Review

Dual modes of ventilation

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How to cite the article: Pradhan D. Dual modes of ventilation. OncoCritiCare2023;1:41-44.

Conventional modes of ventilations are popular because they are simple, well understood, easy to troubleshoot and most widely used. Often these common modes are not able to match patient specific requirements. Comfort comes at the cost of complexity, over the years, the incorporation of advanced algorithms and closed loop control have allowed delivery of volume assured breaths with variable pressure control. They are also known as dual control modes and can be classified into three groups .[1]

Intra-breath	Inter-breath		Combination
	Pressure limited: Flow cycled	Pressure limited: Time cycled	
VAPS Paug	VSV Variable PS	PRVC AutoFlow VC+ Adaptive pressure ventilation Variable PC	ASV Automode

Table 1: Various types of Dual mode ventilation

Presence of the term "volume" in the name often creates a false impression that these modes are volume controlled, but they are pressure-controlled modes with targeted volume delivery. Also, the use of various proprietary names by different manufacturers creates an impression that each name is a unique mode although all are similar in function. In dual modes, ventilator adjusts the peak inspiratory pressure based on the patient's airway resistance and compliance to deliver a minimum tidal volume (VT) with desired pressure limits. [1,2]

Dual modes have two options: control option for patients with inadequate respiratory drive and support option for spontaneously breathing patients. In control option, VT and respiratory rates (RR) are pre-set for time triggered breaths and patient triggered breaths are supported targeting the minimum VT within appropriate pressure limits. In the control option, the dual control is provided between breaths, changes needed to meet VT and pressure goals are made between breaths based on the previous breath. The support option allows the patient to breathe spontaneously but provides support to achieve the set VT within each breath. This means that if the patient is not on target to meet the minimum tidal volume goal, the machine will augment respiration to achieve the goal within the breath. Patient's contribution towards the set tidal volume target determines the amount of support to be provided by ventilator. The set parameters for dual modes include VT, sensitivity, PEEP, FiO_2 for support modes, and rate and inspiratory time (Ti) added in the control modes. [1,2,3]

Pressure augmentation/ Volume assured pressure support: In pressure augmentation (PAug) or volume-assured pressure support (VAPS) mode, every breath is having dual control-targeted volume delivery and pressure limitation. VAPS is the term used to describe this mode on the Bird 8400st (CareFusion, Viasys Corp, San Diego, Calif.). Breaths are patient triggered (not appropriate with deep sedation, use of muscle relaxants and patients with ineffective inspiratory triggering) and pressure supported to achieve targeted tidal volume. The set parameters include desired VT, minimum RR, inspiratory gas flow, sensitivity settings, pressure above the base line. The algorithm explains the working principle of VAPS/PAug mode.[4]

