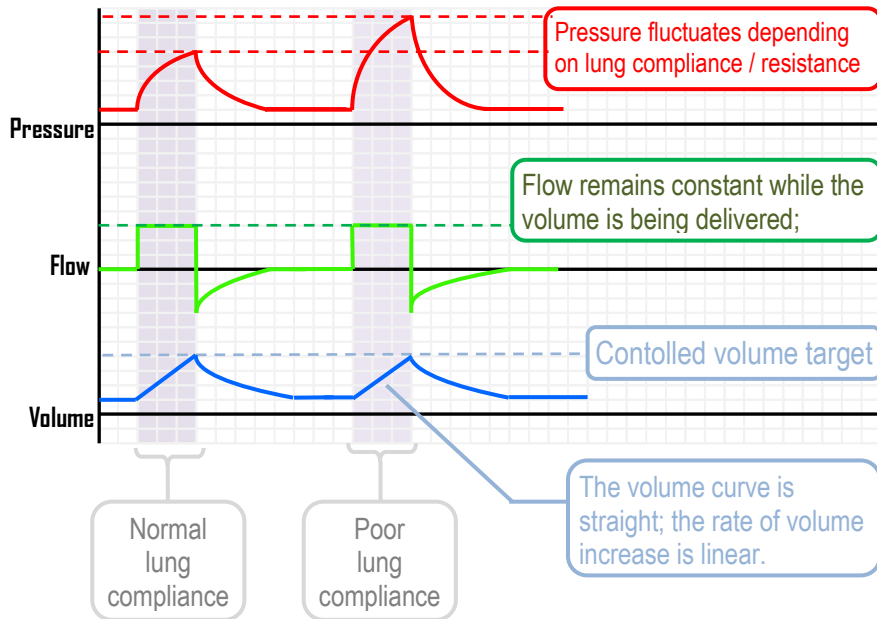


CONTROL VARIABLES IN MODES OF VENTILATION:

VOLUME CONTROLLED

Demonstrated using CMV (Continuous Mandatory Ventilation): the curves below



Volume is controlled: There is a set volume; once you reach it, that's it. The ventilator then either exhales (like in volume-cycled ventilation) or holds an inspiratory pause.

Time is also a controlled variable here. There is a set respiratory cycle time; the inspiration must be completed within a predetermined period, let's say 1 second.

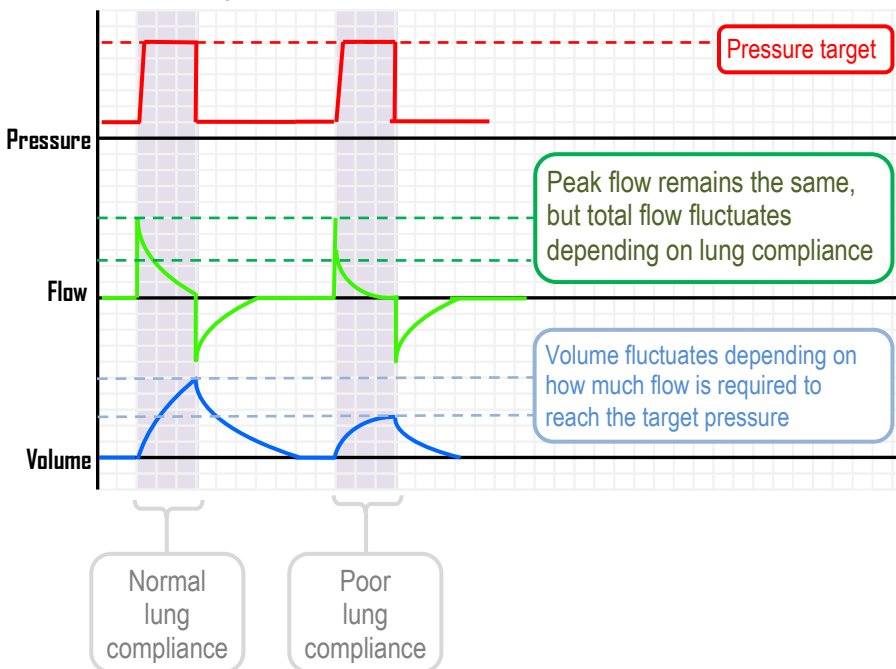
Flow remains constant until the volume is delivered. Flow is defined as volume over time. Thus the flow curve does not change if the volume is the controlled variable, and there is a set respiratory cycle time.

