Noninvasive Ventilation Downloads and Monitoring

Philip Choi, MD[a], Veronique Adam, RRT[b], David Zielinski, MD, FRCPC, FCCP[c,*]

KEYWORDS

• Noninvasive ventilation • Downloads • Adherence • Exhaled tidal volume • Leak • Oximetry • Transcutaneous CO_2

KEY POINTS

- Patients on chronic NIV therapy require close monitoring through interpretation of data downloads.
- Proper mask interface should be chosen to minimize leak and maximize patient adherence.
- Several factors impact exhaled tidal volume including leak, set pressures, mode of ventilation, and inspiratory time.
- Overnight oximetry and transcutaneous CO_2 are used to help interpret challenging data downloads.
- Clinicians should take a stepwise approach to download interpretation.

INTRODUCTION

Noninvasive ventilation (NIV) is becoming increasingly prescribed for nonobstructive sleep apnea–related conditions[1–3] including neuromuscular disease,[4] thoracic cage disorders,[5] chronic obstructive pulmonary disease,[6] and hypoventilation syndromes.[7] Although understanding the indications for NIV therapy can be challenging in and of itself, once patients are started on NIV, management over time is particularly challenging. Structures put in place to manage home NIV may differ based on institution, region, and even insurance plans. However, regardless of the health care system in place, effective management and monitoring of NIV relies on the close interactions between pulmonary clinicians, respiratory therapists, and patients. This article discusses various parameters found within the data downloads and provides suggestions based on clinical experience to help provide high-quality care for patients on home NIV. Although there are multiple manufacturers, for the purpose of this article we focus on practical aspects of Philips Respironics and ResMed devices because they are the predominant manufacturers in North America. An extensive discussion of NIV devices and modes is provided in Gaurav Singh and Michelle Cao's article, "Noninvasive Ventilator Devices and Modes," in this issue.

PARAMETERS

One of the first steps in interpreting NIV downloads is to understand what the parameters are and how they are determined. NIV at home is typically delivered through a single-limb passive circuit (**Fig. 1**). This means that during inhalation, the device delivers a flow toward the patient to reach its target pressure. Certain parameters during this phase are directly measured by the device. Adherence data are measured in hours used, and is often reported as percentage of days used and percentage of days used greater than 4 hours, given

[a] University of Michigan, 3916 Taubman Center/1500 East Medical Center Drive, SPC 5360, Ann Arbor, MI 48109, USA; [b] Programme National d'assistance Ventilatoire à Domicile, McGill University Health Center, Building V - Division of Clinical Epidemiology, 1025 Pine Ave W, Montreal, Quebec H3A 1A1, Canada; [c] Montreal Children's Hospital, Research Institute of McGill University Health Centre, McGill University, 1001 Decarie Boulevard, Montreal, Quebec H4A 3J1, Canada
* Corresponding author.
E-mail address: david.zielinski@muhc.mcgill.ca

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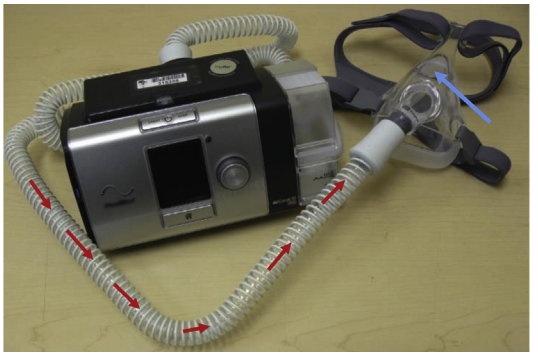

Fig. 1. In a single limb passive circuit, flow through the tubing is always in the direction of the patient as indicated by the *red arrows*. The *blue arrow* identifies the leak valve on the mask where excess flow and exhalation leave the circuit.

current insurance guidelines for adherence. Inspiratory and expiratory pressures are set in standard bilevel modes, but with more advanced volume-targeted algorithms, inspiratory and expiratory pressures are measured and reported as averages, medians, and 95th percentiles depending on the specific device. Several aspects of the respiratory cycle are reported from direct measurements including the delivered breath rate, patient triggering (percent of breaths initiated by the patient), and inspiratory time (Ti).

Tidal volume and leak, however, are calculated by the devices.[8] The volume that leaves the ventilator is not exclusively the inspired tidal volume, because a significant portion is lost to leak. Furthermore, during exhalation, air escapes via a leak valve in the mask to ensure that expired CO_2 does not reenter the tubing and cause CO_2 rebreathing with the next inhalation. Therefore, it is important to acknowledge that reported tidal volumes are not actually measured and are dependent on the calculations of device-specific algorithms. Studies have shown that leak estimations may vary by device, and with increasing expiratory leak, calculated tidal volume accuracy decreases.[9,10] Therefore, clinicians must be cognizant of these potential limitations of calculated versus measured data included in each individual device download.

