Testing the Performance of Positive Airway Pressure Generators
From Bench to Bedside

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KEYWORDS

• Bench evaluations • Clinical evaluations • PAP treatment • Sleep disordered breathing

KEY POINTS

- Positive airway pressure (PAP) devices use different proprietary algorithms for sleep-disordered breathing event detection and response.
- Clinical evaluations allow measuring long-term treatment efficacy, but have limitations such as patient variability and high cost.
- Bench studies are necessary to evaluate devices in predefined conditions for understanding algorithms of detection and treatment of disordered breathing events.
- Combining results of bench tests and clinical studies is essential to improve the management of patients with PAP treatment.

INTRODUCTION

The clinician applying a positive airway pressure (PAP) treatment to a patient needs to obtain the following information:

1. Is the treatment safe for the overall condition of the patient?
2. Is the treatment efficient on the disease abnormalities?
3. Is the treatment adherence adequate for obtaining the best outcomes?
4. Is there any side effect at the interface (leaks) or inadequate patient–device interaction (such as arousals linked to the device functioning) that may impair treatment efficacy or tolerance?

Newer PAP generators can track adherence, hours of use, mask or mouth leak, and residual apnea–hypopnea index (AHI). Such data seem very useful to follow chronic disease outcomes. However, there are no standard for recording adherence data, scoring flow signals, or measuring leak, or for how clinicians should use these data.

According to the US Food and Drug Administration and the European Community regulations, PAP generators are class II devices, which may carry risks to the patient. Marketing approval for positive airway generators in the United States follows the simplified 510(k) procedure in which a device only require that clinical studies demonstrate equivalent ability to suppress sleep-disordered breathing (SDB) events in comparison with a previously approved apparatus.[1] This historical comparison may go back to devices manufactured many years before the newly sold device,

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incorporating very different technology. The European directives also have a requirement for approving family of devices on clinical data, which may be "published and/or unpublished reports on other clinical experience of either the device in question or a similar device for which equivalence to the device in question can be demonstrated."[2]

Indeed, for these devices there is no required thorough certification process similar to what is required for any new drug. Because clinical studies are long and costly, it is common practice to introduce a new product to the market without specific clinical evaluation.

The PAP generators are in their principle, simple devices based on a blower that takes room air and generates airflow through flexible tubing at a preset pressure that is determined at the mask interface with the patient. Continuous PAP (CPAP) devices are used in most sleep apnea patients in the long term, but the settings are usually titrated during several nights at home, using an autoadjusting PAP (APAP) because manual titration in the sleep laboratory is costly and suffers long waiting lists. Because algorithms often are not disclosed, this technology is often seen as a "black box" that collects and analyses data to detect breathing abnormalities and provide a treatment supposedly adapted to the patient condition.[3]

Given that APAP are a relatively new technology, there are no generally accepted criteria for defining the optimum method of modifying the mask pressure in response to breathing events so that devices provide different results when subjected to the same breathing pattern. Therefore, the individual demonstration of their efficacy is very relevant. This evaluation cannot rely on symptoms, because controlled trials have demonstrated a noticeable placebo effect[4,5] and would require costly sleep laboratory studies. An alternative approach is the use of bench testing to challenge each device by events as close as possible to patients breathing events.

PAP usages seem to be reliably determined from device-reported compliance data, but a definitive accuracy study has not been published. The residual events (apnea or hypopnea) and leak data are not as easy to interpret and the definitions of these parameters differ among PAP manufacturers.[6]

Any observed difference in residual AHI between bench values and device-reported ones bear considerable clinical implications, because the current follow-up of patient often relies on device-reported residual AHI, which may be very different from actual patient values.[7–12]

It is the aim of this paper to describe this methodology and investigate how bench results can help clinicians in evaluating the treatment efficacy of PAP devices and the reliability of device-reported data.

