

Setting up home noninvasive ventilation

Chronic Respiratory Disease
Volume 16: 1–14
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DOI: 10.1177/1479973119844090
journals.sagepub.com/home/crd



Jean-Michel Arnal¹ , Charles-Philippe Thevenin²,
Benoit Couzinou², Joelle Texereau³ and Aude Garnero¹

Abstract

Home noninvasive ventilation (NIV) is widely used to correct nocturnal alveolar hypoventilation in patients with chronic respiratory failure of various etiologies. The most commonly used ventilation mode is pressure support with a backup respiratory rate. This mode requires six main settings, as well as some additional settings that should be adjusted according to the individual patient. This review details the effect of each setting, how the settings should be adjusted according to each patient, and the risks if they are not adjusted correctly. The examples described here are based on real patient cases and bench simulations. Optimizing the settings for home NIV may improve the quality and tolerance of the treatment.

Keywords

Home noninvasive ventilation, waveform analysis

Date received: 15 November 2018; accepted: 19 March 2019

Introduction

Home noninvasive ventilation (NIV) is frequently implemented to correct nocturnal alveolar hypoventilation in a number of chronic respiratory diseases. The most widely used ventilatory mode is pressure-support (PS) ventilation with a backup respiratory rate spontaneous timed (ST) mode. This mode requires six main settings; the effects of these settings are complex and difficult to understand as they can differ depending on the disease. Moreover, the settings' names and the modes are often specific to each manufacturer. This can result in errors when adjusting settings, which may reduce the effectiveness of the treatment, generate patient–ventilator asynchronies, and subsequently impact on patient compliance.

The purpose of this review is to describe the main pitfalls encountered with ventilator settings and their consequences to patients, with the aim of helping to avoid these pitfalls. In fact, most of the pitfalls described can be avoided by careful NIV titration and bedside monitoring when initiating the treatment. The figures are based on real patient data and simulations

performed at the Explor research unit (Air Liquide, Gentilly, France) on an ASL 500 lung simulator (Ingmar Medical, Pittsburgh, Pennsylvania, USA). An informed consent has been signed by all patients allowing the use of the data presented herein for teaching and research purposes.

Confusion between IPAP and PS

Depending on the ventilator's manufacturer, expiratory pressure may be called positive expiratory

¹ Service de Réanimation Polyvalente, Hôpital Sainte Musse, Toulon, France

² Centre EXPLOR, Air Liquide HealthCare, Gentilly, France

³ VitalAire France, Air Liquide HealthCare, Gentilly, France

Corresponding author:

Jean-Michel Arnal, Service de Réanimation Polyvalente, Hôpital Sainte Musse, 54 Avenue Henri Sainte Claire Deville, 83056 Toulon, France.

Email: jean-michel@arnal.org



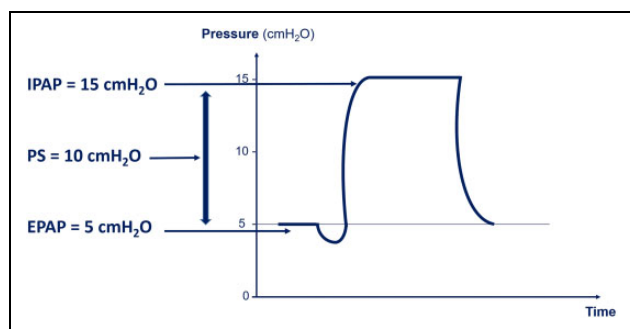


Figure 1. Confusion between inspiratory IPAP and PS settings. The initial drop in pressure before the pressure increase from EPAP to IPAP represents the patient's effort to trigger the mechanical breath. IPAP: inspiratory positive airway pressure; PS: pressure support; EPAP: expiratory positive airway pressure.

pressure, positive end-expiratory pressure (PEEP), or expiratory positive airway pressure (EPAP).

Similarly, inspiratory pressure may be called positive inspiratory pressure (PIP) or inspiratory positive airway pressure (IPAP).

The difference between IPAP and EPAP is PS, which corresponds to the pressure delivered by the ventilator at each insufflation. PS is the main parameter influencing the correction of nocturnal alveolar hypoventilation.

Some ventilators apply the algorithm “IPAP/EPAP,” resulting in the automatic setting of PS that may also be displayed subsequently to avoid errors. Other ventilators apply the algorithm “PS/PEEP,” resulting in the automatic setting of IPAP.

The main pitfall to be avoided is confusing IPAP and PS, which can result in a lower or higher PS than prescribed, whereby a lower PS is more frequent. Being aware of the difference between IPAP and PS is of great importance when prescribing home NIV and adjusting the ventilator settings. If an EPAP of 5 and a PS of 10 cmH₂O are prescribed, IPAP must be set at 15 cmH₂O (Figure 1). If IPAP is set at 10 cmH₂O, the patient will only receive PS of 5 cmH₂O, which is unlikely to correct alveolar hypoventilation.

EPAP setting

The EPAP setting may be adjusted with different objectives depending on the pathology being treated. In obstructive patients chronic obstructive respiratory disease (COPD), severe asthma, cystic fibrosis, etc.) who frequently present with intrinsic PEEP, applying extrinsic PEEP decreases the respiratory work

required to trigger an inspiration.¹ Indeed, to generate an inspiratory flow in assisted or spontaneous breathing, the alveolar pressure needs to be lower than the mouth pressure. In the case of intrinsic PEEP, the respiratory effort needed to lower the alveolar pressure below the mouth pressure is significant. Applying EPAP increases the mouth pressure, thus reducing the effort needed by the patient to trigger an inspiration. EPAP can be adjusted progressively while observing the effort produced by the patient at each inspiration. If the EPAP setting is too low, the patient will make a significant respiratory effort to inhale, potentially resulting in delayed inspiratory triggering and ineffective inspiratory efforts (Figure 2(a)).

In patients with obesity-hypoventilation syndrome or a neuromuscular disorder, applying EPAP prevents upper airway collapse. If the EPAP setting is too low, a partial or complete airway obstruction will occur during sleep, resulting in arterial desaturation and micro-awakenings (Figure 2(b)). Conversely, if the EPAP setting is too high, it may result in leaks and patient discomfort.

Backup respiratory rate

Setting a backup respiratory rate ensures minimal ventilation when the patient is unable to trigger a mechanical breath.² When the patient triggers a mechanical breath, the patient makes an inspiratory effort, while the ventilator delivers inspiratory pressure. When the ventilator triggers a mechanical breath, the ventilator delivers inspiratory pressure at a specific time independently of the patient effort. Thus, a breath triggered by the patient results in a greater tidal volume than a breath triggered by the ventilator (Figure 3(a)). For this reason, the backup respiratory rate should be set to less than the patient's spontaneous respiratory rate to favor breaths triggered by the patient, which are more efficient and may also be more comfortable. In severe neuromuscular and COPD patients, it may be desirable to control the patient by imposing a ventilator respiratory rate, accepting complete asynchrony.

There are several reasons why the ventilator may switch to a backup respiratory rate:

- The patient is making ineffective inspiratory efforts. This situation is frequently observed during NIV, in the intensive care unit, or at home.^{3,4} Risk factors are related to either the patient or the ventilator settings (Figure 3(b)).

