The Mask Interface Designs

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Introduction

The use of noninvasive ventilation (NIV) therapy has increased in the last two decades, in both the critical care unit and home setting [1]. It is used as a first-line management for acute exacerbation of chronic obstructive pulmonary diseases and cardiogenic pulmonary edema [2]. NIV can also be used in the management of other diseases like asthma, chest wall deformity, and neuromuscular diseases [3, 4]. Studies have shown that NIV can reduce the risk of intubation and decrease the mortality rate and the cost [5–7]. It uses positive pressure most commonly in a form of continuous positive airway pressure (CPAP) or bi-level positive airway pressure (BiPAP) to be applied noninvasively to a patient via different forms of interfaces. Interface is an adjunct device that holds the NIV tubing on a patient' face. The success of NIV therapy depends on multiple factors and one of these factors is selecting the appropriate interface for a patient [8]. In order to help the healthcare providers in selecting the appropriate NIV interface to a patient with least interface-related complications, this chapter will discuss the interface and its types, and it will compare the designs of the interfaces. It will also describe the effect of the type of interface on the upper airway dynamics. In addition, the chapter will explain interface fitting and the relationship between the interface type and carbon dioxide rebreathing. Finally, it will list the common interfaces' problems and some practical solutions.

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Interface

Interface is either factory-manufactured, semi-customized, or customized. Factory-manufactured interfaces differ in shape, design, size, and material. Silicone is the most commonly used material to construct an interface [9]. Semi-customized interfaces are factory-manufactured and then customized to fit the individual [10]. For example, some manufacturers use gel to construct the interface which will help to adapt the interface to the contours of the patient's face [9]. No studies compared this type of interfaces with the standard ones [10]. Customized interfaces are created by centers specializing in NIV. Customized interface is an interface, made for a certain patient [10]. Due to the advancement of medical technology and the availability of 3D medical printing, 3D-printed custom interface can be developed for both adults and children [11]. For example, patients who have craniofacial malformation can benefit from having customized interfaces that are created specific to them.

Types of Interfaces

This section lists and describes the different types of interfaces commonly available in the market:

Nasal Pillow or Nasal Prongs

It has two soft nasal tubes that fit into the nostrils. It is held in place by a strap that wraps around the back of the head. It is preferred to be used with patients who have skin allergy [12] or those who find nasal or oronasal mask uncomfortable or those who have skin breakdown on the nasal bridge since it has least contact with the skin [9]. It is also preferred with those who are suffering from claustrophobia [12].

Nasal Mask

It covers the nose only from its bridge down to the upper lip. It is recommended to be used with patients who have good nasal breathing and facial symmetry. The nasal mask is discouraged to be used with patients who have facial anatomical deformations or facial paralysis [12].

Oronasal Mask or Full-Face Mask

It covers the nose and the mouth and rests on the chin. The cushion of a typical oronasal mask is triangular in shape. The top of the triangle should be placed on the nasal bridge, whereas the bottom of the triangle should be placed between the lower lip and the mentum. It is preferred to be used with patients who have acute respiratory failure since they breathe through their mouth to bypass the nasal resistance and with other kinds of patients who have considerable mouth breathing. It is also indicated with patients who have nasal obstruction [12]. To prevent rebreathing in case of ventilator malfunction, recent advances added quick-release straps and anti-asphyxia valves to the oronasal mask [13].

Oral Mask or Mouthpiece

It fits inside the mouth and is placed between the patient's teeth and lips; thus; it requires active participation of the patient [9]. It is indicated commonly to support daytime ventilation for patients with neuromuscular diseases [14].

Total Face Mask

It covers the whole face, including the nose, mouth, and eyes. It is mainly used with acute respiratory failure [9].

Helmet

It is a transparent latex-free polyvinyl chloride hood that covers the entire head and all or part of the neck with no contact with face or head and has a soft collar neck seal. It is a valuable interface for the management of acute hypoxemic respiratory failure and acute cardiogenic pulmonary edema in certain countries [15].