BENCH TESTING OF DYNAMIC PERFORMANCE OF POSITIVE AIRWAY PRESSURE DEVICES

Pressure Stability and Effects of Leaks

PAP devices should maintain a stable positive pressure or provide a bilevel pressure in the airway during respiratory cycles with the presence of normal pressure swings from breathing and deviations in pressure caused by leaks. Therefore, these devices should offer both static and dynamic pressure stability, that is, to compensate pressure swing during each respiratory cycle. For older PAP devices, airway pressure significantly varied during the respiratory cycle, especially when the breathing flow rate was high.[13,14] Bench studies showed a higher dynamic pressure stability in bilevel PAP devices than in CPAPs owing to different technologies applied in the blowers.[13,14] Recent devices can measure the pressure loss in the patient's tubing and adjust the pressure in dynamic conditions.[15]

PAP devices can also compensate for up to a certain level of leaks.[16] **Fig. 1** shows an example of airway pressure changes of 2 CPAP devices subjected to different levels of leak. The pressure stability with leaks has significant impacts on treatment efficacy. Bench studies on APAPs demonstrated that air leaks may affect the responses of devices and cause airway pressure to significantly

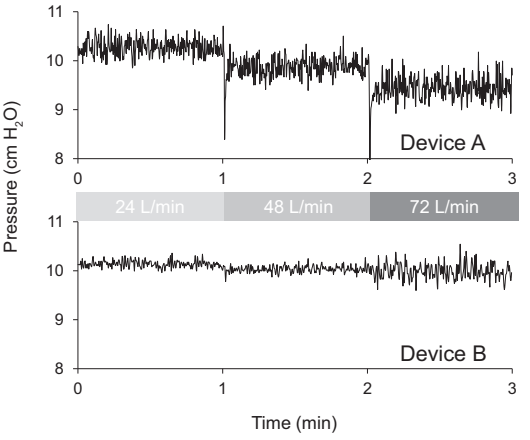

Fig. 1. Airway pressure change of 2 continuous positive airway pressure (CPAP) devices subjected to 3 levels of leak: 24, 48, and 72 L/min calibrated at 10 cm H_2O. The pressure of CPAP devices were set at 10 cm H_2O. Differences between these 2 devices are significant in pressure stability and in the capacity of leak compensation.

drop below a set pressure.[17,18] Regarding bench studies on bilevel PAP, Mehta and colleagues[19] showed that leaking interfered with cycling, inverting I:E ratio, shortening expiratory time thus reducing delivered tidal volume, and suggested adjusting ventilator settings to avoid patient–ventilator asynchrony. Borel and colleagues[20] demonstrated that patient's tidal volume was significantly reduced because of leaks higher than 40 L/min, which led to reduced capacity of achieving and maintaining inspiratory pressure in bilevel devices. Bench studies also showed that increased patient's work of breathing could result from leaking[15] or pressure swings during breathing cycles.[14]

Pressure Compensation for Altitude Change

Changes in altitude do not significantly alter absolute pressure requirement in patients with obstructive sleep apnea (OSA) treatment.[21] However, a bench evaluation performed by Fromm and colleagues[22] demonstrated that altitude exposure could significantly alter the delivered pressure of PAP devices. When the altitude increased, fan speed of the blower of PAP devices needed to increase to maintain the set pressure.[22,23] Many devices on the market can automatically adjust to altitude.[23] A recent study of bench simulation confirmed that CPAP devices equipped with a pressure sensor were more reliable in maintaining the pressure level regardless of altitude and ambient pressure changes.[24]

BENCH TESTING OF ALGORITHMS OF AUTO-ADJUSTING POSITIVE AIRWAY PRESSURE DEVICES

Principles of Bench Models

Bench studies have been proposed to evaluate the responses of APAP devices in various but controlled conditions, such as the presence of predefined SDB patterns with[17,18,25] and without nonintentional leaks.[26–33] In the literature, bench models for evaluating APAP devices can be divided into 2 main categories according to the response of the model to tested devices: the systems that do not react to changes in airway pressure (open loop) and those that take into account pressure changes administrated by the tested devices (closed loop). **Table 1** shows the principles of these bench models in the literature.

The first open-loop bench model for APAP evaluation was reported by Farré and colleagues.[17] This model principally consisted of a breathing simulator that was able to reproduce breathing flow signals recorded from actual patients. Snoring and leakage could also be simulated with the model. During the test, the airway pressure and flow signals were acquired and these signals allowed further analysis of the responses of the tested device, which was subjected to predefined breathing patterns. A similar model was developed by Lofaso and colleagues[27] for evaluating flow limitation detection by APAP devices. Note that no mechanical obstruction was simulated in either model, and obstructive breathing events were simulated at the "flow generator" level instead of the "upper airway."

