Seminars in Fetal and Neonatal Medicine 24 (2019) 101041

Contents lists available at ScienceDirect

Seminars in Fetal and Neonatal Medicine

journal homepage: www.elsevier.com/locate/siny

Transitioning from an ICU ventilator to a portable home ventilator

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ARTICLE INFO

Keywords:
Mechanical ventilation
Chronic respiratory failure
Home mechanical ventilation

ABSTRACT

There is a variety of portable ventilators on the market, each with its' own features. A clinician needs to understand the unique characteristics of the ventilators available in his or her region, as well as the nuances of primary and secondary settings for these portable home ventilators in order to create a comfortable breath that allows for adequate gas exchange for the patient. Understanding the interplay of the portable home ventilator and the ventilator circuit is also a key component of transitioning a patient to a portable home ventilator. This review details characteristics of some of the more commonly used machines in the United States, as well as the settings to be considered in supporting a child with chronic respiratory failure outside of the hospital. As more patients are being discharged from the hospital with mechanical home ventilation, new ventilators are being developed that expand upon features of current machines.

Making the transition to a portable home ventilator (PHV) is often one of the last major steps prior to discharge for a patient requiring long term mechanical ventilation. Some considerations when making this transition include the timing of changing support from the ICU ventilator to a portable model, the choice of what type of PHV and circuit is most appropriate for a patient, and the ventilator settings necessary to allow the patient to breathe comfortably and naturally while supporting his or her breathing in the most appropriate manner.

The optimal time to transition to a PHV is determined by the patient's condition and the anticipated time to discharge. The patient should be medically stable, weaned off inhaled gases such as nitric oxide or helium-oxygen, and if appropriate, gaining weight well and able to tolerate therapies on current ventilator settings. The child should also have a stable airway, whether that is the natural airway or tracheostomy. If the transition is made too soon and the patient does not tolerate the transition well, it may be unclear to the medical team if this is due to an issue related to the PHV and ventilator settings or a confounding factor related to an underlying medical condition. The child should be supported by the PHV for at least 2 weeks before discharge, with no changes made to ventilator settings over that period of time. Ideally, the actual ventilator that the child will use outside of the hospital should be used for several days before discharge to make sure no adjustments are necessary.

1. Factors to consider when selecting a PHV

The current generation of PHVs can support most patients adequately, but children who are very small or weak, or who have severe obstructive or restrictive lung disease occasionally require support that is unique to certain machines. Thus, one must consider not only the patient's medical condition and his or her ventilator needs, but also any limitations of the ventilator.

If the signal to end inspiration cannot be adjusted adequately, some patients can experience ventilator asynchrony with difficulty cycling a breath, particularly if there is a large leak in the circuit. For instance, the LTV® ventilator series (CareFusion) can only be adjusted to a cycle sensitivity of 40% of peak flow for Pressure Support breaths. If an excessive leak does not permit a reduction in flow to that level, then inspiration will be prolonged and its termination requires a backup time termination setting.

A final consideration when selecting a PHV is the familiarity of the community nurses and respiratory therapists with a particular machine. As new ventilators come to market, it will take time for clinicians and respiratory therapists to feel comfortable using these machines and training caregivers on how to manage them in the outpatient setting.

2. Types of circuits

The ventilator circuit connects the ventilator to the patient. It can include tubing for separate inhalation and exhalation limbs, a humidifier or heat/moisture exchanger, an exhalation valve or port, a pressure and/or flow measuring device, inline filters, and adaptors for delivering medications [1]. The proximal part of the circuit is connected to the patient via a tracheostomy (invasive modality) or mask/

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https://doi.org/10.1016/j.siny.2019.101041

