setting the inspiratory time by setting the I:E ratio.



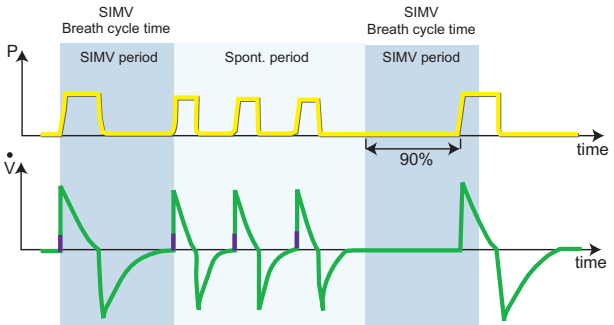

*The following settings are made in this example:*

1. *SIMV rate = 6*
2. *Breath cycle time = 3 (the time for the mandatory breath)*
3. *The SIMV cycle in seconds is calculated as follows: 60 seconds divided by the SIMV rate - in this example 60/6 = 10 s.*
4. *The SIMV cycle is divided into an SIMV period and a spontaneous period.*
5. *The time for the spontaneous period is 10 s - 3 s = 7 s.*

*The time for the mandatory breath is:*

6. *3 s = SIMV period*
7. *I:E ratio 1:2 = 1 s for inspiration and 2 s for expiration.*

## SYNCHRONIZED INTERMITTENT MANDATORY VENTILATION (SIMV)




When the patient starts to breathe, then Pressure Support is delivered during the spontaneous period, and if triggering occurs in the SIMV period then the set mandatory breath is delivered. The ventilator will wait during the next SIMV period for the patient to trigger. However, if the patient has not triggered within the first 90% of the breath cycle time (SIMV period), then a mandatory breath is delivered.

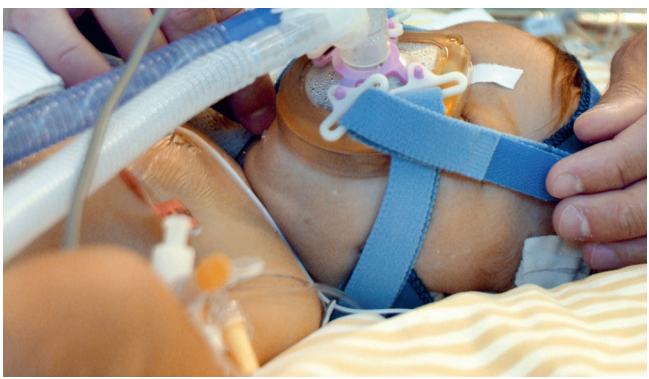
## NIV - General

Non Invasive Ventilation (NIV) refers to the delivery of mechanical ventilation using a face mask or similar device, rather than an endotracheal tube.

A major driving force behind the increasing use of NIV has been the desire to avoid complications caused by invasive ventilation, such as infections and airway trauma.

NIV also shortens the hospital stay thus reducing the treatment cost for the patient (18).

When using NIV, the patient is able to speak and eat under relatively normal circumstances, which are important factors for patient self-esteem.



## NON INVASIVE VENTILATION - NIV

### Indications for NIV

- Chronic Obstructive Pulmonary Disease (COPD) (18)
- Acute Cardiogenic Pulmonary Edema (ACPE)
- Chest wall deformity
- Parenchymal effect e.g. pneumonia
- Immunocompromised patients (19)
- Asthma (20)

### Contraindications for NIV

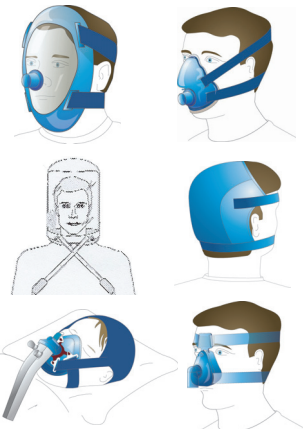
- Cardiac or respiratory arrest (21)
- Non respiratory organ failure (21)
- Severe gastrointestinal bleeding (21)
- Hemodynamic instability (21)
- Upper-airway obstruction (21)
- Unconsciousness

### Possible complications during NIV treatment

- Gastric distention
- Skin irritation or ulceration
- Eye irritation
- Claustrophobia
- Air leaks
- Aspiration pneumonia

## Interfaces for the application of NIV

There are several types of patient interfaces on the market: oronasal or full-face masks, total face mask and nasal masks. The masks are available in different sizes. As patients have different facial contours, it is very important to have a variety of masks to ensure a proper fit, as a poorly fitting mask usually results in failure of NIV.



