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Conventional and Non Conventional Interfaces for Non Invasive Respiratory Support

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Conventional and non conventional interfaces for non invasive respiratory support in adults and children. Part one: rationale and physiologic approach

Conventional management of acute respiratory failure (ARF) in adults and children consists of endotracheal intubation with their associated risks such as the need for sedation, infections, ventilator-associated pneumonia, and laryngeal-tracheal damage. Non invasive respiratory support (NRS) is an alternative form of respiratory treatment, which includes various techniques for augmenting alveolar ventilation, oxygenation, and unloading of respiratory muscles without the need of an endotracheal tube (Nava and Hill 2009).

Introduction

NRS includes continuous positive airway pressure (nCPAP) and positive pressure ventilation (nPPV) delivered via an interface (nasal facial mask, mouth-piece or helmet) and ICU or home mechanical ventilators. By virtue of its effectiveness NRS has become more frequently used in different acute and chronic pathologic conditions in adult and paediatric patients. In adults highlevel of evidence supports the use of nCPAP in cardiogenic pulmonary oedema and postoperative patients and nPPV in exacerbation of COPD, neuromuscular disorders or respiratory distress in the immunocompromised patients. Conversely, the application of NRS in infants and children is less well established, and so far, case series constitute the vast majority of the available knowledge (Calderini et al. 2010).

During NRS for ARF or long term mechanical ventilation, the efficacy of the treatment as well as patient comfort are important to determine the success of the treatment. The choice of the interface is a major determinant of NRS success or failure, mainly because the interface strongly affects patient comfort. Furthermore, the interface choice can strongly influence the development of NRS drawbacks, such as air leak, claustrophobia, facial skin erythema, acneiform rash, skin damage, and eye irritation (Nava et al. 2009).

The choice of each interface depends on:
a) Anatomical characteristic of the patient;
b) The clinical condition and disease;
c) The NRS used;
d)The expected duration of the treatment; and
e)The environment where the NRS will be provided in acute setting.

In Part One of this brief review, we will discuss the role of conventional and non conventional interfaces in acute (short term) and chronic (long term) settings. We will continue with descriptions of each interface and the advantages and contraindictations of using each in Part Two, which will be included in the upcoming issue of ICU Management.

Rationale for NRS

NRS is the delivery of respiratory support without the need of an endotracheal tube. NRS could be delivered as non invasive continuous positive

airway pressure (nCPAP) and non invasive positive pressure ventilation (nPPV) (Nava and Hill 2009). nCPAP applies a constant distending airway by increasing intrathoracic pressure throughout the entire respiratory cycle, while the patient is spontaneously breathing. In other words during nCPAP the pressure applied to the respiratory system is only applied by the respiratory muscles. Main physiological effects of CPAP are:
• Prevention of atelectasis and increase in functional residual capacity thus increasing oxygenation;
• Counterbalancing intrinsic PEEP (PEEPi) thus reducing the work of breathing;
• Improvement in left ventricular afterload and haemodynamics;
• Preventing obstructive apnoea by stenting and stabilising upper airways; and
• Stabilising the high compliant chest wall in infants and pre-term babies.

Conversely, during nPPV the pressure applied to the respiratory system is generated both by patient's respiratory muscle and by the ventilator in the so called "assisted modes" or only by the ventilator during "controlled modes". In the former modes the patient is active and patient's spontaneous inspiratory effort triggers the ventilator to provide a volume (volume targeted ventilatory modes) or pressure (pressure targeted ventilatory modes). Thus, during each spontaneous inspiration, the patient receives a volume or pressure supported breath. Conversely, in controlled modes the patient is passively supported by the ventilator. The main physiological effects of nPPV, particularly when using "assisted modes" as pressure support ventilation (PSV), are:
• Compared to CPAP, improvement in breathing pattern (increasing in tidal volume and decreasing in respiratory rate) resulting in a better respiratory muscle unloading and decreased work of breathing;
• Alveolar recruitment thus improving ventilation/perfusion mismatching. Recruitment is then maintained by the contemporary use of CPAP;
• Compared to CPAP, better CO_2 washout due to alveolar recruitment and/or an improvement in breathing pattern.
• However, because air leaks are common during NRS patient-ventilator asynchrony may become a major issue leading to nPPV treatment failure (Vignaux et al. 2009).