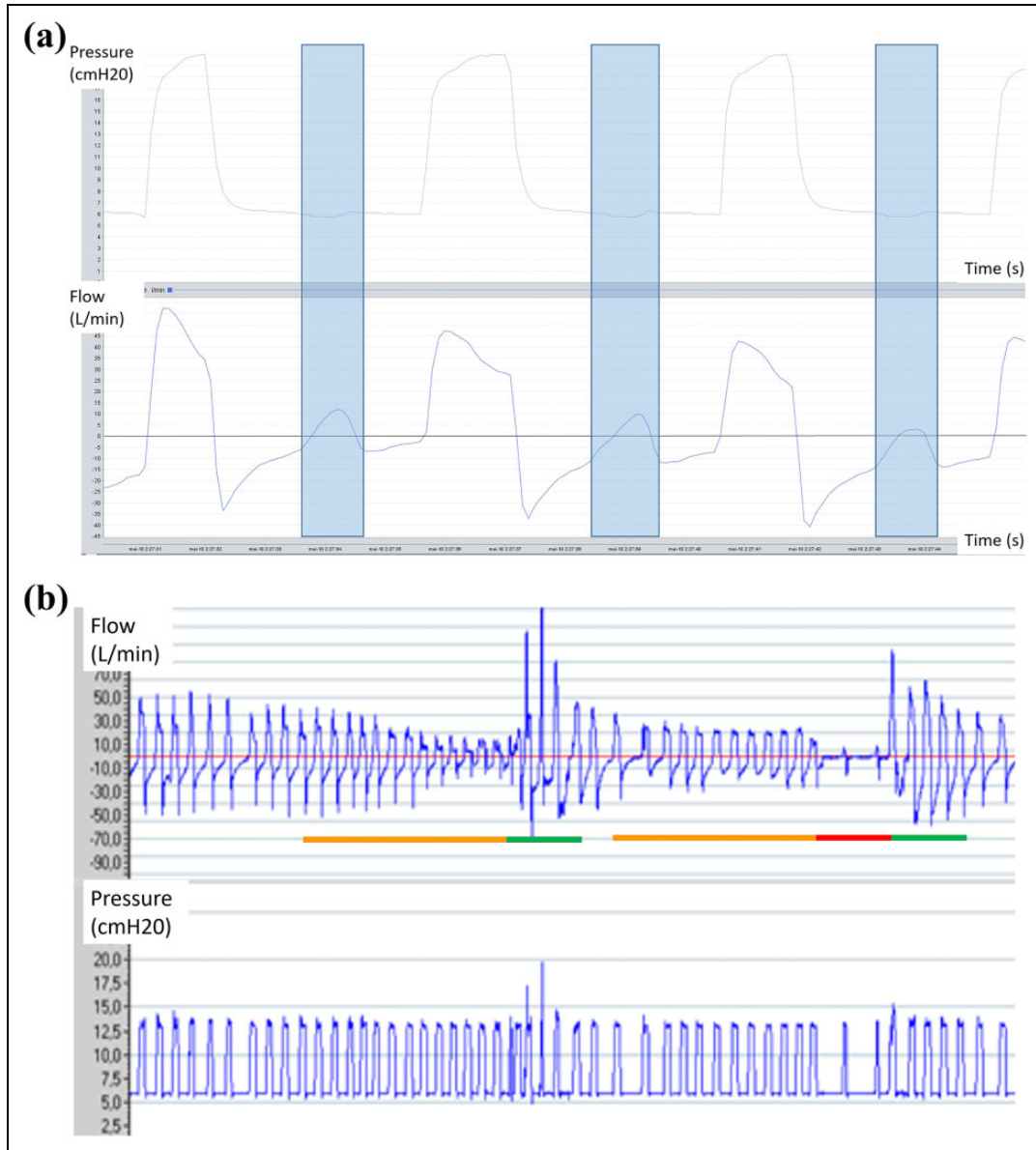


Figure 2. (a) Asynchrony resulting from an EPAP setting that is too low in an obstructive patient with intrinsic PEP. Blue bars indicate ineffective inspiratory efforts. (b) Upper airway obstruction during NIV in a patient with obesity-hypoventilation syndrome. Airway obstruction can be partial (orange lines) or complete (red line), resulting in arousals with a large inspiratory flow (green lines). PEP: positive expiratory pressure; EPAP: expiratory positive airway pressure; NIV: noninvasive ventilation.

Inspiratory trigger

- The backup respiratory rate is set at a rate higher than the spontaneous respiratory rate of the patient (Figure 3(c)).
- The patient is over-ventilated because the IPAP setting is too high, resulting in hypocapnia and a decrease in ventilatory drive. The spontaneous respiratory rate slows down and drops below the ventilator backup respiratory rate (Figure 3(d)).

The inspiratory trigger setting varies according to the ventilator’s manufacturer. It can be a numerical scale where the lowest number is the more sensitive trigger (i.e. the most sensitive for detecting a weak patient inspiratory effort) or may have different levels such as high, medium, and low. The default setting is a medium trigger. It may be adequate when the patient is awake, but is usually not sensitive enough during sleep, resulting in ineffective inspiratory efforts (Figure 4(a)).

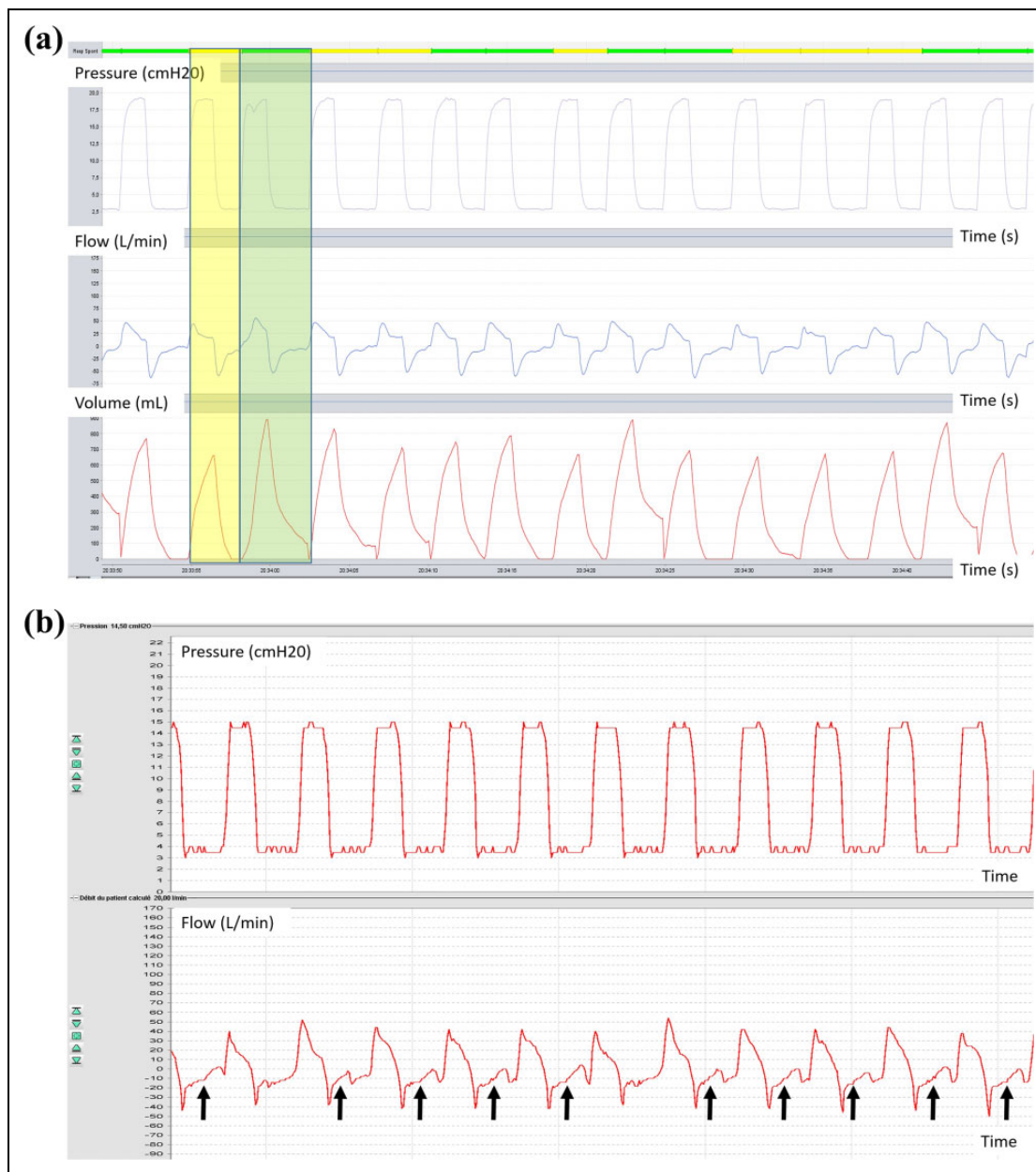


Figure 3. (a) Mechanical breaths in a patient receiving home NIV triggered alternately by the patient (green lines) and the ventilator (yellow lines). Patient-triggered mechanical breaths result in a greater tidal volume than ventilator-triggered mechanical breaths. (b) A patient in complete asynchrony with the ventilator, making ineffective inspiratory efforts at their own pace (arrows) while the ventilator delivers controlled mechanical breaths according to the set backup respiratory rate. One possible reason is an inspiratory trigger set at a low sensitivity, which means the ventilator does not detect the patient's inspiratory effort. (c) Mechanical breaths in a patient receiving home NIV triggered alternately by the patient (green lines) and the ventilator (yellow lines). The backup respiratory rate is set close to the spontaneous respiratory rate of the patient, thus "capturing it" (pink line). (d) Mechanical breaths in a patient on home NIV triggered alternately by the patient (green lines) and the ventilator (yellow lines). The expiratory time after the second patient-triggered mechanical breath is long without a patient inspiratory effort (pink line), which indicates a reduced ventilatory drive. NIV: noninvasive ventilation.

