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### Helmet Non-Invasive Ventilation

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#### Introduction

Non-Invasive Ventilation (NIV), the provision of ventilator assistance using techniques that do not bypass the upper airway, is widely used in the management of selected patients with acute respiratory failure (ARF). The main theoretical advantage of NIV is avoiding the side effects and complications related to endotracheal intubation (Pingleton 1988).

NIV interfaces are devices that connect ventilator tubing to the face, allowing the delivery of pressurised gas into the airway. The choice of an appropriate interface is one of the critical issues affecting NIV success and requires scrupulous evaluation of the anatomical features of the patient, the etiology of ARF, and the ventilator mode used to administer NIV. In a recent web-based survey (Crimi et al. 2010) of 272 intensive care units and respiratory wards throughout Europe, the oronasal mask

was the most widely used interface for ARF, followed by nasal mask, full face mask and helmet, irrespective of clinical scenarios. By focusing the analysis on the Italian subsets of responders, the helmet was rated as the second most employed interface for the treatment of cardiogenic pulmonary oedema (Crimi et al. 2011).

The following sections will concentrate on the characteristics, advantages and disadvantages of the helmet, as well as the physiologic aspects of NIV delivered by the helmet.

#### Characteristics, Advantages of and Contraindications to the Helmet

Use of the helmet has been reported in the management of patients with both hypoxemic and hypercapnic ARF (Antonelli et al. 2004). The helmet is a clear plastic hood that contains the patient's head and is joined to a hard plastic ring supporting a soft rubber collar. Two pipeconnectors are placed at the two sides of the helmet for the expiratory and the inspiratory limbs of the circuit. The helmet is generally secured to the patient by armpit braces. All the helmets are latex-free and available in different sizes.

Compared with oronasal mask, the helmet has important advantages:

- a) It is better tolerated and allows a satisfactory interaction of the patient with the environment;
- b) Its fixation system provides a good seal without major compression at contact points, thus minimising skin lesions;
- c) It can be applied to any patient regardless of the facial contour, edentulism or facial trauma;
- d) It causes less interference with speech;
- e) It allows cough;
- f) A specific connector placed in the plastic ring of the helmet can be used to allow the passage of a straw, thus allowing the patient to drink or to be fed a liquid diet.

The helmet cannot be used in either claustrophobic or tetraplegic patients. Also, the need for tidal volume monitoring may be considered a relative contraindication to the use of a helmet. In fact, during helmet-delivered NIV, patients receive only part of the large volumes given by the ventilator after inspiratory trigger activation. The rest of the volume is compressed around the head, pressurising the helmet. It is not possible therefore to measure patient tidal volumes and flows by conventional bedside monitoring.

#### Ventilatory Modes

Helmet-delivered NIV is mostly applied as pressure support ventilation (PSV). Also Continuous Positive Airway Pressure (CPAP) may be administered non-invasively in various forms of ARF. CPAP delivers a constant pressure throughout spontaneous breathing in patients with an intact respiratory drive and adequate alveolar ventilation. CPAP can increase functional residual capacity and open underventilated alveoli, thus decreasing right to left intrapulmonary shunt and improving oxygenation and lung mechanics (Katz et al. 1985). In addition, CPAP may reduce the work of breathing and dyspnea in patients with chronic obstructive pulmonary disease (COPD) by counterbalancing the inspiratory threshold load imposed by intrinsic positive end-expiratory pressure (PEEP) (Petrof et al. 1990). Finally, by lowering left ventricular

transmural pressure in patients with left congestive heart failure, CPAP may reduce left ventricular afterload without compromising cardiac index

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(Naughton et al. 1995). CPAP can be delivered by various devices including low flow generators with an inspiratory reservoir, high flow Jet Venturi circuits (both of them with an expiratory mechanical or water valve), and bilevel or critical care ventilators. The helmet represents an elective interface to deliver CPAP, not needing the conventional reservoir and applicable also outside the intensive care unit to treat cardiogenic pulmonary oedema (Foti et al. 2009).

PSV is a pressure-triggered, pressure-targeted, flow-cycled mode of ventilation. PSV delivers a preset inspiratory pressure to assist spontaneous breathing, augmenting spontaneous breaths and offsetting the work imposed by the breathing apparatus.

In a physiologic study (L'Her et al. 2005) performed in patients with acute lung injury, non-invasive PSV combined with PEEP improved dyspnea and gas exchange, and lowered neuromuscular drive and inspiratory muscle effort. In such patients, CPAP used alone improved oxygenation but failed to unload the respiratory muscles.

#### **Carbon Dioxide Rebreathing**

Due to the large internal gas volume of the helmet, a possible problem related to the use of the helmet for NIV or CPAP might be the rebreathing of carbon dioxide (CO<sub>2</sub>). Compared to the oronasal mask, the helmet behaves differently in respect to CO<sub>2</sub> exchange. It has been shown that the oronasal mask constitutes an additional mechanical deadspace, and its effect on CO<sub>2</sub> rebreathing is proportional to its internal volume (Criner et al. 1994). Because this volume is small compared with the patient's tidal volume, the amount of CO<sub>2</sub> that is rebreathed is also small. By contrast, CO<sub>2</sub> exchange during helmet ventilation follows the model of a semiclosed environment, such as a closed room provided with an air exchange system (Taccone et al. 2004). According to this model, the factors determining CO<sub>2</sub> concentration inside the helmet are the amount of CO<sub>2</sub> produced by the patient and the fresh gas flow that flushes the helmet. As a consequence, the volume of the helmet has no direct effect on the CO<sub>2</sub> concentration, but only on the rate at which a given CO<sub>2</sub> concentration is reached.