Comparisons of the NIV Interfaces

An ideal NIV interface is the one that has the following characteristics: transparent, leak-free, lightweight, good stability, non-allergenic material, durable, nontraumatic, minimal dead space, low resistance to airflow, available in several sizes, adaptable to variations in facial anatomy, easy to clean and disinfect, connectable with any ventilator, easy to secure and take off in order to avoid aspiration, nondeformable, and affordable [16, 17]. In reality, there is no universally ideal interface. Each of the aforementioned NIV interface has advantages and disadvantages. It is important for clinicians to understand them in order to select the appropriate interface for a patient. These are summarized in Table 1.

Many studies had an interest to compare the efficacy of different types of interfaces during NIV therapy. The following section will present these studies:

Table 1 Comparisons of the NIV interfaces

Interface	Advantages	Disadvantages
Mouthpiece	• Less claustrophobic • No pressure on the nasal bridge	• Less effective for acute respiratory failure • Requires nasal or oronasal interface when sleeping • Nasal leak
Nasal mask	• Less claustrophobic • Coughing and expectoration are easier • Speaking and eating are easier • Less danger in case of vomiting • No risk of asphyxia in case of ventilator malfunction • Gastric distension is less likely	• Nasal patency required • Mouth leak • Mouth dryness • Nasal irritation and rhinorrhea • Contraindicated with nasal obstruction or malformation, mouth breather, or soft palate surgery
Nasal pillows	• Less claustrophobic • Coughing and expectoration are easier • No pressure on the nasal bridge • Speaking is easier	• Nasal patency required • Mouth leak • Mouth dryness • Nasal irritation and rhinorrhea • Contraindicated with nasal obstruction or malformation
Oronasal mask	• Better mouth leak control • More effective in mouth breather	• More claustrophobic • Increased aspiration risk • Speaking, eating, and expectoration are difficult • Asphyxiation with ventilator malfunction • Contraindicated with patients who have vomiting or claustrophobia
Total face mask	• No pressure on the nasal bridge • Easier to fit • More comfortable for some patients	• High level of noise • Eye irritation
Helmet	• No pressure on the nasal bridge • Speaking is easier • Can be applied regardless of the facial contour, facial trauma, or edentulism • Coughing is easier • More comfortable for some patients	• High level of noise • High gas flow required to prevent rebreathing • Hearing loss • Poor patient-ventilator synchrony • Contraindicated with patients who have tetraplegia or claustrophobia

Data from [16–18]

Mouthpiece vs. Nasal Mask

Nicolini et al. [14] compared the effectiveness of two interfaces (open mouthpiece [angled mouthpiece without lip seal fixation] and nasal mask) on improving arterial blood gases and breathing frequency after 2 h of NIV therapy and then after 12, 24, and 48 h in patient with mild to moderate acidosis due to exacerbation of chronic obstructive pulmonary disease. Fifty participants were enrolled in the randomized study, and they were found to have similar trends in arterial blood gases and breathing frequency in both mouthpieces and nasal mask. However, more patients accepted mouthpiece over the nasal mask when analyzing the survey with the Likert scale ($p < 0.01$).

Nasal Mask vs. Oronasal Mask

Kwok et al. [19] found no differences between oronasal mask and nasal mask in terms of improvement in clinical data, such as vital signs, gas exchange, and avoiding intubation. However, nasal mask was less tolerated by the participants than oronasal mask when they are used to manage acute respiratory failure caused by chronic obstructive pulmonary disorder and cardiogenic pulmonary edema in emergency department or intensive care unit.

In a meta-analysis study that included five randomized and eight non-randomized trials, Andrade et al. [20] found that oronasal mask is associated with higher level of CPAP with an average of 1.5 cmH_2O, more residual apnea/hypopnea index with an average of 2.8 events/h, and less adherence with 48 min/night, when compared to nasal mask with participants who have obstructive sleep apnea.

A systematic review and individual participant data meta-analysis compared the effect of nasal and oronasal mask on home NIV efficacy and adherence in patients with COPD and obesity hypoventilation syndrome. Thirty-four prospective randomized control trial participants were recruited between 1994 and 2019 with at least 1-month duration of NIV therapy. The study reported that oronasal mask was used more for home NIV compared to nasal mask; however, there was no difference in the NIV efficacy or tolerance between the two used interfaces [21].