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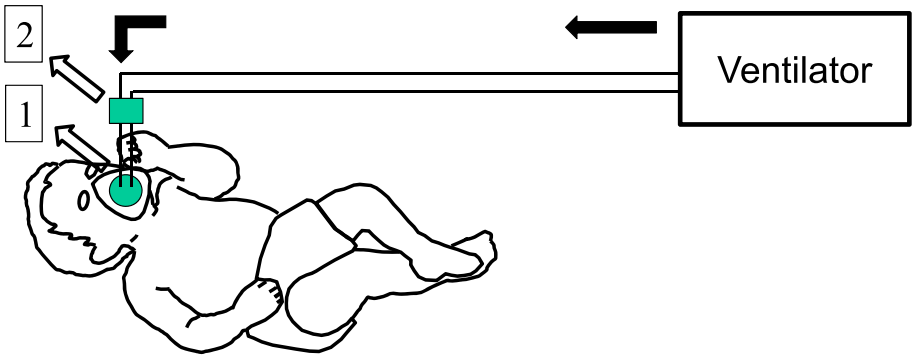

Fig. 1. Ventilation via passive circuit. Fresh gas from the ventilator is delivered to the patient through a single limb circuit (solid arrows) and exhaled gas travels through the same tubing (open arrows). The passive circuit has no active exhalation valve, and so exhaled gas leaves the circuit through a fixed leak in the circuit, either via an intentional leak in a mask (1) or into an orifice within the circuit tubing (2).

mouthpiece (non-invasive modality). There are 3 types of respiratory circuits that are determined by the type of exhalation device used and whether pressure or flow is monitored. Choosing between specific types of circuits will be based on the type of ventilator to be used, ventilator settings and mode requirements of the patient, special features that are only available with certain circuit configurations, and how narrowly FiO_2 must be regulated.

2.1. Passive circuit

The passive circuit has no active exhalation valve, and so exhaled gas leaves the circuit "passively" through a fixed leak in the circuit. It uses a single tube for both inspiration and exhalation. An intentional leak is built either into a mask or into an orifice within the circuit tubing created by a device such as a Whisper Swivel (Respironics) placed close to the patient's airway. Exhalation occurs through this intentional leak point (Fig. 1).

Because the passive circuit does not contain a true nonrebreathing expiratory valve and the inspiratory and expiratory paths share a single limb, there is a risk for rebreathing carbon dioxide when exhaled gas becomes part of the following breath's delivered tidal volume [2]. To avoid this, the ventilator delivers a continuous flow of fresh gas during exhalation at a rate high enough to wash out the dead space of the circuit. The expiratory pressure setting (positive end expiratory pressure (PEEP) or expiratory positive airway pressure (EPAP)) determines the leak rate (flow) across the exhalation port. Since the resistance across the expiratory opening is fixed, by Ohm's law, pressure and flow will be proportional to each other. Thus, the minimum expiratory pressure must be high enough to create adequate flow to wash out the circuit dead space. If the expiratory pressure were set too low so that it could not wash out the dead space of the circuit, a portion of the exhaled gas would accumulate in the ventilator tubing. With the patient's next breath, rebreathing of CO_2 would occur, thereby increasing dead space ventilation [3].

Tidal volume is not measured directly in a passive circuit. Rather, an algorithm is used that estimates the exhaled tidal volume while taking into consideration the flow delivered to the patient and the leak flow through the port [4]. However, as has been shown in multiple studies, the algorithm used to determine the leak and tidal volume differs among homecare ventilators; tidal volume is underestimated and this underestimation increases in the setting of larger circuit leaks [5–7].

A major benefit of a passive circuit is its ability to compensate for unintentional leaks in delivering the preset pressure by adjusting flow to achieve the set pressures. While these ventilators make up for unintentional leak in pressure control (PC) modes, the Respironics Trilogy can also compensate for unintentional leaks in volume control (VC) modes. To compensate for an unintentional leak, the ventilator constantly monitors pressure and flow outputs during each breath, and adjusts ventilator output on the subsequent breath based on that feedback. This type of leak compensation is not available for circuits with active expiratory valves. It is important to note that when using a low flow oxygen source to deliver an FiO_2 greater than ambient air, an increase in air flow from the ventilator in response to a variable leak will dilute the concentration of oxygen being delivered and can be detrimental for patients who are sensitive to supplemental oxygen delivery.

