

Interfaces and Humidification for Noninvasive Mechanical Ventilation

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During noninvasive ventilation (NIV) for acute respiratory failure, the patient's comfort may be less important than the efficacy of the treatment. However, mask fit and care are needed to prevent skin damage and air leaks that can dramatically reduce patient tolerance and the efficacy of NIV. Choice of interface is a major determinant of NIV success or failure. The number and types of NIV interface has increased and new types are in development. Oronasal mask is the most commonly used interface in acute respiratory failure, followed by nasal mask, helmet, and mouthpiece. There is no perfect NIV interface, and interface choice requires careful evaluation of the patient's characteristics, ventilation modes, and type of acute respiratory failure. Every effort should be made to minimize air leaks, maximize patient comfort, and optimize patient-ventilator interaction. Technological issues to consider when choosing the NIV interface include dead space (dynamic, apparatus, and physiologic), the site and type of exhalation port, and the functioning of the ventilator algorithm with different masks. Heating and humidification may be needed to prevent adverse effects from cool dry gas. Heated humidifier provides better CO₂ clearance and lower work of breathing than does heat-and-moisture exchanger, because heated humidifier adds less dead space.

Key words: noninvasive ventilation, acute respiratory failure, mask, air leak, ventilator, humidification, heat-and-moisture exchanger. [Respir Care 2009;54(1):71–82. © 2009 Daedalus Enterprises]

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Dr Nava has had relationships with ResPironics, ResMed, Dräger, Breathe, and Fisher and Paykel. He reports no other conflicts of interest in the content of this paper.

Dr Nava presented a version of this paper at the 42nd RESPIRATORY CARE Journal Conference, "Noninvasive Ventilation in Acute Care: Controversies and Emerging Concepts," held March 7-9, 2008, in Cancún, México.

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Introduction

Noninvasive ventilation (NIV) has an important role in the treatment of acute respiratory failure (ARF)¹⁻¹² and stable chronic hypercapnic respiratory failure.¹³⁻¹⁵

In the acutely ill patient, comfort may be less important than the efficacy of the treatment. However, even if the mechanical ventilation is short-term, mask fit and care are needed to prevent skin damage. Choice of interface is a major determinant of NIV success or failure, mainly because the interface strongly affects patient comfort.^{16,17}

Interface choice can strongly influence the development of NIV problems, such as air leak, claustrophobia, facial skin erythema, acneiform rash, skin damage, and eye irritation.¹⁸⁻²⁶ In a survey of over 3,000 home-care patients ventilated with continuous positive airway pressure (CPAP), Meslier et al²⁷ found that only about half of the patients classified their interface fit as “good” or “very good.” A review based on a MEDLINE search¹⁸ found that in studies in which NIV was used to treat ARF, oronasal mask was used in 70% of the cases, and nasal mask was used in the remaining 30%.

Recent data²⁸ collected in a Web-based survey of about 300 intensive care units and respiratory wards throughout Europe confirmed that oronasal masks are the most commonly used for ARF, followed by nasal masks, full-face masks, and helmets. The main reasons for that preference were the nurses’ and/or respiratory therapists’ confidence, patient comfort, and minimization of leaks and complications.

Characteristics, Advantages, and Disadvantages of the Various NIV Interfaces

In the last few years the industry has made a great technological effort to better meet the preferences of patients and the needs of clinicians and provide more comfortable, better-tolerated, easier-to-use, and safer interfaces. Table 1 summarizes the characteristics of an ideal NIV interface. Because patient anatomy differs dramatically, proper selection of the interface size is mandatory to achieve the best clinical results.

The classes of NIV interface are:

- Mouthpiece: placed between the patients lips and held in place by lip-seal
- Nasal mask: covers the nose but not the mouth
- Nasal pillows: plugs inserted into the nostrils
- Oronasal: covers the nose and mouth
- Full-face: covers the mouth, nose, and eyes²²
- Helmet: covers the whole head and all or part of the neck; no contact with the face or head²⁹

Table 1. Characteristics of an Ideal Noninvasive Ventilation Interface and Securing System

Ideal interface
Leak-free
Good stability
Nontraumatic
Light-weight
Long-lasting
Nondeformable
Nonallergenic material
Low resistance to airflow
Minimal dead space
Low cost
Easy to manufacture (for the molded interfaces)
Available in various sizes
Ideal securing system
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
Disposable, for hospital use

Interfaces include standard commercially available, ready-to-use models in various sizes (pediatric and adult small, medium, and large) or custom-fabricated, molded directly on the patient or from a molded cast previously obtained.^{21,23} Depending on the model, the time required to custom-fabricate a mask ranges from 10 to 30 min for a skilled operator,^{24,25} so custom-fabricated masks are not for critically ill patients in ARF.