The apnea-hypopnea index (AHI) is another important parameter calculated on NIV devices. The AHI does not replicate an AHI determined by polysomnography (PSG), so should not be used for diagnostic purposes. However, there is evidence that there is good correlation with PSG particularly at higher AHI.[11] Although each individual manufacturer has different proprietary algorithms, the key concept is that devices measure obstructive events as they sense changes in flow or impedance.[12–14] For example, newer generations of Philips Respironics devices use a system called AHI_{flow}, which score a hypopnea as a 10-second decrease in flow of 40% to 80% and an apnea as a 10-second decrease of flow greater than 80%. This correlates well with PSG, especially when the AHI is less than 10 per hour.[15] New NIV devices with autotitrating expiratory positive airway pressure (EPAP) use a forced oscillation technique to adjust EPAP to minimize obstructive events.[14,16]

ADHERENCE

When obtaining data downloads, a clinician must first look at adherence. This is particularly important in the United States where the Centers for Medicare and Medicaid Services have set guidelines for NIV adherence within the first 30 to 90 days after device initiation. Patients are required to show adherence of greater than 4 hours per night for 70% of the nights during a consecutive 30-day period to receive continued coverage of the device. However, beyond using it solely for insurance coverage issues, adherence data can also guide clinicians in their history taking to help determine what specific issues may be limiting patient tolerance. Clinicians should first determine whether patients have received the appropriate interface.[17–19] Interfaces range from nasal to various forms of oronasal units. Comfort of these various interfaces is often determined by objective factors, such a facial size and features, and subjective factors, such as feelings of claustrophobia. Finding the appropriately sized and designed interface for each individual patient may be the only step necessary to improve adherence for many patients. Logistical factors can sometimes be to blame. For example, patients with neuromuscular disease with limited arm movement may have difficult putting on certain interfaces without assistance. In this case, some newer interfaces have such features as magnetic clasps that make putting the headgear on easier for those with limited movement and strength.

For those patients who state that the interface is comfortable, but still find positive pressure difficult to tolerate, clinicians must explore other factors that may impede tolerance. Even with a comfortable interface, high leaks may make treatment uncomfortable and lead to asynchrony, thereby leading to poor adherence. If patients are not synchronous with the device, then clinicians must determine whether the Ti, rise time, and trigger are set appropriately. Patients with various pathologies may have different physiologic needs that may aid in patient-device synchrony. In the rest of

this article, we discuss approaches to these parameters that ultimately help with patient adherence.

Aerophagia is another common side effect of NIV use. Mild symptoms are treated with medication, such as simethicone. However, some patients may have severe symptoms that limit their use of NIV. If patient adherence does not improve with reassurance and conservative measures, considerations can include increasing rise time and Ti. As a further step inspiratory pressure or target volume settings may need to be decreased to minimize the amount of aerophagia.

Another common side effect with NIV is excessive dry mouth. Most patients use active heated humidification systems. Furthermore, proper hydration with adequate fluid intake should be assessed and recommended. For patients using NIV during the day, heat and moisture exchanger filters may be used. However, this may add resistance into the circuit and may have limited benefit because exhalation occurs via the leak valve and this is assessed on a case-by-case basis. Despite taking these measures, some patients may still find dry mouth to be a side effect that limits adherence. If a patient has this complaint, clinicians must first determine whether there is excessive leak that is exacerbating dry mouth. If the leak is minimal, the level of heated humidity should be increased if that has not yet been maximized. Finally, if dry mouth is still a problem, over-the-counter oral moisturizing products may be used for symptomatic relief.

To maximize patient adherence, clinicians should take measures to educate patients on potential side effects. This allows patients to understand the most common issues that may arise in the initial setup period. In addition, close follow-up should be scheduled to troubleshoot any problems that can easily improve patient adherence. Table 1 lists some common problems that affect patient adherence and potential solutions.

Table 1
Problems that may affect patient adherence to NIV with potential solutions

Problem	Potential Solutions
Pressure sores	Switch mask interface
High leak	Properly size mask Switch mask interface
Dry mouth	Check leak Increase heated humidification Ensure adequate hydration Oral moisturizer rinses for symptomatic relief
Aerophagia	Simethicone for symptomatic relief Increase rise time, inspiratory time Decrease inspiratory pressure Decrease target tidal volume if in volume-assured pressure support
Asynchrony	Adjust inspiratory time, rise time, trigger

LEAK

Before interpreting the multitude of data from an NIV download, one must first examine the leak within the system. Total leak is made up of intentional and unintentional leak. Intentional leak is built into all NIV interfaces, to prevent the recycling of CO_2 rich air, and depends on the inspiratory pressure flow and the type of mask used. Unintentional leak refers to any leak in excess of this that may include leak around the mask and leak from the mouth.

With excessive leak, ventilation may ultimately become ineffective. The reliability of autotitrating volume-assured pressure support (VAPS) algorithms, such as average VAPS (AVAPS) and intelligent VAPS (iVAPS), rely on a reasonable leak, so it is imperative that leak is controlled so that information from the download is being interpreted appropriately.