The inspiratory trigger should therefore be set at the most sensitive level for best detection of patient inspiratory efforts without causing auto-triggering (Figure 4(b)).

Pressure rise time

The pressure rise time is the time needed for the airway pressure to increase from EPAP to IPAP. This parameter can be set according to a numerical scale

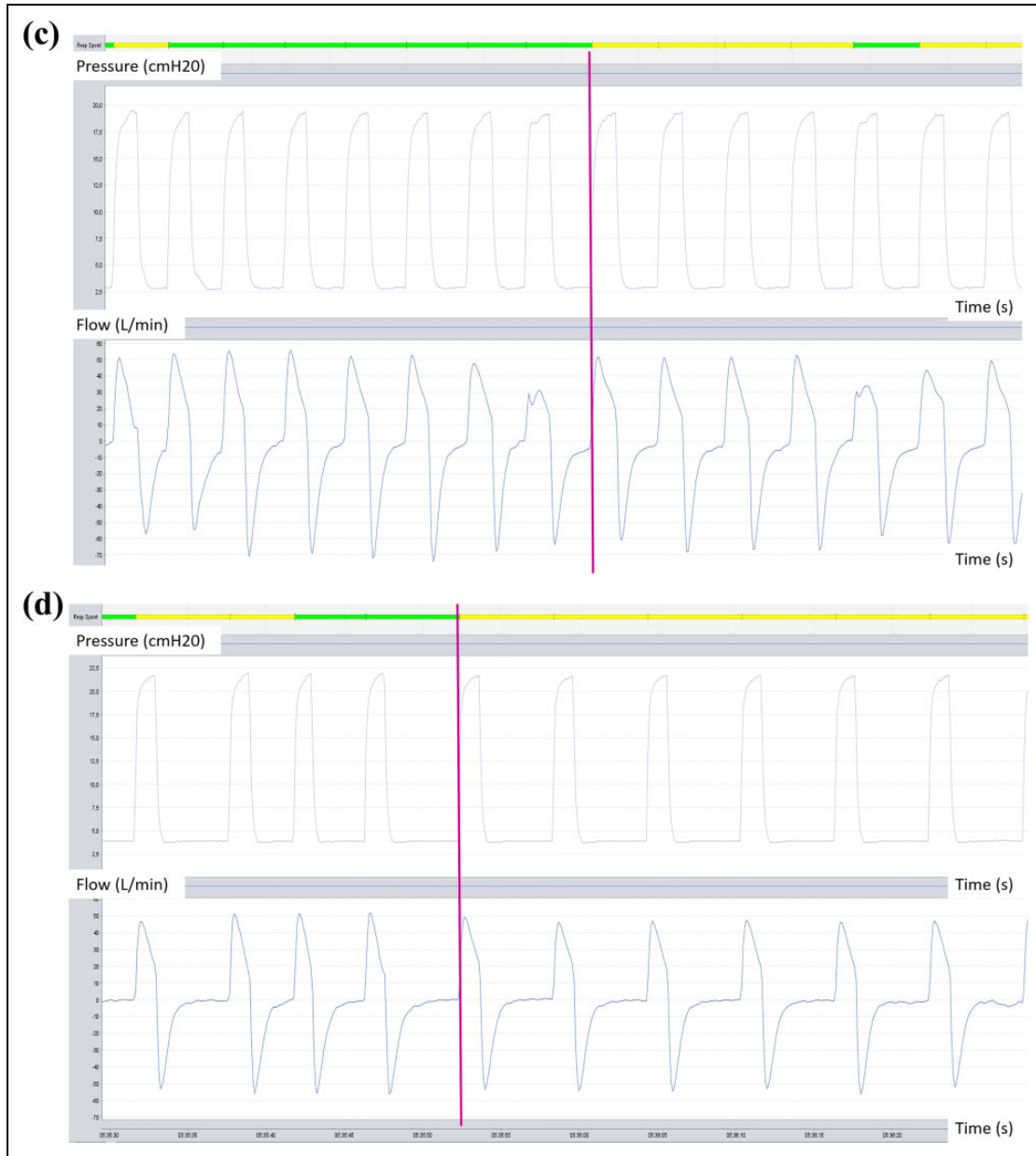


Figure 3. (continued)

where the lowest number is the quickest slope, or according to a time scale. The shape of the pressure rise time depends on the type of ventilator turbine and on the algorithm that drives it (Figure 5(a)).

A pressure rise time that is too long increases the inspiratory work of the patient, who does not receive sufficient inspiratory flow.^{5,6} In extreme cases, a pressure rise time longer than the insufflation time results in insufficient IPAP below the set amount, meaning that the patient does not receive the intended inspiratory pressure (Figure 5(b)).

A short pressure rise time should therefore be preferred. However, too short a pressure rise time can result in uncomfortable pressure and flow peaks. This peak in inspiratory flow may also induce premature cycling (Figure 5(c)).

Minimum inspiratory time

In PS, when a breath is triggered by the patient, the insufflation time depends mainly on the patient's effort and respiratory mechanics (lung compliance