Straps or caps that hold the mask in place are important for the patient's comfort and for avoiding leakage. These straps and caps are available in several designs and materials.

If the patient's facial contours change during the treatment due to edema, changing the mask model and/or size could be beneficial. Avoid leakage to the eyes as the dry gas may irritate and cause dry eyes.

The helmet can only be used for pediatric and/or adult patients.

The success of NIV is dependent on staff competence and patient compliance.

Before initiating the treatment it is necessary to make the patient feel comfortable and reassured. It is important that the staff are calm and that they spend time with the patient.

## NON INVASIVE VENTILATION - NIV

Keep the head of the bed at a 30° angle to obtain a respiratory physiological positioning for the patient. This will lead to a decrease in the intra-abdominal pressure and a decrease in work of breathing (WOB) (20).

It is common that the patient becomes anxious. To avoid anxiety it could be beneficial to let the patient practice breathing in the mask without connecting the tubing system and ventilator.

A nasal mask can be an alternative if the patient feels claustrophobic with a full face mask. Make sure that the patient is breathing with a closed mouth.

A helmet is another alternative if a good mask fit is hard to achieve.

Note that leakage is not a primary concern when using a helmet, but rather the large volume of gas that will have an impact on triggering. In many cases the invasive function of the SERVO-i will be superior to the NIV function for the helmet application.

**Note:** The user must monitor the patient with extra care to ensure that the chosen helmet is safe for the individual patient. Note that the helmet can only be used for pediatric and/or adult patients.

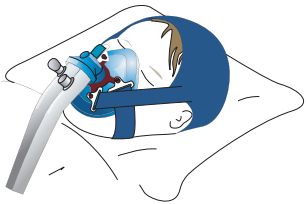
Monitoring patient comfort and tolerance during NIV is very important and must be performed at the bedside whilst observing and querying the patient.

### Humidification

Humidification during NIV has been shown to be helpful. The dry medical gas dehydrates the mucous membranes in the airways making these more prone to infection.

## The NIV application

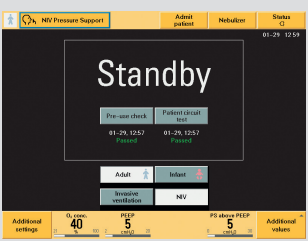
In the *"Standby"* mode the user selects a patient category, adult or infant, and then either Invasive or Non Invasive Ventilation.



When NIV is selected the User Interface changes frame color from grey to yellow, along with the NIV icon shown in the "*Mode of ventilation*" soft key. Pressure Support, Pressure Control and Nasal CPAP are the ventilation modes available in NIV.

The first part of this description of NIV will cover NIV Pressure Support and NIV Pressure Control. The second part deals with Nasal CPAP.

- NIV Pressure Support from 3 kg and above.
- NIV Pressure Control from 3 kg and above.
- Nasal CPAP 500 g to 10 kg.

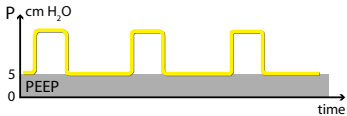



***Notes:***

1. *It is strongly recommended that the pre-use check is performed and passed shortly before the patient is connected to the ventilator.*
2. *Observe that the default settings are automatically changed when switching between Invasive and Non Invasive modes.*

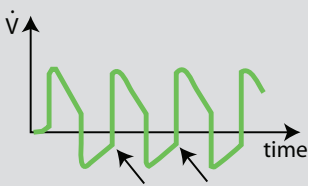
## PEEP

Positive End Expiratory Pressure (PEEP) can be set in the range of 0 - 50 $cmH_2O$. A Positive End Expiratory Pressure is maintained in the alveoli and may prevent collapse of the airways.