Majorski et al. [22] compared oronasal mask and nasal mask in terms of quality of sleep using objective and subjective measurements with the nocturnal NIV in COPD patients. The randomized crossover trial found a tendency toward improved sleep efficiency and sleep stages III and IV with the oronasal mask ($p = 0.054$ and $p < 0.001$, respectively). Subjective mask preference was independent from the objective measures, but it is associated with nocturnal dyspnea.

Nasal Pillow vs. Nasal Mask vs. Oronasal Mask

In a randomized control crossover trial, Goh et al. [23] investigated the effect of interface type on the adherence and efficacy of CPAP treatment on patients with moderate to severe obstructive sleep apnea. Three interfaces were compared: nasal pillow, nasal mask, and oronasal mask. The study reported that participants with CPAP and nasal mask were more adherent than those with nasal pillow and nasal mask. Additionally, they found that higher apnea/hypopnea is associated significantly with oronasal mask. Moreover, participants who have less nasal obstruction and a proportionally increased chin-lower lip distance to midface width had better adherence to oronasal mask.

Blanco et al. [24] compared the impact of three different interfaces, nasal pillow, nasal mask, and oronasal mask on the effectiveness of and adherence to unattended home-based CPAP titration in patients with obstructive sleep apnea. In this retrospective study, nasal mask was selected by most of the participants and had the lower leak rates, and nasal pillows presented a similar performance.

Total Face Mask vs. Helmet

In a single-center randomized control trial of 83 patients with acute respiratory distress syndrome, helmet was compared to total face mask in terms on intubation rate. The study found that helmet significantly reduced intubation rate and 90-day mortality [25]. Another single-center randomized control study was conducted with similar purpose as the aforementioned study in 60 COVID-19 patients. The study reported that helmet also was associated with reduction in intubation rate, better oxygenation, greater patients' comfort, and shorter ICU length of stay compared to face mask [26]. Both studies recommended further research with large sample size and multi-centers to confirm the findings.

Effect of the Type of NIV Interface on the Upper Airway Dynamics

During NIV therapy, it has been thought that upper airway obstruction can be induced by nasal obstruction, pharyngeal collapse, and/or glottis closure [27]. However, Vrijsen et al. [28] reported a case in which oronasal mask can induce obstructive events in the upper airways, which resulted in decreased sleep and NIV efficiency.

Ebben et al. [29] compared the nasal mask and the oronasal mask on the retroglossal and retropalatal anterior-posterior space in patients suffering from obstructive sleep apnea and using CPAP. Ten participants were imaged with real-time cine magnetic resonance imaging with the aforementioned interfaces at different CPAP (5, 10, and 15 cmH_2O) in the supine position along the sagittal plane while awake. The study found that oronasal mask produced significantly less airway opening in the retropalatal region of the upper airway compared to the nasal mask.

In a retrospective four case series, Ng et al. [30] reported that nasal mask should be considered when obstructive sleep apnea is incompletely controlled by CPAP with oronasal mask and/or surprisingly when patients require high CPAP with evidence of residual upper airway obstruction. The four patients were on CPAP with oronasal mask, and when they were switched to nasal mask, there was significant reduction in the average of residual apnea-hypopnea index. In two of the four cases, the patients required much lower CPAP.

Similarly, another prospective study found that nasal mask is superior than oronasal mask in preventing upper airway obstruction, specifically pharyngeal collapse, under the same pressure in 13 participants who underwent drug-induced sleep endoscopy exam with positive airway pressure [31].

Therefore, it is recommended to use the oronasal mask in acute settings, and once the patient's condition becomes stable, switching to nasal mask is preferred, if tolerated [9].

Interface Fitting

After selecting the appropriate interface to the patient, it is crucial to select the correct size to increase patient's tolerance and decrease complications resulted from skin breakdown [8]. To help select the correct size, fitting gauge is usually provided by the manufacturer of the interface and it can be used as a guide [9]. After selecting the appropriate size, it is important to maintain the interface in its place by a well-fitted headgear. The headgear should be made of soft material that allows sweating [32]. The headgear should be fixed symmetrically on a patient according to the instruction. It is also recommended to always permit one to two fingers of distance beneath the headgear to avoid pressure-related skin lesions [33]. Additionally, air leak should be checked around the interface by hands or via the NIV monitoring to ensure the interface is well-fitted [18].