Considering this inconvenient, Rigau and colleagues[25] improved the model of Farré and colleagues by adding a servo-controlled valve, which allowed the simulation of obstructive events by imposing the mechanical impedance of the upper airway. According to the authors, this valve was controlled in a closed loop driven by pressure in the airway. The airway obstruction could thus respond to the APAP-administrated airway pressure, whereas the control law of the valve was not detailed in the publication. Identical to the previous model, the improved model was able to reproduce any flow waveforms recorded in patients. This model was recently updated by Isetta and colleagues[33] and the library of patients' SDB events was enriched. However, it should be highlighted that recorded patient's flow signals for driving the flow generator were already the consequences of the combination of inspiratory efforts and upper airway obstructions. It is, thus, difficult to determine the contribution of each separate abnormality from the resultant flow signal alone. Therefore, the interaction between the tested APAP device and the servo-controlled valve was limited by the control law and the algorithm of the bench model.

Instead of a servo-controlled valve, a "Starling resistor" consisting of a collapsible tube in a sealed chamber was used to simulate the human upper airway.[18,26,28–30,32,34] The opening of the tube was adjusted by changing the transmural pressure applied on the tube. This mechanical element allowed the bench model to work in a closed loop by adapting the opening of the tube precisely in response to the tested APAP device. However, the characteristics of the breathing flow waveform, which may influence the reaction of APAP devices, were difficult to reproduce precisely with a Starling resistor.

In addition to the upper airway, the lung model is important especially for evaluating ventilators in diseased lung conditions. Among the bench models previously mentioned, 3 types of lung models were applied: Training and Test Lung (Michigan Instruments, Grand Rapids, MI; "Michigan lung"),[18,26–28] servo-controlled

Table 1
Bench model for auto-adjusting positive airway pressure and adaptive servo-ventilation evaluations

Related Publications	Lung Model	Upper Airway Model	Control
Farré et al,[17] 2002	Computer-controlled pump	N/A	Open-loop control The pump was driven by patient's signal
Abdenbi et al,[26] 2004	"Michigan" test lung	Starling resistor	Closed-loop control Test lung generated sinusoidal flow
Coller et al,[18] 2005	"Michigan" test lung	Starling resistor; adjusted by a syringe	Closed-loop control Test lung generated sinusoidal flow
Lofaso et al,[27] 2006	"Michigan" test lung	N/A	Open-loop control Test lung was driven by a flow generator that regulated by a servo-controlled valve
Rigau et al,[26] 2006; Isetta et al,[31] 2015; Isetta et al,[33] 2016	Computer-controlled pump	Servo-controlled valve	Closed-loop control at the upper airway
Hirose et al,[28] 2008	"Michigan" test lung	Starling resistor	Closed-loop control Additional upstream resistance was added in the upper airway
Zhu et al,[34] 2013	Computer-controlled pump with respiratory balloon	Starling resistor	Closed-loop control
Netzel et al,[29] 2014	"Hamburg" active lung model	Starling resistor	Closed-loop control
Zhu et al,[30] 2015; Zhu et al,[32] 2016	ASL 5000	Starling resistor	Closed-loop control

Abbreviation: N/A, not applicable.

pump,[17,25,31,33] and sophisticated active test lung models.[29,30,32] The Michigan test lung was a mechanical model consisting of 2 bellows. One bellow (master bellow) was connected to a driving ventilator and simulated the activities of inspiratory muscles, and the second bellow (slave bellow) was driven by the master bellow and was connected to the tested PAP device. The lung properties such as intrathoracic airway resistance and compliance could be adjusted mechanically, for example, the system compliance was modified by manually changing the position of a spring on the bellow. This system was not designed for complex inspiratory effort simulations.

The computer-driven piston was able to replicate the breathing waveform with high accuracy, and the response of PAP device subjected to specific breathing patterns could be analyzed. However, the system worked in an open loop and did not react to administrated pressure of tested PAP devices owing to limited mechanical properties of the artificial lung. As a solution, a respiratory balloon could be added in parallel to the flow generator to provide compliance.[34] In addition, sophisticated active lung models such as ASL 5000 (IngMar Medical, Pittsburgh, PA) that simulates mechanical lung properties and inspiratory efforts were used for bench evaluations of PAP devices.[29,30] This allowed testing PAP devices in a closed loop at the lung level. Fig. 2 gives an example of bench model for APAP device evaluations.

