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Influence of Two Different Interfaces for Noninvasive Ventilation Compared to Invasive Ventilation on the Mechanical Properties and Performance of a Respiratory System*

A Lung Model Study

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Background: **Noninvasive ventilation (NIV) is increasingly used in intensive care medicine, but only little information is available how different NIV interfaces affect the performance of a ventilatory system. Therefore, we compared delay times, pressure time products (PTPs), and wasted efforts during inspiration among patients receiving invasive ventilation and NIV with a helmet (NIV-H) or a face mask (NIV-FM).**

Methods: **Using an *in vitro* lung model capable of simulating spontaneous breathing, gas flow and airway pressure were measured with varying positive end-expiratory pressure and pressure support (PS) levels. Wasted efforts were determined while lung compliance, respiratory rate (RR), continuous positive airway pressure (CPAP), and PS levels were changed.**

Results: **Delay times were more than twice as long with a helmet compared to NIV-FM or invasive ventilation ($p < 0.001$), but decreased during NIV-H with increasing CPAP ($p < 0.001$) and PS levels ($p < 0.001$). During the initial inspiratory phase, PTP was smaller with NIV-H compared to NIV-FM or invasive ventilation, but not so when a complete inspiration with PS was evaluated. Wasted efforts occurred earlier during NIV-H and were aggravated with rising PS, RR, and compliance.**

Conclusions: **Although delay times are prolonged during NIV-H, PTP is initially smaller compared to NIV-FM and invasive ventilation, indicating less work of breathing due to the high volume the patient can access. Increasing the CPAP or PS level decreases delay times in NIV-H and should therefore be considered whenever possible. Wasted inspiratory efforts occurred at higher RRs and should carefully be monitored during NIV.** ***(CHEST 2006; 129:1424–1431)***

Key words: facemask; helmet; invasive ventilation; noninvasive ventilation; pressure support ventilation; trigger

Abbreviations: CPAP = continuous positive airway pressure; Delay$_{PEEP}$ = time interval from the initiation of an inspiration until the preset positive end-expiratory pressure was reached again; Delay$_{TRIGGER}$ = time interval between the initiation of an inspiration until the deflection of the airway pressure-time curve showed no further decrease in airway pressure; NIV = noninvasive ventilation; NIV-FM = noninvasive ventilation with a face mask; NIV-H = noninvasive ventilation with a helmet; NPSV = noninvasive ventilation with inspiratory pressure support; Paw = airway pressure; PEEP = positive end-expiratory pressure; PS = pressure support; PSV = pressure support ventilation; PTP = pressure time product; PTP$_{PEEP}$ = corresponding pressure time product from the initiation of an inspiration until the preset positive end-expiratory pressure level was reached again; PTP$_{TOT}$ = pressure time product calculated over complete inspiration; PTP$_{TRIGGER}$ = corresponding pressure time product interval between the initiation of an inspiration and the time point when the deflection of the airway pressure-time curve showed no further decrease in airway pressure; RR = respiratory rate

Noninvasive ventilation (NIV) is increasingly used in the treatment of acute and chronic respiratory failure and during weaning from invasive ventilation.[1–4] NIV has been applied in patients with acute hypoxemic respiratory failure,[4–6] severe cardiogenic pulmonary edema,[7] or acute exacerbation of COPD[3] in order to decrease the need and the complications of endotracheal intubation.

Noninvasive respiratory support can be applied either as continuous positive airway pressure (CPAP) alone or as NIV with inspiratory pressure support (NPSV) by means of a nasal or face mask. Problems with the widely used face masks result partially from

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air leakage,[8,9] discomfort of the patient,[10] and pressure-related ulcerations of the nose.[11,12] These problems may limit the duration of use and account for a large proportion of NIV failures. In an attempt to improve NIV tolerance, a helmet was developed that has been successfully used in different clinical situations.[5,13–16]

The increased importance of NIV in intensive care medicine and the new interfaces for its application led to the development of special modes of intensive care ventilators to overcome the problems related to higher gas leakage and dead space. Only limited data are available on how the performance of a ventilatory system is affected by such a helmet or a face mask compared to standard invasive ventilation. With demand flow systems, an inspiratory effort of the patient is necessary to trigger gas flow from the respirator. Thus, the trigger sensitivity of the whole respiratory system is of major importance for the work of breathing.[17,18] The helmet for NIV may affect the trigger sensitivity due to its large compressible volume. Furthermore, besides the specific settings of the ventilator, individual patient characteristics like compliance and resistance of the respiratory system and respiratory rate (RR) as well as the amount of gas leakage may affect the performance of the system and could potentially result in desynchronization between ventilator and patient. Consequently, during NPSV, the patient may inspire with delayed or even without any support from the ventilator (wasted efforts). Therefore, the aim of this study was to characterize the effects of two commonly used interfaces for NIV, face mask and helmet, on the performance of an ICU ventilator in comparison to invasive ventilation, by the following means: (1) measuring delay times after an inspiratory effort; (2) calculating pressure time products (PTPs) for different inspiratory phases; and (3) analyzing the occurrence of wasted inspiratory efforts during varying trigger sensitivities, pressure support (PS) levels, RRs, and lung compliance values.

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Materials and Methods

Equipment

CPAP and NPSV were performed with a helmet (Starmed Castar R; Mirandola; Modena, Italy) or a face mask (King Systems Corporation; Noblesville, IN) put on a glass head that was connected to a lung model (Fig 1). The Castar R Helmet (size medium) has an internal volume of 7.5 L with inflated cuffs. When the head is inserted into the helmet, the internal volume is reduced to approximately 2.4 L due to the volume of the glass head used in this study. Two underarm laces attached to a ring at the lower site of the helmet should prevent the helmet from lifting when it is inflated. A plastic collar fitting around the neck prevents leakage during ventilation. Inspiratory and expiratory tube connectors are fitted in the upper part of the helmet.

The standard face mask (size medium, 125-mL internal gas volume) has an inflatable cushion fitted tightly to the head by dedicated rubber head straps. The cushion was inflated with 10 to 20 mL of air to adhere tightly to the glass head. When the mask is put on the head, the internal gas volume is reduced to approximately 100 mL.

For invasive ventilation, the lung model was connected to the ventilator via an endotracheal tube (Portex, 7.5 mm; Portex Ltd.; Kent, UK). CPAP and PS ventilation were performed using a conventional ICU ventilator used in our ward capable of invasive ventilation and NIV (Evita 4; Dräger Medical; Lübeck, Germany).

Lung Models and Measurements

Gas flow was measured with a pneumotachometer (Fleisch II; Fleisch; Lausanne, Switzerland) at the inspiratory side of the helmet (Fig 1). The ventilator and lung model were connected by standard disposable ventilator tubes (B&B Beatmungsprodukte GmbH; Neunkirchen, Germany). Flow signals were stored on a personal computer using an analog-digital converter, and the signals were integrated to obtain volume during off-line evaluation. The pneumotachometer was calibrated by a mass flowmeter (TSI 4040 D; TSI Inc.; Shoreview, MN). Airway pressure (Paw) was measured at the inspiratory side before the helmet with differential pressure transducers (Sensortechnics; Puchheim, Germany), adjusted meticulously during zero flow conditions before each measurement.

Measurements of Time Delay

To simulate spontaneous breathing, we used a modified lung model (LS1500; Dräger Medical). This lung model consists of an electrically driven pneumatic lung simulator that allows the adjustment of tidal volume, RR, compliance, and resistance.