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The FLOW-i anesthesia system offers a number of ventilation modes which clinicians can tailor to their patients' needs. The aim of this pocket guide is to provide information about these modes, and to present some of the most important ventilatory settings. It is however important to remember that it only covers selected topics and cannot replace the user's manual and the service manual. For detailed information, always refer to these manuals. Details about the modes of ventilation, for example, can be found in the relevant FLOW-i user's manual.
Summary of FLOW-i's mechanical ventilation modes

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In addition, it is also possible to ventilate patients manually by using the manual ventilation system (MAN), or in case of emergency by using the emergency ventilation system (see below). An option on the FLOW-i is the Additional Fresh Gas Outlet (AFGO), which allows connection of breathing systems such as a Jackson-Rees, Bain or Mapleson system.
INTRODUCTION

Examples of flow patterns in mechanical ventilation

Flow pattern in Volume Control (VC)

The flow is constant during inspiration in Volume Control and SIMV (VC). 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.
Flow pattern in Pressure Control (PC)

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

Ventilating patients with FLOW-i

In addition to the mechanical ventilation modes listed above, the user may also choose to ventilate a patient manually.

The MAN/AUTO switch

The MAN/AUTO switch sets the status of the FLOW-i to either manual (MAN) or automatic (AUTO) ventilation.

When the switch is set to MAN, the manual ventilation valve opens and the manual ventilation bag is connected to the breathing system. This setting will also enable APL regulation via the APL (Adjustable Pressure Limit) valve. Some machines also have an optional Additional Fresh Gas Outlet (AFGO) that allows connection of special breathing circuits. Manual ventilation is described under the next subheading.
When the switch is set to AUTO, the manual ventilation valve closes and the manual ventilation bag is disconnected from the breathing system. The APL valve is then also disabled.

The screen shot below shows how to select a mechanical ventilation mode after turning the MAN/AUTO switch to AUTO.
INTRODUCTION

The next two screen shots below illustrate the settings for Volume Control, together with an example showing this mode activated and running on the FLOW-i.
Select the correct breathing bag and tube depending on the patient category. The pressure limit is set with the help of the APL valve.

The pressure can be set anywhere between a value corresponding to a fully open valve (for spontaneous breathing) and 80 cmH₂O.
INTRODUCTION

At values above 30 cmH₂O, an increased tactile resistance can be felt and a slight click can be heard at every 5 cmH₂O interval.

The set pressure limit (APL) is displayed at the bottom left of the screen.
Emergency ventilation

The FLOW-i anesthesia system's emergency ventilation includes:

- the emergency ventilation on/off switch
- the O₂ gas supply knob and flowmeter
- the emergency APL valve regulator
- clear and simple instruction for accessing this function

In case of a total power (mains power and battery) or system failure, the patient can be manually ventilated using the emergency ventilation system.

The system is activated by turning on the activation switch and adjusting the oxygen flow, which can be set to up to 10 l/min. The pressure level is adjusted by the mechanical APL regulator.

The patient is ventilated with the help of the manual ventilation bag.

If the emergency ventilation system is activated while the anesthesia system is in operation, the anesthesia system will be shut down.
**Important ventilatory settings**

**PEEP**

Positive End Expiratory Pressure (PEEP) can be set in the range of 0 - 50 cmH\textsubscript{2}O. A positive end expiratory pressure is maintained in the airways and may prevent collapse of the alveoli.

**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 FLOW-i whether the patient has an auto PEEP.

- The expiratory flow will not go back to zero before the next inspiration starts, as shown on the curve above.
- The measured value $V_{ee}$ is not zero.
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 to suit 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 (0-0.4 s) if:
- the FLOW-i is configured to show inspiratory time in seconds
- the patient is being ventilated in Pressure Support mode

The inspiratory rise time is shown as a percentage (0-20%):
- in all controlled modes of ventilation if the FLOW-i is configured for the I:E ratio
Inspiratory cycle off

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

**Important:** 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 1% to 80% of inspiratory peak flow for both adults and infants (default values are 50% for adults and 50% 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 cmH₂O above the set Pressure Support level above PEEP, ventilation switches from inspiration to expiration.
**Trigger sensitivity**

Trigger sensitivity determines the level of patient effort needed to trigger the FLOW-i to deliver an inspiration.

Trigger sensitivity can be set as either flow triggering or pressure triggering.

**Important**: The trigger level should be set as sensitively as possible without causing autotriggering.

During expiration, the FLOW-i continuously delivers a fresh gas flow of 2 l/min (approx. 33 ml/s) for adults and 0.5 l/min (approx. 8.25 ml/s) for infants.

When the difference between the inspiratory and expiratory flows reaches the preset flow trigger level, the FLOW-i will start to deliver a new inspiration.
Examples of flow and pressure triggering

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 and there is therefore a risk for autotriggering.

The pressure trigger sensitivity can be set within the range 0-(-20) cmH₂O. To initiate a breath the patient has to create the negative pressure that is set as trigger sensitivity. The higher the negative trigger pressure set on the FLOW-i, the more work of breathing the patient must perform. The trigger level should be set as sensitively as possible without causing self-triggering – autotriggering.

If an external gas analyzer is connected to the system, the trigger sensitivity may need adjusting to avoid autotriggering.
When the patient triggers a breath, "Triggering" appears above the pressure curve or flow curve in the waveform display area. A section of the pressure or flow curve also changes color to indicate that the patient is triggering the breath.

Notes:
1. If the breath is flow-triggered, then the color change is seen on the flow curve.
2. If the breath is pressure-triggered, then the color change is seen on the pressure curve.
In this controlled mode of ventilation the FLOW-i 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 patient's compliance and/or resistance change.