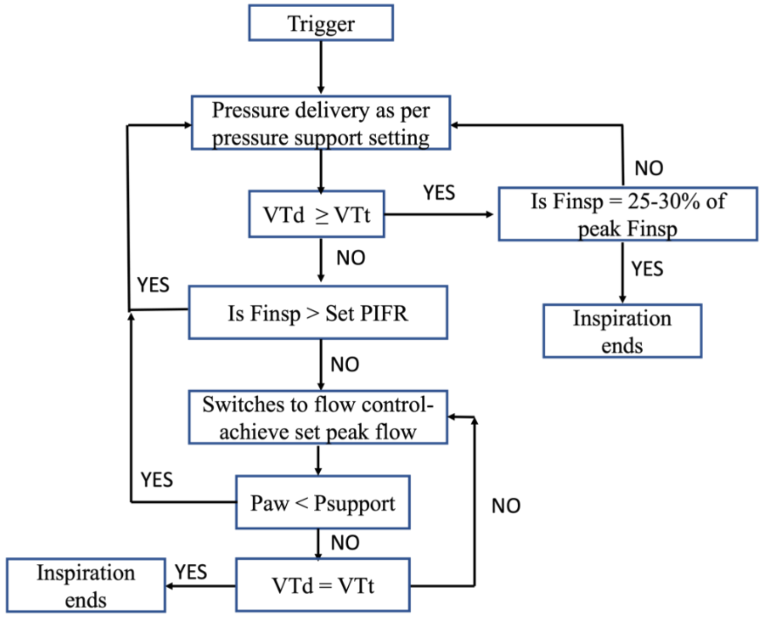

Figure 1: Algorithm for volume assured pressure support mode

Pressure-regulated volume control: Pressure-regulated volume control (PRVC) was first introduced in Servo 300 ventilator during 1990s. It has been in use under the same name in various ventilators such as - Servo-i and Servo-s from Maquet, Inc, Wayne, New Jersey and the CareFusion AVEA from CareFusion, Inc., Yorba Linda, California. PRVC has been used under various different proprietary names - AutoFlow on the Dräger Evita E-4 (Dräger Medical Inc., Telford, Pennsylvania), and VC+ on the Covidien PB 840 (Covidien, Puritan Bennett, Boulder, Colorado), Adaptive Pressure Ventilation (APV) on the Hamilton G5 and C3 ventilators (Hamilton Medical, Bonaduz, Switzerland) (explained below). [4]

PRVC breaths are patient- or time-triggered, volume-targeted, pressure controlled and time cycled. As described in the algorithm (Figure-2), control is from breath to breath. Troubleshooting is required when the pressure alarm goes off indicating the need of higher pressure for the targeted VT delivery. As the compliance improves ventilator keeps reducing pressure control till it reaches the set PEEP. Beware of hypoventilation when the targeted tidal volume (VTt) and the maximum pressure alarm settings are incompatible. [4]

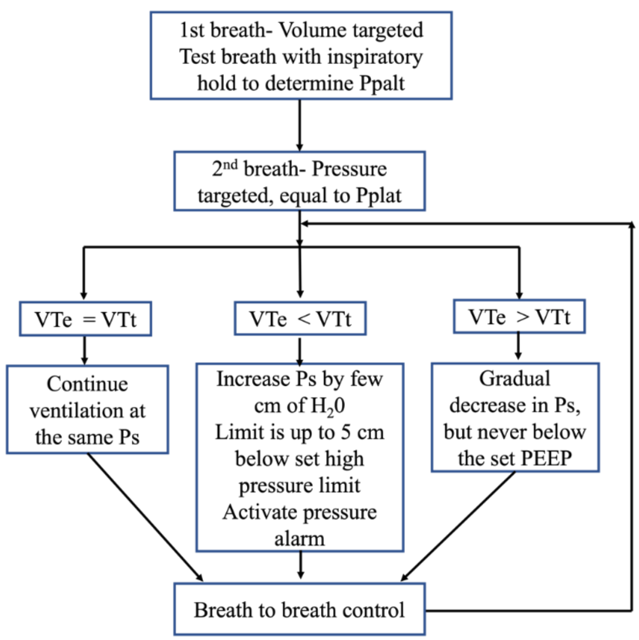

Figure 2: Algorithm for pressure regulated volume control mode

Autoflow mode in a Drager ventilator works on the same principle as that of PRVC. As soon as autoflow is enabled in a VC-SIMV or VC-AC mode, it does not alter the cycling characteristics, rather it regulates inspiratory flow and inspiratory pressure during the mandatory breaths. Also, it improves breathing comfort, especially if spontaneous breathing interacts with mandatory breaths. In such situation, AutoFlow provides gas flow according to the patient's needs and prevents air starvation. The level of pressure support is not affected by AutoFlow and remains same as conventional volume-controlled ventilation. Autoflow mode should not be confused with Automode available in Servo-i ventilator (PRVC + VS). [4]