Pressure fluctuates depending on lung resistance, because the flow remains the same (seeing as $\text{pressure} = \text{flow} \times \text{resistance}$)

This is a **Volume-Controlled Pressure-Variable** mode.

PRESSURE CONTROLLED

Demonstrated using PCV (Pressure Control Ventilation): the curves below



Pressure is controlled: There is a set pressure; once you reach it, it is maintained for the duration of the inspiratory phase. The waveform is square, or nearly so.

Time is again a controlled variable here. There is a set respiratory cycle time; the inspiration must be completed within a predetermined period.

Flow starts high (to reach the desired pressure) and decreases on a slope, to maintain that pressure (as the lungs fill with air, they stretch and become less compliant, and so less flow is required to maintain the same pressure).

When lung compliance is poor, less flow is required to maintain the same high pressure.

Volume fluctuates depending on flow: seeing as volume is flow times time, and with the time being a set value, volume will decrease if flow decreases remains the same (seeing as $\text{pressure} = \text{flow} \times \text{resistance}$)

This is a **Pressure-Controlled Volume-Variable** mode.

PHASE VARIABLES IN MODES OF VENTILATION:

INITIATION AND TRIGGERING: who decides when to take a breath?

When the trigger variable is met, the ventilator cycles to inspiration.

Multiple trigger variable can be active at the same time.

For example, SIMV is a mode which is time triggered as well as flow-triggered.

- **TIME-TRIGGERED:** "MANDATORY", Machine decides when you breathe. The timer triggers.
- **FLOW-TRIGGERED:** Patient triggers by sucking a small amount of flow away from the circuit
- **PRESSURE-TRIGGERED:** Patient triggers by generating a small amount of negative pressure
- **VOLUME-TRIGGERED:** Patient triggers by inhaling a certain set volume of gas

LIMIT: what decides when inspiration stops?

A "limit" is reached before the end of inspiration. It doesn't necessarily end the inspiration; it just restricts that variable so that it doesn't increase beyond that limit. All of the limits can be set all at once.

- **FLOW-LIMITED:** There is a set flow, and the ventilator will not allow any greater rate of flow during inspiration
- **PRESSURE-LIMITED:** the ventilator will not exceed the set pressure during inspiration
- **VOLUME-LIMITED:** the ventilator will not exceed the set volume during inspiration
(so if the volume is reached before the inspiration is over, there is an inspiratory pause)

CYCLING: what decides when to switch from inspiration to expiration?

When the cycling variable is met, it causes the ventilator to open its expiration valve, and the patient exhales.

There can be only one cycling variable.

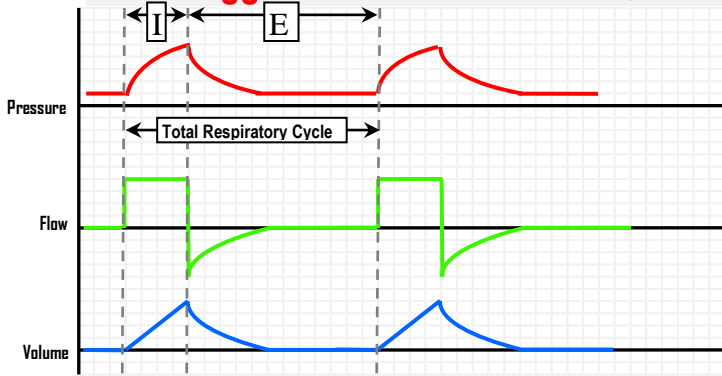
- **TIME-CYCLED:** the clock decides. The inspiratory pause is timed.
- **FLOW-CYCLED:** once the inspiratory flow rate falls to a certain set rate, the ventilator allows you to exhale.
- **PRESSURE-CYCLED:** once the set peak inspiratory pressure is reached, the ventilator allows you to exhale.
- **VOLUME-CYCLED:** once you reach the target volume, the ventilator allows you to exhale.

