33

Ventilatory Modes: Neurally Adjusted Ventilatory Assist (NAVA)/Pressure Support Ventilation/Bi-PAP Mode/Continuous Positive Airway Pressure

Carmine Iacovazzo, Claudia Veropalumbo, Annachiara Marra, Maria Vargas, and Giuseppe Servillo

Abstract

The purpose of this chapter is to describe the following ventilatory modes: neurally adjusted ventilatory assist (NAVA), pressure support ventilation, bi-PAP mode, and continuous positive airway pressure.

The aim is to analyze their main features, focusing on their indications, contraindications, and fields of application.

Keywords

Assisted ventilation · Neurally adjusted ventilatory assist (NAVA) · Pressure support ventilation (PSV) · BIPAP mode · Continuous positive airway pressure (CPAP)

Abbreviations

ARDS	Acute respiratory distress syndrome
BIPAP	Bilevel positive airway pressure
CPAP	Continuous positive airway pressure
CPE	Cardiogenic pulmonary edema
EAdi	Electrical activity of the diaphragm
FRC	Functional residual capacity
ICU	Intensive care unit
IMV	Intermittent mandatory ventilation
NAVA	Neurally adjusted ventilatory assist
OSA	Obstructive sleep apnea
PCV	Pressure Controlled Ventilation
PEEP	Positive end-expiratory pressure
PEEPH	PEEP high
PEEPL	PEEP low
PSV	Pressure support ventilation
WOB	Work of breathing

33.1 Introduction

The listed ventilatory modes need to be acknowledged from the clinicians who wish to refine their practice in the management of invasive and non-invasive ventilation.

C. Iacovazzo (✉) · C. Veropalumbo · A. Marra
M. Vargas · G. Servillo
Department of Neuroscience and Reproductive and Odontostomatological Sciences, Intensive Care Unit, University of Naples Federico II, Naples, Italy
e-mail: giuseppe.servillo@unina.it

A. M. Esquinas (ed.), *Pulmonary Function Measurement in Noninvasive Ventilatory Support*,
https://doi.org/10.1007/978-3-030-76197-4_33

Neurally adjusted ventilatory assist is a proportional ventilatory mode that uses the electrical activity of the diaphragm to offer a better patient-ventilator interaction, with a fine proportion to the patient effort.

Pressure support ventilation is a form of assisted ventilation in which the ventilator provides a constant pressure during inspiration once the patient has made an inspiratory effort.

Continuous positive airway pressure is a spontaneous breathing mode that take place at a certain level of positive pressure maintained throughout the whole ventilatory cycle, while in bilevel positive airway pressure the circuit switches between a high and a low airway pressure level.

33.2 Discussion and Analysis of the Main Topic

33.2.1 Neurally Adjusted Ventilatory Assist

Neurally adjusted ventilatory assist (NAVA) is a proportional ventilatory mode that uses the electrical activity of the diaphragm (EAdi) to offer ventilatory assistance in proportion to the patient's effort, in contrast to all other modes of ventilation, which adopt conventional pneumatic signals (flow, volume, and airway pressure). The diaphragm's electrical activity is considered the best available signal to assess the respiratory drive, to trigger on and cycle off the mechanical assistance, and to regulate its amount [1].

The motivation that led to the development of NAVA mode is essentially the necessity to reduce the occurrence of patient-ventilator asynchrony in patients receiving mechanical ventilation. It has been estimated that 25% of mechanically ventilated patients experience asynchrony events, increasing the length of ventilatory support [2, 3].

When a patient is not synchronized to the ventilator, this can potentially damage the diaphragm, resulting in a loss of force-generating capacity [4]. Moreover, when asynchrony is present, it is common practice in ICU settings to sedate the patient, to further reduce diaphragm activity.

In the NAVA mode, the inspiratory signal is detected using diaphragmatic electromyography through the Edi catheter, which is basically a nasogastric tube with miniaturized electrodes near the distal tip. The Edi catheter is inserted into the esophagus, and the electrodes are positioned at a level that is adjacent to the diaphragm. The values are reported in microvolts (μV) (Fig. 33.1).