### *Auto PEEP*

*If the respiratory rate is set high or the expiratory time is not long enough there is a risk for auto PEEP. The patient does not have enough time to exhale and it is evident on the flow curve that flow will not return to zero before the next breath starts.*



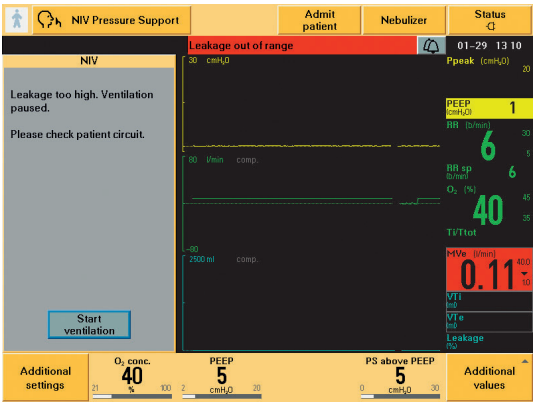
## Leakage compensation


During NIV, the ventilator automatically adapts to the variation of leakage in order to maintain the required pressure and PEEP level. The leakage is presented on the SERVO-i as the Leakage fraction % and is a measurement of how well the mask fits the patient. A grey frame around the volume values indicates that the volumes are leakage compensated.

When the patient breathes irregularly the leakage value varies. The leakage value displayed represents leakage during inspiration (an average taken during 2 - 3 breaths). The volumes shown in the measured value box are compensated for leakage, meaning that they correspond to the actual volume the patient breathes in and out.

**Note:** Leakage compensation during expiration is up to 40 l/min for adults and up to 15 l/min for infants.

## Disconnect position (Ventilation paused)




If the leakage is excessive (>65 l/min for adults and >25 l/min for infants) or if the patient is disconnected, the SERVO-i will pause ventilation and issue a high priority alarm. A text message will appear on the screen stating *"Leakage too high. Ventilation paused. Please check patient circuit"*.

An alarm is activated and an alarm message is displayed on the User Interface, “*Leakage out of range*”. To reduce any disturbance caused by the alarm it is possible to pre-silence patient-related alarms before disconnecting the patient from the ventilator.

The ventilation is paused to minimize patient discomfort. A bias flow is delivered with a constant flow of 7.5 l/min to detect the breathing effort of the patient. Once the leakage has been reduced or the patient reconnected, ventilation is automatically resumed and the screen dialog will disappear after three breaths.

It is also possible to manually start ventilation by pressing the fixed key *"Start breath"* or the soft key *"Start ventilation"* on the User Interface.

## Trigger Sensitivity

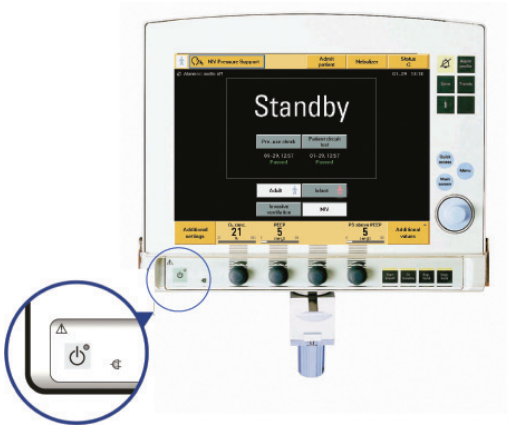

The Trigger Sensitivity determines the level of patient effort needed to initiate the inspiratory flow i.e. how much additional work or breathing the patient has to create to start the inspiration. The Trigger Sensitivity is fixed in NIV.

If the patient lowers the pressure to 1 $cmH_2O$ below PEEP during expiration or causes an expiratory flow decrease of 6 ml during 100 ms, then the SERVO-i delivers a breath.

The dynamic pressure and flow compensation will maintain the Trigger Sensitivity even in the case of a considerable leakage.

When the patient triggers a breath, a purple T appears between the text message and the alarm message areas on the screen. The initial part of the flow curve changes to purple to indicate when the patient triggers the breath.

## Waiting position




After pressing the fixed key *"Start/Stop"*, a 2-minute waiting position is initiated.
The waiting position gives the user the chance to adjust the ventilator and the interface e.g. mask.

During this phase, all audible alarms are deactivated and no ventilation is delivered. Settings and alarm limits can be changed in the waiting position.

**Note:** The waiting position increases the patient´s comfort, as the ventilator will not deliver an excessive flow before the patient makes an inspiratory effort.