PEEP: Positive End Expiratory Pressure: what happens before the next breath

- Also known as the "baseline" variable

Initiation and Triggering of Mechanical Ventilations Breaths

Time-Triggered: it's the machines' choice; this is MANDATORY ventilation



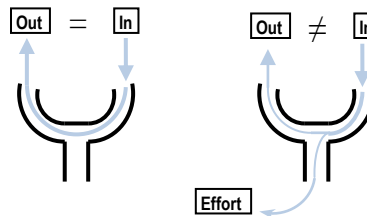
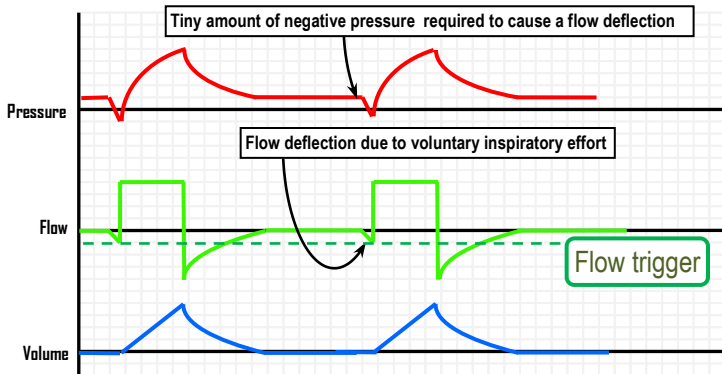
The machine has a set respiratory cycle time, and a set I:E ratio (ratio of inspiration to expiration).

When time runs out, the machine takes a breath for you, and you don't get a choice.

The patient is not involved in the triggering process.

This triggering mode is typically used when the patient is heavily sedated or paralysed; they can not be expected to make any respiratory effort.

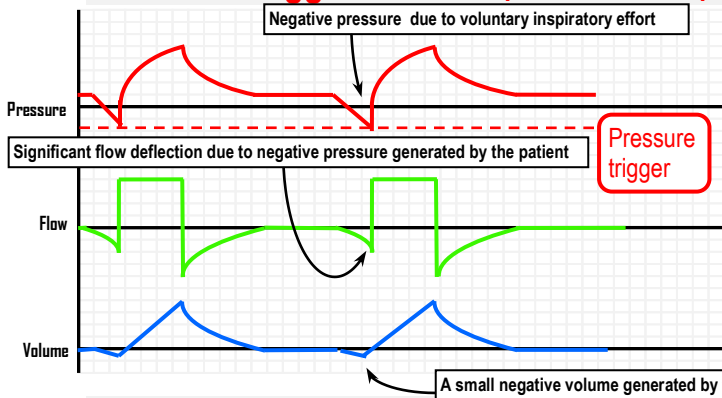
Flow-Triggered: it's the patients' choice



The circuit has a constant flow in and out of the T-piece. It measures that flow; while you aren't breathing, flow out of patient equals flow into patient. When you try to take a breath, you suck some flow off the circuit- and the machine detects that as an inequality of in-flow and out-flow. This triggers a breath.

This is good mode of triggering for sedated patients, as it requires minimal effort. The disadvantage, is that its TOO easy, and sometimes a non-respiratory effort will trigger the ventilator (eg. the heart beat or a hiccup)

Pressure-Triggered: it's the patients' choice, provided they can summon the effort it requires

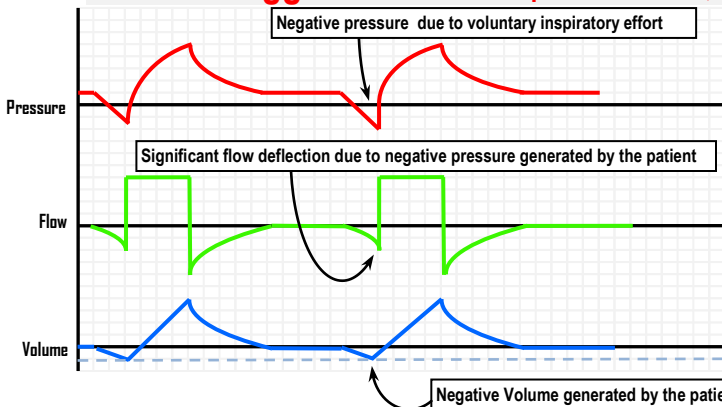


Instead of watching for a negative flow, the machine measures negative pressure. The patient must generate a sufficient negative pressure before the machine will give them a breath.

This is hard work- while trying to generate a negative pressure, you are fighting the whole ventilator, sucking on a two metre hose with humidifiers and god knows what else installed in-line. Needless to say, you wouldn't use this on some sort of crap-lung ARDS patient, or someone with congestive heart failure.

This mode of triggering is used to wean patients off ventilator by strengthening their own respiratory muscles. It can be used intermittently in people who have had respiratory muscle weakness due to critical illness polyneuropathy.

Volume-Triggered: it's still the patients choice, and harder still.



This is very similar to pressure-triggered ventilation, except the ventilator watches for a specific inspiratory volume, instead of a negative pressure or a flow deflection.