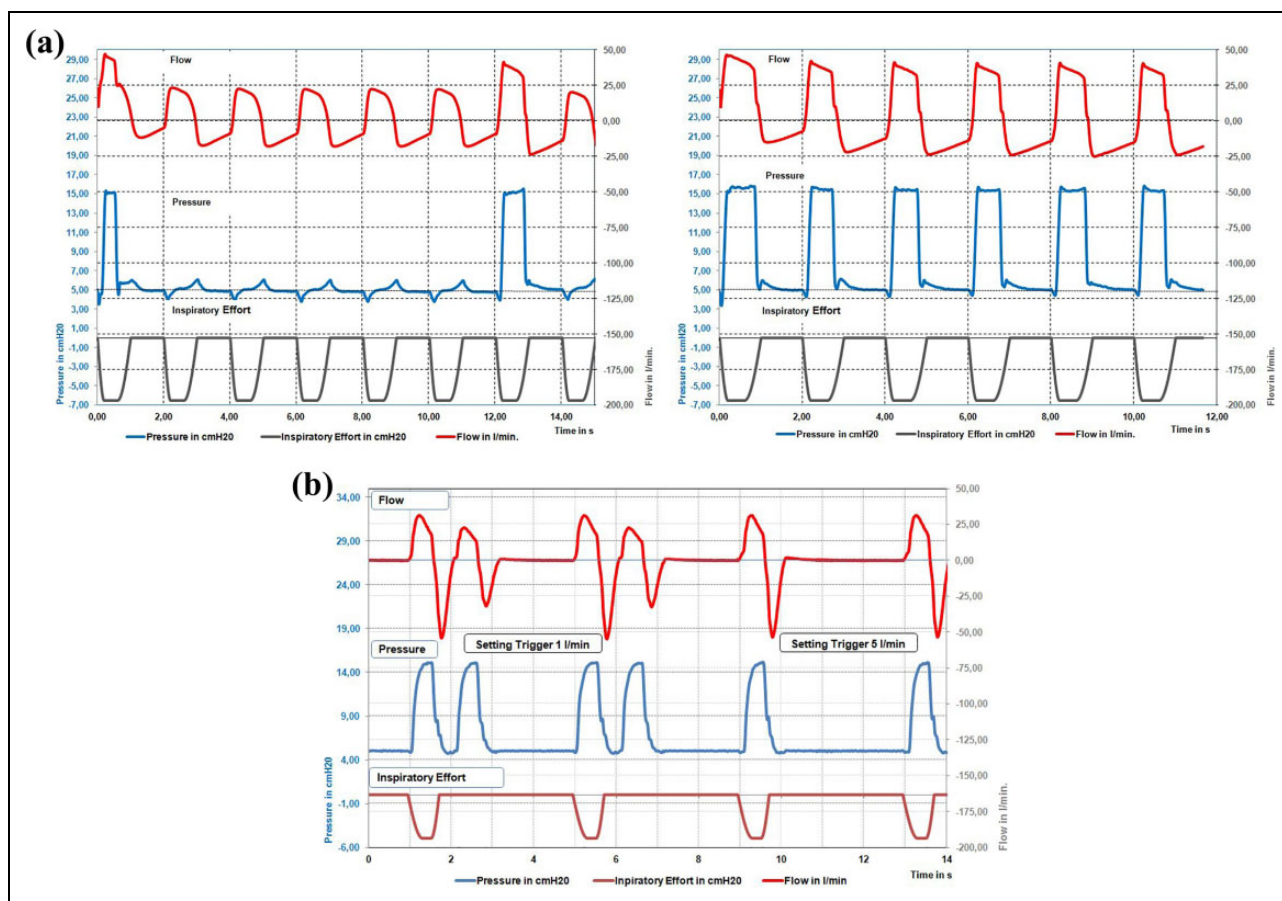


Figure 4. (a) Example of an ineffective inspiratory effort due to a trigger setting that is not sensitive enough (left). Synchrony between the patient and ventilator is improved when the inspiratory trigger is set at the most sensitive level (right). (b) Auto-triggering due to an inspiratory trigger set at too sensitive a level.

and resistance) and on some ventilator settings, namely, the pressure rise time, IPAP, and expiratory trigger sensitivity (Figure 6(a)). Therefore, for any given patient with certain ventilator settings, there is a maximum insufflation time that corresponds with the point of zero inspiratory flow, when the alveolar pressure equals IPAP. This maximum insufflation time may be particularly short in patients with severe restrictive disease. The number of home ventilators proposes a minimum inspiratory time on patient's triggered breath, which may result in asynchronies when incorrectly set. Patient-ventilator synchrony can be considered satisfactory when the insufflation time (inspiratory time of the ventilator) equals the neural time (inspiratory time of the patient).

Prolonging insufflation beyond the maximum insufflation time is not beneficial, as no flow can be generated after this time. Doing so will result in an inspiratory pause at the end of inspiration, which is often uncomfortable for the patient (Figure 6(b)). In

extreme cases, the patient may actively attempt to expire during this pause (Figure 6(c)). Therefore, the minimum inspiratory time should be set below the spontaneous inspiratory time of the patient.

Expiratory trigger

The expiratory trigger sensitivity (or cycling) is the setting that allows the end of insufflation. It therefore influences the insufflation time, which should ideally correspond to the patient's inspiratory time. Premature cycling occurs when insufflation ends while the patient is still inspiring and is usually uncomfortable (Figure 7(a)).

Conversely, late cycling is observed when the insufflation time is longer than the patient's inspiratory time and is also uncomfortable for the patient (Figure 7(b)).

The expiratory trigger sensitivity is set as a percentage of the maximal inspiratory flow. Therefore,

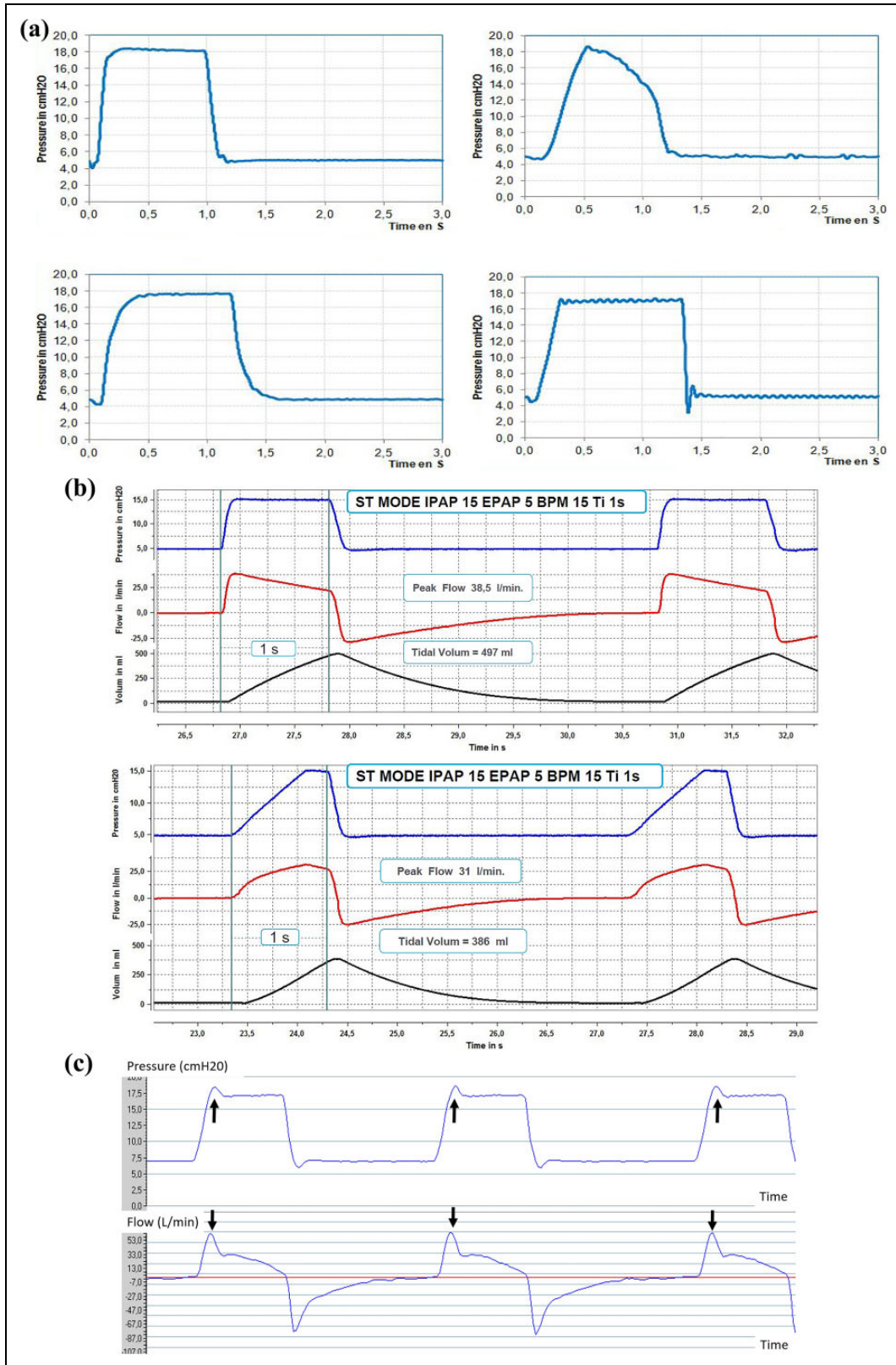


Figure 5. (a) Variations of the inspiratory pressure shape for the same EPAP and IPAP settings in four different ventilators. (b) Effect of a pressure rise time set at 100 ms (upper) and 700 ms (lower). When a long (shallow) pressure rise time is set, the IPAP of 15 cmH₂O is reached only at the end of inspiration. Inspiratory flow and tidal volume are reduced. (c) The peak in pressure and flow at the beginning of insufflation indicates that the increase in pressure (i.e. the pressure rise time) is too fast. EPAP: expiratory positive airway pressure.