Bench Evaluations of Positive Airway Pressure Devices

Auto-adjusting positive airway pressure

APAP devices on the market perform differently on bench tests.[17,30] This may result from difference in the algorithms for detection and/or response of the devices. To understand the algorithms of devices, bench-simulated breathing

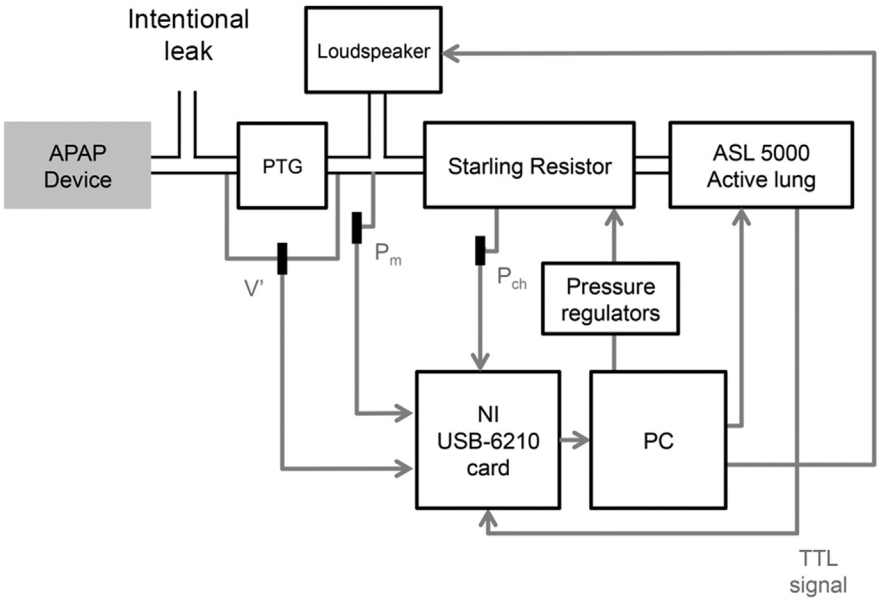

Fig. 2. An example of bench model with upper airway simulation for auto-adjusting positive airway pressure (APAP) evaluation. Intentional leak, 24 L/min calibrated at 10 cm H_2O; Pch, measured chamber pressure of the Starling resistor; Pm, measured mask pressure; PTG, pneumotachograph; TTL, transistor-transistor logic; V′, measured mask flow. (*From* Zhu K, Roisman G, Aouf S, et al. All APAPs are not equivalent for the treatment of sleep disordered breathing: a bench evaluation of eleven commercially available devices. J Clin Sleep Med 2015;11(7):726; with permission.)

sequences with repetitive single-type SDB events allowed testing detection and reaction to specific SDB events.[17,29,30] Results showed a large variability between devices in the capacity of SDB event detection, which could be caused by the detection techniques used by each device. For example, some devices considered cardiac oscillations as a surrogate of an open upper airway,[23,30] whereas the sensitivity of cardiac oscillation was reported as only 60% for central apnea diagnosis.[35] In contrast, the forced oscillation technique applied by some devices was considered more mature and reliable because this technique was widely used for measuring the airway impedance in lung function tests.[36] The detection of SDB events was also influenced by the definitions applied by device manufacturers, such as airflow amplitude, event duration, and acoustic vibrations, and so on, which are often at variance with the American Academy of Sleep Medicine guidelines.[37,38] In addition to SDB event detection, the protocols for increasing and decreasing pressure also differed between device manufacturers.[23,30]

Test protocols of repetitive single-type SDB events had limitations, because such controlled, regular breathing flow rarely occurred in real clinical conditions. A variety of characteristics and phenotypes exist not only between patients, but also occur within the same subject during different sleep stages and body positions. New APAP devices were equipped with advanced algorithms to recognize long sequences of events from measured patient's flow, and the pressure response of the device to such events could be different to a single isolated event. For example, repetitive apneas that persisted at high PAP were considered as "non-responding" events by some devices such as the RemStar APAP devices (Philips Respironics, Murrysville, PA). The administrated pressure thus decreased when the device was subjected to periodic breathing.[32] To approach clinical and complex conditions, 2 recent bench studies have simulated patient's full-night sleep breathing scenarios including a variety of SDB patterns: Zhu and colleagues[30] evaluated 11 APAP devices on a 5.75-hour scenario including the simulated breathing patterns of 4 sleep cycles. They found that only 5 devices obtained a residual obstructive AHI of less than 5 per hour. Isetta and colleagues[33] simulated a typical night of sleep of a female patient with OSA and tested 10 APAP devices. As a result, only 3 devices were able to overcome flow limitations and 5 devices presented a residual AHI of less than 5 per hour.