An additional advantage of a passive circuit is that it allows for use of some ventilator setting options like trigger and cycle algorithms (i.e. Auto-Trak with the Philips Respironics Trilogy) and volume-targeted pressure modes (Average Volume Assured Pressure Support (AVAPS) or Intelligent Volume Assured Pressure Support (iVAPS)), which will be discussed in additional detail below. Finally, a passive circuit involves less tubing for caregivers to have to handle and manipulate, making it lighter and less burdensome as compared to a double limb circuit (Table 1).

2.2. Active pressure and flow circuits

There are two types of active circuits: the active proximal airway pressure (PAP) circuit and the active flow circuit (Fig. 2A and B). The ***active PAP*** circuit is a single limb circuit with two small pressure lines. One pressure line monitors proximal airway pressure while the second connects to an active expiratory valve (i.e., a mushroom valve or diaphragm valve) which opens on exhalation and closes on inspiration. The active PAP circuit measures the inspiratory tidal volume.

The ***active flow*** circuit can be assembled in either a single limb or a double limb configuration. The double limb circuit includes an inspiratory and expiratory limb: the distal ends are connected to the inspiratory and expiratory ports of the ventilator, respectively, and the proximal ends are connected to a Y-piece terminating at the patient

Table 1
Features to consider when choosing a circuit.

Passive Circuit	Active Circuit
Single limb	Single limb (active PAP/active flow) or double limb (active flow)
Positive expiratory pressure is mandatory	EPAP/PEEP are optional
Flow trigger; Specific ventilator trigger algorithms are available	Flow or pressure trigger
Variable FiO_2	Constant FiO_2
Tidal volume is estimated	Tidal volume is measured
Volume-targeted modes available (AVAPS (Respironics)/iVAPS (ResMed))	Limited volume-targeted modes (Pressure Support with Volume Guarantee (ResMed))