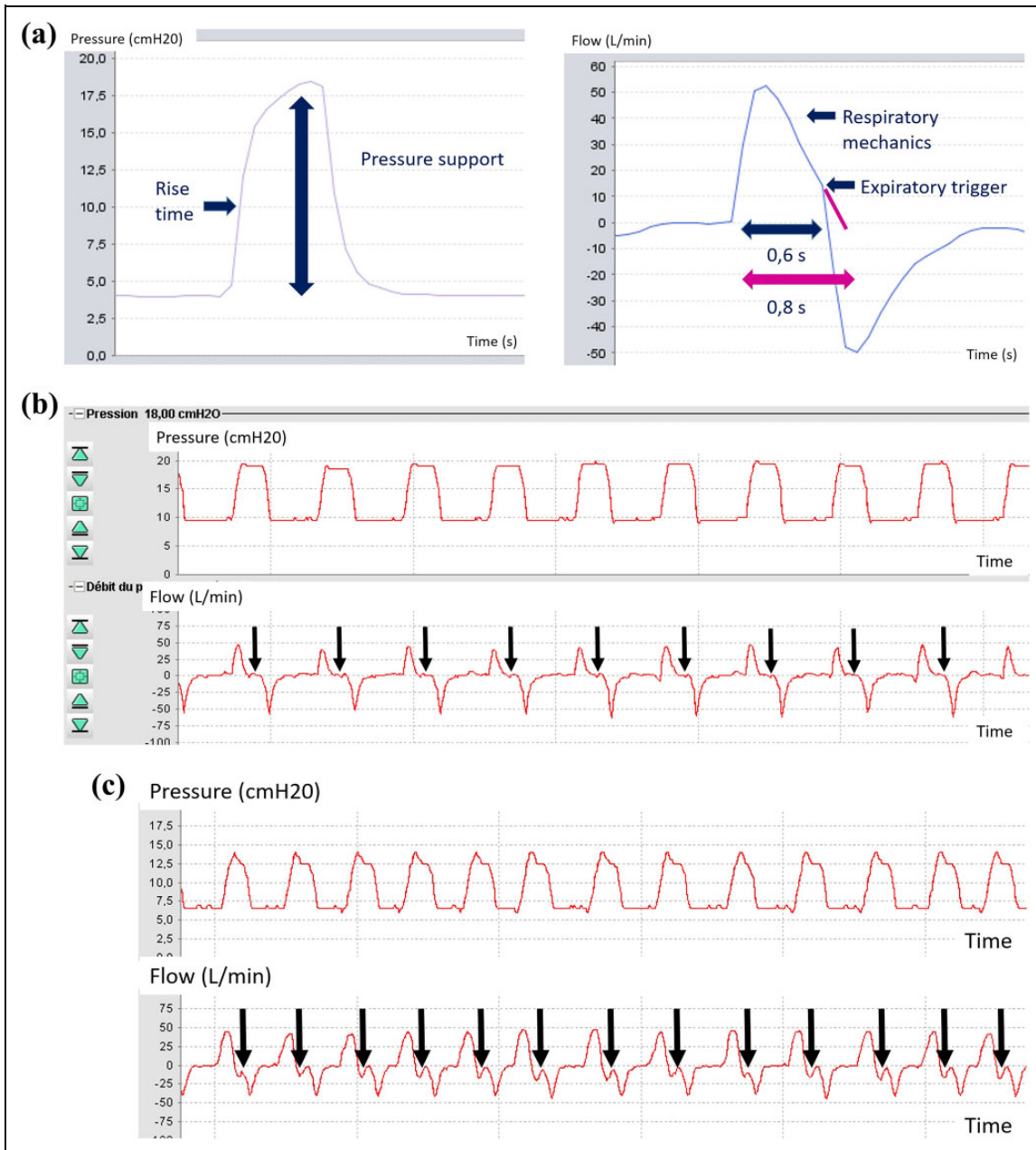


Figure 6. (a) Insufflation time depends on the pressure rise time, IPAP, expiratory trigger, and the patient's respiratory mechanics which influences the inspiratory flow shape. The maximum insufflation time is achieved when the inspiratory flow reaches the baseline (pink line and arrow). (b) The minimum inspiratory time is set higher than the insufflation time. This results in a pause at the end of the inspiration (arrows) where the flow is zero. This pause occurs at the time the patient would start expiration, resulting in asynchrony that is usually uncomfortable for the patient. (c) During the pause, the flow becomes negative (arrows), indicating the patient is making an active expiratory effort.

a low setting corresponds to a long insufflation time (Figure 7(c)).

Depending on the ventilator, the expiratory trigger sensitivity can be set as a percentage, or using a numerical scale or the levels high, medium, and low, which are defined as certain percentages. Some ventilators allow a wide setting range (from 90% to 10%

of the maximum inspiratory flow), while others only allow a narrower range (from 50% to 8%).

The shape of the inspiratory flow curve depends on the patient respiratory mechanics. In an obstructive patient, the flow decay is progressive due to the increased inspiratory resistance. In these patients, the expiratory trigger is set at between 60% and 70% to