Some masks are formed from a single piece of material, but many commercially available masks consist of ≥ 2 parts: the cushion of soft material (polyvinyl chloride, polypropylene, silicon, silicon elastomer, or hydrogel) that forms the seal against the patient’s face, and the frame of stiff material (polyvinyl chloride, polycarbonate, or thermoplastic), which in many models is transparent. The 2 parts may be glued or hooked together. With a modular mask the face-seal cushion can be replaced, so the frame can be used longer than a mask without a replaceable seal, which may reduce cost. There are 4 types of face-seal cushion: transparent noninflatable, transparent inflatable, full hydrogel, full foam.

The mask frame has several attachment points (eg, prongs) to anchor the headgear. The higher the number of attachment points, the higher the probability of obtaining the best fit and the greater the ability to target the point of maximum pressure. Prongs positioned more peripherally produce a more uniform pressure distribution.²⁶ Many types

Table 2. How to Reduce the Risk of Skin Damage During Noninvasive Ventilation

Rotate various types of interfaces
Proper harness and tightening
Skin and mask hygiene
Nasal-forehead spacer (to reduce the pressure on the bridge of the nose)
Forehead pads (to obtain the most comfortable position on the forehead)
Cushioning system between mask prong and forehead
Remove patient's dentures when making impression for molded mask
In home care, replace the mask according to the patient's daily use
Skin pad (Restore, Hollister, Libertyville, Illinois; or Duoderm, Bristol-Myers Squibb, Princeton, New Jersey)

of strap assemblies are available.¹⁷ Straps secure with hooks or Velcro.

Some masks have one or more holes in the frame, to prevent rebreathing. Such a mask should not be used with a circuit that has separate inspiratory and expiratory limbs or with an expiratory valve or other external device for CO₂ clearance.

The mask 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. There can also be additional ports in the frame, to add oxygen or measure airway-opening pressure and/or end-tidal CO₂.

A few nasal mask models have flexible tubing between the frame and the connector, to improve comfort by allowing patient movement without affecting mask stability. However, the tubing increases dead space (V_D), which may be important with low tidal volume (V_T).

A mask-support ring, which is available for most nasal masks, provides extra support to the flail or cushion. A comfort flap (which is a thin, flexible membrane) reduces leak by improving the seal. A tube adapter allows insertion of a nasogastric tube and prevents the air leak and facial-skin damage that could occur if the nasogastric tube were tucked under the seal of a conventional mask.^{17,19}

Chin straps, lips seals, and mouth taping have been proposed as means to prevent air leaks,^{16,17} but, in our opinion those strategies, with a few exceptions, are quite ineffective.

Reducing the risk of skin damage is one of the major goals (Table 2). The most common sites of friction and skin damage are the bridge of the nose, the upper lip, the nasal mucosa, and (with the helmet) the axillae. 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. A simple method to avoid this risk is to leave enough space to allow 2 fingers to pass beneath the headgear.²⁶ A small amount of air leak is acceptable and should not strongly affect patient-ventilator interaction.³⁰

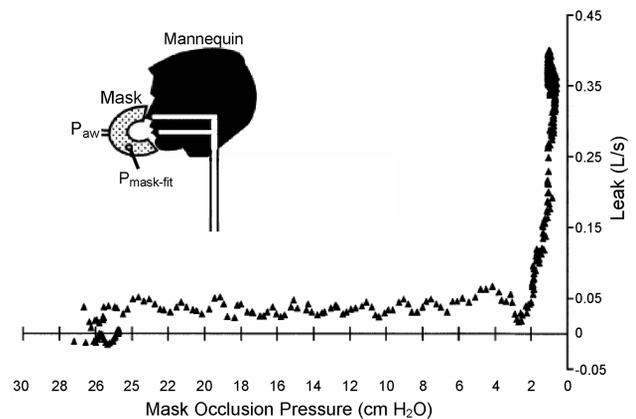


Fig. 1. Mask leak versus mask pressure against the face, as measured by the pressure inside the mask cushion (P_{mask-fit}). Mask-occlusion pressure = P_{mask-fit} - P_{aw} (airway pressure). (Adapted from Reference 38.)

