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LASTING LEGACY IN INTENSIVE CARE

Helmet noninvasive support in hypoxemic respiratory failure

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Noninvasive support techniques can improve hypoxemia in respiratory failure and acute respiratory distress syndrome (ARDS) and may help avoid endotracheal intubation. However, patients who fail noninvasive support are burdened by worse clinical outcome. This possibly occurs due to delays in endotracheal intubation with progression of lung injury caused by the prolonged exposure of injured lungs to high inspiratory effort combined to ventilatory heterogeneities [1, 2].

High-flow nasal oxygen is currently recommended as first-line strategy to treat hypoxemic patients, due to its ease of use, enhanced comfort, and improvement of clinical outcomes [3, 4].

Recently, there has been renewed interest in the use of noninvasive ventilation (NIV) and continuous positive-airway pressure (CPAP) delivered through the helmet interface. This comes from a deeper understanding of the physiology of spontaneous breathing during lung injury, and the possible beneficial effects of helmet specific settings, that relieve muscle workload, favor homogeneous ventilation, possibly mitigating the risk of self-inflicted lung injury [5].

Set-up

The helmet is a transparent hood that covers the entire head of the patient, is sealed through a soft collar around the neck that avoids air leaks once the device is pressurized, and is further secured through arm straps (Fig. 1). In contrast to facemask NIV and CPAP, skin ulcers are seldom observed, and the interface is well tolerated for long-term uninterrupted treatments. Furthermore, minimal air leaks permit the successful application of high positive end-expiratory pressure (PEEP) with good comfort [6].

The helmet can be used to deliver NIV and CPAP. For NIV, patients are connected to a mechanical ventilator through a bi-tube circuit, and the ventilator is set in the pressure support mode (PEEP 10–14 cmH_2O, PS 12–16 cmH_2O, flow trigger 2 L/min, fastest pressurization time, cycling off criteria 10–40% of the maximum inspiratory flow, maximum inspiratory time 1–1.2 s) [6, 7]. For CPAP, a high-flow generator (turbine, air/oxygen blender or venturi system) is connected to the interface through a single tube and generates a flow of at least 50 L/min; adequacy of the delivered flow prevents decreases in system pressure during inspiration and facilitates CO_2 washout. PEEP ranging between 10 and 14 cmH_2O is produced by a valve placed on the exhalation ports of the interface [8].

Gas heating and humidification through heated humidifiers could be advisable during CPAP when gas flow (> 35 L/min) and FiO_2 (> 60%) are high, especially if an air/oxygen blender is used [9]. Lowering humidification chamber temperature may limit water condensation in the interface, in case of discomfort. During NIV, no external system for heating and humidification is needed, as the interface itself acts as a mixing chamber, enabling adequate conditioning of inhaled gasses [10].

Physiology

The most relevant feature of the helmet interface is the possibility to apply higher levels of PEEP in spontaneously breathing patients for prolonged periods of time. High PEEP during spontaneous breathing exerts relevant physiological effects which include: (1) alveolar recruitment, improving hypoxemia and relieving dyspnea,

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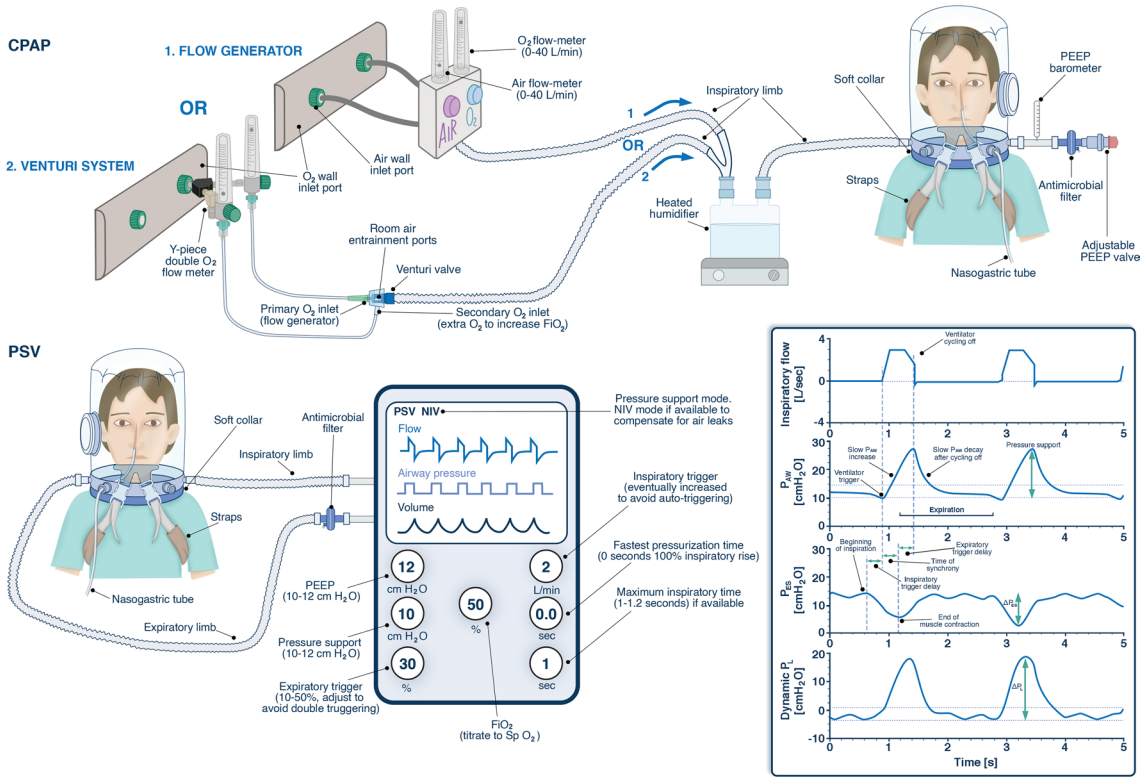