This is also hard work, as you now have to draw 50ml of air out of a non-compliant machine. The amount of pressure this requires is variable, and depends on the ventilator tubing length, amount of water rained-out into it, how moist your humidifier is, how small your endotracheal tube is, and so forth.

Limit variables of mechanical ventilation

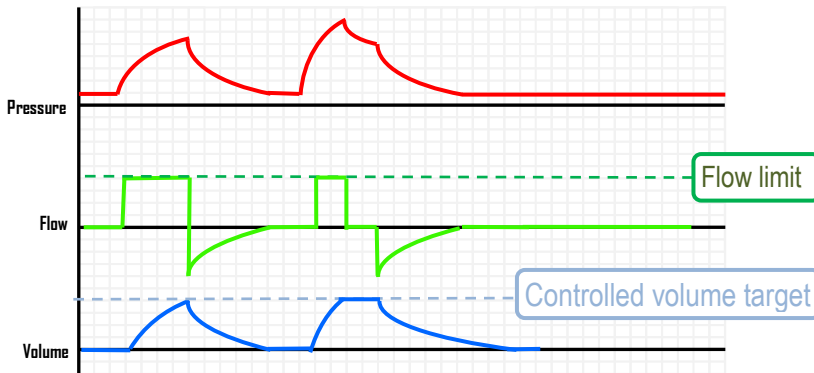
The “control” variable is definitely going to be achieved; limits are set to make sure all the other variables don’t go out of control in the process of achieving the control variable

Limit variables don’t stop the inspiratory phase; they merely limit the flow so that the limits aren’t breached. ...Thus, time cant be a limited variable: a time-limit, when reached, would abort inspiration! It could be a “time-cycled” breath.

Each breath can have ALL of the limit variables set.

One of those limit variables is going to be the control variable; for example you cant have a volume control mode without a volume limit (otherwise, what are you controlling?)

Flow-Limited



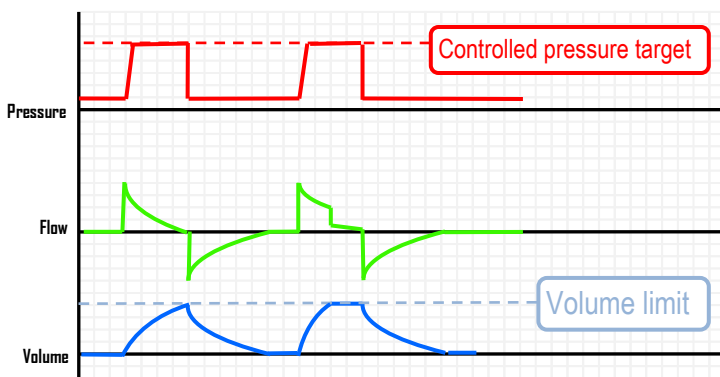
When the flow is limited, it will not exceed the specified parameter until the cycling variable is met.

In this example, the mode is

- flow-limited
- volume controlled
- time-cycled

Until the volume objective is reached, the flow will be maintained. The guaranteed controlled volume will be delivered. The flow wont exceed the specified threshold.

Volume-Limited



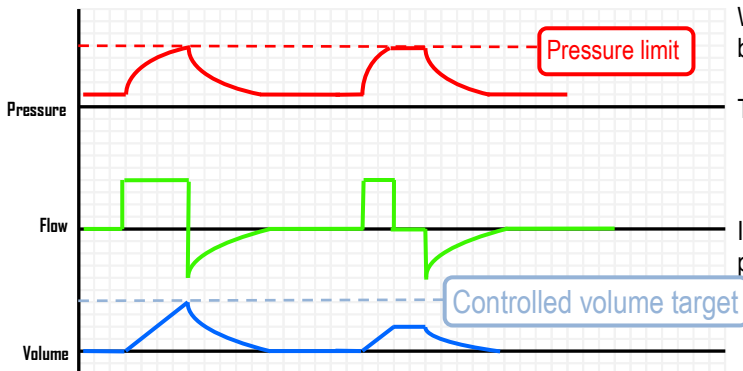
When volume is limited, and the volume limit is met, inspiration will not cycle to expiration, but there wont be any further flow.

This mode is

- Volume-limited
- Pressure-controlled
- Time-cycled

When the volume limit is reached, the flow stops, but the pressure is maintained at the controlled level (because the time of the cycle has not yet elapsed).

Pressure-Limited



When pressure is limited, the pressure limit will be maintained if it is reached before the end of inspiration.