Contraindications to NRS for both adults and children in the acute setting are:
• Cardiac or respiratory arrest;
• Non respiratory organ failure like severe encephalopathy (i.e. GCS<10), severe upper gastrointestinal bleeding, hemodynamic instability or unstable cardiac arrhythmia;
• Facial surgery, trauma or deformity;
• Upper airway obstruction;
• Inability to cooperate, protect the airways, clear secretions (absence of cough) and swallowing;
• Severe air leaks causing severe patient ventilator asynchronies leading to NRS failure; and
• High risk of aspiration.

Characteristics, Advantages and Disadvantages of the Various NRS Interfaces

The main characteristics of an ideal NRS interface are:
• Leak-free;
• Good stability;
• Nontraumatic;
• Lightweight;
• Long lasting;
• Nondeformable;
• Nonallergenic material;
• Low resistance to air flow;
• Minimal dead space;
• Low cost;
• Easy to manufacture (for the moulded interfaces); and
• Available in various sizes.

On the other hand, the main characteristics of an ideal NRS ideal securing system are:
• Stable (to avoid interface movements or dislocation);
• Easy to put on or remove;
• Nontraumatic;
• Light and soft;
• Breathable material;
• Available in various sizes;
• Works with various interfaces;
• Washable, for home care; and
• Disposable, for hospital use.

Because patient anatomy differs dramatically, proper selection of the interface size is mandatory to achieve the best clinical results. Interfaces include standard commercially available, ready-to-use models in various sizes (paediatric and adult small, medium, and large) or custom-fabricated, moulded directly on the patient or from a moulded cast previously obtained. In the last few years the industry has made a great technological effort to better meet the needs of clinicians and provide more comfortable, better-tolerated, easier-to-use, and safer interfaces (Fraticelli et al. 2009; Gregoretti et al. 2002; Navalesi et al. 2000; Girault et al. 2009).

Custom-fabricated masks still find a role in the management of chronic respiratory failure. It has been demonstrated that the likelihood of skin breakdown may be reduced in long term mechanically ventilated children by using tailored custom-fabricated masks.

According to the mode of application to the airway NRS interfaces may be divided into the following:
• Mouthpiece: placed between the patients lips and held in place by lip-seal;
• Nasal pillow or plugs: inserted into the nostrils;

• Nasal mask: including the nose but not the mouth;
• Oronasal or full face mask: including the nose and mouth;
• Total full-face mask: including the mouth, nose, and eyes; and
• Helmet: including the whole head and all or part of the neck; no contact with the face or head.

Some important issues related to masks characteristics must be emphasised:
• Masks may be formed from single or double pieces of material. In the latter case, they are composed by: 1) the cushion of soft material (transparent noninflatable, transparent inflatable, full hydrogel, full foam) that forms the seal against the patient's face, and 2) the frame or "body mask" of stiff material (polyvinyl chloride, polycarbonate, or thermoplastic), which in many models is transparent. The two parts may be glued or hooked together. The size of the "body mask" may theoretically affect CO_2 clearance (see the dedicated paragraph);
• Masks may have or not have the vent system (one or more holes or slots built in the frame or in the swivel connector) to prevent rebreathing. These masks belong to the so called intentional leaks circuit. The vented masks should not be used with a circuit that has separate inspiratory and expiratory limbs or with an expiratory valve or other external device for CO_2 clearance;
• Masks may be connected to the ventilator circuit with a connector, swivel piece, and/or adapter, which may be externally applied or built into the frame. Again, as mentioned before there are masks that can have a built-in vent system in the swivel connector;
• The swivel connector of the vented full-face or total full-face mask may include an anti-asphyxia valve that automatically opens to room air in case of ventilator malfunctioning when airway pressure falls below 3 cmH_2O; and
• Some mask can also have additional ports in the frame, to add oxygen or measure airway-opening pressure and/or endtidal CO_2.

The level of intentional leaks in the vented masks may range from 12 to 45 L/min for different given pressure levels. The presence of an intentional leak may influence both the inspiratory trigger performances as well as the capacity to achieve and maintain the set inspiratory pressure. This may lead to a significant reduction in delivered tidal volume. Interestingly, expiratory cycling seems not to be affected by the level of intentional leaks except in obstructive lung conditions (Borel et al. 2009).