Interface and Carbon Dioxide Rebreathing

It is crucial when selecting the interface to be familiar with the type of the ventilator's circuit that will be used and which type of mask (vented mask or non-vented mask) is suitable with it. NIV can be applied either via closed dual-limb circuit (it has inspiratory limb and expiratory limb and inspiratory and expiratory valves, such as those used with critical care ventilator) or single-limb circuit (it has one limb for both inspiration and expiration) [9].

For the closed dual-limb circuit, a non-vented mask must be used to maintain the closed circuit. In this case, expiration occurs through the exhalation port or filter in the expiratory limb of the circuit. By contrast, single-limb circuit requires either a vented mask (a mask built-in exhalation port) or a non-vented mask and an additional exhalation valve in the circuit. When using a vented mask, expiration occurs through the holes in the mask. If a non-vented mask will be used with the open single-limb circuit, an additional exhalation valve in the circuit must be added to allow carbon dioxide (CO_2) washout. In this case, the exhalation valve is open during expiration to permit CO_2 removal and closed during inspiration to avoid loss of delivered tidal volume. It is recommended to have the exhalation valve near the patient to minimize CO_2 rebreathing [9, 17, 18].

The interface itself can act as additional dead space to the system. Theoretically, the internal volume of the interface can play a role in increasing CO_2 rebreathing.

An in vitro study found that increasing internal volume of an interface can increase CO_2 rebreathing when the face mask (inner volume of 165 mL) is compared to total face mask (inner volume of 875 mL) [34]. The study also reported the position of the exhalation port can affect the CO_2 rebreathing, too. Face mask with a built-in exhalation port (i.e., vented mask) demonstrated lesser CO_2 breathing compared to face mask with an exhalation valve in the circuit [34]. Another study concluded that effective dead space is not related to the internal gas volume of the interface since they found that the effective dead space differed only modestly (110–370 mL) among the three interfaces (oronasal mask, integral mask, and helmet) that had been tested although their internal volumes were markedly different (110–10,000 mL) [35]. The study suggested that internal volume of the interface should not be considered as a limiting factor for their efficacy during NIV [35]. In vivo studies reported that no apparent dead space effect was observed on minute volume, work of breathing, and arterial CO_2 level despite using four interfaces with different internal volumes: two face mask (internal volume of 977 mL and 163 mL), oronasal mask (84 mL), and mouthpiece (virtually no internal volume) [36]. The study suggested that with the exception of mouthpiece, facial interfaces may be interchangeably used in clinical practice with the adjustment of the ventilatory device parameters [36].

Common Interfaces' Problems and Practical Solutions

Problems related to NIV interface is not uncommon. The section below will cover the most common problems such as air leak, skin breakdown, mucosal dryness, eye irritation, and noise. Healthcare providers should be familiar with these problems and how they can be prevented or reduced to optimize the success of NIV therapy.

Air Leak

One of the common interface-related problems is air leaks. Leak can be around the edge of the interface or through the mouth with nasal pillow or nasal mask, or it can be through the nose when the patient uses mouthpiece [9]. Small air leak can irritate the patient. Large air leak interferes with the effectiveness of NIV therapy and then can lead to NIV failure. The large leak can lead to patient-ventilator asynchrony by affecting trigger functions which causes auto-triggering since it can cause a significant drop in the delivered intra-alveolar pressure that reduces the delivered tidal volume [37].

Leak can be prevented by using an appropriate type, size, and headgear of interface. After fitting the mask, it is recommended to place the back of the hand around the interface to assess the presence of leak [18]. Asking the patient about how comfortable they are with the interface and about the eye irritation is also an important step after fitting the interface and throughout the treatment [18]. Regular monitoring of the amount of the unintentional leak on the panel of NIV is recommended.

Additionally, monitoring the flow-time waveform can help in detecting the presence of leak, particularly in dual-limb circuit. When inspiratory tidal volume is similar to the expiratory tidal volume, it is expected to observe that the length of inspiratory flow is comparable to the expiratory flow. In case there is a difference between the length of inspiratory flow and that of expiratory flow in the flow-time waveform, then leak is suspected [38]. The optimal unintentional leak is zero. Small air leak can be compensated by modern ventilators designed for NIV to a variable extent [39]. Sometimes, small air leak does not disturb the patients and can be accepted [18].