In addition, a recent bench study questioned the impact of pressure relief modes on CPAP treatment efficacy.[32] The pressure relief modes are

aimed at improving patients' comfort during CPAP treatment. The results of the bench study showed that the CPAP efficacy could be attenuated if the set pressure was not adjusted for, at the time of introduction of pressure relief modes, and suggested enabling such features before initial pressure titration.

In addition, new PAP devices provide treatment reports on which the device-estimated residual AHI is shown. The accuracy of this index was questioned in one bench study.[30] As a result, 7 devices out of 11 identified AHI with an accuracy of greater than 90%. Such differences could be explained by the different definitions of SDB events applied by device manufacturers, which obviously must differ from American Academy of Sleep Medicine rules for scoring respiratory events,[37,38] because they do not take into account oxygen desaturations and arousals to determine hypopneas, or total sleep time to compute an actual AHI.

Bilevel positive airway pressure and adaptive servo-ventilation

Bilevel PAP device alternates the airway pressure during inspiration (inspiratory PAP) and expiration (expiratory PAP, EPAP). Note that bilevel PAP without backup rate (BiPAP, Philips Respironics) is indicated for patients with OSA who cannot tolerate a high level of pressure. The objective is to increase patient comfort and improve the treatment compliance.[39]

Bilevel PAP noninvasive ventilation with backup rate is aimed at improving gas exchange in hypercapnic patients with obstructive and central apneas and respiratory insufficiency caused by obstructive or restrictive lung diseases. In the literature, bench evaluations of bilevel devices focused on pressurization rate,[40] patient–ventilator interactions such as triggering and cycling,[41,42] the effect of condensate in the tubing,[43] and the accuracy of estimations of tidal volume and leakage.[44–47] Different from the bench models previously mentioned for APAPs, most benches for bilevel PAP evaluation did not use a variable upper airway resistance, although occurrence of obstructive events are frequent in patients treated by such devices. In addition, a recent review of studies on bilevel PAP devices[48] highlighted several limitations: unclear impacts of different lung models applied, inconsistent settings of tested devices, different terminology, and lack of standard criteria for measurement.

Adaptive servo-ventilation is a specific bilevel PAP that provides variable pressure support, that is, the difference between inspiratory PAP and EPAP. New devices use similar algorithms to APAP for adjusting the EPAP to overcome obstructive SDB patterns.[49] The device is indicated for treating patients with central and mixed apneas and periodic breathing such as Cheyne-Stokes breathing. Zhu and colleagues[34] reported a bench evaluation of 3 adaptive servo-ventilation devices, of which 2 devices had autotitrated EPAP. The 3 tested devices eliminated all bench-simulated central apneas of Cheyne-Stokes breathing, and these events were transformed to hypopneas. The obstructive events were treated differently between devices. For the adaptive servo-ventilation with constant EPAP (AutoSet CS, Resmed [San Diego, CA], is similar to VPAP Adapt available in the US market), the obstructive events were partially cleared with high-level pressure support despite of a low EPAP value of 4 cm H_2O. Autotriggering was also observed in this device during normal breathing. The accuracy of the device-estimated AHI depended on initial settings of devices. Advantages and limitations of bench tests are summarized in **Table 2**.

WHAT CAN WE LEARN FROM CLINICAL EVALUATIONS?

Compared with bench evaluations, clinical tests allow access to long-term safety evaluations and measurement of associated physiologic parameters (see **Table 2**). However, these studies are often limited by small numbers of patients, short follow-up, and limited compliance. Sometimes, well-conducted studies did not reflect clinical practice because patients with hypnotic treatment or significant comorbidities such as insomnia or chronic obstructive pulmonary disease were excluded, limiting the generalization of findings to real patient populations.