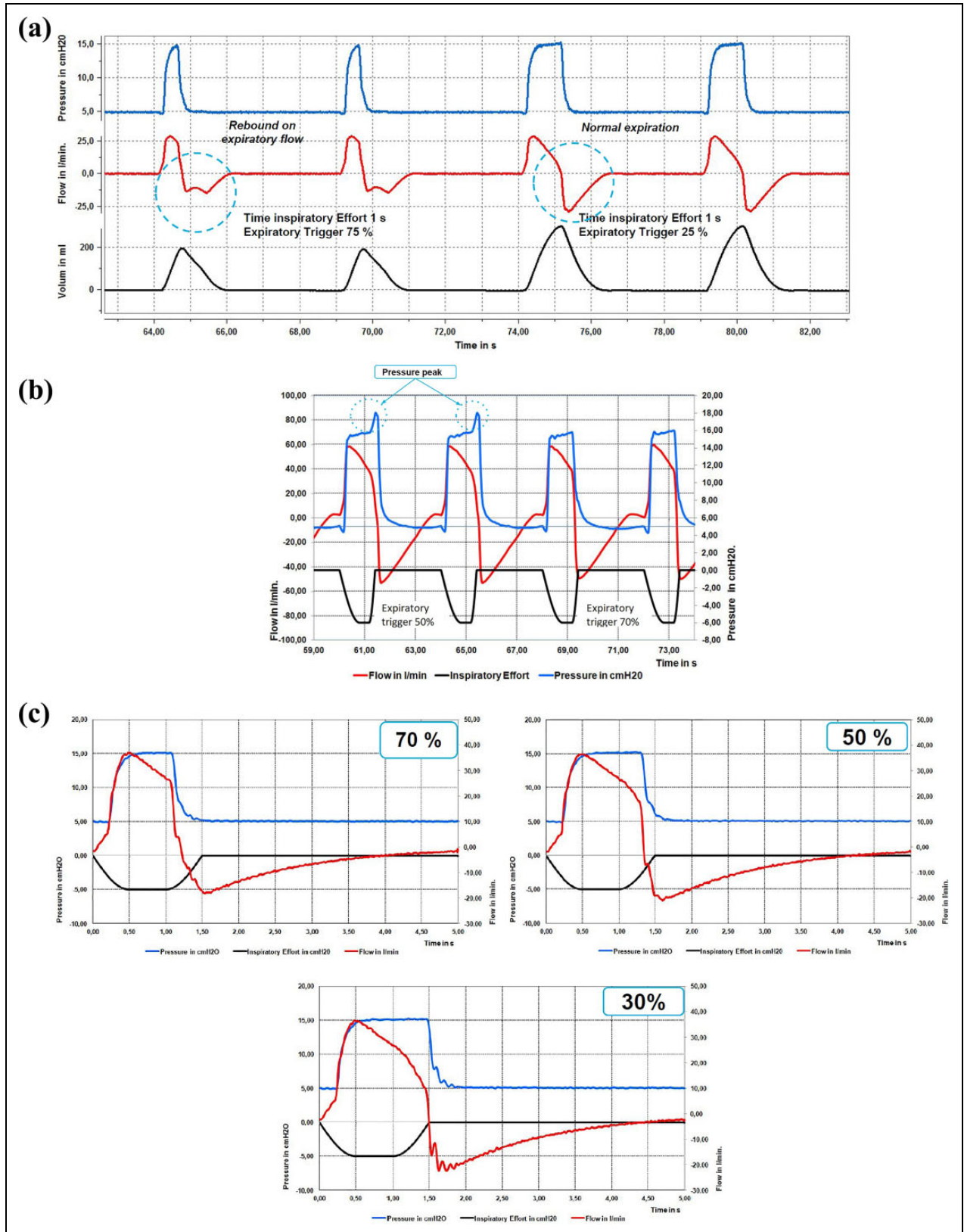


Figure 7. (a) Mechanical breath ending while the patient is still inspiring, as shown by the lower peak expiratory flow (first breath). This asynchrony disappears when the expiratory trigger setting is decreased (third breath). (b) Mechanical breath prolonged beyond the end of the patient inspiratory effort, as indicated by the pressure peak at the end of inspiration. The pressure peak disappears when the expiratory trigger setting is modified. (c) From left to right, the expiratory trigger is set at 70%, 50%, and 30% of the maximal inspiratory flow, respectively. The insufflation time increases when the expiratory trigger setting is lowered (1.1, 1.3, and 1.5 seconds, respectively).

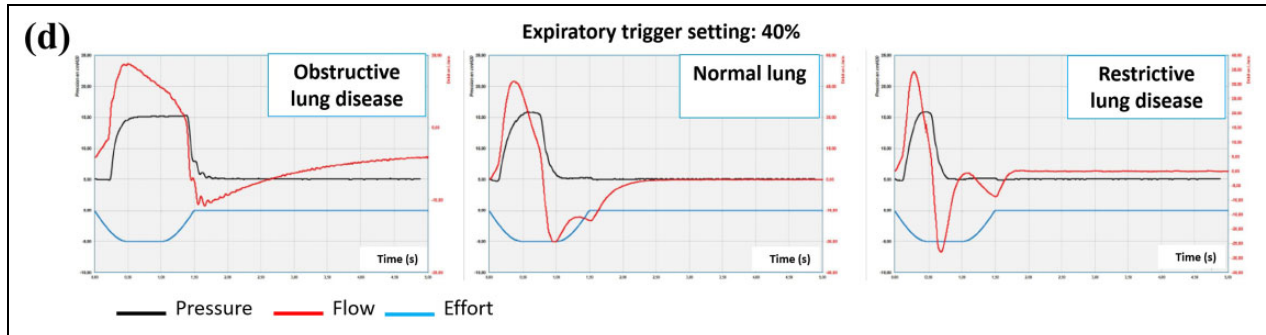


Figure 7. (continued) (d) The shape of the inspiratory flow curve depends on the patient's respiratory mechanics: an obstructive lung (left), a normal lung (middle), and a restrictive lung (right). The same expiratory trigger setting (40%) results in an insufflation time that is too long for the obstructive and too short for the restrictive lung.

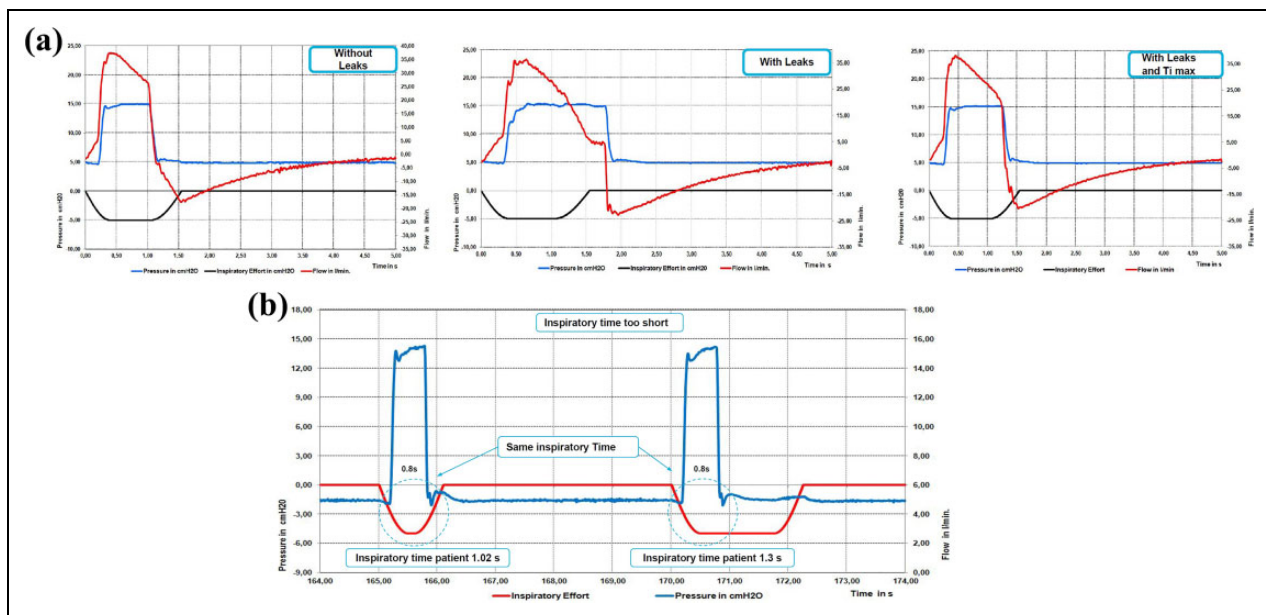


Figure 8. (a) Usually, insufflation is ended by the expiratory trigger setting (percentage of the maximal inspiratory flow; left). Unintentional leaks prolong insufflation and create cycling asynchrony (middle). Setting a maximum inspiratory time results in an adequate insufflation time despite the leaks, and thus limits the leak-related asynchrony (right). (b) The inspiratory time setting is too short. All insufflations are of equal duration, irrespective of the patient's neural time.

achieve an adequate insufflation time. Conversely, in a restrictive patient, the flow decay is rapid due to decreased compliance. In these patients, setting the expiratory trigger at 10–20% may prolong the insufflation time slightly (Figure 7(d)).

Maximum inspiratory time

In PS, cycling (end of insufflation) is based on the expiratory trigger sensitivity and determines a variable inspiratory time according to the patient inspiratory effort and respiratory mechanics. The number of

home ventilators proposes a maximum inspiratory time on patient's triggered breath in order to limit the insufflation time in the case of unintentional leaks. Without leaks, insufflation ends when the inspiratory flow reaches the threshold set by the expiratory trigger sensitivity. In the case of unintentional leaks, the inspiratory flow is maintained because the threshold is never reached and insufflation is prolonged beyond the patient's inspiratory time. This results in delayed cycling (Figure 8(a)).