Patients who are using nasal mask or nasal prongs and are mouth breather can have leak through the mouth. In this case, using chinstraps can be a solution, but this strategy is not recommended to be used for a long period of time since it can cause jaw or teeth pain and patients' discomfort and can increase snoring due to returning the jaw backward which narrows the airways [12]. Instead, it is recommended to change the interface to a one that covers the mouth, such as oronasal mask. When a leak comes from the nose when a patient uses mouthpiece, nasal clip can be used to prevent the leak [40].

Skin Breakdown

Skin breakdown can be caused by prolonged pressure resulted from the NIV interface or its headgears at the site of skin contact. The affected skin areas depend on the type of interface chosen. However, the most common areas are the bridge of the nose, forehead, and sides of the interface (cheeks, mentum, etc.) [1].

The skin breakdown ranges from transient erythema, prolonged erythema, to skin necrosis in the very severe cases. Pediatric population can experience facial flattening due to pressure from the interface on the growing face. It can be resulted in maxilla underdevelopment that leads to midface flattening and malocclusion of the teeth [10]. To reduce facial flattening, it is advised to change the interface periodically which can alternate pressure points. Additionally, reducing the number of ventilation hours if the patient's condition is allowed can help in reducing facial growth restriction [40, 41].

To prevent skin breakdown related to the interface, it is crucial to select an appropriate mask type and size to the patient as well as appropriate headgear and optimal tension when fitting the interface and headgear to the patient. Regular assessment of skin integrity especially in the pressure points of the interface is also important to identify early any skin breakdown and to take immediate intervention to avoid further severe skin lesions [18].

To maintain a good seal of the interface without pressurizing the skin, most masks have a cushion [12]. Using water to fill the cushion of a face mask showed delay in the appearance of facial ulcer compared to that filled with air [42].

To reduce or prevent skin damage, pressure relief dressing such as hydrocolloid dressing can be used to improve the situation [43]. Alternating between two types of interface can be another solution to vary the area of skin insulted. Additionally, taking regular breaks from the mask can be another strategy [44].

Mucosal Dryness

Dryness of nasal and oral mucosa is one of the most complained-about issues by the patient which can be caused by either dry, cold air coming from the NIV ventilator or by the unintentional leak [45, 46]. If the cause of mucosal dryness is air leak, then decreasing air leak will help to reduce the dryness. Heated humidification is recommended if the patient reports mucosal dryness or if the secretions are thick and tenacious, making it difficult to be expectorated [44]. Although there is no clear evidence to support using nasal topical treatments (nasal rinses, topical corticosteroids, or decongestants), they have shown to be effective in controlling the nasal symptoms (nasal dryness, inflammation, and irritation) [47].

Eye Irritation

Leak from the interface toward the eye can cause eye irritation and redness, such as conjunctivitis [18]. Therefore, it is important to check the good seal fit of the interface and do regular assessment of interface fit during NIV therapy. In case eyes are affected, artificial tears can be applied [18].

Noise

Noise can be caused by either the leak or by using the high flow system, such as helmet. If the noise is caused by the leak, then the interface must be refitted. If the noise is caused by the high flow system, then earplug can be used [18].

Summary

Effectiveness of NIV therapy depends on selecting the appropriate interface. Different types of NIV interfaces are available. Therefore, healthcare providers should be familiar with the advantages and disadvantages of each interface to help them select the appropriate interface for a patient, taken into consideration the other related factors, such as underlying disease, facial characteristics, patient preference, breathing pattern, staff experiences, and compatibility of the interface with the used ventilator circuit. Proper interface fitting is also challenging; therefore, clinicians should select the appropriate size by using interface's size guide and the appropriate headgears. Additionally, it is crucial to be aware with the problems related to the interfaces to reduce or prevent them by using the recommended strategies. Regular assessment of the interface fitting and its associated related adverse effects is needed throughout the NIV therapy to take early actions, if needed, to optimize the patient's adherence and satisfaction which at the end can lead to successful NIV therapy.

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