Masks that have angle adjustments between the forehead support and the interface can help prevent pressure and friction against the bridge of the nose. Wound-care dressing has also been used to limit or treat skin damage.³¹ Rotating interfaces might reduce the risk of skin damage, by changing the distribution of pressure and friction, especially on the bridge of the nose.²⁰ Long-term use of tight-fitting headgear retards facial skeletal development in children.^{32,33}

Physiologic Aspects

Air leaks may reduce the efficiency of NIV, reduce patient tolerance, increase patient-ventilator asynchrony (through loss of triggering sensitivity), and cause awakenings and sleep fragmentation.^{34,35} During pressure-support ventilation (PSV) leaks can hinder achievement of the inspiration-termination criterion.^{30,36} In patients with neuromuscular disorders receiving nocturnal NIV, leaks are associated with daytime hypercapnia.³⁷

Schettino et al³⁸ studied air leaks and mask mechanics and estimated the pressure required to seal the mask to the skin and prevent leaks (mask-face seal pressure) as the difference between the airway pressure and the mask pressure against the face (measured as the pressure inside the mask cushion) (Fig. 1). With mask-face seal pressure > 2 cm H₂O the air leaks were negligible and nearly constant, whereas with mask-face seal pressure < 2 cm H₂O air leaks became relevant. Higher mask pressure against the face decreases air leaks, as does decreasing the airway pressure applied by the ventilator. However, if the mask pressure against the face exceeds the skin capillary pressure and therefore impairs tissue perfusion, this can cause skin damage.¹⁷⁻³⁹ Table 3 lists methods to reduce air leak.

Table 3. How to Reduce Air Leaks During Noninvasive Ventilation

Proper interface type and size
Proper securing system
Mask-support ring
Comfort flaps
Tube adapter
Hydrogel or foam seals
Chin strap
Lips seal or mouth taping

Alveolar ventilation decreases as dynamic V_D (ie, the physiologic V_D plus the apparatus V_D) increases. The physiologic V_D depends on V_T , whereas the apparatus V_D depends on the inner volume of the interface.

Navalesi et al²⁰ measured the differences in apparatus V_D between a nasal mask and a full-face mask. Although the in vitro difference was substantial (full-face mask 205 mL vs nasal mask 120 mL), the in vivo results (which took into account anatomical structures) were similar (full-face mask 118 mL vs nasal mask 97 mL). Nasal pillows add very little V_D and can be as effective as face mask in reducing P_{aCO_2} and increasing pH, but are less tolerated by patients.²⁰

Different flow patterns and pressure waveforms may also influence the apparatus V_D . Saatci et al⁴⁰ found that a face mask increased dynamic V_D from 32% to 42% of V_T above physiologic V_D , during unsupported breathing. The addition of positive end-expiratory pressure lowered dynamic V_D nearly to physiologic V_D . Pressure support without positive end-expiratory pressure reduced dynamic V_D less, which left dynamic V_D higher than physiologic V_D .

Other investigators confirmed the importance of the site of the exhalation ports on CO_2 rebreathing.⁴¹ CO_2 clearance was better with the exhalation port built into the mask.⁴²

The helmet has a much larger volume than any of the other NIV interfaces (always larger than V_T), and the helmet behaves as a semi-closed environment, in which the increase in inspired partial pressure of CO_2 is an important issue. In a pressurized aircraft a fresh gas flow of about 200 L/min/passenger is usually needed to keep the inspired partial pressure of CO_2 at the recommended value.⁴³ Inspired partial pressure of CO_2 in a semi-closed environment depends on the amount of CO_2 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 CO_2 , but only the rate at which the predicted inspired partial pressure of CO_2 is reached. Therefore, decreasing the size of the helmet will not necessarily prevent CO_2 rebreathing. Anything that increases helmet ventilation (eg, air leak, delivery of

fresh gas) may decrease the inspired partial pressure of CO_2 .

Taccone et al⁴⁴ found in a bench study with a lung model and helmets of various sizes that a 33% reduction in helmet volume had no effect on the amount of CO_2 rebreathing at steady state. During either CPAP or NIV, a helmet affects CO_2 clearance.^{28,45-55} High gas flow (40–60 L/min) is required to maintain a low inspired partial pressure of CO_2 during helmet CPAP.⁴⁵ In contrast, when they delivered CPAP with a ventilator, Taccone et al found considerable CO_2 rebreathing.⁴⁴ 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 CO_2 , CPAP is delivered with a gas flow that is equal to the patient’s minute ventilation.

The effect of a helmet on CO_2 during NIV was also evaluated in 2 physiologic studies.^{51,52} In both the studies the inspired partial pressure of CO_2 was significantly higher with helmet PSV than with mask PSV.