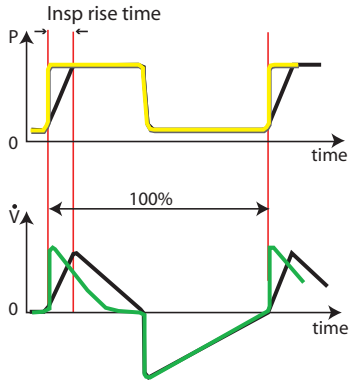

Ventilation starts when one or both of the following criteria have been met:

- the ventilator detects a patient's attempt to breathe.
- the user presses the soft key *"Start ventilation"*.

If neither of these two criteria have been met within two minutes, an alarm alerts the user. During the waiting phase, all audible patient-related alarms are deactivated and no ventilation is delivered.

## Inspiratory rise time

The Inspiratory rise time is the time taken to reach peak inspiratory flow or pressure at the start of each breath as a percentage of the respiratory cycle time or in seconds. The Inspiratory rise time has to be set to a comfortable value for the patient and can be evaluated by the shape of the flow and pressure curves.




The fast response of the SERVO-i will achieve the set Pressure Support almost instantaneously. This implies that effective gas delivery will be present from patient initiation of inspiration. This may be utilized in two ways. If the patient is severely dyspneic, Pressure Support may be delivered with a short Inspiratory rise time.

A longer Inspiratory rise time, on the other hand, will allow the patient a greater control over the Inspiratory flow.

## IMPORTANT VENTILATORY SETTINGS - NIV

The Inspiratory flow profile has to be set to a comfortable value for the patient and can be evaluated by the shape of the flow and pressure curves.

**Note:**
Inspiratory rise time will be shown in seconds if:

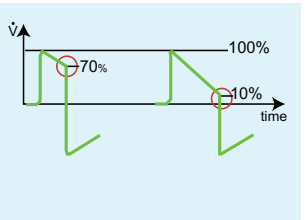
- the ventilator is configured for Inspiratory time in seconds.
- if ventilating in NIV Pressure Support.

Inspiratory rise time is shown in %:

- in the NIV Pressure Controlled mode of ventilation, if the ventilator is configured for I:E ratio.

## Inspiratory cycle off

Inspiratory cycle off is the point at which inspiration changes to expiration in NIV Pressure Support.

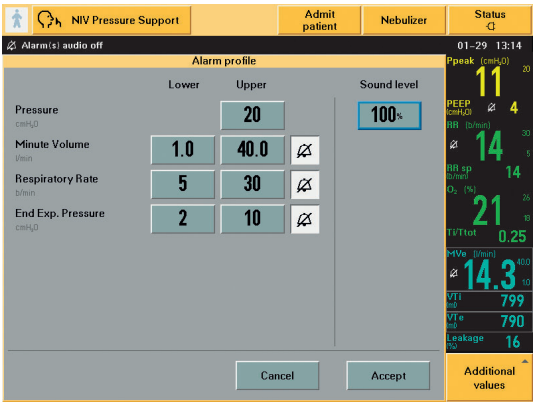



**Important:**
It is important to set the Inspiratory cycle off correctly to avoid hyperinflation of the lungs and increased work of breathing. It is possible to set the Inspiratory cycle off from 10% to 70% of inspiratory peak flow for both adults and infants (default values are 50% for adults, and 30% for infants).

If the Inspiratory cycle off cuts off inspiration too early, the patient will not get enough Tidal Volume.

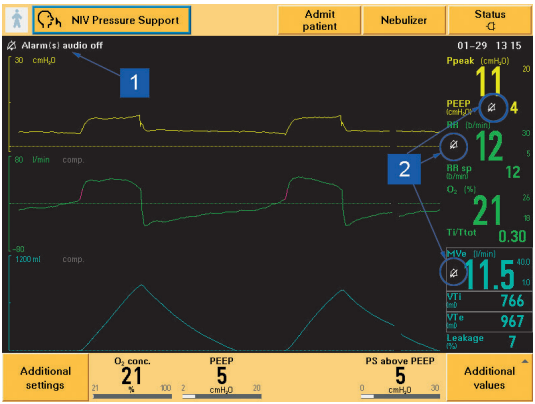
If the pressure increases 1 $cmH_2O$ above the set Pressure Support level above PEEP, the ventilator changes from inspiration to expiration.

## Alarms




Since the leakage often varies during NIV, alarms may be activated more often than necessary. To reduce this disturbance, it is possible to set audible alarms to *"Audio Off"* for all patient-related alarms, excluding the high-pressure alarm.

