Shedding Light on Positive Airway Pressure Algorithms for Correcting Sleep-Disordered Breathing

In this issue of RESPIRATORY CARE, 2 studies used bench testing to compare responses of positive airway pressure (PAP) devices to simulated respiratory events. The first by Fasquel et al[1] tested the response of 3 autoCPAP devices to events with and without unintentional air leak. The second by Delorme et al[2] tested the response of adaptive pressure settings of 4 noninvasive ventilators to simulated central and obstructive respiratory events. These papers highlight that a greater understanding of how different PAP algorithms work can facilitate their optimal use and help troubleshoot clinical responses. Whereas the authors state that the algorithms are largely an unknown black box, some manufacturers have shared and verified key elements that are reported in *Principles and Practice of Sleep Medicine, 7th edition*,[3] and 2 other publications.[4-5]

Fasquel et al[1] concluded that ResMed's AirSense S10 autoCPAP "was not able to respond correctly to obstructive apnea and hypopnea" in the setting of unintentional air leak. In response to events and unintentional air leak, AirSense S10's algorithm rapidly maintained fairly constant pressure of 7–8 cm H_2O, whereas Philips' DreamStation slowly increased the pressure to near 10 cm H_2O and Löwenstein Medical's prisma20A slowly increased to almost 15 cm H_2O. We differ with their opinion that the correct response to these events in the setting of unintentional air leak is to keep raising the pressure.

The main difference between invasive ventilation and noninvasive ventilation (NIV) or PAP therapy is the need to adjust for leak. Algorithms need to adjust for both intentional leak from the outflow through mask exhalation ports and unintentional air leak from mouth opening or around the mask. Appropriate leak control and algorithm response are critical for both function and tolerance. There are 2 main reasons to limit pressure responses in the setting of high leak. First the devices may be unable to accurately differentiate types of respiratory events, leading to incorrect response. Second, if the pressure continues to increase in

the setting of leak, the mask may be unable to reseal, worsening the leak. Thus limiting further pressure increases is advantageous until the leak is resolved. AirSense S10's algorithm specifically limits pressure increases to events in the setting of high leak as confirmed by the bench testing.[3]

A major finding of the study by Fasquel, which was not discussed, was huge differences among devices in the response to simulated obstructive apneas (OAs) and obstructive hypopneas (OHs) when there was not intentional leak.

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AirSense S10 had the most rapid response, increasing pressure to 7 cm H_2O by the second OA and to 5.5 and 7.6 cm H_2O by the second and third OH, respectively. DreamStation and prisma20A had no change in pressure by the second OA or OH, only reaching a pressure of 7 cm H_2O after the seventh OA or OH for DreamStation and the sixth OA and seventh OH with prisma20A.

The initial large pressure increase by AirSense S10's algorithm compared to the other devices relates to its algorithm, which adjusts pressure quickly and more rapidly than the other devices. AirSense S10's algorithm adjusts the rate of increase proportionally to both the type of event and the initial pressure. For example, a maximum 3 cm H_2O/min increase occurs with a starting pressure of 4 cm H_2O, and a much slower rate of increase occurs when the pressure is 10 cm H_2O. AirSense S10's algorithm also limits pressure increases to snore signal at higher pressures in the absence of other events as the higher air flow may be the cause of the vibratory signal.[3] DreamStation's algorithm, on the other hand, requires 2 hypopneas or apneas to trigger a pressure change and limits pressure to 1 cm H_2O increases per 45 s. DreamStation also has a nonresponsive apnea-hypopnea logic to limit further pressure increases to apneas above 11 cm H_2O or 3 cm H_2O higher than pre-apnea baseline.[3]

The slow initial response of DreamStation's and prisma's autoCPAP algorithms to obstructive events without unintentional air leak is more likely than AirSense S10's to result in desaturations or arousals before optimal pressure is reached. Thus, especially with less responsive algorithms, it is important to have the pressure range close to the highest pressures needed in supine position and rapid eye movement (REM) sleep. A narrow pressure range can also limit arousals from

sudden pressure changes in the middle of the night. Our typical starting pressure range for most patients is 8–20 cm H_2O, since in our experience initial under titration is often more of a problem than over titration. We often adjust pressures based on device data, bringing the expiratory PAP minimum close to the median pressure for AirSense S10 or 95th percentile pressure for less responsive devices.