The total amount of unintentional leak that is tolerated is patient dependent and should factor in symptomatic complaints (discomfort, dry mouth, tolerance) and effectiveness of ventilation. Similar leaks in different patients may lead to important clinical differences. However, there are certain levels that should alert the clinician that further adjustments should be made. When analyzing the leak data from a device download, clinicians must first understand whether they are looking at total leak or unintentional leak. ResMed devices provide the unintentional leak only. The intentional leak is subtracted out based on the expected leak of the mask being used. Interpreting these data correctly is contingent on having the appropriate interface entered into the device. Assuming that the correct mask is entered into the device, we recommend looking at two values to determine whether the leak is appropriate. Ideally the median leak should be less than 10 L/min and the 95th percentile leak less than 24 L/min (Fig. 2). Philips Respironics devices, however, report the total leak. Ideally clinicians should have easy access to charts with expected leaks for the different masks used in their practice at different pressure settings. Whereas most masks with

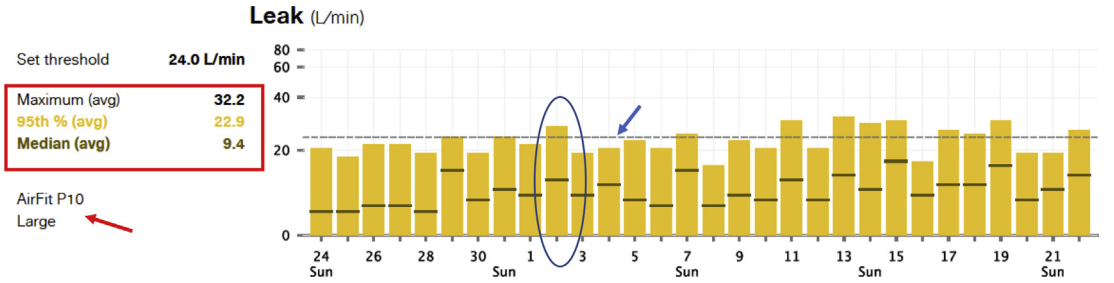

Fig. 2. Unintentional leak data as presented from a ResMed device. The *blue circle* outlines a 24-hour period with the top of the *yellow bar* representing the 95th percentile leak and the *solid black line* in the bar representing the median leak for that day. The *dotted line* across the graph identified by the *blue arrow* represents the set threshold for elevated unintentional leak of 24.0 L/min. The *red box* indicates the average daily median, maximum, and 95th percentile leaks for the 30-day period. Because ResMed downloads provide the unintentional leak only, it is important to ensure that the selected mask interface as indicated by the *red arrow* is the same interface the patient is using. In this example the patient's average median are less than 10 L/min and most nights the 95th percentile leak is less than 24 L/min. However, careful assessment of the daily graphs reveals that the leaks are elevated on many nights and further assessment to correct this should be considered.

mean pressures of 10 cm H_2O have an expected total leak ranging from 25 to 35 L/min, at pressures of 20 cm H_2O the expected total leaks are more typically at the 40 to 55 L/min range. As with ResMed devices, aiming for median leaks less than 10 L/min higher than the expected is reasonable. In the absence of easy access to expected leak charts, the clinician may choose to use as a general rule that once total leaks are in excess of 60 L/min, titrating algorithms may not be accurate. If greater than 5% of the night is spent in a high leak state, Philips Respironics recommends that the leak needs to be addressed. Fig. 3 provides an example of high leak.

When encountering a high and persistent leak, one must first consider the mask interface and ensure that patients are installing and adjusting them appropriately and whether it is the right interface for them. Nasal mask or nasal pillow interfaces are often preferred by patients who suffer from an element of claustrophobia, or who require daytime ventilation, because they facilitate better speech and vision as a result of less facial obstruction. There is also smaller surface area contacting

