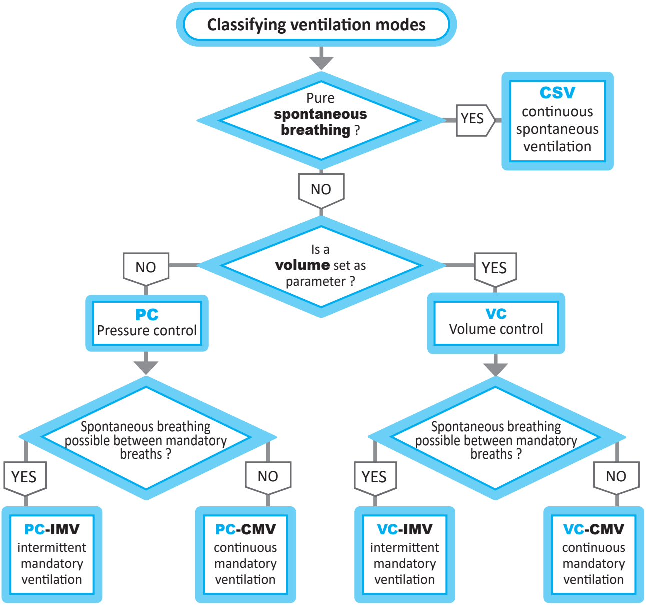
Explanations of the individual modes, tabular comparisons of manufacturer-specific designations and classification according to DIN ISO 19223:2021 create the transparency necessary for the user.

The authors are aware that similar forms of ventilation often differ in small details. Likewise, ventilation modes can also be modified by setting the parameters (e.g. PSV with a pressure support of 0 = CPAP). For the sake of comparability, however, these details were carefully weighed, evaluated and then assigned to the corresponding categories.

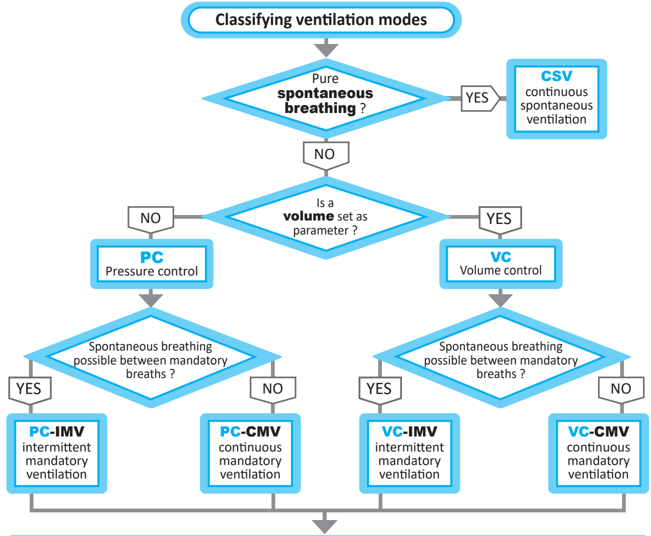
We would like to thank the RespiCode Training and Simulation Centre Karlsruhe, Tobias Becher (UKSH Kiel) and Löwenstein Medical for their professional exchange.

Karlsruhe, September 2024
Peter Kremeier, Christian Woll

Chatburn 2007



Chatburn, Robert L. 2007. "Classification of Ventilator Modes: Update and Proposal for Implementation." Respiratory Care 52 (3): 301 LP-323. http://rc.rcjournal.com/content/52/3/301.abstract.