This mode is

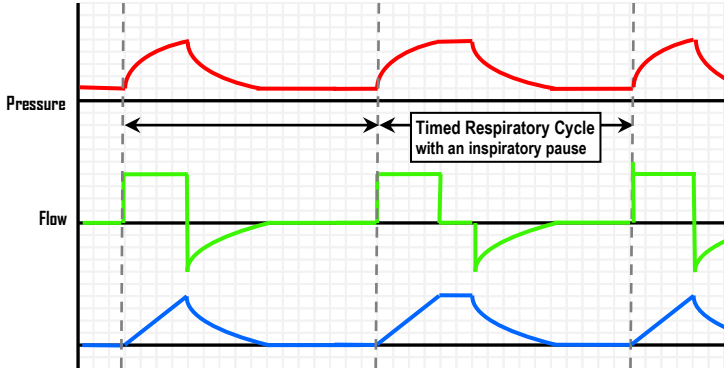
- pressure limited
- volume-controlled
- time-cycled

In the second breath, the volume control objective was not reached because the pressure limit kicked in. This happens when lung compliance is poor.

Cycling from Inspiration to Expiration

A "cycling" variable determines when the ventilator "cycles", which just means "changes over from inspiration to expiration". When this variable is reached, the expiration is triggered.

TIME-cycled: it's the machines' choice again.

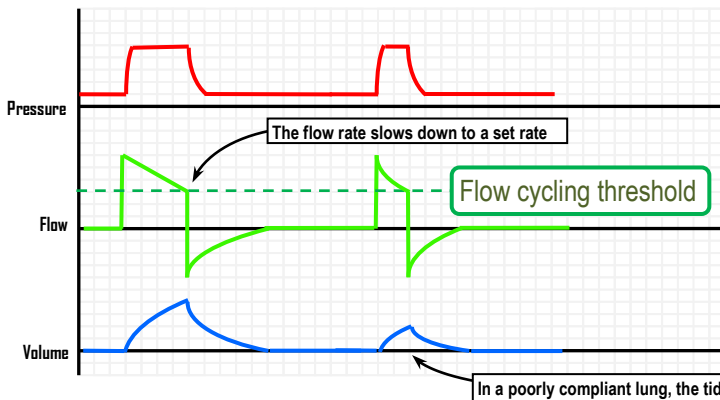


The machine has a set respiratory cycle time, and a set respiratory rate. The ventilation pattern is set: for example, 1 second for inspiration, 1 second for inspiratory pause, 3 seconds for expiration. Once the timer counts down to 1 second, the machine cycles to inspiratory pause, and then to expiration.

The decision to start expiration depends on what time it is, not on what the patient is doing, or what the other variables are.

The patient is not involved in the triggering process, does not control their respiratory rate, and does not get to decide when to stop holding their breath.

FLOW-cycled



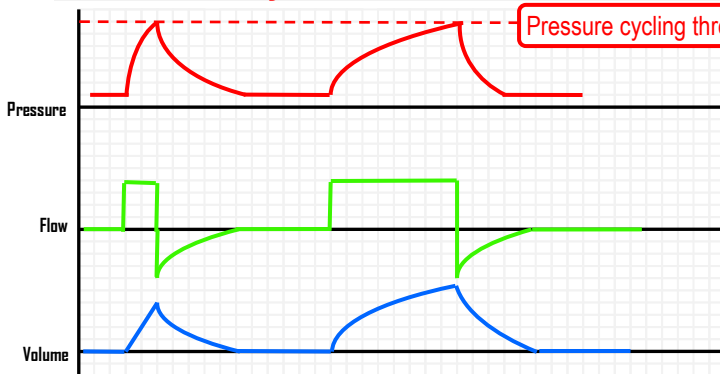
Once the flow rate reaches a certain minimum, the machine cycles to expiration or inspiratory pause.

Here it is demonstrated in Pressure Support Ventilation, which is where you would normally find this sort of cycling.

The flow rate starts high to reach the designated pressure limit; it then slows to maintain a steady regulated pressure. If the flow rate slows down to the cycling threshold, the ventilator assumes that the patient is finished with that breath, and it cycles to exhalation.

Obviously, in lungs with poor compliance, the cycling threshold will be reached more quickly and the exhalation starts early, resulting in a smaller tidal volume.