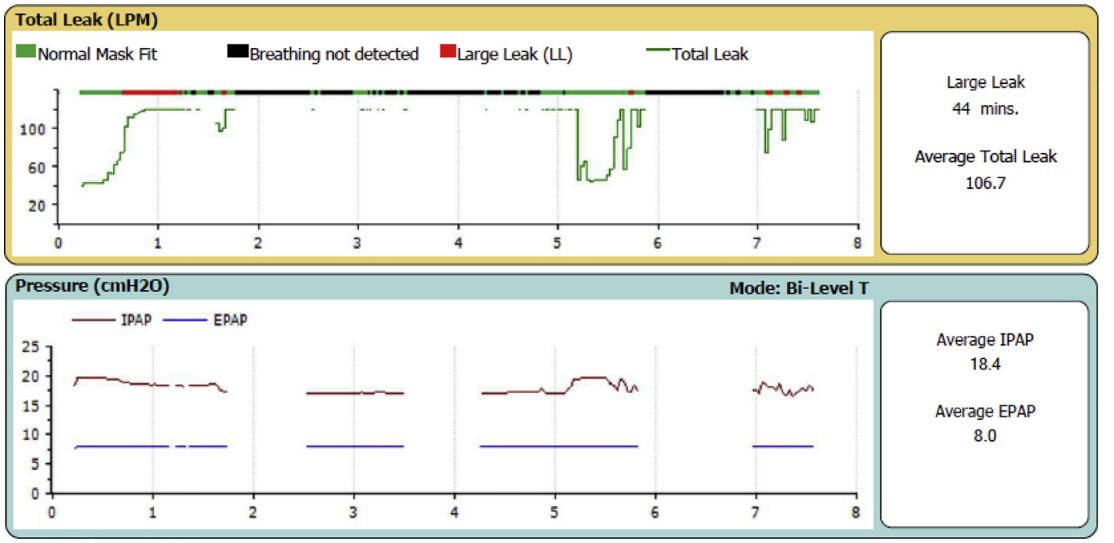

Fig. 3. Total leak data on a Philips Respironics device showing a large leak. In this example, although only 44 minutes are indicated for a large leak, in fact it is almost 50% of the night without breathing detected because of the leak being too high. Furthermore, the impact of the leak does not allow the delivered pressure. The patient's IPAP and EPAP settings are 20 cm H_2O and 8 cm H_2O, respectively; however, the attained average IPAP is only 18/8 cm H_2O. IPAP, inspiratory positive airway pressure.

the skin, making them easier to adjust to minimize leaks. However, for those who have some degree of mouth breathing and/or facial muscle weakness, the leak may be too large to maintain adequate ventilation. Chin straps are used, but patient tolerance may vary greatly. Nasal masks, as opposed to nasal pillows, can cause excess pressure at the bridge of the nose, which can lead to skin breakdown. For those patients unable to use nasal masks because of high leaks, full facemask interfaces may minimize the leak in the system. Standard oronasal masks must be sized appropriately to ensure a tight seal. Facial shape differs between patients and must therefore be considered when choosing the mask. Some of the challenges of full facemasks include pressure at the bridge of the nose, more surface area covered by the mask leading to potential high leaks, and more adjustments needed to obtain proper fit. For those patients predisposed to developing sores at the bridge of the nose with prolonged NIV usage, newer oronasal masks that fit just below the nares may be more comfortable for some patients. They also allow for eyewear to be worn to improve quality of life for some patients. Regardless of which interface is chosen, the best interface for each individual patient balances quality of life with adequate ventilation and safety. Clinicians must remember that patients with neuromuscular disease, quadriplegia, or decreased mental status may not be able to remove full face masks on their own. This must be considered when the interface is chosen.

In situations where median leaks are appropriate but 95th percentile is high, this may be indicative of variable mouth and/or positional leaks. Efforts should be taken to adjust the interface to have the 95th percentile leak closer to the median leak. **Table 2** lists some suggestions for interface and circuit assessment to help prevent leak.

Table 2
Suggestions for interface and circuit assessment to help prevent leak

Type of mask	Nasal mask has a smaller surface to cover, may limit leaks Facial mask may limit leak from the mouth
Headgears	Use the minimum tension required to keep in place the mask When adjustment is needed, always detach both sides and place them equally on both sides of the head
Position	Always adjust the mask in the position in which it will be used
Machine	Start the machine before readjusting the mask
Silicone air cushion[a]	Lift the mask to inflate the air cushion to optimize the comfort and decrease leaks
Cleaning silicone	Clean the mask daily to remove the greasy film left by the sebum of the skin
Chin strap	Could help to decreased mouth leaks Could be tried before considering to change for a full face mask
Circuit	Check: Circuit parts are well connected Check that each part of the circuit is in good condition (no cracks or other signs of wear and tear) Ensure that the circuit is adequately positioned so that there is no pulling or tension on the circuit
Humidity chamber	Make sure it is correctly installed in the device No cracks or holes

[a] Air cushion: All types of masks have an air cushion, sometimes they have a double wall or other times created only by the bulge of the silicone bubble. The role of the air cushion is to maintain a good seal and to avoid high pressure points on the patient's face. To be effective, it must be able to inflate when positive pressure is started. If the headgears are too tight, the air cushion is not able to inflate and does not function appropriately.

EXHALED TIDAL VOLUME

For patients who are using NIV for ventilation purposes (as opposed to pure sleep apnea), maintaining adequate minute ventilation is of vital importance. Current NIV is based on positive pressure technology. The difference between inspiratory and expiratory pressure, along with chest wall and lung compliance, determine the delivered tidal volume. Given that current NIV technology are pressure modes of ventilation with built in leak, the delivered volume is estimated by a calculated exhaled tidal volume. We generally aim for 8 mL/kg ideal body weight estimated by height as a target volume.[14] For patients with neuromuscular disease, chest wall compliance decreases as the

disease progresses. For standard modes, such as spontaneous (S), spontaneous/timed (S/T), and pressure control, if the exhaled tidal volume declines between visits, then the inspiratory pressure must be increased to maintain the same exhaled volume. With VAPS modes, target tidal volumes (AVAPS) or alveolar ventilations (iVAPS) are set to maintain an adequate minute ventilation.[16] However, exhaled tidal volumes must still be evaluated on the data downloads to ensure that these volumes are being delivered. If the exhaled volumes do not match the target tidal volumes, then one must troubleshoot the underlying problem. First, the leak must be assessed to make sure that the delivered pressure is primarily being delivered to the respiratory system. Furthermore, if the leak is excessive, increasing the inspiratory pressure may further worsen the leak. If the leak is appropriate, then there are several reasons the exhaled volume may not match the target volume. First, the volume may be limited by the maximum inspiratory pressure. When the VAPS feature is being used, a range of inspiratory pressures (since one can set pressure support in AVAPS AE) is set. If the maximum inspiratory pressure is set too low in patients with poor lung or chest wall compliance, the delivered pressure may consistently reach that inspiratory pressure maximum. In this case, the average inspiratory pressure would equal the maximum inspiratory pressure. If the maximum pressure is being reached and target volume has not yet been attained, this is remedied by increasing the maximum inspiratory pressure or pressure support. The data downloads will provide the inspired pressure ranges and the clinician can also examine the nightly graphic summaries to observe this. Most standard bilevel devices with VAPS can deliver a maximum inspiratory pressure of 30 cm H_2O and ventilators (eg, ResMed Astral and Philips Respironics Trilogy) can deliver pressures up to 50 cm H_2O.