In a system with no leakage, the inspired tidal volume should be the same as the expired tidal volume. The time for inspiration and expiration can be configured so that it is set either as the I:E ratio or as inspiration time in seconds.
When using the FLOW-i anesthesia system, you can choose whether you want to set the tidal volume (as in the screen shot above) or the minute volume. The flow during Volume Control ventilation is constant. The inspiratory rise time in % is seen in the information area in the "Set ventilation mode" menu. Inspiratory rise time: time to peak inspiratory flow at the start of each breath as a percentage of the respiratory cycle time.

It is very important to set a sensitive triggering level so as to allow the patient 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 by the patient is crucial to synchrony between patient and machine.
In this controlled mode of ventilation the FLOW-i delivers a flow at the preset pressure throughout the preset inspiratory time at the preset respiratory rate.

During the inspiratory time, the pressure is constant and the flow is decelerating. The peak pressure (Ppeak) is the sum of the settings for PEEP and PC above PEEP. If for any reason 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/or resistance change.

**Important:** Always set the expiratory minute volume alarm limits to adequate levels.
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 \( \frac{60}{15} = 4 \) sec

\[
\text{Inspiratory rise time 10\%} = \frac{4 \times 10}{100} = 0.4 \text{ sec}
\]
The FLOW-i immediately senses the smallest deviations in pressure during inspiration, and compensates 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.
Active expiratory valve

If a patient tries to exhale during inspiration then pressure increases. When the pressure increases to 3 cmH₂O 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 is a controlled mode of ventilation which combines the advantages of volume controlled and pressure controlled ventilation. The FLOW-i delivers the preset tidal volume with the lowest possible pressure.

**Important:** PRVC is not recommended when there is a leakage in the patient’s breathing circuit.
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 FLOW-i 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/lungs/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 cmH₂O) until the preset tidal volume is delivered.

The maximum available pressure level is 5 cmH₂O below the preset upper pressure limit. If the pressure reaches 5 cmH₂O below the preset upper pressure limit, the FLOW-i 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.
The FLOW-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, 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, the FLOW-i provides adequate flow to balance and further enhance the opening process.
Pressure Support is a spontaneous mode of ventilation. The patient initiates the breath and the FLOW-i delivers support with the preset pressure level. With support from the FLOW-i, 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. The peak pressure (Ppeak) is the sum of the settings for PEEP and Pressure Support above PEEP.
Any change in the mechanical properties of the lung/thorax and/or patient effort will affect the delivered tidal volume. If this occurs, the Pressure Support level must be adjusted to ensure the desired ventilation.

The higher the preset inspiratory pressure level from the FLOW-i, the more gas flows into the patient. As the patient becomes more active, the set 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 (see diagram below). It is important to monitor the corresponding tidal volume levels.
PRESSURE SUPPORT (PS)

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 FLOW-i is constant, the flow will decrease until the inspiratory cycle off (1) is reached, when the expiration starts. Depending on how the inspiratory rise time (2) is set, the pressure will either rise very quickly or more slowly at the beginning of the breath.

Expiration starts:
- when the inspiratory flow decreases to the preset inspiratory cycle off level.
- if the pressure increases 3 cmH₂O or 10% above the Pressure Support level (highest value applicable).
- if the upper pressure limit is exceeded.
- if the inspiration exceeds 2.5 s for adults and 1.5 s for infants.
Important:
1. The trigger sensitivity should be set optimally for the patient without increasing the work of breathing and while 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 FLOW-i may cycle off prematurely resulting in an 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.
Backup ventilation in Pressure Support (which is Pressure Control) is controlled by the settings for backup respiratory rate and PC above PEEP.

If no breath is detected within the interval determined by the backup respiratory rate, the FLOW-i will deliver a controlled breath using the set PC above PEEP setting.
Backup ventilation example

The screen shot above shows that the backup respiratory rate has been set to 6 breaths per minute. 60 seconds divided by 6 is 10 seconds. This means that if the patient fails to take a breath within 10 seconds, the FLOW-i will deliver a PC breath with the set PC above PEEP, which in this case is 10 cmH₂O.

The backup respiratory rate may be set to between 2 and 60 breaths per minute. PC above PEEP may be set to between 5 and 120 cmH₂O for adult patient category and between 5 and 80 cmH₂O for infant patient category. The I:E ratio is preset to 1:3 for adult and 1:2 for infant patient category respectively.

Backup ventilation can be disabled by setting the backup respiratory rate to "off".
There is also a high priority apnea alarm, shown in the screen shot below. The apnea alarm is based on the presence of CO$_2$. In other words, if there is no CO$_2$ then the apnea alarm will be activated.

When such apnea is detected, the FLOW-i will go to backup ventilation to ensure breath delivery to the patient.

The apnea time may be set to between 5 and 45 seconds for infant patient category and between 15 and 45 seconds for adult patient category.
Synchronized Intermittent Mandatory Ventilation (SIMV)

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

The mandatory breath is defined by the basic settings (ventilation mode, 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 (cmH₂O) 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 two different SIMV modes:

- SIMV (Volume Control) + Pressure Support
- SIMV (Pressure Control) + Pressure Support
SYNCHRONIZED INTERMITTENT MANDATORY VENTILATION (SIMV)

SIMV (Volume Control) + Pressure Support

SIMV (Pressure Control) + Pressure Support
Breath Cycle Time (Breath Cycle T)

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

**Note:** The breath cycle time is only applicable if the FLOW-i is configured for setting the inspiratory time using 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.

![SIMV cycle diagram](image-url)
When the patient starts to breathe, Pressure Support is the mode used to deliver breaths during the spontaneous period. If triggering occurs in the SIMV period, the set mandatory breath is delivered. The FLOW-i will then 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 (within the SIMV period), a mandatory breath is again delivered.
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