Non intentional air leaks may reduce the efficiency of NRS, decrease patient tolerance, and increase patient-ventilator asynchrony, possibly causing awakenings and sleep fragmentation. In patients with neuromuscular disorders receiving nocturnal NRS, leaks are also associated with daytime hypercapnia. In order to decrease air leaks during NRS, the following issues must be taken into consideration: a) Proper interface type and size; b) Proper securing system; c) Appropriate mask-support ring and comfort flaps; d) Tube adapter; e) Hydrogel or foam seals; f) Chin strap; g) Lips seal or mouth taping.

Masks may cause friction and skin damage at the bridge of the nose, the upper lip, and the nasal mucosa. Skin irritation is sometimes due to skin hypersensitivity to certain materials or excessive sweat. However, the most important strategy to prevent skin damage is to avoid an excessively tight fit (Gregoretti et al. 2002). Some simple and easy suggestions to reduce the risk of skin damage during NRS by masks are: a) Rotate various types of interfaces; b) Proper harness and tightening; c) Skin and mask hygiene; d) Nasal-forehead spacer (to reduce the pressure on the bridge of the nose); e) Forehead pads (to obtain the most comfortable position on the forehead); f) Cushioning system between mask prong and forehead.

A Physiological Approach to the Interfaces: The Interface Volume and its Effect on CO_2 Rebreathing and Patient Effort

The dead space added by the interface may be also recognised as a major problem, in particular for the treatment of hypercapnic patients, because it may reduce NRS effectiveness in correcting respiratory acidosis. Bench studies have suggested that CO_2 rebreathing is significantly increased with masks having a large internal volume, and conversely decreased with masks having a built-in vent system. These findings may raise concern about the use of facial masks with a large internal volume and without built-in vent system, as those designed for use with double-circuit critical care ventilators (Navalesi 2009).

Alveolar ventilation decreases as dynamic dead space (the physiologic dead space plus the apparatus space) increases. The physiologic dead space depends on tidal volume, whereas the apparatus dead space depends on the inner volume of the interface. It was found, comparing the dead space between a nasal mask and a full face mask, that although the in vitro difference was significantly higher with the oro-nasal mask, the in vivo results (which took into account anatomical structures) were similar (118 vs. 97 mL with full face mask and nasal mask, respectively) (Kwok et al. 2003). In this regard the nasal pillows and masks add very little dead space and can be as effective as face mask in reducing arterial carbon dioxide and increasing pH, but are less tolerated by patients. Different flow patterns and pressure waveforms may also influence the apparatus dead space. It has been shown that a face mask increased dynamic dead space from 32% to 42% of tidal volume above physiologic dead space, during unsupported breathing. The addition of positive endexpiratory pressure lowered dynamic dead space nearly to physiologic dead space. Pressure support without positive end-expiratory pressure reduced dynamic space less, which left dynamic dead space higher than physiologic dead space (Kwok et al. 2003). Other investigators confirmed the importance of the site of the exhalation ports on CO_2 rebreathing (Schettino et al. 2003).
The clinical efficacy of a total full-face mask versus an oronasal mask was assessed in patients with acute hypercapnic respiratory failure in a recent randomised controlled study (Girault et al 2009). None of the measured parameters including carbon dioxide showed statistically significant differences between the masks at each time point throughout the study period.

Physiologic effects of four interfaces with different internal volumes in patients with hypoxemic or hypercapnic ARF receiving NRS through ICU ventilators have been evaluated (Fraticelli et al. 2009). Breathing pattern, inspiratory effort, arterial blood gases, comfort, and patient–ventilator interaction have been assessed with three facial masks with very high (977 mL), high (163 mL), and moderate (84 mL) internal volume, and a mouthpiece having virtually no internal volume. Despite these major differences in internal volume, compared with spontaneous breathing, NRS decreased inspiratory effort and improved gas exchange with no significant difference between the four interfaces. An increased rate of air leaks and asynchrony as well as a reduced comfort were observed with the mouthpiece, as opposed to all three facial masks. Although this study does not exclude that some rebreathing may occur, it definitely indicates that its extent is limited and of no clinical impact.