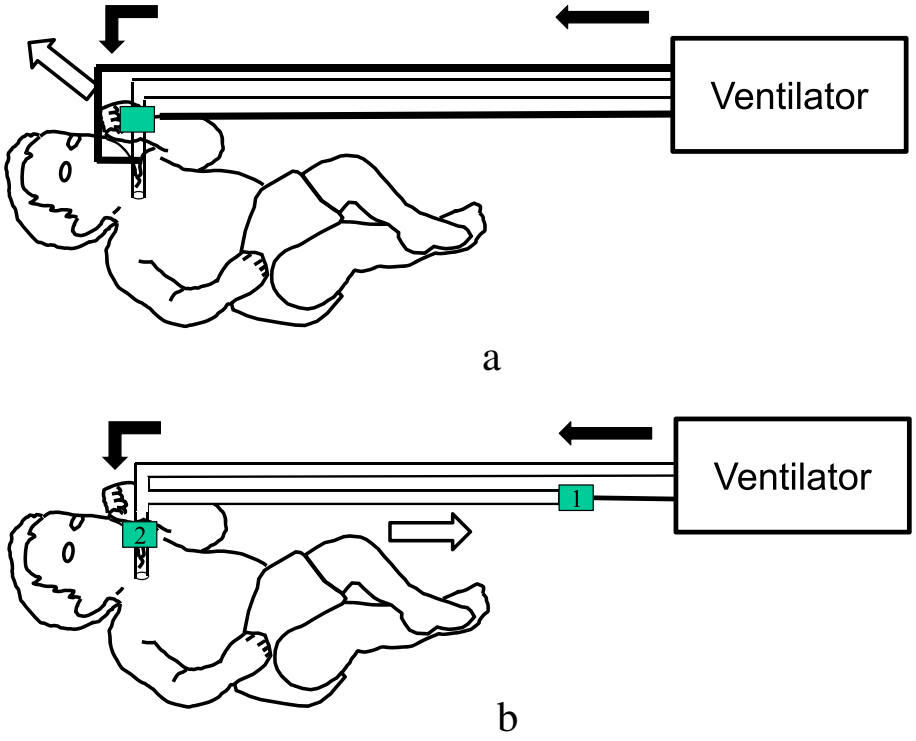

Fig. 2. Ventilation via active circuits. A: The active PAP circuit is a single limb circuit with two small pressure lines, one measuring proximal airway pressure while the second connects to an expiratory valve that opens on exhalation and closes on inspiration. Fresh gas from the ventilator is delivered to the patient through a single limb circuit (solid arrows) and exhaled gas exits the circuit through the active valve (open arrow). B: The active flow circuit includes an inspiratory and expiratory limb. Fresh gas from the ventilator is delivered to the patient through the inspiratory limb (solid arrows) and exhaled gas exits the circuit through the expiratory valve (open arrow) (1). The distal ends of the circuit are connected to the inspiratory and expiratory ports of the ventilator, respectively, and the proximal ends are connected in a Y-piece terminating at the patient interface. Flow is measured either close to the patient interface (2) or via a sensor in the ventilator (not pictured).

interface. The flow sensor is located at different points in the circuit depending on the PHV; it may be located in-line just distal to the airway opening (Phillips Trilogy, Hamilton-T1, CareFusion LTV®), or at the ventilator (ResMed Astral™).

An active circuit limits the use of some ventilator algorithms. For example, with the ResMed Astral™ and the Phillips Respironics Trilogy ventilators, certain algorithms can only be used with a passive circuit (VSync, AVAPS, iVAPS, Auto-Trak) [8,9].

One advantage of active circuits is that the use of EPAP or PEEP is optional. A passive leak circuit requires continuous flow through the valve during exhalation, which is generated by setting a positive expiratory pressure. The active PAP circuit eliminates CO_2 via a non-rebreathing expiratory valve, whereas the active flow circuit includes a non-rebreathing valve or a second limb for exhalation; thus the concerns related to rebreathing of CO_2 that can occur with passive circuits are no longer present.

In contrast to the variable FiO_2 generated in passive circuits, active circuits provide consistent delivery of supplemental oxygen. The FiO_2 delivered through an active circuit remains constant since flow does not increase to compensate for unintentional leaks.

Another attribute of active circuits is their ability to measure, rather than estimate, the delivered tidal volume. The active PAP circuit measures inhaled tidal volume whereas the active flow circuit measures exhaled tidal volume.

Finally, just as some features of a PHV are only available when using a passive circuit, other features are only offered with an active circuit. Many home ventilators can deliver volume-controlled breaths (i.e., Volume Control-Assist/Control or Volume Control- Synchronized Intermittent Mandatory Ventilation) only when an active circuit is used; one exception to this is the Respironics Trilogy, which can provide Volume Control ventilation with all circuit configurations. The use of an active flow circuit with the ResMed Astral™ ventilator allows for a greater range of flow triggers, down to 0.5 LPM, and also allows for use of a pressure trigger [9] (Table 1).

2.3. Limitations of circuit options based on available PHV

A passive/single limb circuit cannot be used with a Hamilton-T1 or CareFusion LTV ®ventilator since each uses a closed circuit with an expiratory limb; even small unintentional leaks will cause these systems to alarm. An active circuit can be used with all currently available PHVs.

3. Features of PHVs

There have been major advances in the design of home care ventilators including the ability to provide continuous flow, an increasing number of available modes of ventilation, lighter weight machines, and machines with longer internal battery life. Machine characteristics, including the range of outputs, available modes, range of sensitivities to trigger and cycle assisted breaths, and other special features all differ between manufacturers and even between different models from the same company. An understanding of these characteristics is critical for making the best match between a PHV and the patient.

3.1. Basic features of PHVs

All of the current PHVs are approved for children weighing 5 kg or more. Newer ventilators are lighter weight, adding to the ease of portability [8,10–12] (Table 2). The internal battery life and availability of external batteries that can extend the time away from an electrical power source determine the ease with which patients can leave their homes, travel a distance to get to appointments, or maintain ventilator support at home in areas with frequent power outages. Manufacturer statements about estimated battery life are based on support of an adult with fairly low ventilatory needs; thus, actual duration of battery life may be a good deal shorter in patients who require high pressures or rates of positive pressure breaths.

The number of prescriptions available on the PHV that can be preset by the practitioner can potentially reduce user error in the case of a

Table 2
Basic features of PHVs.