Treatment Efficacy of Auto-adjusting Positive Airway Pressure Devices

The clinical efficacy of APAP has been questioned by some studies showing a large residual AHI with some devices.[50] Early studies that attempted to explore PAP device effectiveness were based on the capacity of normalizing the AHI manually scored with a polysomnography (PSG). One limitation is that evaluations were performed during the titration night and did not reflect long-term use of treatment. The poor performances of some devices may explain the observation of a poorer control of blood pressure with APAP, which was associated with a higher residual AHI.[51] More recent studies have also underlined a less beneficial effect of APAP than CPAP on autonomic nervous system activation measurements, such as

Table 2
Advantages and limitations of bench and clinical evaluations

	Advantages	Limitations
Bench evaluation	• Reproducibility of test conditions • Predefined specific test conditions • Results of specific needs (eg, delay of response to an event; pressure rising time) • Objectivity • Reliability • Didactic methods and results • Possibility to measure the dynamic performances and to understand the algorithms • Low cost • Study duration relatively short	• Short-term performance of PAP devices; impossible to deduce long-term therapeutic effects • Impossible to get subjective feedback from patients • Simulated patient characteristics are limited; some physiologic conditions are not taken into account (eg, neurologic loop) • Consequence of some physiologic parameters cannot be evaluated (eg, SpO_2)
Clinical evaluation	• Data available for long-term therapeutic effects • Unique way to measure the compliance of patient • Get patient's subjective treatment feedback directly • Measurement of physiologic parameters (SpO_2, arousals, etc.) • Long-term safety evaluation	• Intrapatient and interpatient variability; a large number of subjects are needed to get reliable results • Difficulty to get strictly identical conditions (impossible to predict identical SDB events in patients of OSA) • Difficulty to measure the dynamic performance of devices • Disturbing factors for clinical evaluation such as medication and alcohol • High cost • Long durations of studies

Abbreviations: OSA, obstructive sleep apnea; PAP, positive airway pressure; SDB, sleep disordered breathing.

heart rate variability[52,53] or pulse wave amplitude.[12] APAP devices have also been questioned in some studies on sleep disturbances linked to arousals seemingly secondary to rapid pressure increases in reaction to SDB events.[54]

A recent metaanalysis showed that the symptomatic effects of treatment are similar between APAP and CPAP.[55] Meurice and colleagues,[50] in 2007, were the first to compare APAP and CPAP devices in a long-term protocol in 83 patients with severe sleep apnea–hypopnea syndrome. Patients were randomly allocated to 1 of 5 different groups: fixed CPAP after titration performed in the laboratory and the 4 other groups used different APAP machines. No difference was demonstrated in average device effectiveness based on PSG parameters between the 5 groups; nevertheless, in some individuals the residual AHI remained elevated particularly for 2 devices (SomnoSmart, Weinmann [Hamburg, Germany] and Pv10i, Breas [Mölnlycke, Sweden]). Furthermore, APAP was shown in some patients to be less effective than fixed pressure on manually scored PSG, even if the average residual AHI given by the device seemed to be correct.

These findings have been confirmed by bench studies, which have found inadequate treatment of certain hypopneas and delayed response in correcting apneas[17,26] and other clinical studies reporting a high proportion of undertreated patients on APAP.[56,57]

Reliability of Device-Reported Apnea–Hypopnea Index

Reports of residual events obtained by the devices have also been questioned by some authors.[7–11,58] Few studies have documented the accuracy of event detection algorithms.

Denotti and colleagues[8] investigated whether deficiencies of APAP resulted from failures to detect or to respond to airway obstruction. In this study, airflow was measured both at nasal mask and directly from APAP devices (Auto-Set T, Resmed) and both signals were recorded on PSG. AHIs at these 2 sites were compared with device-estimated AHI in the device reports. The

authors found that nasal flow AHI was in agreement with APAP flow AHI, although agreement was lower with device-estimated AHI. There was a trend for APAP to underestimate the AHI at higher actual value and overestimate it at lower values. Failure in OSA detection resulted in risks of inadequate treatment. The results suggested that the built-in detection algorithm might result in incorrect estimation of residual AHI in some patients with OSAs and alert clinicians to interpret APAP reports with caution.