The maximum inspiratory time is usually set 0.2 seconds longer than the insufflation time in the

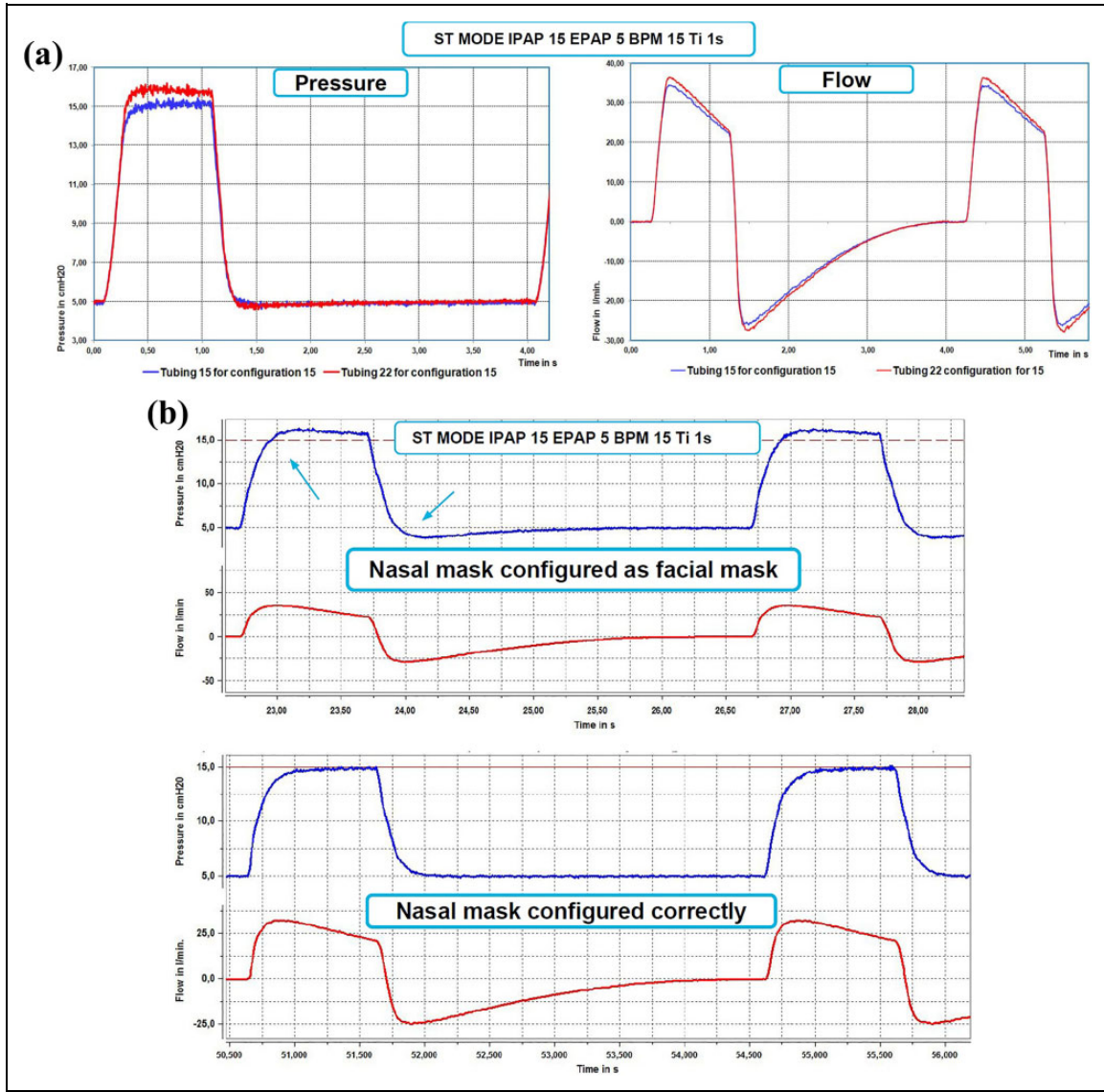


Figure 9. (a) Pressure curve measured at the mask level with a 22-mm circuit with no configuration and no calibration (red line), and correctly configured (blue line). EPAP = 5 cmH₂O; IPAP = 15 cmH₂O. If the circuit is incorrectly configured and not calibrated, the pressure delivered at the mask may be different from the set pressure. (b) Pressure and flow measured at the mask when a face mask has been configured instead of a nasal mask. The inspiratory pressure delivered at the beginning of expiration is different from the setting. EPAP: expiratory positive airway pressure.

absence of unintentional leaks, in order to limit leak-related asynchronies. If the maximum inspiratory time setting is too short, all mechanical breaths will have the same insufflation time; in effect, this is a pressure-assist mode⁷ that does not allow the patient to vary his insufflation time (Figure 8(b)).

The correct setting of the maximum inspiratory time can be assessed by analyzing unintentional leaks and the percentage of inspirations ended by the expiratory trigger. This monitoring parameter is available in some ventilators.

Configuration of the patient breathing circuit and interface

Some ventilators allow for configuration of the breathing circuit's caliber (15 or 22 mm) and the type of patient interface, as well as calibration of the circuit.

Configuration and calibration of the circuit allow the ventilator to measure and compensate for the circuit resistance, in order to ensure the patient receives the prescribed pressure at the mask (Figure 9(a)).

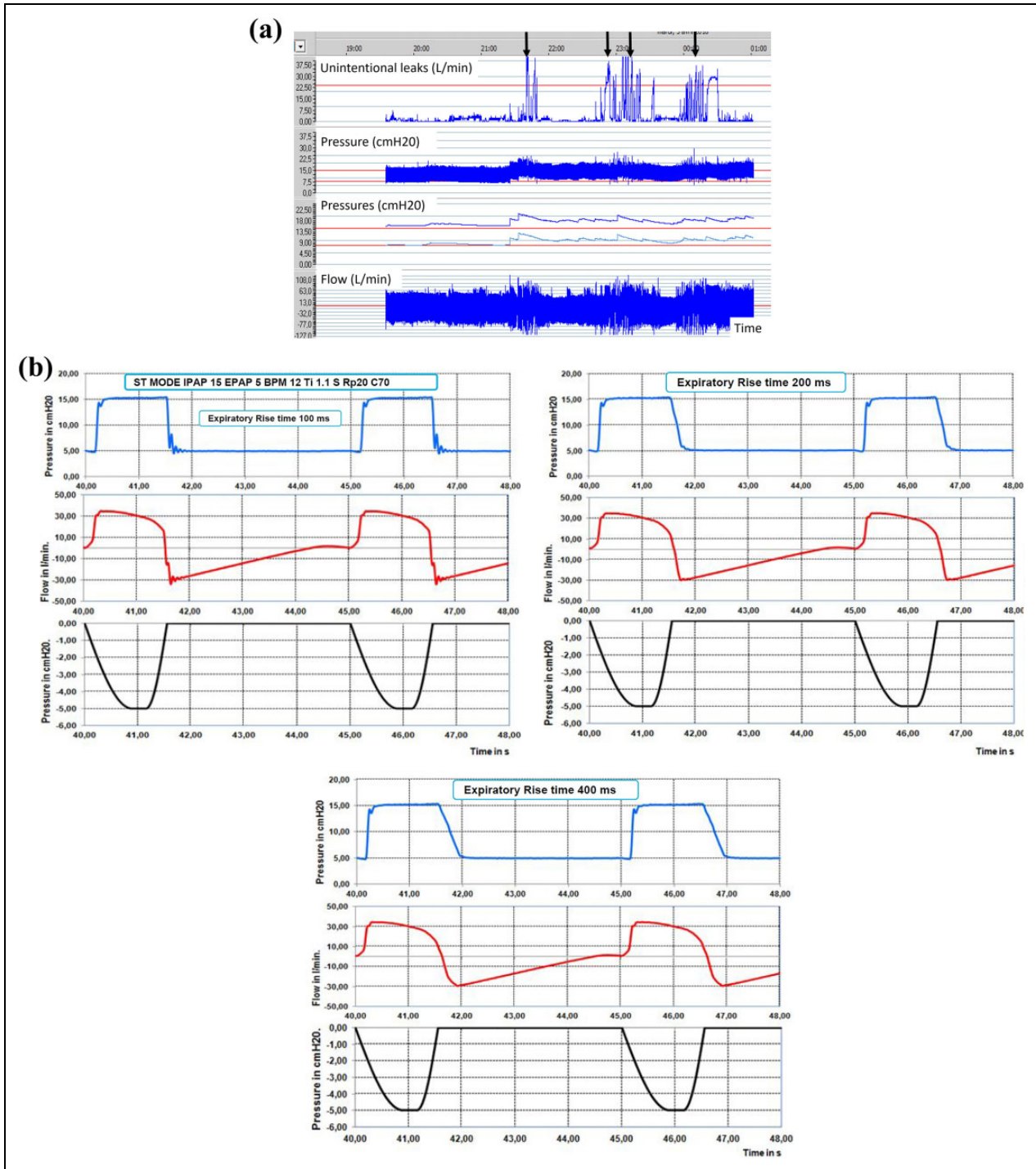


Figure 10. (a) Example of an automatic ventilatory mode that increases EPAP when an obstructive event is detected (arrows). IPAP increases to maintain the set inspiratory pressure and unintentional leaks occur. (b) The pressure decay time is set longer from top to bottom. Peaks in pressure and flow are observed when the slope is too steep. (c) Progressive decrease in PS after accidental activation of negative ramping. The tidal volume is decreased and alveolar hypoventilation might occur. (d) Ramping decrease is activated accidentally at the beginning of ventilation. IPAP and EPAP diminish progressively over 5 minutes, and the patient spends the night with EPAP = IPAP = 3 cmH₂O, resulting in a marked reduction in tidal volume. EPAP: expiratory positive airway pressure.