Patient-ventilator asynchrony may increase with interface volume. However, a recent study of 2 full-face masks found no significant negative effect from V_D on gas exchange or patient effort.⁵⁶

In contrast, studies of masks versus helmets found helmet less efficient in unloading the respiratory muscles,⁵⁴ especially in the presence of a resistive load,⁵² and higher likelihood of patient-ventilator asynchrony. 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 pressurize the helmet.^{49,51,52} Some portion of inspiratory effort is unassisted because of greater inspiratory-trigger and expiratory-trigger delay.^{52,54} Helmet ventilation may require doubling the minute ventilation to maintain an end-tidal P_{CO_2} value similar to that with mask ventilation.⁵² And 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 a 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 CPAP or PSV pressure decreases the delay in helmet PSV and should therefore be considered whenever possible.⁵³

Oral Interfaces

Figure 2 shows oral NIV interfaces, which are of 2 types: standard narrow mouthpieces with various degrees of flexion, which are held by the patient’s teeth and lips; and custom-molded bite-plates. Oral interfaces are used, especially in North America, for long-term ventilation of patients with severe chronic respiratory failure due to neu-

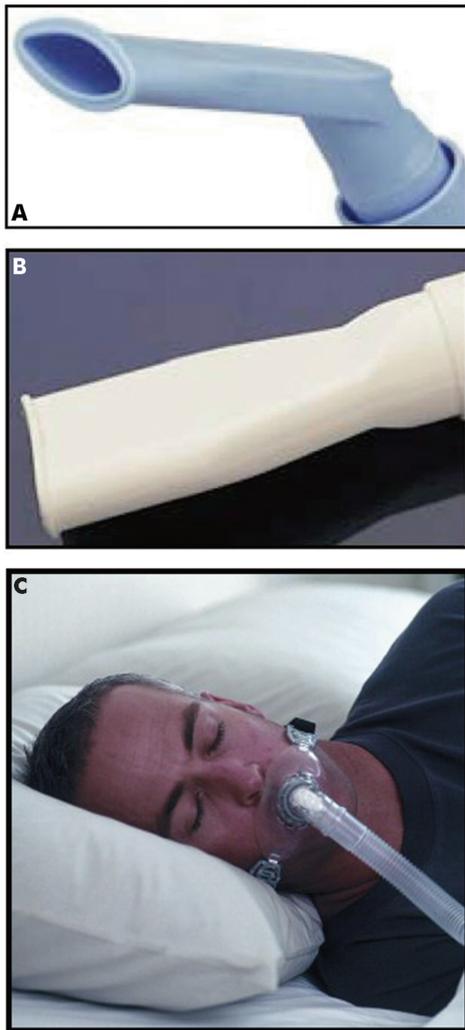


Fig. 2. Oral interfaces. A and B: Respironics. C Fisher and Paykel Oracle. (Courtesy of the manufacturers.)

romuscular disease.^{57,58} In subjects who required several hours of ventilatory support, Bach et al⁵⁷ reported the sequential use of a narrow flexed mouthpiece during the daytime and a nasal mask overnight. They suggested the possible use of a standard mouthpiece with lip-seal retention or custom-molded orthodontic bites for overnight use.⁵⁷

One study used mouthpieces in patients with cystic fibrosis and acute or chronic respiratory failure.⁵⁹ A recent preliminary study suggested that mouthpiece is as effective as a full-face mask in reducing inspiratory effort in patients receiving NIV for ARF.⁵⁶

Several types and sizes of mouthpiece are commercially available, to improve patient comfort and patient adherence to NIV. A standard mouthpiece is available that the patient can hold in place with his or her teeth and can therefore easily be expelled.

Mouthpieces may elicit gag reflex, salivation, or vomiting. Long-term use can also cause orthodontic deformi-

ties. Vomit aspiration is another potential complication, though so far that risk has only been theoretical.⁵⁷ Mouth air leaks may be controlled with a tight-fitting lip seal. Nasal pledges or nose clips can be used to avoid air leak through the nares.⁵⁷ However, air may be swallowed and cause gastric distention.

Nasal Masks and Pillows

Figure 3 shows nasal masks, which are preferable for long-term ventilation but have also been used for acute hypercapnic^{1,2,9,60-66} and hypoxemic^{64,67-75} respiratory failure. Preliminary studies with normal adults suggested that nasal ventilation is of limited effectiveness when nasal resistance exceeds 5 cm H₂O.⁷⁶ Types of nasal mask are:

- Full nasal mask: covers the whole nose
- External nostril mask (also called nasal slings): applied externally to the nares

Table 4 summarizes advantages of and contraindications to nasal masks. Nasal pillows (Fig. 4), like nasal slings, have less V_D than do masks, are less likely to produce claustrophobia, and allow the patient to wear glasses.¹⁷ They offer advantages similar to those of nasal masks; they allow expectoration, food intake, and speech without removing the mask.