If the target volume is not being reached, one must also consider whether airway obstruction is adequately being treated. If persistent obstruction is suspected based on history or the presence of an elevated AHI, even with an adequate inspiratory positive airway pressure (IPAP) or IPAP range, target volumes may remain low. In this case, the EPAP should be increased to minimize obstructive events. VAPS with autoadjusting EPAP (AVAPS-AE, iVAPS-AE) is used for patients with ventilation needs who may also have variable obstruction through the night. These algorithms maintain airway patency with an adjustable EPAP, while maintaining adequate minute ventilation based on the volume-targeted algorithms.

Another reason the exhaled volume may be suboptimal is an inadequate Ti being delivered. This is especially relevant to patients with underlying neuromuscular disease because they are predisposed to developing rapid shallow breathing patterns as their respiratory muscles weaken. At high respiratory rates with short Ti, there may not be adequate time during inspiration to achieve the set inspiratory pressure and/or deliver the target tidal volume.[20] In examining the download, the clinician should first look at the data addressing the respiratory cycle. This information may be reported differently based on device manufacturer. For ResMed devices, depending on the platform, either a Ti or an inspiratory/expiratory (I/E) ratio is reported as median, 95th percentile, and maximum values. For Philips Respironics devices, an average Ti/total duration of the respiratory cycle value is reported. In neuromuscular disease, if I/E ratios are close to 1:1 and respiratory rates remain high, then it is unlikely that the device will be able to deliver the desired volume of air for each breath.[20] In this case the clinician needs to look at whether the Ti is inadequate, the set respiratory rate needs to be adjusted, or the mode should be reconsidered. As such, the clinician must also understand the various modes of NIV and the differences between manufacturers.

With Philips Respironics devices, in spontaneous mode (S), the set inspiratory pressure is provided with each patient-triggered breath and the Ti is determined by the duration of the patient's effort. Patients with extreme neuromuscular weakness may continue with rapid shallow breathing because of a naturally short Ti. In S/T, a backup rate and Ti are added. However, if the patient is breathing higher than the ventilator set rate, the breaths will remain spontaneous and may not achieve an adequate Ti. Only machine-triggered breaths will deliver the set Ti.[16] Therefore, if the Ti is low, one should examine the percentage of patient-triggered breaths and if most breaths are patient triggered, adjusting the Ti will have minimal impact. The clinician may choose to increase the set respiratory rate to closer match the patient's rate or preferably the mode is changed to a pressure control mode where a fixed Ti is delivered with each breath, whether patient or machine triggered (**Fig. 4**).[20]

With ResMed devices with S and S/T modes, the clinician sets a minimum and maximum Ti and can therefore ensure that an adequate Ti is allowed. The default settings for Ti minimum and maximum are 0.3 and 2.5 seconds, respectively. These extremes allow for patients to essentially breathe spontaneously, which may provide more

