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Review

New modes in non-invasive ventilation

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EDUCATIONAL AIMS

This paper serves:

- To discuss the most recent advances in ventilatory modes and features available to provide non-invasive ventilation.
- To provide a comprehensive analysis of new modes and features.
- To illustrate technical aspects and modes of operation and settings of these new features, as well as their benefits and limits.
- To provide an exhaustive review of published data,
- To illustrate the potential place of these devices in clinical practice.

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SUMMARY

Non-invasive ventilation is useful to treat some forms of respiratory failure. Hence, the number of patients receiving this treatment is steadily increasing. Considerable conceptual and technical progress has been made in recent years by manufacturers concerning this technique. This includes new features committed to improve its effectiveness as well as patient-ventilator interactions. The goal of this review is to deal with latest advances in ventilatory modes and features available for non-invasive ventilation. We present a comprehensive analysis of new modes of ventilator assistance committed to treat respiratory failure (hybrid modes) and central and complex sleep apnea (adaptive servo ventilation), and of new modes of triggering and cycling (neurally adjusted ventilatory assist). Technical aspects, modes of operation and settings of these new features as well as an exhaustive review of published data, their benefits and limits, and the potential place of these devices in clinical practice, are discussed.

Since the first studies in the early 1990s showing the usefulness of non-invasive ventilation (NIV) in the management of some forms of respiratory failure [1], the number of patients receiving this treatment is steadily increasing. This is explained by a growing number of indications in which the effectiveness of NIV has been proved, but also because the technique of application has been greatly refined. Most important advances include the development of interfaces able to deal with different facial morphologies, the availability of powerful built-in monitoring systems and finally some innovative developments in terms of ventilatory modes and features. The goal of this paper is to deal with recent advances in ventilatory modes and features.

For that, we will successively discuss the following topics:

- New modes of ventilatory assistance
- committed to treat respiratory failure: hybrid modes

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- committed to treat central and complex sleep apnea: adaptive servo ventilation (ASV)
- A new mode of triggering and cycling: neurally adjusted ventilatory assist (NAVA)

NEW MODES OF VENTILATORY ASSISTANCE

Modes committed to treat respiratory failure

Most initial studies concerning NIV used volume-targeted modes (VTM) [1]. However, pressure-targeted modes (PTM) surpassed VTM at the end of the '1990s. Single circuit pressure-targeted ventilators provided with a calibrated leak have become the most commonly used devices nowadays. These devices cycle between an inspiratory positive airway pressure (IPAP) and an expiratory positive airway pressure (EPAP). Additionally, a backup respiratory rate (BURR) can be added. These settings need to be independently titrated on an individual basis. EPAP needs to be titrated to stabilise the upper airway, whereas IPAP and BURR must be adjusted to deliver appropriate ventilatory support.

Recently, manufacturers proposed innovative modes supposed to facilitate NIV adjustments. These modes, also called "hybrid modes," use intelligent algorithms to automatically adjust one or more settings to achieve predefined targets. Table 1 shows the characteristics of these modes.

The first of these modes, target volume with variable pressure support, combines features of pressure and volume ventilation. In VTM, the ventilator delivers a fixed volume during a given time span. Its advantage is the strict delivery of the preset volume. Its disadvantages are that that the effective volume falls with increasing leaks and that this mode is not able to take into account the patients' varying requirements. In PTM, airflow is adjusted to generate a constant positive pressure during a given time span. The volume delivered depends on the interaction between the preset pressure, the inspiratory effort and the respiratory mechanics. PTM improves synchronisation since flow can vary on a breath-by-breath basis. Another advantage is its ability to compensate for leaks. Moreover, PTM generates lower airway pressures for a given tidal volume (Vt), allowing less mask tightness. A limitation of PTM is that it cannot guarantee a Vt, which may lead to insufficient ventilation. Hybrid modes, also called volume targeting pressure ventilation (VTPV), combine characteristics of both modes and are supposed to overcome these limitations. These modes provide a predetermined target volume (TV) while maintaining the physiological benefits of PTM. The ventilator measures or estimates each single expired volume and automatically adjusts inspiratory pressure within a predetermined range to ensure a stable TV. Ventilators provide VTPV either with a single-limb circuit with an intentional leak or with single or double circuit-limb with an expiratory valve. Moreover, some new devices give the possibility to also set a variable BURR. They automatically adjust both IPAP and BURR level (in a predefined range) to achieve a target ventilation [2]. These devices also include a "learn" mode in which the ventilator "copies" the patient's breathing pattern and determines target ventilation. Finally, the newest devices combine VTPV with an auto-adjusted EPAP level committed to maintain airway patency. Additionally, they provide an "automatic" BURR. By automatically adjusting IPAP, EPAP and BURR, these devices are featured as being able to provide a "full automatic" mode. Examples of different settings automatically adjusted by "intelligent" algorithms may be seen in Figure 1.