With nasal pillows and masks, the presence of expiratory air leak makes V_T monitoring unreliable.²⁰ Nasal pillows can be alternated with oronasal and nasal masks to minimize friction and pressure on the skin, at least for a few hours, which could improve tolerance of NIV and therefore allow more hours of ventilation per day. The advantages of and contraindications to nasal pillows are the same as for nasal masks.

Oronasal and Full-Face Masks

Fig. 5 shows some oronasal masks. Oronasal masks are preferred for patients with ARF, because those patients generally breathe through the mouth to bypass nasal resistance.⁶¹ Recent engineering advances remarkably improved mask-face seal comfort and added quick-release straps and anti-asphyxia valves to prevent rebreathing in the event of ventilator malfunction.

A full-face mask (Fig. 6) has a soft cuff that seals around the perimeter of the face, so there is no pressure on areas that an oronasal masks contacts. The frame of the full-face mask includes an anti-asphyxia valve that automatically opens to room air in case of ventilator malfunction when airway pressure falls below 3 cm H₂O.

Oronasal and full-face masks are preferred for patients with severe ARF. In less severe ARF we recommend switch-

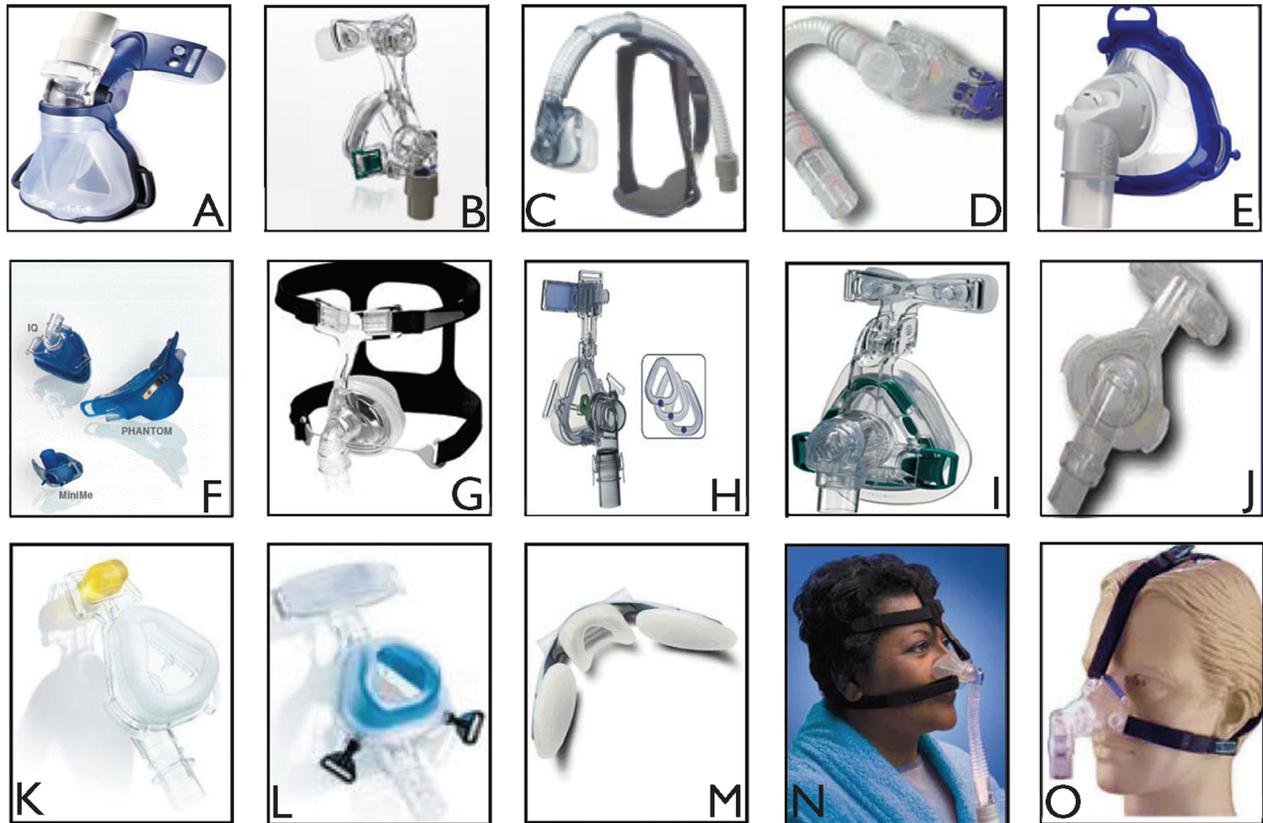


Fig. 3. Nasal masks. ResMed (A) Papillon, (B) Vista, (C) Activa, (D) Mirage Micro, (E) Hospital Mirage Micro. (F) SleepNet IQ, Phantom, and MiniMe. (G) Fisher and Paykel HC407. (H) Koo Deluxe. (I) Hans Rudolph Nasal Alizes 7800. (J) Viasys Hospital Nasal Mask. (K) Respirationics (L) Comfort Classic, (M) Comfort Curve, (N) Simplicity. (O) Covidien Breeze DreamSeal. (Courtesy of the manufacturers.)

Table 4. Advantages of and Contraindications to Nasal Masks for Noninvasive Ventilation

Advantages	
Less interference with speech and eating	
Allows cough	
Less danger with vomiting	
Claustrophobia uncommon	
No risk of asphyxia in case of ventilator malfunction	
Less likely to cause gastric distension	
Contraindications	
Relative	
Edentulism	
Mouth open during sleep	
Absolute	
Respiration from the mouth or unable to breath through the nose	
Oronasal breathing in severe acute respiratory failure	
Surgery of the soft palate	

ing for a short period to a nasal mask, which is better tolerated,²⁰ or nasal pillows, which are less likely to cause skin damage. However, in mild ARF we recommend trying a nasal mask first, and switching to a oronasal or full-face mask only if necessary. Table 5 describes the