	LTV ® (CareFusion)	Trilogy (Philips Respironics)	Astral™ (ResMed)	Hamilton	Vivo 65 (Breas)
Weight (kg)	6.6	5	3.2	4.9	5.3
Internal battery (hours)	1	3	8	4	3.5
External battery (hours)	6	3	16 (Two 8 h batteries)	4 (2nd 4 h battery)	8
Available Prescriptions	1	2	2–4	1	3

Table 3
Primary settings of PHVs.

	LTV ® (CareFusion)	Trilogy (Philips Respironics)	Astral™ (ResMed)	Hamilton	Vivo 65 (Breas)
PIP maximum (cm H_20)	99	50	50	60	35
PEEP (or EPAP) maximum (cm H_20)	20	25	20	35	20
Ti min (sec)	0.3	0.3	0.2	0.2	0.3
Bias Flow (LPM)	10	Variable (up to 200)	Variable (up to 250)	3	5

patient who requires different ventilator settings routinely under different conditions, i.e., for mouthpiece ventilation during waking hours and nasal ventilation during sleep, or in the case of a patient who has regular and "sick day" ventilator settings.

3.2. Primary settings

Pressure and volume control modes are available for all of the current PHVs; however, there is variation in terms of the upper or lower limits of these settings across machines (Table 3). For example, the peak inspiratory pressure of the Philips Respironics Trilogy and ResMed Astral™ ventilators (the sum of the baseline PEEP/EPAP and the inflating pressure above the PEEP/EPAP) is limited to 50 cm H_2O, which may be restricting in a child with high airway resistance or low respiratory system compliance. The amount of PEEP required to support a patient could influence the choice of PHV. Most machines can deliver a PEEP up to 20 cm H_2O, but some patients, like those with severe bronchopulmonary dysplasia who can have high intrinsic PEEP or severe tracheomalacia, may require higher levels of PEEP and so will need a machine that can provide this necessary support [13,14]. Finally, the bias flow in a CareFusion LTV® and Hamilton-T1 ventilator is constant whereas the Philips Respironics Trilogy and ResMed Astral™ have variable flow.

When transitioning from an ICU ventilator to a PHV, the clinician needs to select a mode of ventilation. A ventilator assists breathing through either pressure control (PC) or volume control (VC) modes. The control variable refers to the function that is preset, or prescribed, by the clinician. PC means the breaths are pressure constant and volume variable, whereas VC means the breaths are volume constant and pressure variable [15].

VC ventilation via PHVs may not be possible if there is a large leak around the tracheostomy tube, or if the desired tidal volume is small. When a child receiving invasive ventilation has a large peri-tracheal leak, delivery of a breath in VC mode can lead to hypoventilation as the preset volume of air leaks out of the system and inadequate pressure is generated to move the chest [16]. Usually, this problem is averted by switching to a PC mode; PC ventilation overcomes such leaks better than VC ventilation by increasing ventilator output until the targeted pressure is reached [16–18]. The Respironics Trilogy ventilator, however, has an algorithm that will compensate for such leaks when the ventilator is set in VC mode using a passive circuit, but other machines do not have such software and that leak compensation is not available with active circuits. If a VC mode of ventilation is preferred, the usual alternative is to switch the patient's tracheostomy tube to a cuffed model so that any leak can be minimized. Since unintentional leaks are common in the case of patients using non-invasive ventilation or those with an uncuffed tracheostomy tube, transitioning these patients to PC ventilation on the PHV may be preferable.

While most machines can deliver a preset tidal volume as small as 50 mL, the inspiratory time is constrained by the prescribed tidal volume and the flow is determined by algorithms of the ventilator that cannot be adjusted. For instance, the PHV will restrict the maximum inspiratory time of a 50 or 60 mL breath to 0.3 s. Thus, a 5 kg infant with bronchopulmonary dysplasia who was supported by a tidal volume of 60 mL and an inspiratory time of 0.7 s on the ICU ventilator would have to receive the same tidal volume over 0.3 s via the PHV. There are several pressure-regulated volume-targeted modes that are offered on PHVs, as discussed below, that can circumvent this problem. Alternatively, switching to PC ventilation allows the clinician to set the inspiratory time as desired.