When helmet CPAP is used, CO<sub>2</sub> rebreathing also depends on the method adopted to deliver CPAP. Applying CPAP with a critical care ventilator may be associated with abnormal CO<sub>2</sub> accumulation inside the helmet. The reason for this effect is that ventilators provide CPAP with a gas flow that is equal to the patient's minute ventilation. Under these circumstances, if the system has no leaks, no additional fresh gas flow is delivered to remove CO<sub>2</sub> during expiration. On the contrary, when helmet CPAP is given with a continuous free flow system, CO<sub>2</sub> rebreathing can be minimised by a high fresh gas flow (Taccone et al. 2004). Using a different experimental setup, the inspired partial pressure of CO<sub>2</sub> seems to be independent of the level of CPAP and inversely correlated to the fresh gas flow delivered. High gas flows of 45-60 L/min render the CO<sub>2</sub> rebreathing clinically irrelevant during helmet CPAP (Patroniti et al. 2003).

Compared to CPAP, helmet-delivered NIV in PSV mode can provide a more efficient CO<sub>2</sub> washout, probably because of the phasic administration of inspiratory flow during such a ventilatory mode. Of note, the analysis of CO<sub>2</sub> rebreathing during helmet-delivered PSV does not show significant reductions in inspired partial pressure of CO<sub>2</sub> by increasing the level of inspiratory assistance (Costa et al. 2005). In a sophisticated computational fluid dynamic model to evaluate the effective dead space between different devices, Fodil et al. (2011) showed that the dead space differed only modestly (110- 370 mL) between total face mask and the helmet, confirming that effective dead space is not related to the internal gas volume included in the interface.

#### **Asynchrony**

Optimal synchrony between the patient's spontaneous breathing activity and the ventilator's set parameters is one of the key factors determining tolerance to NIV. Patient-ventilator asynchrony may be determined by a number of events including ineffective triggering, double-triggering, auto-triggering, premature cycling, and delayed cycling. The lack of an optimal patient-ventilator interaction can lead to an increase in the work of breathing and patient discomfort (Kondili et al. 2003).

Physiologic studies on healthy subjects (Chiumello et al. 2003; Racca et al. 2005) found helmet less efficient in unloading the respiratory muscles when compared with standard oronasal mask. An explanation hypothesised for this finding is that the pressure delivered by the ventilator during helmet ventilation is partially spent to pressurise the large inner volume of the helmet, with a lower level of assistance in the initial phase of the breathing effort. In addition, because of the mechanical characteristics of the helmet, expiratory trigger efficiency might be adversely affected when non-invasive PSV is given through the helmet, thus worsening patient-ventilator asynchrony.

Moerer et al. (2006) found that, although delay times are prolonged during helmet ventilation, pressure time product is initially smaller (indicating less work of breathing) compared to NIV with the oronasal mask, due to the large volume inside the helmet that the patient can access. In this study, the authors also suggested that the highest PEEP and PS levels clinically indicated and tolerated by the patient should be applied when NIV with a helmet is used, in order to increase the elastance of the system, enhancing the trigger sensitivity. However, when adding PS level, a close and careful clinical monitoring is needed because it is likely to further shorten the delay times and promote the occurrence of wasted inspiratory efforts, thus reducing the tolerability of the technique (Moerer et al. 2006).

Vargas et al. (2009) suggested that increasing both PEEP and PS level and using the highest pressurisation rate may be advisable when providing NIV via a helmet. In their study, the helmet with the same settings as the oronasal mask was associated with less inspiratory-muscle unloading and with worse patient-ventilator asynchrony. In contrast, specific settings provided similar unloading, as well as improved the inspiratory trigger delay, and induced no further discomfort. Navalesi et al. (2007) showed that despite the inspiratory and expiratory delays the duration of diaphragmatic assistance in PSV is comparable between the mask and the helmet. Anyway, an optimal ventilator setting is crucial to

NIV outcome irrespective of the interface used.

#### **Clinical Applications**

Use of the helmet to deliver either CPAP or NIV has been described in the management of ARF of various etiologies (Antonelli et al. 2004; Foti et al. 2009; Squadrone et al. 2005). However, caution should be applied in using the helmet to treat decompensated COPD patients because the efficiency of the helmet in eliminating CO<sub>2</sub> is reduced as compared to the conventional oronasal mask. Accumulating evidence supports the use of the helmet to improve gas exchange and avoid endotracheal intubation in selected hypoxemic ARF patients, in particular those with acute cardiogenic pulmonary oedema (Foti et al. 2009) or postsurgical respiratory failure (Squadrone et al. 2005). Furthermore, the helmet should be considered in all patients undergoing long term NIV/CPAP treatments to limit the complications of the technique and improve patients' tolerance. In this context, alternating different interfaces may be the best strategy.



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