Triggering of a breath occurs when a deflection greater than the set threshold (mostly 0.5 μV) occurs in the Edi waveform [5].

Delivery of pressure during inspiration is based on the strength of the Edi signal and the level of NAVA support ("NAVA level"), set by the operator together with the PEEP level. The NAVA level determines the amount of pressure delivered by the ventilator in proportion to the Edi. An estimated peak pressure that will be delivered during the breath is based on the following equation: [6]

$$\text{NAVA P peak} = \text{NAVA level} \times (\text{Edi peak} - \text{Edi min}) + \text{PEEP}$$

This means that the final mechanical assist delivered by the ventilator in NAVA will be proportional to the neural output as measured by the Edi signal: in this way, the support delivered by the ventilator is constantly under the control of the patient's respiratory center and corresponds, moment by moment and breath to breath, to the patient's ventilatory request.

Furthermore, the clinician has to set two different backup modes: the first one is a pressure support ventilation (PSV) that is activated in case the Edi signal is lost (e.g., displacement or deterioration of the catheter); the second one is a pressure controlled ventilation (PCV) backup mode that switches on in case of apnea (e.g., for excessive sedation, curarization) [6].

NAVA mode is specifically for use in patients who are capable of spontaneous breathing, that is, patients who have an Edi signal. Patients with the following conditions are excluded from the use of the NAVA mode:

Fig. 33.1 Maquet Critical Care, NAVA monitor [6]

- Heavily sedated and/or paralyzed.
- Damaged brain center.
- Absence of phrenic nerve activity.
- Diseases that prohibit neuromuscular transmission.
- Presence of apnea.

Further limitations are contraindications to Edi catheter placement, such as recent gastric or esophageal surgery and the presence of esophageal varicose veins.

Compared to other modes, NAVA shows the achievement of a better patient-ventilator interaction in terms of number of asynchrony events, but the ventilator-related complications (e.g., barotrauma, VAP), ICU mortality, ICU stay time, and hospital stay time are not significantly reduced, while the duration of ventilation can be even longer when NAVA is compared to PSV [7].

In conclusion, there is no direct evidence from human clinical trials that better patient-ventilator synchrony with NAVA results in better outcomes, but it remains a useful, promising tool.

33.2.2 Pressure Support Ventilation

Pressure support ventilation (PSV) is a form of assisted ventilation in which the ventilator provides a constant pressure during inspiration once it senses that the patient has made an inspiratory effort. Specifically, this ventilation mode is:

- *Patient-triggered*: Inspiration begins if a negative airway opening pressure (pressure-triggering) or a drop in flow (flow-triggering) is detected by the ventilator, of which the clinician has to set the sensitivity; this setting determines the patient's effort (in terms of pressure or flow change) that is required to trigger the ventilator.
- *Pressure-limited*: The ventilator pushes a volume of gas into the circuit, which leads to a rise in pressure until it reaches a certain value, set by the clinician.
- *Flow-cycled*: The ventilator switches into the expiratory phase once the flow has decreased to a predetermined value during inspiration, usually a certain percentage of the peak inspiratory flow.

While the operator sets the sensitivity level, inspiratory pressure (along with PEEP, if needed), and flow cycle criteria, the patient establishes the rate, inspiratory flow, and inspiratory time. Tidal volume is the result of pressure gradient (ΔP = Set pressure − EEP), patient effort, respiratory system compliance, and resistance.

It is important to recognize that, as a patient-triggered mode, pressure support should be used exclusively in patients with a reliable, steady spontaneous respiratory pattern, even though more recent ventilators provide backup ventilation (volume-controlled or pressure-controlled mandatory ventilation) if apnea occurs during PSV.