Fig. 1 Top: Circuit set-up for helmet CPAP, using a high-flow generator or a Venturi system. Bottom: Circuit set-up for helmet NIV in the pressure support mode, using a ventilator. In the lower right box, the characteristic pattern of patient-ventilator de-synchronization during helmet NIV is shown; these are representative tracings of inspiratory flow, airway pressure (P_{AW}), esophageal pressure (P_{ES}) and dynamic transpulmonary pressure (P_L, calculated as $P_{AW}-P_{ES}$) during helmet pressure support ventilation in a hypoxemic patient. Inspiratory and expiratory trigger delays and the short time of synchrony are displayed together with the slow increase and decay of airway pressure due to the high interface compliance (slopes of the P_{AW} vs. time tracing). This de-synchronization makes the inspiratory effort (ΔP_{ES}) and ventilator assistance (Pressure support) not fully synchronous, avoiding positive dumps in the transpulmonary pressure during inspiration (ΔP_L). Moreover, due to cycling off delay and the slow decay in pressure after cycling off, the mean expiratory airway pressure is higher that set PEEP (dotted lines in the P_{AW} tracing) and the mean expiratory transpulmonary pressure is higher than end-expiratory transpulmonary pressure (dotted lines in the P_L tracing). This contributes to alveolar recruitment

which are the most frequent causes of treatment failure [5, 7]; (2) modulation of the inspiratory effort by diaphragmatic electro-mechanical uncoupling, yielding lower tidal volume, transpulmonary driving pressure and transvascular pressure; (3) prevention of the diaphragmatic myotrauma induced by intense inspiratory effort; (4) more homogeneous distribution of the inspiratory effort, with reduction of ventilator inhomogeneities and pendelluft phenomenon (the intra-tidal shift of gas from non-dependent to dependent lung regions, that causes overstretch in the dorsal areas of the lung, perpetuating lung injury) [11].

During NIV, but not during CPAP, pressure support is applied to assist the inspiration. This helps unload respiratory muscle, which may be preferrable in case of intense inspiratory effort. The risk of applying pressure support in hypoxemic patients is that this sums up with the inspiratory effort, finally generating high transpulmonary driving pressure. However, not all applied pressure support reaches patient's airways and contributes to the stress applied to the lungs, as part of it is dissipated to pressurize and distend the interface. Moreover, due to the significant trigger delays caused by interface compliance, inspiratory effort and ventilator assistance are (at least in part) out-of-phase, avoiding excessive dumps in transpulmonary pressure during inspiration. This de-synchronization may further enhance lung protection [12] (Fig. 1). In this sense, the onset of incidental or systematic patient-ventilator asynchronies is only an apparent disadvantage of helmet NIV. These are mostly related to inspiratory and expiratory trigger delays, and the slow increase/decrease in airway pressure caused interface compliance. These asynchronies are well tolerated and may not be relevant, as the helmet has a large internal

volume pressurized at PEEP level that can satisfy the flow needs of the patient regardless of ventilator response. Double triggering, a commonly observed phenomenon, may be prevented by acting on the cycling off criterion, or by switching to a ventilator mode with a time-regulated cycling off (Pressure assist-control).

The major drawback of helmet NIV and CPAP is the impossibility to measure the tidal volume. During NIV, the tidal volume displayed on the ventilator does not inform about the actual tidal volume delivered to the patient, as it also includes all the gas volume spent to distend the helmet. For accurate monitoring of tidal volume/inspiratory effort, other tools as esophageal manometry, electrical impedance tomography and diaphragm ultrasound are being evaluated. From a clinical standpoint, lack of improvement/worsening oxygenation, persistent tachypnea and dyspnea should be considered signs of treatment failure and prompt endotracheal intubation.

Clinical implications

As compared to high-flow nasal oxygen, helmet NIV improves hypoxemia, reduces inspiratory effort and dyspnea, with a mixed effect on transpulmonary driving pressure that mostly depends on the entity of inspiratory effort [7]. Two small, randomized trials and a network metanalysis suggested that helmet NIV may reduce the rate of endotracheal intubation compared to facemask NIV and high-flow nasal oxygen [6, 7, 13]. One of the major advantages of helmet NIV pertains to patients with intense inspiratory effort, possibly identified by the presence of hypocapnia [14]. These observations suggest the need for a personalized approach to hypoxemic respiratory failure based on physiologic phenotypes, such as patients with low (< 10 cmH_2O) vs. high (> 10 cmH_2O) inspiratory effort. Direct head-to-head comparisons between helmet high-PEEP CPAP and NIV are lacking, but ongoing studies may illuminate these important considerations (NCT04241861, NCT05089695).

From a clinical standpoint, noninvasive oxygen support in hypoxemic respiratory failure has high failure rates regardless of the variety of forms of respiratory support [15]. Thus, developing clinical expertise in the use of these devices and strict physiological monitoring remain important to promptly identify patients at risk of failure, to avoid delays in endotracheal intubation and institution of protective ventilation.

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Author contributions
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Data availability
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Declarations

Conflicts of interest
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