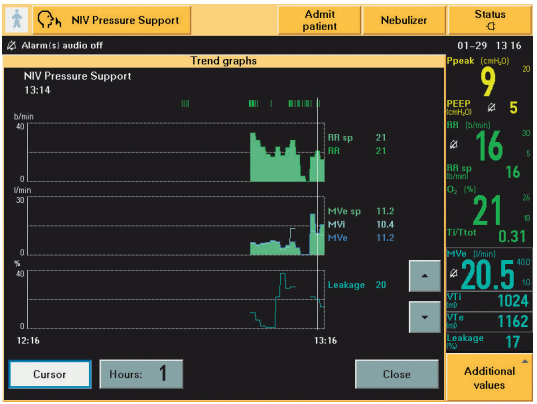
To enable the *"Audio Off"* function, press the soft key with the *"Bell"* symbol displayed next to the relevant alarm.




A crossed-over bell indicates the activation of the *"Audio off"* function, both in the *"Alarm profile"* window and in the measured value box (2). Moreover, the message *"Alarms - audio off"* appears at the top left of the User Interface (1). Alarms will still be shown visually.

If a SERVO $CO_2$ analyzer is connected to the ventilator, *"End tidal $CO_2$"* is displayed in the *"Alarm profile"* window.

## Trend Graph




In the *"Trend graphs"* window, information about when NIV was last used is displayed in the upper left corner of the window.
Leakage is shown as a separate parameter.

## NIV Pressure Support

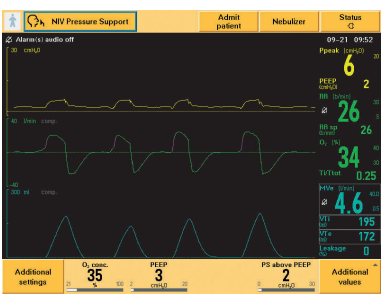
NIV Pressure Support is a spontaneous mode of ventilation. The patient initiates the breath either by lowering the pressure to 1 $cmH_2O$ below PEEP during expiration or causing an expiratory flow decrease of 6 ml during 100 ms. The SERVO-i delivers support with the preset pressure level and a decelerating flow. With support from the ventilator, the patient also regulates the Respiratory Rate and the Tidal Volume.

If the mechanical properties of the lung/thorax and patient effort change, delivered Tidal Volume will be affected. The Pressure Support level must be regulated to obtain the desired ventilation.

As the patient becomes more active, the Pressure Support level may be gradually reduced. The Inspiratory rise time and the Inspiratory cycle off must be set to a comfortable value for the patient.

## NIV PRESSURE SUPPORT


**Note:** The fast response from the SERVO-i may require a lower Pressure Support level. Normally in NIV the treatment is started with a low Pressure Support level, 2-3 $cmH_2O$. The Pressure Support level above PEEP is then slowly titrated to the level that will give a comfortable breathing pattern.



## Backup rate

During NIV Pressure Support, the system ensures a minimum NIV backup rate and maintains the set inspiratory pressure and PEEP level. The NIV backup rate is activated when the spontaneous breathing rate is lower than the NIV backup rate.

The NIV backup rate assists the patient breath to a minimum set level per minute with ranges for:

- Adults - 4 to 20 breaths/min
- Infants - 4 to 40 breaths/min

The NIV backup Ti is the inspiratory time for the NIV backup breaths, adjustable for:

- Adults - 0.50 to 2.0 s
- Infants - 0.3 to 1 s

# NIV PRESSURE CONTROL

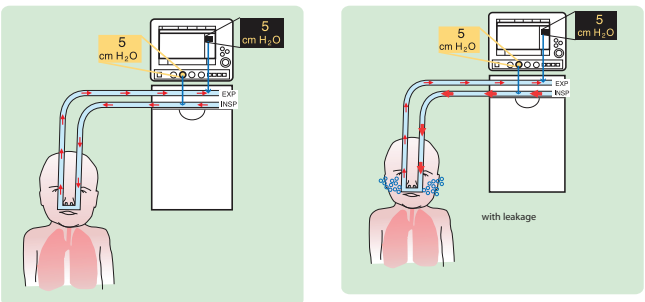
## NIV Pressure Control

In this controlled mode of ventilation, the ventilator delivers a flow to maintain the preset pressure at a preset respiratory rate and during a preset inspiratory time. The pressure is constant during the inspiratory time and the resulting flow rate is decelerating. If for any reason the pressure decreases during inspiration, the flow from the ventilator will immediately increase to maintain the set inspiratory pressure. The volume may vary from breath to breath if the patient's compliance and resistance changes.