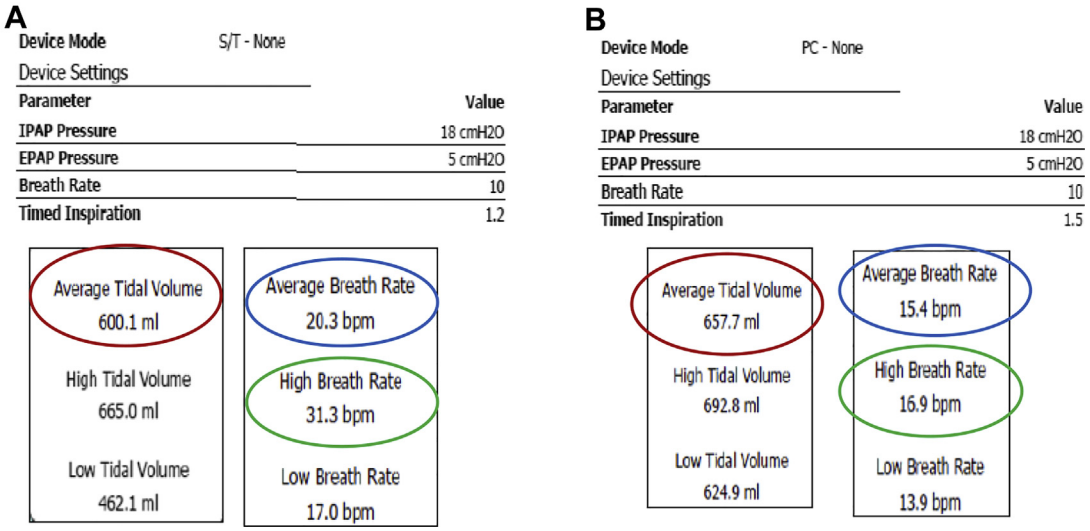

Fig. 4. Summary of two downloads in a 23 year old with diaphragmatic paralysis indicating the impact in change of two parameters as indicated by *blue circles*. Changes in mode from S/T (*A*) to pressure control (*B*) and an increase in inspiratory time from 1.2 to 1.5 seconds led to a significant increase in tidal volume (*red circle*) and decreases in average breath rate (*blue circle*) and high breath rate (*green circle*) to more physiologic levels. PC, pressure control.

comfort. However, this may not be appropriate for certain pathologies including neuromuscular disease, thoracic cage abnormalities, or obesity.[16] To provide more consistent controlled breaths, the minimum Ti should be increased to a time well higher than the default settings. This ensures that enough time is allowed for the target tidal volume to be delivered. With that increased amount of support, the respiratory rate will likely decrease as the patient experiences less air hunger. It should be noted that the newest version of the Philips Respironics Trilogy, the Trilogy Evo, also allows the user to set a minimum and maximum Ti in S and S/T modes.

In chronic obstructive pulmonary disease, because of airway obstruction and decreased elastic recoil, patients are predisposed to developing air trapping and hyperinflation, which may lead to worsening hypercapnia. In this situation, careful attention should be paid to the Ti. Too long of a Ti may lead to worsening of air trapping. Therefore, the Ti should be adjusted appropriately based on the percentage of time spent in the inspiratory cycle. A prolonged I/E ratio is preferred in patients with obstructive physiology.

PERCENT TRIGGERED BREATHS

Clinicians should also look at the percentage of breaths that are triggered by the patient. The interpretation of this depends on the patient's underlying conditions and the clinical settings. A low percentage of patient-triggered breaths may indicate that the trigger sensitivity setting is not set sensitive enough and not able to sense the patient's spontaneous efforts. In these circumstances the clinician may need to increase the trigger sensitivity. With ResMed devices this entails going to a "higher" sensitivity (eg, from medium to high) and with Philips Respironics devices, this entails changing from autotrak to autotrak sensitive or to a flow trigger with a lower flow setting (eg, from 5 L/min to 3 L/min).

Alternatively, a low-percent triggered breath may indicate the backup rate is set at or greater than the patient's own physiologic respiratory rate and the device may be delivering a breath before the patient initiates their own breath. In neuromuscular disease this may be desirable and some clinicians aim to provide "respiratory muscle rest" overnight and have the device initiate and deliver most breaths. In this circumstance downloads are used to increase the respiratory rate until less than 10% to 20% patient-triggered breaths at their baseline.[21] The clinician, however, may require clinical assessments over time to ensure that as the patient's neuromuscular disease progresses, the trigger sensitivity remains adequate because the patient will still need to trigger the device intermittently and during times of illness.

High leaks may also interfere with patient triggering and cause autotriggering. This is more difficult to ascertain from a download.

OVERNIGHT OXIMETRY

Although a significant amount of information is interpreted from the data download alone, these data have limitations in terms of physiologic changes through the night. Although PSG is the gold standard to monitor overnight physiologic changes during sleep, repeat PSG may be undesirable given the burden to patients, particularly those with neuromuscular weakness, and cost and resource limitations.[22] Overnight oximetry is a cost-effective alternative for physiologic monitoring for patients already initiated on NIV. It has several advantages including simplicity of use, easy installation, and relative affordable cost.[9,23]

Overnight oximetry alone, however, has several limitations. There may be artifact depending on position or movement, and moments of poor perfusion at the site of monitoring. Also, desaturation events cannot be interpreted in isolation because there may be various reasons for low oxygen saturations, including obstructive events, hypoventilation, or changes in ventilation/perfusion matching. Another challenge is the lack of standardized criteria for oximetry assessment of NIV. The most specific criteria for suspected hypoventilation include Sa_{O_2} less than 88% for 5 consecutive minutes and/or a mean Sa_{O_2} less than 90% or Sa_{O_2} less than 90% for greater than 10% of the night.[24] However, there would need to be significant impairment before those are met. Other groups have used a 4% desaturation index (ODI4%) to monitor NIV outcomes.[25] The ODI4% is useful in long-term monitoring and if it is increasing may be a sign that ventilator or mask adjustments may be required.

The most informative way to interpret the oximetry is in conjunction with a data download. If periods of desaturation coincide with periods of large leak, then efforts should be focused on the mask interface to attempt to minimize the periods of leak (**Fig. 5**). If mask leaks seem to be well controlled, the clinician must consider whether there are residual obstructive events present. If the AHI on the download is elevated, one should consider increasing the EPAP.

If leaks and obstructive events are controlled, and desaturations are suspected to be caused by periods of nocturnal hypoventilation, then adjustments are made to various settings including backup rate, tidal volume, or inspiratory pressures to increase minute ventilation. However, given the limitations of overnight oximetry, appropriate follow-up with repeat oximetry should be scheduled. If desaturations persist, PSG should be considered.