The role of PSV, alone or combined with other modes, is substantially to overcome ventilator system resistance and reduce work of breathing (WOB) in spontaneous breaths; PSV is the most commonly used mode during weaning from mechanical ventilation [8, 9].

33.2.3 Continuous Positive Airway Pressure

Continuous positive airway pressure (CPAP) is a spontaneous breathing mode that takes place at an operator-determined level of positive pressure, which is maintained throughout the whole ventilatory cycle. No mandatory breaths are delivered: CPAP provides patient-triggered and patient-cycled breaths.

CPAP can be provided as a standalone mode or in combination with other modes, like PSV or even intermittent mandatory ventilation (IMV). It can be applied by mask or via a cuffed endotracheal or tracheostomy tube; it may be provided through the ventilator or even using a high-flow gas source and a PEEP valve. Portable CPAP machines have also been developed for non-acute care setting and even in-home use.

With CPAP, the airway pressure is elevated during inspiration and expiration. In this way CPAP may both reduce the inspiratory WOB during spontaneous breathing, improve oxygenation, prevent alveolar collapse and atelectasis, and increase FRC and the lung surface area for gas exchange.

CPAP setting requires careful hemodynamic monitoring, as the augmentation of intrathoracic pressure decreases venous return, cardiac output, and blood pressure.

The CPAP mode is most commonly used to evaluate whether the patient can be weaned from the ventilator in spontaneous breathing trials but is also applied with the aim of improving gas exchange in patients with respiratory failure or preventing postoperative atelectasis [10]. Moreover, CPAP is considered as a first-line strategy in the management of patients with cardiogenic pulmonary edema (CPE), as it decreases the systemic venous return and left ventricle filling pressure, limiting pulmonary edema; CPAP has been proven to decrease the need for endotracheal intubation and hospital mortality in these patients [11].

Moreover, very high levels of CPAP for brief periods of time (e.g., 40 cmH_2O for 40 s) have been suggested as a part of recruitment maneuvers to open collapsed alveoli in selected patients with ARDS.

CPAP could be also used both in hospital and home settings, and in the treatment of obstructive sleep apnea (OSA): noninvasive CPAP delivered by oral or nasal mask at pressures in the range of 4–20 cmH_2O forces air into the upper airways to prevent soft tissues from collapsing, airway obstruction, and apnea [12]. If a CPAP of 20 cmH_2O fails to adequately control OSA, BIPAP may be employed.

33.2.4 Bilevel Positive Airway Pressure

Bilevel positive airway pressure (BIPAP) is another form of pressure ventilation in which the circuit switches between a high and a low airway pressure level in an adjustable time sequence.

The main operator controls are:

- FiO_2.
- PEEPH: High pressure level, set to achieve an inspiratory pressure of 5–15 cmH_2O above PEEPL and titrated to achieve adequate ventilation and reduced work of breathing.
- PEEPL: Low pressure level, initially set in the range of 5–10 cmH_2O and titrated to achieve desirable oxygenation, minimizing patient discomfort.
- TH: Length of time at PEEPH.
- TL: Length of time at PEEPL.

– Pressure support: Additional ventilator support can also be added in the form of PS at both pressure levels to augment the patient effort and can be left at 0 if no additional pressure is needed.

Inspiration is typically patient triggered; ventilation can be flow or time cycled. It is commonly used as a NIV mode through an oral or nasal mask, but it is often applied to intubated or tracheostomized patients.

Even though inspiration is patient triggered, the BIPAP mode cannot be considered as a pure assisted ventilation, since the transition between PEEPL and PEEPH inevitably generates a mandatory inspiration, similar to a PCV. During the mandatory inspiration, in opposition to PCV in which the expiratory valve is closed, the patient is able to exhale anytime. Similarly, when the pressure level changes from PEEPL to PEEPH, it provokes an expiration.

During the phases with no change in pressure level, technically the patient is essentially receiving a CPAP, with an established pressure value, high or low.