## Nasal CPAP (for infants from 500 g to 10 kg)

Nasal CPAP helps to recruit collapsed alveoli, improve oxygenation, stabilize the chest wall and inhibits paradoxical movements during inspiration and collapse during expiration.

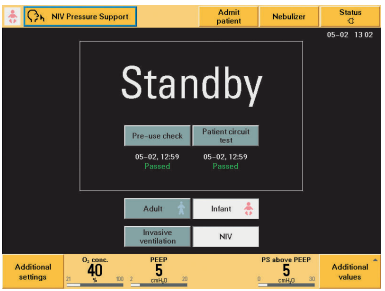
Nasal CPAP in the SERVO-i ventilator delivers the flow necessary to maintain the pressure set by the user.



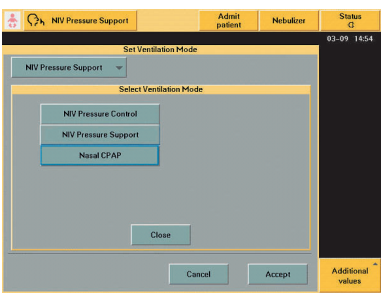

For example, if there is a leakage around the nasal prongs, then the SERVO-i will automatically and immediately increase the flow on the inspiratory side in order to maintain the set pressure. The maximum available flow in Nasal CPAP is 33 l/min.

## NASAL CPAP

### Entering Nasal CPAP from Standby



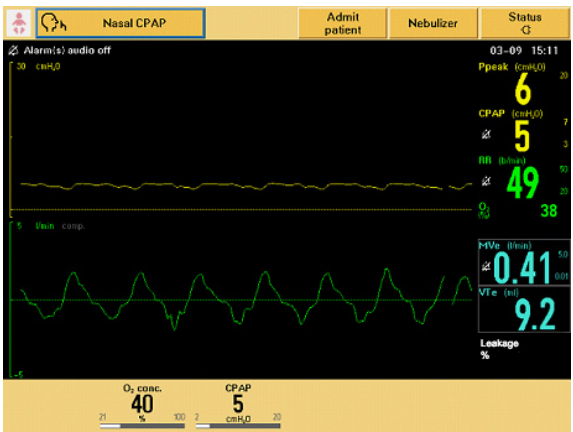

From *"Standby"* mode select patient category "*Infant*" and mode "*NIV*"




Press the soft key "*Nasal CPAP*" to select this mode of ventilation.

## Pressure and flow curves

In Nasal CPAP the pressure level and the oxygen concentration have to be set. The CPAP pressure can be set from 2 - 20 $cmH_2O$.

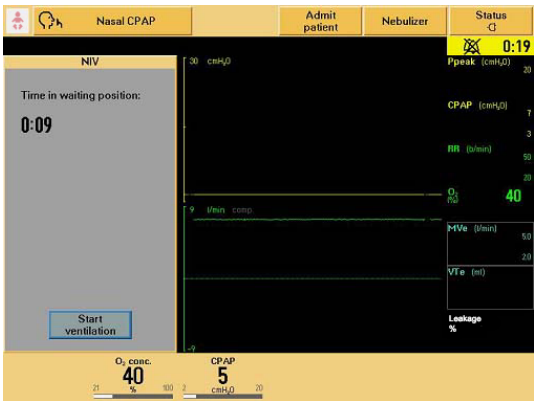



SERVO-i regulates the pressure from the set CPAP level in order to minimize the pressure fluctuation, while the flow varies.

In Nasal CPAP, the infants breathe spontaneously from the delivered flow and there are no triggering criteria.

## NASAL CPAP

### Waiting position



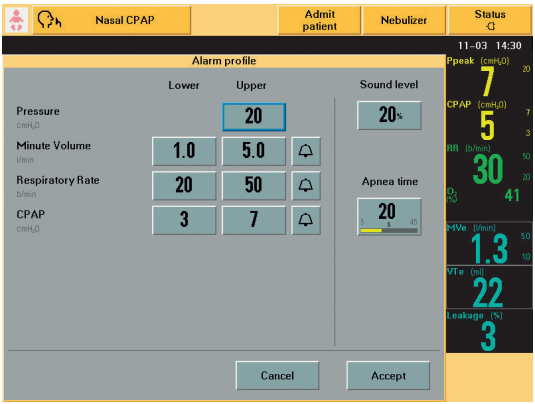

When the Nasal CPAP mode of ventilation starts, a Waiting position is initiated. The patient will feel more comfortable, as during this period the ventilator will not deliver an excessive flow until the patient makes in inspiratory effort.