advantages of and contraindications to oronasal and full-face masks.

Helmets

A mechanical-ventilation helmet (Fig. 7) has a transparent hood and soft (polyvinyl chloride or silicon) collar that contacts the body at the neck and/or shoulders. A helmet has at least 2 ports: one through which gas enters, and another from which gas exits. The helmet is secured to the patient by armpit straps. All the available helmets are latex-free and available in multiple sizes.

Helmets were originally used to deliver a precise oxygen concentration during hyperbaric oxygen therapy. The United States Food and Drug Administration has not approved any of the available helmets, but helmets have been approved in some other countries.^{28,29,44-54,77-87} Recent engineering improvements gave helmets more comfortable seals, better seal against leak, and anti-asphyxia valves to prevent rebreathing in the event of ventilator malfunction. Table 6 describes the advantages of and contraindications to helmets.



Fig. 4. Nasal pillows. A: Covidien Breeze. B: Aeiomed Headrest. ResMed (C) Mirage Swift II and (D) Mirage Swift. E: InnoMed Nasal-Aire II. F: Fisher and Paykel Infinity. G: Resprionics OptiLife. H: Resprionics Comfort Lite 2. (Courtesy of the manufacturers.)

Humidification During NIV

Humidification and warming of the inspired gas may be needed to prevent the adverse effects of cool, dry gases on the airway epithelium. Unidirectional inspiratory nasal airflow, which can worsened by mouth air-leak, can dry the nasal mucosa, because the nasal mucosa receives little or none of the moisture it would receive from the exhaled gas.⁸⁸ The nasal mucosa can lose the capacity to heat and humidify inspired air, and the mucosa progressively dries and releases inflammation mediators such as leukotrienes, with an associated increased vascularity.⁸⁹ If the gas delivered from the ventilator is not humidified, it will have lower than the ambient air,⁹⁰ and this is particularly true as the level of inspiratory support increases.⁹¹ Humidification can prevent these adverse effects. The 2 types of humidification device, heated humidifier, and heat-and-moisture exchanger (HME), are used both for both short-term and long-term NIV.⁹² HMEs are widely used in intubated patients, because HMEs are easy to use and may be less expensive than heated humidifiers. However, an HME, which is usually placed between the Y-piece and the interface, can add an important amount of dead-space, com-

pared to a heated humidifier, which is placed in the inspiratory limb.