Adaptive pressure ventilation: These modes are similar to PRVC and available in Hamilton Ventilators (Hamilton Medical, Bonaduz, Switzerland) and can be APVcmv or APVsimv based on breath sequencing. The ventilator automatically regulates the inspiratory pressure and flow to maintain a target tidal volume. The operator sets the target VT, the rate, the PEEP and the high-pressure alarm limit. The ventilator then compares the measured VT to the target VT and adjusts the PIP to the lowest level possible to achieve the target VT. The rationale behind volume targeting is to avoid the variations in VT that may result from changes in lung compliance while undergoing pressure-controlled ventilation, as these may cause ventilator induced lung injury.[5]

Volume support ventilation: Volume support ventilation (VSV) is very similar to PRVC. It is a pressure supported breath triggered by patient with volume target and flow cycling. This is purely a spontaneous mode with a backup mode for the event when patient becomes apnoeic. As with PRVC, the ventilator adjusts the pressure, over several breaths, to achieve the set volume. If volume is too low, then pressure is increased. Conversely, the pressure is reduced if the volume is too high. VSV can be used for patients who are ready to be weaned from the ventilator and can breathe spontaneously. Unlike PRVC which is time cycled, VSV is flow cycled, expiratory valve opens as flow drops to a set percentage of peak flow. It also can be time cycled (when Ti is prolonged for some reason) or pressure cycled (when the pressure rises too high). [4]

Adaptive support ventilation: Adaptive support ventilation (ASV) is a closed-loop mechanical ventilation which combines Pressure support ventilation (PSV) (when the spontaneous RR higher than the target), Pressure control ventilation (PCV) (if no spontaneous breathing effort) and Synchronised intermittent mandatory ventilation (SIMV) (spontaneous RR is lower than the target). It automatically adjusts the support intra-breath as well as inter-breath to optimize the work of breathing (WOB).[6] It uses the Otis *et al.* and Mead *et al.* equation developed in 1950, that states that for a given level of alveolar ventilation, there is a particular RR which achieves a lower WOB. More physiological and individualised ventilation is provided in an energy efficient manner while minimizing the cumulative effects of elastic and resistive load.[7]

The set parameters include height of the patient (in cm, to calculate ideal body weight and dead space 2.2 ml/kg), gender, % minute volume {range 25-350%, normal 100%, asthma 90%, acute respiratory distress syndrome (ARDS) 120%, others 110%, add 20% if temperature >38.5°C (101.3°F) or add 5% for every 500 m (1640 feet) above sea level, trigger: flow trigger (2 l/min), expiratory trigger sensitivity: start with 25% and 40% in Chronic obstructive pulmonary disease (COPD), tube resistance compensation (100%), high pressure alarm limit, PEEP and FiO_2. It starts with few test breaths to obtain measurements and the adjusts the respiratory parameters. Ventilation is pressure and volume limited and % minute ventilation can be titrated according to clinical criteria and blood gas results.[6]

Lack of precise tidal volume control in most of the currently available dual control modes may lead to large variations in VT and associated lung injury, especially in patients requiring low-tidal-volume ventilation.[1,3] Inaccurate feedback (large leak or malfunctioning of sensors) will lead to inappropriate ventilatory output. Modes dependent on physiologic models should be able to measure the model parameters accurately (Inability to measure the compliance and or plateau pressure in patients with high respiratory drive). Mathematical calculations should fit the actual patient, for example incorrect assumptions of ratio of dead space to VT, normal minute ventilation requirement will compromise appropriate delivery of ASV.[8]

Mechanical ventilation has evolved to provide physiological, personalised and high-fidelity respiratory support while allowing the patient to recover from their disease process. In future though ventilators will be able to initiate, maintain, wean and escalate or deescalate ventilatory support without much user interference, but the user need to know the mechanics of these modes and their limitation to be able to take over the control when machines fail to save humanity and also not to forget the science behind mechanical ventilation.

Conflicts of interests: Nil

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