Theoretical advantages

The first advantage of these newer modes is their ability to ensure a relatively constant Vt whatever the changes in respiratory mechanics while providing the physiologic benefits of PTM [3]. The delivery of an appropriate Vt is crucial in critically ill patients requiring mechanical ventilation. VTPV is able to fulfill this goal by generating lower airway pressures than VTM, with improved comfort and synchronization. Initial studies evaluating these modes in intubated patients suggested a reduction in muscle workload and an improvement in patient-ventilator synchrony [4]. However, Battisti was unable to show any beneficial effect of VTPV as compared to PTM in acutely ill patients treated with NIV [3].

When applying NIV in patients with chronic respiratory failure, NIV is applied mainly during the night. Sleep induces ventilatory changes in the respiratory system that modify ventilatory control, lung mechanics, respiratory muscle recruitment and upper airway patency. In healthy subjects, minute ventilation falls 15-20% from wakefulness to sleep [5]. This phenomenon is further exaggerated during the different sleep stages, in particular during rapid eye movement sleep (REM) sleep. In addition, changes in respiratory impedance may be observed during changes in body position, in particular in overweight patients, which may lead to a fall in Vt [6,7]. Fixed settings do not allow adaptation to these physiological changes. A second theoretical advantage of VTPV is its ability to respond to changes in respiratory mechanics, ensuring relatively constant ventilation throughout the night. This is accomplished by increasing the level of pressure support (but also EPAP and/or BURR when possible) when needed, and by reducing it when the support is excessive. By preventing over- or under-ventilation, these modes are supposed to ensure more stable ventilation with a lower mean inspiratory pressure. Therefore, VTPV may be beneficial in patients unable to tolerate high IPAP levels [8].

Table 1
Summary of different devices providing hybrid modes and their characteristics

	Characteristics	Brands
Target volume with variable pressure support	Automatically adjust IPAP level (in a predefined pressure rang) to achieve a stable predetermined target Vt	AVAPS™ (A40™, Trilogy 100™ and 200™ *Philips*) Target volume pressure support (Vivo™ 50 and 60, *Breas*; Ventilogic™, *Weinmann*, Monnal T50™, *ALMS*; Elysee™ 150, 250, 350, *Resmed*)
Target volume with both variable pressure support and back-up respiratory rate	Automatically adjust both IPAP and BURR level (in a predefined pressure rang) to achieve a stable target predetermined minute ventilation	IVAPS™ (VPAP S9™, Stellar™ 100 and 150, Lumis™ Astral™, *Resmed*)
Target volume with variable pressure support, back-up respiratory rate and autoadjusted EPAP	Automatically adjust both IPAP (in a predefined pressure range) to achieve a stable target Vt, and EPAP level (in a predefined pressure rang) to maintain airway patency Additionally, provides "automatic" BURR to match the awake spontaneous patient respiratory rate	Avaps AE™ (A40™, Trilogy™ 100 and 200 *Philips*)

IPAP: inspiratory airway positive pressure, EPAP: expiratory airway positive pressure, BURR: backup respiratory rate. AVAPS: Average volume assured pressure support. IVAPS: Intelligent volume assured pressure support.