Berry and colleagues[58] compared the automatic event detection (AED) of SDB events of a PAP device (REMstar Auto M-Series, Philips Respironics) with manual scoring of PSG during PAP treatment. The agreement for apnea detection was better than hypopnea. An event-by-event analysis showed that the AED algorithm had a sensitivity of 0.58 and a specificity of 0.98, and an AED-AHI greater than 10 events per hour had a sensitivity of 0.58 and a specificity of 0.94. Thus, AED algorithms are reliable when the residual AHI is low. An AED-AHI of less than 10 events per hour indicates good treatment efficacy. The authors also suggested coupling the current algorithm with oximetry to better estimate the residual AHI and to detect periods of hypoxemia owing to hypoventilation.

Similar results were obtained for this particular device on a bench study at a much lower cost, showing a good control of the apnea, although hypopnea only partly reversed. Reported residual AHI did not significantly differ from the bench value indicating a good performance of the detection algorithm.[30]

Underestimated AHIs in some APAP devices were observed in bench studies with short treatment durations (95 minutes), although the difference in AHI was not significant between device report and bench when treatment duration is long (5.75 hours).[30] Device-reported AHI could be affected by leaks, but to our knowledge no bench study has specifically addressed this point.

Compliance with Auto-adjusting Positive Airway Pressure Treatment

Long-term compliance with PAP treatment cannot be predicted on the bench. One approach has been suggested by Netzel and colleagues[29] by computing an arbitrary performance scale on the bench test and comparing it with the mean compliance data obtained in a large sample of patients using this device. Nevertheless, this kind of relationship is necessarily linked to many other factors then the device itself: mask interface used, pressure settings, education, and care of the patients, which are difficult to control for.

Pressure Relief Features

Pressure relief features are developed to overcome patient difficulty of exhaling against a fixed pressure during fixed CPAP treatment and to improve the treatment adherence. However, for C-Flex, better adherence has not been consistently proven in clinical studies,[12,59–66] and the majority of studies reported similar adherence[59,61,66,67] and treatment efficacy[61] between CPAP with and without C-Flex. Adherence and similar treatment efficacy are not available in the literature for the other pressure relief features in CPAP devices.

Regarding APAP treatment with pressure relief features, Mulgrew and colleagues[68] found a nonsignificant trend of greater subjective comfort with C-Flex. Kushida and colleagues[69] reported identical treatment adherence and efficacy between A-Flex and conventional CPAP after either 3 or 6 months, but a higher AHI at the initiation phase. In a recent study, Chihara and colleagues[70] compared the adherence between conventional APAP, APAP with C-Flex, and APAP with A-Flex, and found a greater adherence in APAP with C-Flex. Of note, at the initiation of the studies of Kushida and colleagues and Chihara and colleagues, the APAP auto-titration was carried out with the activated pressure relief feature. However, the question rises concerning the risk of undertreating some patients, because the mean pressure is reduced by these “comfort modes,” as shown on the bench, if pressure is not readjusted to a higher level.[32]

Adaptive Servo-Ventilation in Patients with Severe Heart Failure

Another concern was recently raised by the safety issue of the Serve-HF study, where increased mortality was observed in patients with severe heart failure.[71] Because the reasons for this serious adverse event are not evident, it is worth questioning the performance of the device used which was Autoset CS2 (Resmed). This device has been shown to deliver a higher mean pressure on the bench compared with other devices and experienced asynchronies.[34] These mechanisms may have impaired further cardiac function with adverse consequences.

Telemonitoring

Telemonitoring of PAP is now available from built-in GSM or WIFI transmission of device data. However, some health care providers rely on external

devices placed on the tubing of the PAP device to analyze events and reports on compliance, residual indices and leaks; these systems clearly need a bench validation.[72] Furthermore, measuring and reporting the parameters from CPAP downloads are not standardized between manufacturers and not well-validated, so that the reports are not easily exportable to electronic medical records. Standardization is needed in this field.

SUMMARY

PAP devices rely on different proprietary algorithms for SDB event detection and response. Most evaluations of such devices are based on clinical studies to test the clinical outcomes, the comfort and adherence of patients, and the impact on quality of life and long-term safety. Clinical studies have obvious limitations, such as patient variability, high cost, and long duration. As a complementary approach, bench studies provide an analysis of algorithms in predefined conditions, which allows understanding contradictory results observed in clinical studies. However, long-term treatment data and physiologic effects of PAP treatment cannot be assessed on the bench. It is important to understand the advantages and the limitations of both kinds of studies summarized in **Table 2**. In fact, clinical and bench studies are complementary. Combining results of bench tests and clinical studies is essential to improve the management of patients with PAP treatment.

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