PRESSURE-cycled

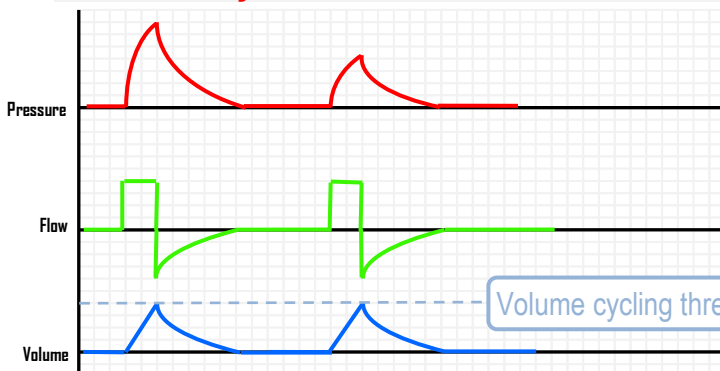


Once the flow rate reaches a certain minimum, the machine cycles to expiration or inspiratory pause.

The tidal volume depends on how long it takes to reach that threshold. This gives you good volumes in nice young compliant lungs, and useless little volumes in stiff non-compliant lungs.

Most ventilators will have a "backup cycling limit" for pressure – to prevent overinflating the patient. They will alarm if the backup limit is reached, and the ventilator will cycle to expiration.

VOLUME-cycled



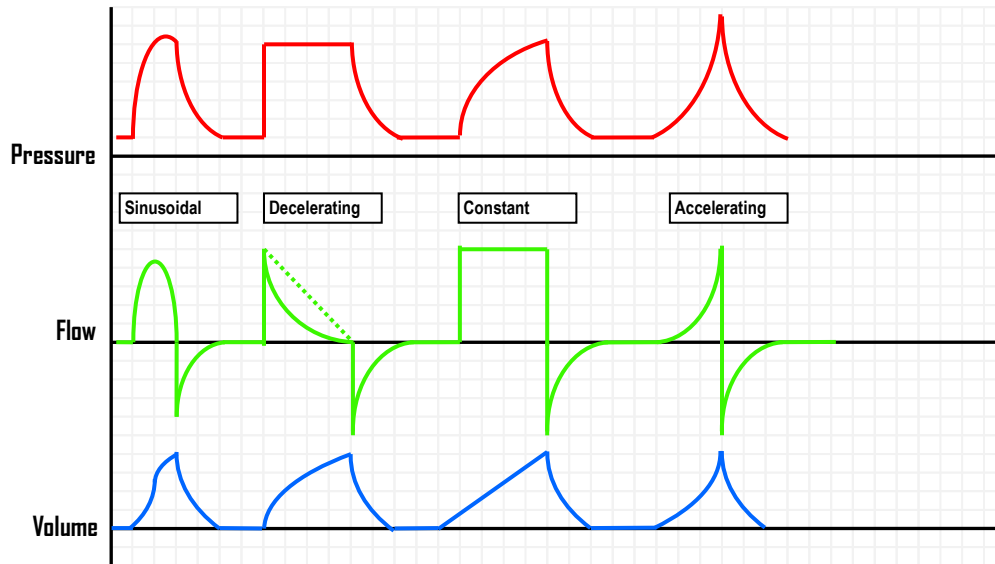
Once a set volume has been achieved, the machine cycles to expiration or inspiratory pause.

While flow-cycling is used in spontaneous modes, volume-cycling is used more in mandatory modes.

Flow Patterns and Breath Types in Mechanical Ventilation

FLOW PATTERN: this depends on the mode of control

- **SINUSOIDAL:** this smooth curve is seen in people who are breathing spontaneously, or on CPAP
- **DECELERATING:** Flow is maximal initially and drops off to maintain the set pressure (in pressure-controlled ventilation). Volume fluctuates depending on compliance.
- **CONSTANT:** Flow is constant until the target volume is delivered. Pressure fluctuates depending on compliance.
- **ACCELERATING:** Flow RISES to a maximum until the set pressure is delivered... this is not used in humans, but a madman might ventilate a sperm whale in this way.



BREATH TYPES: what kind of breath will you take?

- **MANDATORY BREATH:** the machine just blew air into you.
- **ASSISTED BREATH:** You triggered the breath, but the machine decided everything else for you: the volume, the pressure, the flow pattern- you didn't get any say in any of those. The definition is, that an assisted breath is **started by the patient, but finished by the machine**.
- **PRESSURE-SUPPORTED BREATH:** You triggered the breath, and you decide how much tidal volume to inhale. The machine decides what pressure to apply while you inhale, and it also decides the pressure limit (it will terminate the breath if the pressure limit is reached)
- **SPONTANEOUS BREATH:** The machine only gave you PEEP and pressure support; flow is controlled by you.