Conclusively BIPAP is a combination of a pressure-controlled ventilation and an assisted ventilation and, thanks to its diversified characteristics and setting chances, its fields of application are wide both in ICUs and non-critical settings for the treatment of acute or chronic respiratory failure linked to difference etiologies [13].

33.3 Conclusion Discussion

The ventilatory modes debated in this chapter offer a wide range of application in different clinical scenarios. Even if there is no direct evidence that better patient-ventilator synchrony with NAVA results in better outcomes, it remains a useful and fascinating tool. Instead PSV has a clear and established role in reducing WOB in spontaneous breaths, being frequently chosen for trials of weaning from mechanical ventilation, similarly to CPAP. Besides CPAP improves oxygenation, prevents alveolar collapse and atelectasis, and increases FRC and the lung surface area for gas exchange; furthermore CPAP is considered a first-line strategy in the management of patients with CPE, being able to decrease the need for endotracheal intubation and hospital mortality in these patients.

Key Major Recommendations

- If asynchrony occurs, NAVA is an advantageous tool to provide a better ventilator-patient interaction.
- PSV can be properly used in trials of weaning from mandatory ventilation.
- CPAP should be considered in the first place in CPE or OSA patients.
- If CPAP fails in case of OSA, BIPAP should be contemplated.

References

1. Lourenço RV, Cherniack NS, Malm JR, Fishman AP. Nervous output from the respiratory center during obstructed breathing. J Appl Physiol. 1996;21:527–33.
2. deWit M, Miller KB, Green KA, et al. Ineffective triggering predicts increased duration of mechanical ventilation. Crit Care Med. 2009;37:2740–5.
3. Thille AW, Rodriguez P, Cabello B, et al. Patient-ventilator asynchrony during assisted mechanical ventilation. Intensive Care Med. 2006;32:1515–22.
4. Levin S, Nguyen T, Taylor N, et al. Rapid disuse atrophy of diaphragm fibers in mechanically ventilated humans. N Engl J Med. 2008;58:1327–35.
5. Jorens WV, Philippe G. Neurally adjusted ventilatory assist: a ventilation tool or a ventilation toy? Respir Care. 2011;56:327–35.
6. Education, Servo. NAVA tutorial. Maquet Critical Care.
7. Chen C, Wen T, Liao W. Neurally adjusted ventilatory assist versus pressure support ventilation in patient-ventilator interaction and clinical outcomes: a meta-analysis of clinical trials. Ann Trans Med. 2019;16
8. Esteban A, Alia I, Ibañez J, et al. Modes of mechanical ventilation and weaning: A National Survey of Spanish Hospitals. Clin Invest Crit Care.
9. Botha J, Green C, Carney I, Haji K, Gupta S, Tiruvoipati R. Proportional assist ventilation versus pressure support ventilation in weaning ventilation: a pilot randomised controlled trial. Crit Care Resusc. 2018;20(1):33–40.
10. Ireland CJ, Chapman TM, Mathew SF, Herbison GP, Zacharias M. Continuous positive airway pressure (CPAP) during the postoperative period for prevention of postoperative morbidity and mortality fol-

lowing major abdominal surgery. Cochrane Database Syst Rev. 2014;

11. Bello G, De Santis P, Antonelli M. Non-invasive ventilation in cardiogenic pulmonary edema. Ann Transl Med. 2018;6
12. Kushida CA, Chediak A, Berry RB, Brown LK, Gozal D, Iber C, Parthasarathy S, Quan SF, Rowley JA. Positive Airway Pressure Titration Task Force and Medicine. Clinical guidelines for the manual titration of positive airway pressure in patients with obstructive sleep apnea. American Academy of Sleep. J Clin Sleep Med. 2008;4:157–71.
13. Paula G. David-João, Murilo H. Guedes, Álvaro Réa-Neto, Viviane B. de Oliveira Chaiben, Cristina P. Baena, Noninvasive ventilation in acute hypoxemic respiratory failure: a systematic review and meta-analysis. J Crit Care 2019;49:84–91.