The Delorme et al[2] study found that ResMed's Stellar 150 (equivalent to Astral or AirCurve) intelligent volume-assured pressure support (PS) (iVAPS) algorithm was most likely to have acceptable or appropriate responses as well as ability to score events. Philips BiPAP A40 Pro average VAPS-autoEPAP (AVAPS-AE) was the least likely to respond especially to OAs and OHs. Not surprisingly, given the differences in algorithms,[5] they found that iVAPS algorithm leads to the largest ventilatory response to obstructive and central events. iVAPS's algorithm targets estimated set alveolar ventilation rather than tidal volume (V_T) and adjusts PS within bounds of set PS minimum and PS maximum. iVAPS also has the quickest pressure changes, measuring air flow throughout the inspiratory cycle; and if target ventilation is not as expected, inspiratory pressure is adjusted throughout inspiration. If V_T decreases or if breathing frequency slows such that ventilation reduces, the PS increases, resulting in larger V_T.[5]

On the other hand, AVAPS-AE's algorithm only increases inspiratory PAP at the beginning of inspiration if the V_T of the prior event was lower than target and at the midpoint of inspiration if the V_T is still under target.[5] If the V_T is larger than desired, the PS will be reduced for the following event. AVAPS-AE's algorithm also limits the degree of PS change, with no more than 0.5–1.0 cm H_2O per breath and with a max change depending on the set rate. Standard AVAPS algorithms in respiratory assist devices or older NIV devices limit the maximum change to 1 cm H_2O per breath, but the AVAPS-AE algorithm allows for it to be set between 1–5 cm H_2O/min.[5] The authors used the 5 cm H_2O/min setting. Only iVAPS increased pressures in response to obstructive apneas (increasing PS from 2 to 16 cm H_2O by 20 s), with the other devices maintaining the same PS. The response to OHs also differed between devices, with iVAPS and prisma VENT40 AutoSet ST +V increasing PS over 20 s, with no change with AVAPS or Breas Vivo 45 PSV-AE.

Whereas in some patients a quicker pressure change may affect tolerance, in our clinical experience, the more rapid response of iVAPS allows for better control of physiological changes including changing of position or sleep state changes that may require large differences in pressure to control ventilation and stabilize breathing. Some patients, however, require reduction of maximum PS to help with tolerance or to improve breathing stability or minimize leak with high pressures. Similar to the pressure changes, the EPAP changes of the autoEPAP algorithms of AVAPS-AE

and iVAPS differ. They follow the manufacturers' APAP algorithms, with more rapid response with ResMed as previously discussed. Another difference between algorithms that may affect tolerance is the breathing frequency. iVAPS supports patient-initiated breaths when the patient rate is below 2/3 the set rate. iVAPS speeds up to the set rate if the patient's rate drops below 2/3 the set rate, which allows for lower V_T to achieve the goal ventilation that can help stabilize breathing.[5] Other algorithms if set at a higher rate may "force" a breath on the patient before they are ready for a next breath, which can be more of an issue when awake. The finding that Philips AVAPS-AE had no scoring of central or OHs may be related to Respironics' protocol to evaluate flow shape (roundness, flatness, skewness, and weighted peak flow) in addition to amplitude changes,[3] so it is possible that the real-life conditions would improve the detection over simulated events.

We appreciate the authors' evaluation of central hypopneas as many patients requiring these adaptive settings have mixed disease. We wonder though, whether the bench model of central hypopneas accurately reflects the native airway physiology. The distinction between central and obstructive events is often muddled because reduced respiratory drive during a central event often leads to upper-airway collapsibility and obstructive features. Because of this limitation, it is difficult for current algorithms to know how pressures should be adjusted. Making this distinction is tricky even when interpreting the air flow on a sleep study. Differentiating factors between central and obstructive events like periodicity, regularity of desaturations, response in REM versus non-REM, and response to pressure increases may be the only way to tell the difference.

Philips' autoCPAP algorithm attempts to adjust for the triggering of unstable central breathing with a variable breathing algorithm. If the breathing becomes more variable after a pressure change, the algorithm will return the pressure back toward the direction of the change. DeVilbiss' IntelliPAP2 APAP is another device that tries to better address more complex sleep apnea. It used periodic breathing pattern to limit pressure increases or even lower pressures.[4]

The 2 studies reported in the Journal highlight the dramatic differences among devices that provide for autoCPAP and for NIV in the response to apneas and hypopneas. This raises the question of whether there should be standards for ranges of acceptable responses for a given event type or artifact like leak. The same autoCPAP settings effective for one device may be largely ineffective with another device. Devices slow to respond to events need EPAP minimum close to effective pressures. Other settings for NIV than V_T (or target alveolar ventilation), EPAP, PS minimum, PS maximum, and rate that affects efficacy and patient tolerance were not evaluated. Optimal trigger, cycle, minimum and maximum inspiratory time, and rise time settings vary

depending upon a patient's physiology, with patients with neuromuscular weakness benefitting from less flow change to trigger and non-obese patients with severe COPD benefitting from less flow decrease to cycle and shorter rise and inspiratory times. It would be interesting to study how different devices respond to those simulated patients.

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