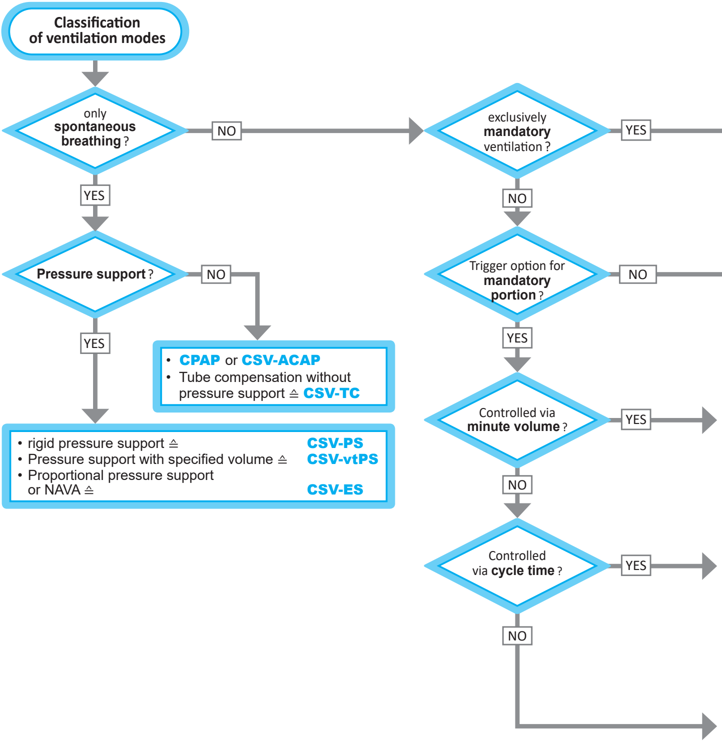


Add the respective characteristics to the ventilation mode:

Target value	s	By setting the pressure ramp (pressure-controlled modes) or the flow pattern (volume-controlled modes)
Dual	d	Automatic switching between volume control and pressure control
Servo	r	Pressure support is proportional to inspiratory respiratory efforts.
Adaptive	a	Depending on the patient's changing condition, the ventilator automatically adjusts one or more target values between two delivered breaths.
Biovari-able	b	The ventilator randomly regulates inspiratory pressure and tidal volume (simulating the variability of normal breathing).
Optimal	o	The ventilator adjusts the control target values of the breathing pattern to achieve an overall performance characteristic (e.g. optimisation of work of breathing).
Intelligent	i	The control algorithms include artificial intelligence such as rule-based expert systems or artificial neural networks.

Chatburn, Robert, Mohamad El Khatib, and Eduardo Mireles-Cabodevila. 2014. "A Taxonomy for Mechanical Ventilation: 10 Fundamental Maxims." Respiratory Care 59 (11): 1747–63. https://doi.org/10.4187/respcare.03057.

ISO Standard 19223:2021



Deutsches Institut für Normung e. V. (2021)
Ventilators and associated devices –Terminology and Semantics ISO19223:2021

Trigger option ?

YES

- with specified pressure ≙ **A/C-PC**
- with specified volume ≙ **A/C-VC**
- with specified pressure and guaranteed volume ≙ **A/C-vtPC**

NO

- with specified pressure ≙ **CMV-PC**
- with specified volume ≙ **CMV-VC**
- with specified pressure and guaranteed volume ≙ **CMV-vtPC**

- Pressure-controlled ventilation ≙ **IMV-PC\ACAP**
- Pressure-controlled ventilation + pressure support ≙ **IMV-PC\PS**

- Pressure-controlled ventilation + pressure support ≙ **MMV-PC\PS**
- Pressure-controlled ventilation + pressure support with specified volume ≙ **MMV-PC\vtPS**
- Volume-controlled ventilation + pressure support ≙ **MMV-VC\PS**
- Volume-controlled ventilation + pressure support with specified volume ≙ **MMV-VC\vtPS**
- Pressure-controlled ventilation with guaranteed volume + Pressure support ≙ **MMV-vtPC\PS**
- Pressure-controlled ventilation with guaranteed volume + pressure support with specified volume ≙ **MMV-vtPC\vtPS**

- Pressure-controlled ventilation + pressure support ≙ **S/T-PC\PS**
- Pressure-controlled ventilation + pressure support with specified volume ≙ **S/T-PC\vtPS**
- Pressure-controlled ventilation + proportional pressure support ≙ **S/T-PC\ES**
- Volume-controlled ventilation + pressure support ≙ **S/T-VC\PS**
- Volume-controlled ventilation + pressure support with specified volume ≙ **S/T-VC\vtPS**
- Pressure-controlled ventilation with guaranteed volume + pressure support ≙ **S/T-vtPC\PS**
- Pressure-controlled ventilation with guaranteed volume + pressure support with specified volume ≙ **S/T-vtPC\vtPS**
- Pressure-controlled ventilation with guaranteed volume + proportional pressure support ≙ **S/T-vtPC\ES**

- Pressure-controlled ventilation + pressure support ≙ **SIMV-PC\PS**
- Pressure-controlled ventilation + pressure support with specified volume ≙ **SIMV-PC\vtPS**
- Pressure-controlled ventilation + proportional pressure support ≙ **SIMV-PC\ES**
- Volume-controlled ventilation + pressure support ≙ **SIMV-VC\PS**
- Volume-controlled ventilation + pressure support with specified volume ≙ **SIMV-VC\vtPS**
- Pressure-controlled ventilation with guaranteed volume + Pressure support ≙ **SIMV-vtPC\PS**
- Pressure-controlled ventilation with guaranteed volume + pressure support with specified volume ≙ **SIMV-vtPC\vtPS**
- Pressure-controlled ventilation with guaranteed volume + proportional pressure support ≙ **SIMV-vtPC\ES**