One must remember that hypoventilation may be masked when supplemental oxygen alone used to treat desaturations; therefore, oxygen therapy alone is not recommended without a clear understanding of the underlying physiology causing the desaturation.

TRANSCUTANEOUS CO_2 MONITORING

Although arterial blood gas (ABG) remains the gold standard for measurement of Pa_{CO_2} levels and acid/base status, regular monitoring using ABG

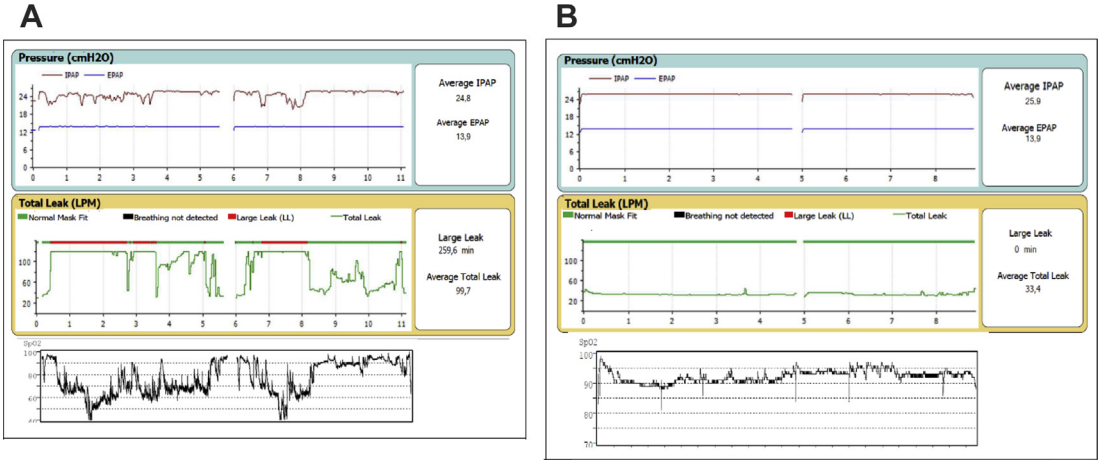

Fig. 5. (*A*) The oximetry in 65 year old with chronic obstructive pulmonary disease and obesity hypoventilation reveals frequent and prolonged desaturations to <80% documented throughout the night with the largest desaturations related to the large leaks on the download. Furthermore, during these periods the set IPAP of 25 cm H_2O is not being reached because of the excessive leak. (*B*) After appropriate teaching for mask adjustment the leak improved with associated improvement in oxygenation.

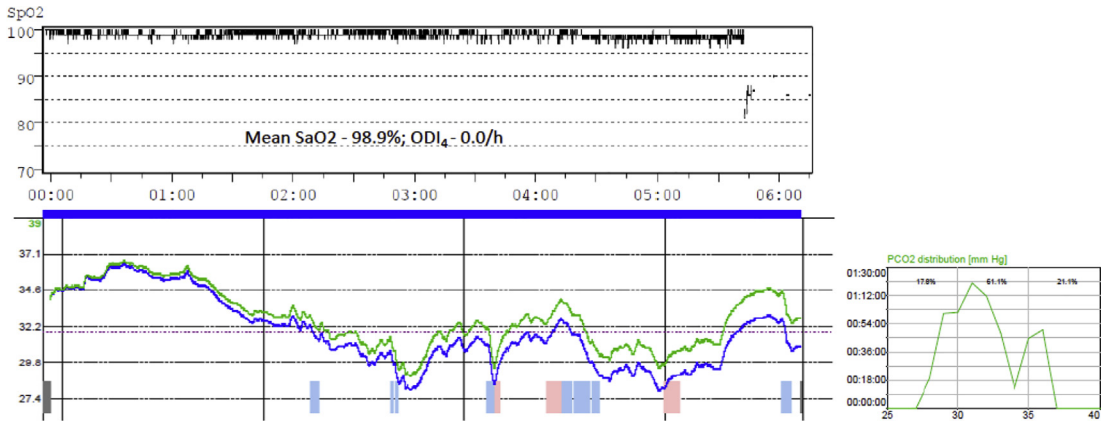

Fig. 6. A 9 year old with spinal muscular atrophy type 2 on NIV. The patient's download (not shown) revealed 100% nightly adherence, normal leaks, exhaled tidal volume of 9 mL/kg, and AHI of 0.2/h. (*Top*) The oximetry is normal with a normal mean saturation and no desaturations of 4% or more as indicated by a 4% desaturation index (ODI4%) of 0.0/h. (*Bottom*) However, the TCO_2 tracing reveals most of the night TCO_2 less than 35 mm Hg indicating they are overventilated on the current settings. On the TCO_2 tracing, the *green line* indicates the measured TCO_2 and the *blue line* is the drift corrected TCO_2 and is the tracing that should be used. To the right is a distribution graph of the cumulative times spent at different TCO_2 during the night.