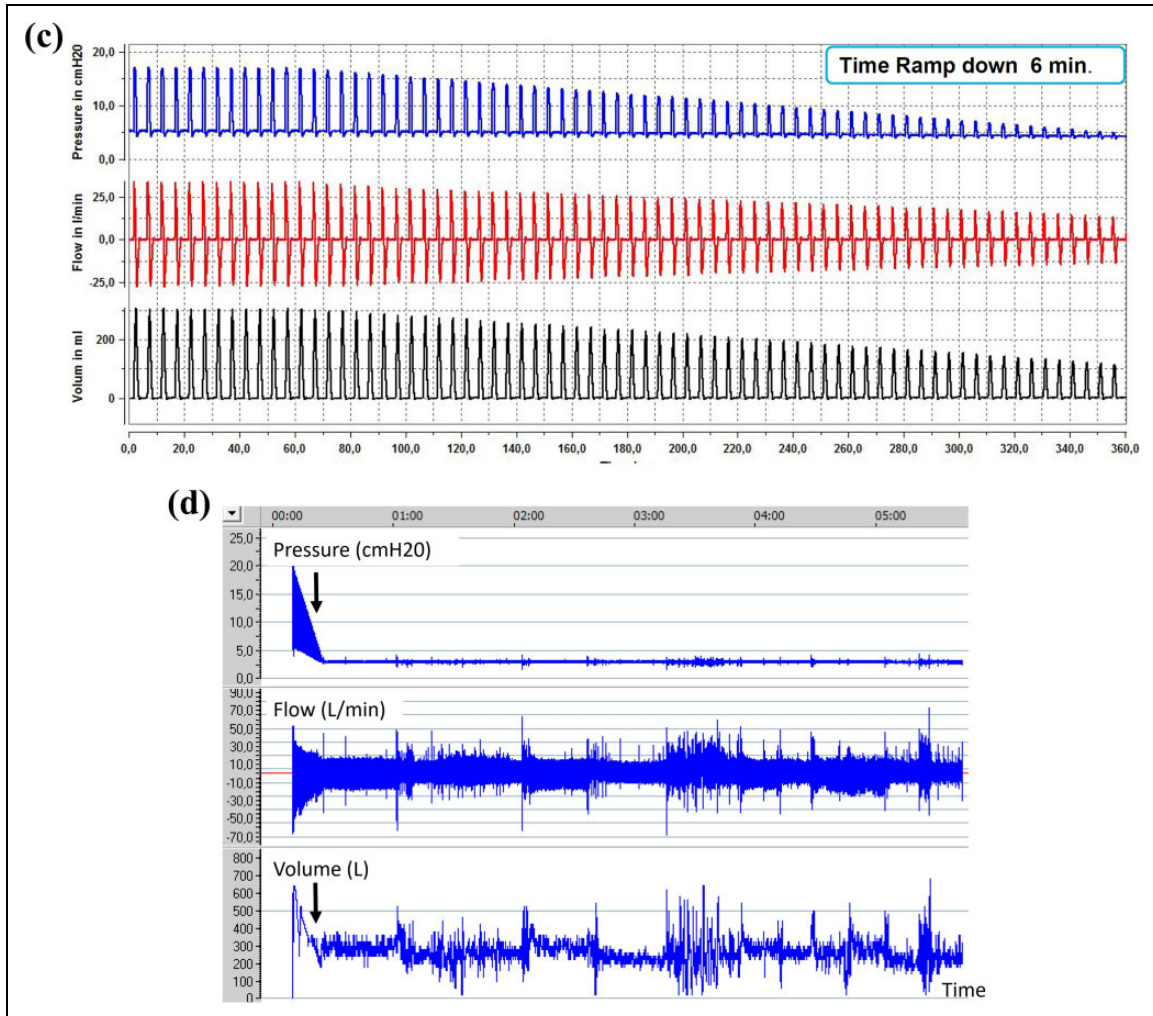


Figure 10. (continued).

Configuring the type of mask with the ventilator algorithm allows for control of the level of intentional leaks and provides a better estimate of unintentional leaks. For ventilators that adapt trigger sensitivity and pressure to unintentional leaks, leak compensation will be more effective and patient–ventilator synchrony improved (Figure 9(b)).

Automatic detection of upper airway obstructions

Some ventilators show an apnea–hypopnea index (AHI), corresponding to a partial or complete collapse of the upper airway. Each manufacturer uses a proprietary algorithm to estimate obstructive events,⁸ which explains the differences in AHI measurements depending on the ventilator. In some cases, the number of events is underestimated. As such, the risk is one of reading a low AHI in a patient presenting with numerous obstructive events, and a visual analysis of

the flow curve is therefore recommended. Obstructive events occurring at the oropharyngeal level can generally be corrected by increasing EPAP.

Other pitfalls

Automatic modes. Some ventilatory modes increase EPAP and/or IPAP when obstructive respiratory events are detected, in order to reach the set tidal volume or targeted alveolar ventilation. When the pressure increases, the risk of unintentional leaks increases if the mask has not been fitted to the patient accordingly. Leaks can result in asynchrony, and even patient awakening (Figure 10(a)).

Pressure decay time. Some ventilators allow for the setting of the pressure decay time (expiratory slope), which reflects the time needed for the airway pressure to decrease from IPAP to EPAP. A short pressure

decay time can cause patient discomfort, especially in restrictive patients. Conversely, a long pressure decay time prolongs the mechanical breath, which can worsen dynamic hyperinflation and interfere with the beginning of the next inspiration (Figure 10(b)).

Ramped increase of pressure settings. In some ventilators, a progressive increase of EPAP and PS can be set for the first few minutes of ventilation. If the patient falls asleep during this period, ventilation may be temporarily ineffective and uncomfortable. Low EPAP can result in obstructive events and patient awakening, while low PS can result in alveolar hypoventilation during the time the patient is asleep.⁹ This phenomenon occurs mostly in patients presenting with orthopnea, who require effective PS as soon as they lie down.

Ramped decrease of pressure settings. Deventilation syndrome is characterized by dyspnea when removing the mask.¹⁰ Causes of this discomfort are multiple, and a progressive decrease in ventilatory support can sometimes reduce this discomfort. Thus, EPAP and PS are lowered progressively during a set time. If the patient falls asleep again or remains lying down, upper airway obstructive events might occur because EPAP decreases, or alveolar hypoventilation because PS decreases (Figure 10(c)). Moreover, some patients accidentally activate the ramp decrease mode when starting their ventilator, which carries the risk of low pressure being delivered throughout the night (Figure 10(d)).

Conclusion

All the settings on home ventilators may impact on the patient. Health professionals and technicians involved with ventilator settings should understand the effects resulting from each setting and the potential harm associated with settings that are not appropriate for the individual patient.

Authors' contributions

JMA designed the review, searched the literature, selected the patient data, and prepared the manuscript. CPT, BC, and JT performed the bench simulations and revised the manuscript. AG revised the manuscript.


Declaration of conflicting interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding

The author(s) received no financial support for the research, authorship, and/or publication of this article.

ORCID iD

Jean-Michel Arnal  <https://orcid.org/0000-0003-3289-366X>

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