Ventilation modes – Classification based on control algorithms

In many cases, ventilation modes were and are differentiated according to the work of breathing performed by the ventilator. This three-level taxonomy comprises:

- **Controlled ventilation modes**

Mandatory or controlled ventilation is the term used for those modes in which the ventilator takes over the work of breathing completely and is therefore solely responsible for ensuring oxygenation and CO_2 elimination. Ergo, the user is responsible for specifying the required settings.

- **Mixed ventilation modes**

In mixed ventilation or augmentative ventilation modes, the ventilator and the patient each take on a share of the work of breathing.

- **Spontaneous breathing**

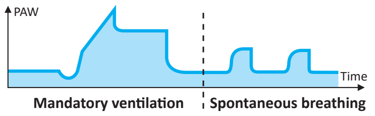
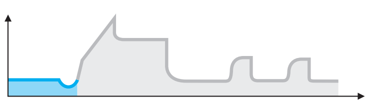
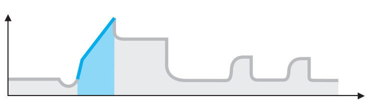
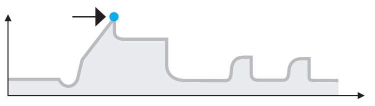
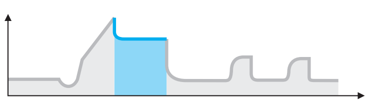
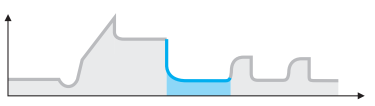
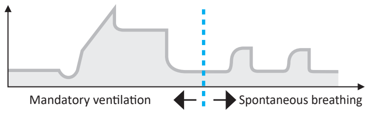
The patient's work of breathing is (almost) completely taken over by the patient.

It is not only with modern closed-loop modes that these simple models reach their limits and do not help the user to distinguish between the multitude of modes.

Continuing and extending the most diverse taxonomies of the last 30 years, the simplest way to clearly distinguish between the multitude of ventilation modes is by control algorithms, phase variables and targets.

Control algorithms, phase variables and targets

A machine-delivered breath can be divided into up to six different phases depending on the algorithm and complexity:

Ventilation mode	
Start variable	
Inspiratory target	
Limit variable	
Switch from inspiration to expiration	
Expiratory target	
Conditional variable	

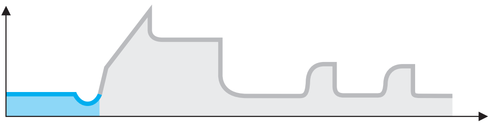
- Start variable
- Inspiratory target
- Limit variable
- Cycle variable
- Expiratory target
- Conditional variable

Within the individual phases, the four basic variables (pressure, volume, flow and time) of the equation of motion are continuously adjusted by the stored algorithms, the sensors and the patient's breathing activities.

Start variable

Ventilators continuously monitor one or more variables in the equation of motion, i.e. time, flow, volume or pressure. Inspiration is started when one of these variables reaches a preset value. The respective variable is therefore also called the triggering or colloquially, the trigger variable.

Start variable



In practice, this means the following:

• Time trigger

Ventilators will trigger a mandatory breath irrespective of the patient's spontaneous breathing efforts when the set cycle time has elapsed. This is referred to as time control. With a set respiratory rate of 12 breaths per minute, the time for a complete cycle is 5 seconds. The ventilator then automatically delivers a mechanical breath every 5 seconds.

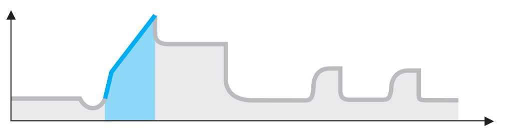
• **Flow trigger**
The patient's inspiratory effort creates a change in flow, the magnitude of which is measured by a flow sensor in litres per minute and starts inspiration when the set trigger threshold is reached. Modern intensive care ventilators are equipped with a so-called leakage-compensated by-flow technology, which achieves a faster trigger speed and optimises the trigger characteristics by adapting the flow more quickly to the patient's needs. The control principle is based on an idea from the 1970s and continuously balances the basic inspiratory and expiratory flow. The patient's inspiration causes a difference in flow which, by almost immediately tracking the flow during this phase, can cover the patient's required flow while it simultaneously starts inspiration by initiating the trigger criterion. The setting of the respective byflow is the prerequisite for avoiding CO_2 rebreathing when using full-face masks or helmet ventilation.