Moreover, all audible, patient-related alarms (except for the $O_2$ alarm) are inactivated during this phase and no ventilation occurs.

Ventilation will start when one or both of the following criteria have been met:

- the ventilator detects a patient´s attempt to breathe. The SERVO-i has a bias flow of 7.5 l/min while in the Nasal CPAP Waiting position.
- the user presses the soft key "*Start ventilation*".

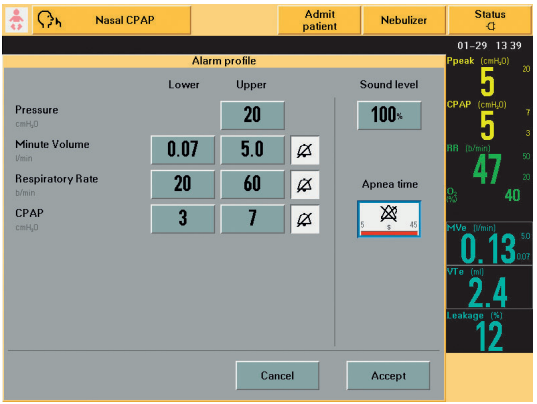
## Nasal CPAP - Alarms




- Pressure
- Minute Volume
- Respiratory Rate
- CPAP
- Apnea time

Since the leakage often varies in Nasal CPAP, alarms may be activated more often than necessary.

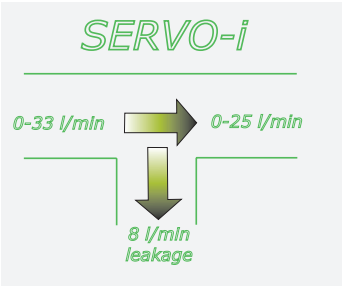
To reduce the frequency of these activations, it is possible to set audible alarms to "*Audio Off*" for all patient-related alarms except the High Pressure Alarm.



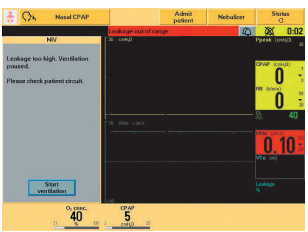

The Upper Pressure limit cannot be silenced permanently. To enable the *"Audio Off"* function, press the soft key with the *"bell"* symbol next to the relevant alarm. A crossed-over bell indicates that the *"Audio Off"* function in both the *"Alarm profile"* window and the *"Measured value"* box will be shown.

## Excessive leakage

The maximum available flow is 33 l/min. If there is a leakage of 8 l/min, then the available flow is 0-25 l/min. If a leakage of 10 l/min has occurred in the patient´s breathing system for a short period of time, or if the patient is disconnected, then the SERVO-i informs the user by displaying the message *"Leakage too high, ventilation paused. Please check patient circuit"* in the dialog box.




A high priority alarm is activated and displayed on the User Interface stating *"Leakage out of range"*.



## NASAL CPAP

Ventilation is paused to minimize patient discomfort. A bias flow is delivered with a constant flow of 7.5 l/min to detect the breathing effort of the patient.

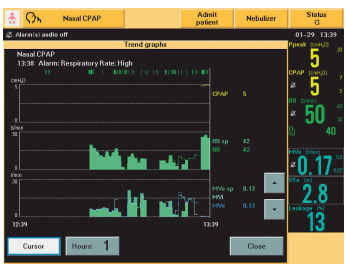
It is also possible to manually start ventilation either by pressing the "*Start breath*" fixed key or the "*Start ventilation*" soft key on the User Interface. However, if the leakage is not remedied then the dialog box will reappear.

The leakage is presented as the leakage fraction (%) on the monitoring section of the User Interface. The volumes shown in the Measured value box are "compensated" for leakage. In other words, these volumes correspond to the actual patient volumes.

## Trends

Data is stored in the ventilator and it is possible to view this data in the *"Trend graphs"* window. The data shown is:

- CPAP level
- Respiratory Rate
- Minute Volume
- Leakage fraction



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