The compliance of the ventilator circuit can become a significant factor when a child supported in a Volume Control mode is receiving a small tidal volume. The circuit compliance could result in a discrepancy between the delivered tidal volume to the patient and that tidal volume measured by the ventilator due to the compressible volume of gas in the circuit. These differences are negligible when the set tidal volume is large relative to the compressible volume of the circuit, but when the set tidal volume is relatively small this difference can result in hypoventilation [19,20]. Some ventilators have the option of automatic circuit compliance compensation during setup; this function measures the compressible volume and compensates for it.

Due to the potential for variations in volumes delivered through PC modes, newer strategies include volume targeted modes that can be used during pressure support (PS) ventilation. In the case of the Philips Respironics Trilogy ventilator, the AVAPS (Average Volume Assured Pressure Support) feature maintains a specified tidal volume by adjusting the pressure support. The PS is varied between a preset IPAP minimum and maximum. The ventilator averages tidal volume over 5 min and changes PS up or down gradually over several breaths to maintain this tidal volume [8]. The AVAPS feature is only accessible with a passive circuit configuration. The ResMed Astral™ has a volume assurance mode called iVAPS (Intelligent Volume-Assured Pressure Support) that targets a patient's pre-calculated alveolar ventilation and changes settings breath to breath within a prescribed range to maintain an alveolar ventilation target. This mode is not recommended for patients who weigh < 30 kg, and it also can only be used with a passive circuit. The ResMed Astral™ also has a Pressure Support with Safety Volume mode; the PS changes breath to breath based on a targeted tidal volume, allowing for a more consistent tidal volume to be delivered with each breath [9]. The mode can be used in any sized patient, including infants, and it is available for use with both passive and active flow circuits. The authors have been able to support even critically ill infants with severe bronchopulmonary dysplasia or pulmonary hypoplasia using this modality, often at lower mean airway and peak

inspiratory pressures than those required when using the ICU ventilator.

When transitioning to PC ventilation with a PHV, reviewing the peak inspiratory pressure the patient achieved over a range of time (such as when asleep or with activity) will allow for determination of the approximate peak pressure setting that is required on the PHV. Constraints around pressure settings for home ventilation are determined by the limits of the machine, as mentioned above. There is no threshold or absolute value of either peak inspiratory pressure or PEEP that would preclude a discharge to home, as long as the equipment chosen can provide the necessary support. We have discharged patients safely who have required PEEP values of 20 cmH2O or higher because of severe intrinsic PEEP, as long as they have demonstrated a period of stability on that support before hospital discharge. It makes little sense to wean a patient to some arbitrary value before home discharge to make a practitioner more comfortable, when the maneuver only makes the patient less stable.

4. Creating a comfortable breath on a PHV

Establishing the secondary settings of a PHV allows the clinician to create a comfortable, yet effective breath for the patient. These phase variables set the terms for the breath the patient is receiving. They are defined as the *trigger* which initiates inspiration; the *limit* which is a predetermined goal of ventilator output that cannot be exceeded; the *cycle* which switches the breath from inspiration to exhalation and back to the baseline variable (PEEP or EPAP). Adjustment of these variables should be made while observing the interaction between the patient and ventilator with regards to synchrony, comfort, and gas exchange. Trigger and cycle variables apply to both spontaneous and mandatory ventilator breaths [21].

4.1. Trigger variable

A ventilator-assisted breath can be triggered, or initiated, either by the ventilator or the patient. Trigger variables used by current PHVs include time, flow, pressure, and special algorithms. Machine- and patient-triggered breaths can exist in the same scheme of ventilator support, i.e. when Synchronized Intermittent Mandatory Ventilation (SIMV) is used with Pressure Support Ventilation (PSV). In the case of the machine-triggered breath, the clinician sets a desired respiratory rate and breaths are delivered according to this preset frequency. For example, if the mandatory respiratory rate is set to 10 bpm, the patient receives a ventilator-delivered breath every 6 s. In the case of SIMV, the ventilator-delivered breath is synchronized with the patient's inspiratory effort to allow for more comfortable breath delivery [22].