In patients undergoing NRS in the acute setting, the addition of a dead space through a heat-and-moisture exchanger was shown to reduce the efficacy of NRS, by increasing arterial carbon dioxide, respiratory rate, minute ventilation, and the work of breathing (Pelosi et al. 1996). The reasons why increasing the internal volume of the mask does not result in similar effects are not entirely clear. However, the application of continuous pressure throughout the expiratory phase has been shown to reduce the actual (dynamic) dead space of the mask. Furthermore, as suggested by the authors, the leakage around the mask could act as a bias flow resulting in mask CO2 washout, which could minimise the possible differences in dead space.

The helmet has a much larger volume than any of the other interfaces (always larger than tidal volume), and the helmet behaves as a semi-closed environment, in which the increase in inspired partial pressure of CO2 is an important issue. In a pressurised aircraft a fresh gas flow of about 200 L/min/passenger is usually needed to keep the inspired partial pressure of CO2 at the recommended value. Inspired partial pressure of CO2 in a semi-closed environment depends on the amount of CO2 produced by the subject(s) and the flow of fresh gas that flushes the environment (with a helmet this is called the "helmet ventilation"). Thus, the volume of the helmet does not directly affect the inspired partial pressure of CO2, but only the rate at which the predicted inspired partial pressure of CO2 is reached. Therefore, decreasing the size of the helmet will not necessarily prevent CO2 rebreathing. Anything that increases helmet ventilation (e.g. air leak, delivery of fresh gas) may decrease the inspired partial pressure of CO2. A bench study with a lung model and helmets of various sizes found that a 33% reduction in helmet volume had no effect on the amount of CO2 rebreathing at steady state (Patroniti et al. 2003). During either CPAP or NRS, the helmet affects CO2 clearance. Helmet ventilation may require doubling the minute ventilation to maintain an end-tidal carbon dioxide value similar to that with mask ventilation. High gas flow (40–60 L/min) is required to maintain a low inspired partial pressure of CO2 during helmet CPAP. In contrast, when CPAP was delivered with a ventilator, considerable CO2 rebreathing was found (Taccone et al. 2004). A critical care ventilator with a double-limb circuit should not be used to deliver helmet CPAP. In the absence of air leaks, which can modify the helmet ventilation by flushing CO2, CPAP is delivered with a gas flow that is equal to the patient's minute ventilation and hypercapnia can easily occur.

Patient-ventilator asynchrony may increase with interface volume (Racca et al. 2006). However, a recent study comparing two fullface masks with different dead space found no significant negative effect of dead space on gas exchange or patient effort (Girault et al 2009). In contrast, studies on masks versus helmets found helmets less efficient in unloading the respiratory muscles, especially in the presence of a resistive load and with a higher likelihood of patient-ventilator asynchrony (Racca et al. 2006). This may be explained by the longer time required to reach the target pressure, because part of the gas delivered by the ventilator is used to pressurise the helmet. Some portion of inspiratory effort is unassisted because of greater inspiratory and expiratory-trigger delay.

In addition, because a PSV breath is flow-cycled, delayed expiratory triggering should be expected because of the helmet's characteristics. However, it has been suggested that, although delay is prolonged with the helmet, the pressure-time product is initially smaller than with a face mask during PSV, which means less work of breathing because of the high volume the patient can access. Increasing the level of PEEP or PSV decreases the delay in helmet PSV and should therefore be considered whenever possible (Chiumello et al. 2003). In a prospective crossover study in patients at risk for respiratory distress the authors applied in random order a face mask and a helmet with "baseline" ventilatory settings and helmet with "specific" setting (50% higher PSV level and highest pressurisation rate). Compared with the facemask, the helmet with the "baseline" settings worsened patient-ventilator synchrony, as indicated by longer triggering-on and cycling-off delays. When the "specific" settings were used the triggering-on delay with helmet was significantly reduced compared to "baseline" settings (Vargas et al. 2009).

The ongoing technical improvement of the helmet has now made possible to reduce the inspiratory and expiratory trigger delay (unpublished data). This upgraded version of the helmet is expected to be released on the market.

Conclusion

Interfaces play a relevant role in the success of NRS. A wide "armamentarium" of conventional and non conventional interfaces may lead to NRS success both in acute and chronic setting. Part Two of this article, which will be featured in the next edition of ICU Management, will include a detailed description of these interfaces, as well as the advantages and contraindications of utilising each.

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