is limited by several factors including patient body habitus, patient discomfort, and practicalities of obtaining real-time ABGs during periods of hypoventilation. Newer transcutaneous CO_2 (TCO_2) devices have been shown to be reliable in estimation of $Paco_2$ levels.[26] Combined with overnight oximetry and data downloads, clinicians can more reliably detect periods of hypoventilation before patients developing daytime hypercapnia. Appropriate adjustments are made to NIV settings to

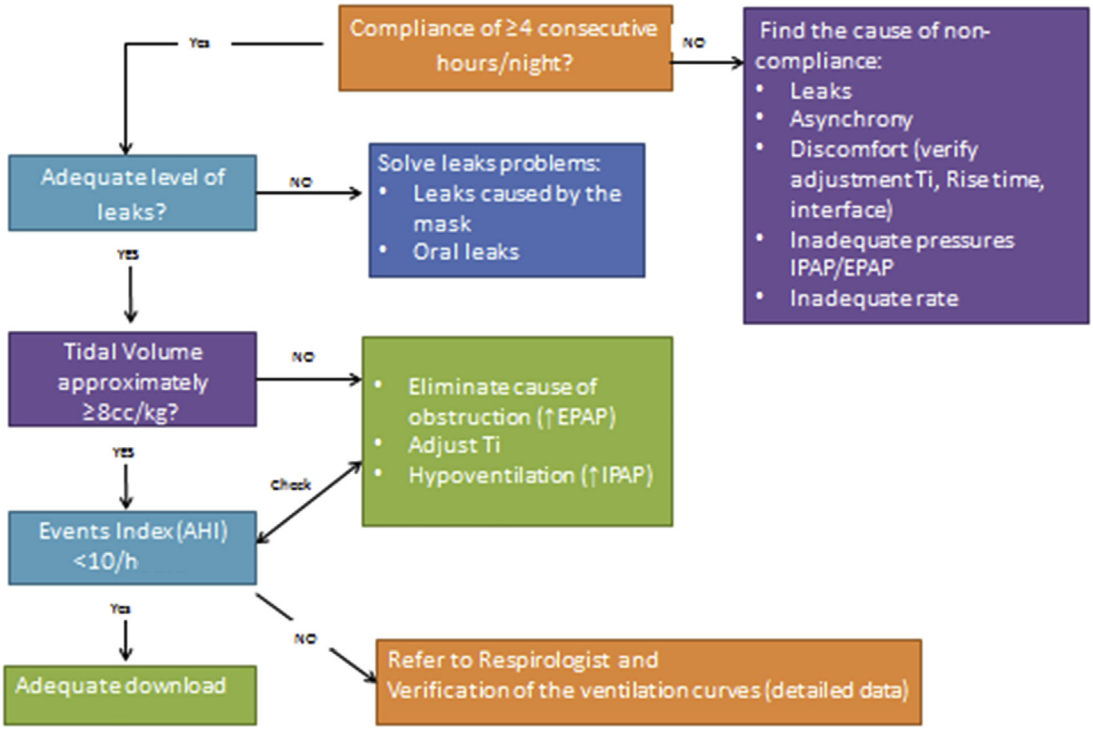

Fig. 7. Approach to evaluating NIV data download. (*Courtesy of* Veronique Adam and Programme National d'Assistance Ventilatoire à Domicile (PNAVD), Montreal, Quebec, Canada.)

minimize these periods of hypoventilation. Furthermore, if a patient is overventilated, then all indices on download and oximetry may be normal and this would not be detected without CO_2 measurements (Fig. 6).

As with overnight oximetry, TCO_2 monitoring may be limited by artifact and poor perfusion. In addition, TCO_2 monitors are expensive, fragile, and not widely used by many home care companies. Therefore, widespread use in the home environment remains limited. However, if TCO_2 monitoring is available, then clinicians should consider it as an additional tool to ensure adequate ventilation for patients on NIV.

PROTOCOLS

Given the complexities involved in monitoring home mechanical ventilation, we recommend instituting respiratory therapy–based protocols for effective longitudinal follow-up. A systematic approach involving a home-based respiratory therapist is vital to ensure most effective adherence to the therapy and appropriate management of settings. In Fig. 7, we outline a systematic approach that can be followed by a home-based respiratory therapist to manage most of the problems that may be encountered when a patient is initiated on home mechanical ventilation. If these parameters are not able to be controlled, then further diagnostic testing, such as PSG, may be warranted.

SUMMARY

Long-term monitoring of patients on home mechanical ventilation is aimed at treating the patient's underlying problem in a cost-effective and efficient manner. Routine PSG and ABG monitoring is not practical, cost-effective, or comfortable for patients. Therefore, proper interpretation of data downloads, in conjunction with noninvasive testing, such as overnight oximetry and TCO_2 monitoring, should be used to optimize NIV settings. Efforts should be made to minimize mask leaks, achieve adequate tidal volumes, and limit obstructive events. Clinicians must also take detailed histories to elicit any symptoms of nocturnal hypoventilation. When performed in a systematic way, home-based respiratory therapists partnered with pulmonary clinicians can provide effective NIV monitoring that can lead to increased adherence to therapy and appropriate ventilation.

DISCLOSURE

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