Patient initiated breaths can be signaled by flow, pressure, or specific ventilator algorithms. Flow-triggered breaths are initiated when the patient's inspiratory effort creates a flow equal to or greater than a preset flow threshold. The change in flow is detected by a flow sensor in the circuit [23]. The flow trigger sensitivity settings vary by machine. In the case of the CareFusion LTV® and Philips Respironics Trilogy, the range for the flow trigger sensitivity is 1–9 LPM; the ResMed Astral™ offers a wider range (0.5–15 LPM), depending on circuit configuration. The option of having a lower flow threshold can be useful for young infants, children with neuromuscular weakness, or patients with severe obstructive lung disease as these conditions can make it more difficult for them to generate the flow necessary to trigger the ventilator.

The Trilogy ventilator also has two algorithms that combine information about volume, flow, and flow pattern to determine when a breath should be initiated and terminated, referred to as Auto-Trak and Auto-Trak[Sensitive]. In addition to analyzing and comparing the shape of the flow pattern of the patient's signal against calculated curves, Auto-Trak requires 6 mL of air to be moved by the patient, while Auto-Trak[Sensitive] requires the patient to move 3 mL of air [8].

The goal of an appropriate trigger is to reduce the amount of work required for a patient to receive positive pressure assistance while minimizing the delay between the time the patient attempts to trigger a breath and the machine delivers the support. This must be balanced with trying to prevent auto-triggering, which is the delivery of a positive pressure breath based on an erroneous flow signal, usually related to an unintentional leak. PHVs with a passive respiratory circuit can compensate for an unintentional leak and overcome issues related to auto-triggering [4]. This can also be accomplished with the CareFusion LTV®, which requires an active circuit. When the leak compensation option is turned on, it adjusts the baseline flow to compensate for a patient circuit leak up to 6 LPM of flow. By setting the sensitivity (flow trigger) above the machine reported leak, triggering is improved in the presence of a circuit leak [10].

The rise time also plays an important role in patient comfort and synchrony. The rise time determines the speed with which a ventilator reaches a set peak inspiratory pressure during PC or PS breaths. This is the time required to change from the baseline pressure to 90% of the peak pressure [24]. The rise time can be adjusted on PHVs, in increments starting at 0.1 s. The higher the number, the slower is the rate of rise to peak pressure [8]. The CareFusion LTV® utilizes a term called 'profile' with available profiles (rise times) ranging from 0.1 to 1 s. Each step up in the profile between 1 and 9 causes an increase in the rise time of 33% over the previous setting. For example, a profile of 1 is 0.1 s and 2 is 0.13 s [10]. Clearly, if the rise time is set too long relative to the inspiratory time, the ventilator may not be able to reach the desired peak pressure.

4.2. Limit variable

The limit variable is a predetermined variable that limits inspiration. That is, the variable cannot be superseded but it does not terminate (cycle) the breath [25]. For example, a PS breath will be *pressure limited and flow cycled*, meaning that when the breath is triggered the pressure will rise to the preset value and remain there until inspiratory flow decreases to a predetermined percentage of the peak flow, after which the pressure returns to the baseline value. Similarly, during a PC breath, the pressure rises to the preset value and remains there until a preset time elapses (*pressure limited and time cycled*). As noted above, current PHVs permit delivery of breaths with both pressure and volume limits, sometimes within the same mode of ventilation (e.g. VC-SIMV with PSV).

4.3. Cycle variable

The cycle variable ends the inspiratory phase of a breath (i.e., cycles off inspiration). A breath can be cycled by one of several variables including time, flow, volume, or pressure [23]. A breath is considered time cycled when it terminates after a prescribed inspiratory time. Traditionally, this inspiratory time is applied to mandatory breaths delivered by the ventilator [4]. For example, an inspiratory time of 0.8 s means that inspiratory flow or pressure is provided for 0.8 s after which the ventilator cycles, or terminates inspiration, and switches to the exhalation phase. If the inspiratory time is longer than that required by the patient, he or she may want to exhale and be unable to do so, resulting in cycle asynchrony. It is important to consider that in a PC mode, the tidal volume is determined by the set pressure, the inspiratory time and the respiratory system mechanics. In the case of a patient with respiratory system mechanics that require a longer inspiratory time to fill (e.g. a high resistance or high compliance system), a longer inspiratory time should be set on the ventilator to achieve the desired tidal volume [23]. A longer inspiratory time will also be useful in infants with established severe bronchopulmonary dysplasia who have heterogeneous regional time constants (the product of resistance and compliance) [13].