Two papers published in 2002 that compared the physiologic effects of HME and heated humidifier found similar results. Jaber et al⁹³ found, in 24 patients, that, compared to heated humidifier, HME was associated with significantly higher P_{aCO_2} . HME was also associated with significantly greater minute ventilation and mouth occlusion pressure at 0.1 s. Lellouche and co-workers⁹⁴ found that hypercapnic patients' inspiratory effort was markedly greater with HME. Alveolar ventilation was maintained only at the expense of a greater work of breathing with HME than with heated humidifier. With zero positive end-expiratory pressure, NIV with HME failed to improve at all the inspiratory effort over the baseline value. Both Jaber et al⁹³ and Lellouche and et al⁹⁴ concluded that humidification devices can strongly affect some physiologic variables. Note that in those 2 studies the patients used face mask. Heated humidification with a helmet would probably be difficult or impossible because of condensation of water inside the helmet ("fog" effect).

Based on the few physiologic and clinical data available, we recommended heated humidification during NIV

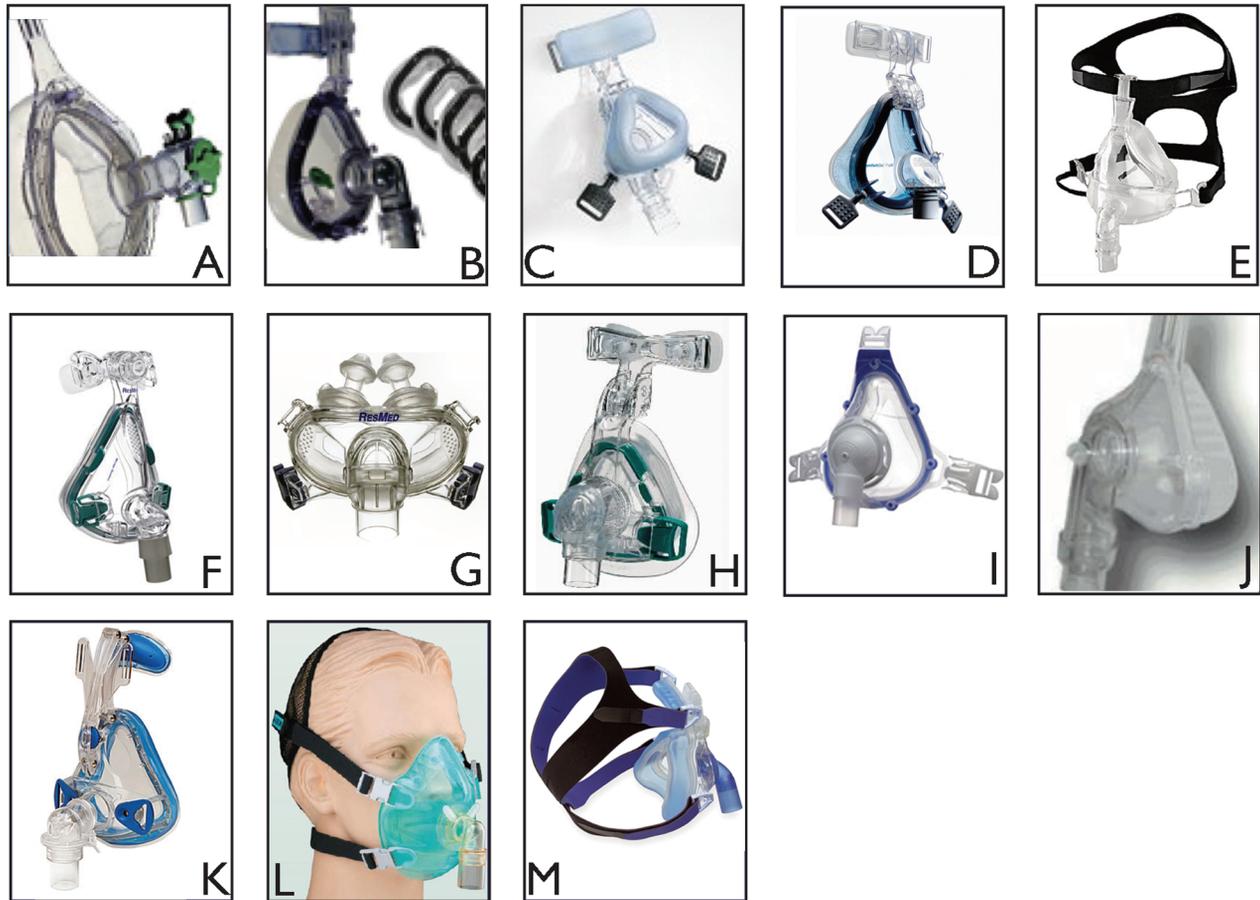


Fig. 5. Oronasal masks. Koo (A) Blustar, (B) Blustar Plus. Respironics (C) Comfort Fusion, (D) Comfort Gel. E: Fisher and Paykel HC431. ResMed (F) Mirage Quattro, (G) Liberty, (H) Mirage, (I) Hospital Mirage. J: Viasys. K: SleepNet Mojo. L: Hans Rudolph VIP 75/76. M: Weinmann Joyce. (Courtesy of the manufacturers.)