• **Volume trigger**
As with the flow trigger, the patient's inspiratory effort creates a change in flow, the extent of which is measured by a flow sensor as volume (flow over time) and initiates inspiration once the set trigger threshold is reached.

• **Pressure trigger**
As the trigger for inspiration, the pressure trigger uses the drop in airway pressure that occurs at the start of a spontaneous inspiratory effort.
The required level of negative pressure below the expiratory airway pressure (PEEP) that the patient must generate by spontaneous breathing is referred to as the trigger threshold. The clinically common adjustment ranges for trigger thresholds are -1 mbar to -3 mbar. In practice, however, the trigger threshold must be tested first, as the patient's required work of breathing can also be significantly higher. On the one hand, the accessories used, such as HME filters, act as additional flow resistance, which can change continuously even under medication nebulisation.

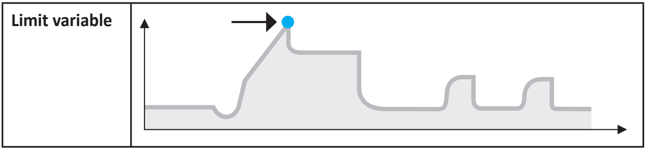
On the other hand, an additional functional PEEP (AutoPEEP) can build up due to insufficient exhalation time, disease-related overinflation of lung regions or an airway obstruction. To successfully trigger a pressure, the patient must first overcome the AutoPEEP, then the additional pressure required by the accessory and then the trigger threshold itself. Accordingly, pressure triggers must be continuously adapted to the patient. They are therefore used rather less frequently these days.

Inspiratory target (control variable)

Inspiratory target	

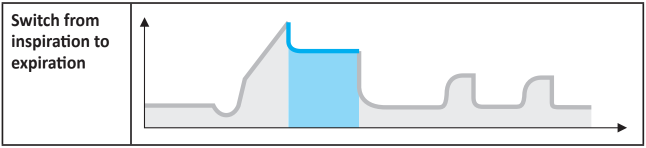
The inspiratory target sets a level of pressure, volume or flow that must be reached and maintained during inspiration. Time cannot be an inspiratory target because time determines the entire inspiratory phase and must therefore be understood as the inspiratory cycle variable.

Limit variable



The limit variable can be used to set a second control variable within the inspiratory phase. For example, an applicable volume can first be specified as an inspiratory control variable. Once a set maximum pressure level (Pmax) is reached, the flow is reduced during the remaining volume delivery until the pressure cannot increase any further. This creates a decelerated flow, which means that the flow velocity decreases over time.

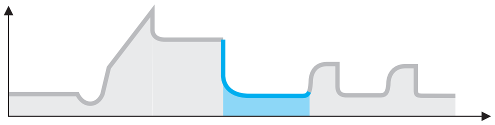
Cycle variable



The inspiratory phase ends whenever a specified variable reaches a certain value. The variable that is measured and used to terminate inspiration is called the cycle variable. It therefore represents the switching criterion from inspiration to expiration. Pressure, volume, flow or time can be used as cycle variables.
The simplest inspiratory cycle variable is time, which is set either as the inspiratory to expiratory time ratio (I:E) or as inspiratory time (Tinsp).
In pressure-supported spontaneous breathing, the control variable is pressure. The ventilator delivers the flow required to achieve the set level of pressure support and the flow initially starts at a relatively high

value. However, reaching the set pressure support does not end inspiration, but is used as a limit variable. The flow then drops exponentially. When the decelerating flow has fallen below the percentage of the peak flow after reaching the set pressure support, the flow is stopped and expiration is initiated. In modern ventilators, the user can adjust the flow cycle threshold to improve patient-ventilator synchrony. Increasing the end-flow criterion shortens the inspiratory time and vice versa.

Expiratory target (baseline variable)

Expiratory target	

The baseline variable specifies the control variable for the expiratory phase. Theoretically, all baseline variables of the equation of motion (pressure, volume, time or flow) could also be applied here. In practice, however, only pressure control is used with modern ventilators. By setting a positive end-expiratory pressure (PEEP), the ventilator uses a valve to regulate the pressure to a level above atmospheric pressure. PEEP prevents alveolar collapse at the end of expiration and improves oxygenation.