There are modes of ventilation that allow for time cycling of patient-triggered breaths. This is the case for the Philips Respironics Trilogy

ventilator in PC mode where both patient- and machine-triggered breaths are time cycled [8]. The ResMed Astral™ ventilator, like many other ResMed machines, offers an option to have an inspiratory maximum time and minimum time set allowing for spontaneous breaths that would normally be flow cycled to be time cycled within a prescribed inspiratory time range if flow cycling would fall outside of that range [9]. Establishing a minimum inspiratory time for patients with stiff chest walls or other causes of short respiratory system time constants, where flow cycling of PS breaths would result in a small tidal volume, can increase inspiratory time and increase the tidal volume. Some machines, like the CareFusion LTV® or the ResMed Astral™, provide a backup time cycle setting (e.g. Time Termination or Ti max) that will terminate a breath after a specified time if the flow cycle threshold is never met (see below). This typically occurs in the setting of a large unintentional leak.

Flow cycling occurs when the inspiratory flow of a spontaneous breath falls to a preset percentage of the peak flow, at which point the ventilator switches to the exhalation phase. The percentage of peak flow at which this occurs can be adjusted on most PHVs, and the chosen threshold is referred to as the cycle sensitivity. For example, a cycle sensitivity of 80% means that when the flow falls to 80% of the peak inspiratory flow, the ventilator cycles to exhalation. The flow cycle will need to be adjusted if the operator observes that the ventilator cycles after the patient's inspiratory effort ends, or if the operator wants to support the patient through a larger percentage of inspiration [23]. It is also important to note that when using a flow cycle, a leak in the ventilator circuit can lead to a lack of decline in the flow signal resulting in an excessively prolonged inspiratory time and ventilator asynchrony [26].

Pressure cycling occurs when a preset peak airway pressure is reached which cycles a breath. This is typically an alarm situation, or safety feature (high pressure alarm), that is set to prevent barotrauma. Volume cycling occurs in a volume controlled mode and takes place when a prescribed volume is preset [23].

5. Future directions

The world of home mechanical ventilation is quickly expanding. As the medical field continues to advance, patients are surviving with chronic illnesses that can progress to subacute or chronic respiratory failure resulting in the need for home mechanical ventilation.

New ventilators are being developed that expand on currently available home ventilator modes, offer greater trigger sensitivity, and extend the lower size range of suitable patients. As new devices and equipment come to market, it will be important that caregivers and providers can be appropriately trained on these devices prior to their entering the homecare setting.

Another exciting direction for home mechanical ventilation is the role of telemedicine. Several studies have shown the potential safety and efficacy of using telemedicine for children supported at home by mechanical ventilation. [27,28] As this path continues to be explored, it may prove to be a very useful and convenient assessment tool for caregivers, especially those who live at considerable distance from the site of the Home Ventilation Program, and providers.

6. Conclusion

The transition from an ICU ventilator to a portable home ventilator requires significant planning and thoughtfulness with regards to the equipment selected and settings used on the PHV. Recognizing the advantages and disadvantages of each component in the system can mean the difference between successful transition to a home machine and failure, with extended hospitalization. Building a comfortable breath for the patient that allows for adequate gas exchange requires knowledge of the secondary settings of the PHV. As the field of home mechanical ventilation continues to grow, providers and caregivers will need to be equipped with the necessary tools to manage complex patients and life sustaining equipment in the home setting.

Declaration of competing interest

Within the last 3 years, Howard B. Panitch was a consultant to Philips Respironics for their development of a portable ventilator for mass casualty and home care use. He has no extramural funding.

Julie L Fierro does not have any conflicts of interest or any funding sources to report.

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