Fig. 6. Full-face masks. Left: Respironics Total. Right: Respironics Performax. (Courtesy of Respironics.)

for ARF, to minimize work of breathing and maximize CO₂ clearance. On the other hand, in long-term use heated humidifier and HME had similar patient tolerance and adverse effects,⁹² so at present we do not make a recom-

Table 5. Advantages of and Contraindications to Oronasal Masks for Noninvasive Ventilation

Advantages Compared to Nasal Mask
Fewer air leaks with more stable mean airway pressure, especially during sleep
Less patient cooperation required
Contraindications
Relative
Tetraparetic patients with severe impairment in arm movement
Absolute
Vomiting
Claustrophobia

mendation about heated humidifier versus HME for patients with chronic respiratory failure.

Summary

Even though the commercial availability of NIV interfaces is increasing and new products continue to be re-

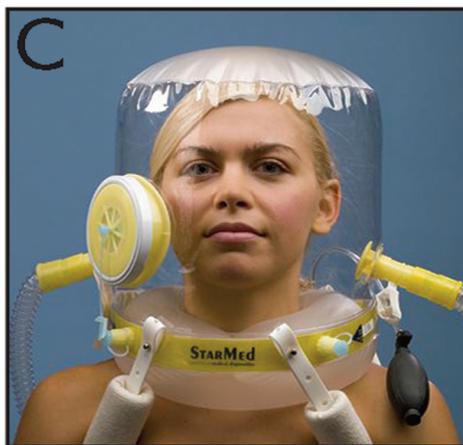
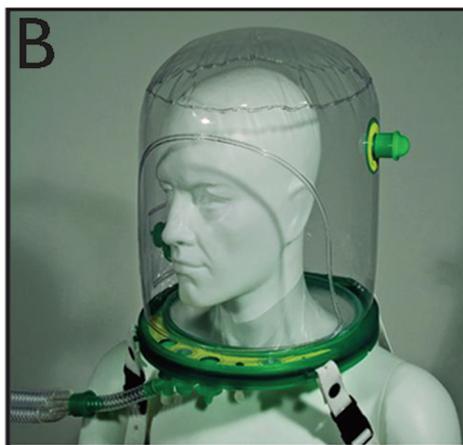
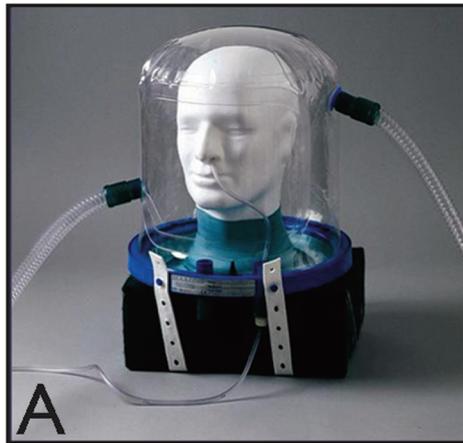


Fig. 7. Helmets. Harol (A) NIV10201, (B) NIV10301/X. C: StarMed Castar R. (Courtesy of the manufacturers.)

leased, there is no perfect NIV interface best for all patients in all situations. The choice of NIV interface requires careful evaluation of the patient, the ventilation mode, and of the clinical setting.⁹⁵⁻⁹⁷ Individualization is key to making the right choice of NIV interface. The severity of ARF, patient tolerance of the interface, and avoidance of adverse

Table 6. Advantages of and Contraindications to Helmets for Noninvasive Ventilation

Advantages Compared to Oronasal Mask	
Less resistance to flow	
Can be applied regardless of the facial contour, facial trauma,* or edentulism	
Allows coughing	
Less need for patient cooperation	
Better comfort	
Less interference with speech	
Securing system has lower risk of causing skin damage	
Contraindications	
Relative	
Need for monitoring of volumes	
Difficult humidification	
Absolute	
Claustrophobia	
Tetraplegia	

* Consider the risk of pneumocephalus with every interface.

effects and problems such as air leak may be major determinants of NIV success and should always be kept in mind.

“I’ve been all around the world, to meet different faces everywhere.”⁹⁸

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Discussion

Keenan: At my institution we primarily use the full-face mask. There's good and bad to that. One thing that I notice is that the RTs who like to use this mask seem to have really bought into NIV. They like that there is one mask, you don't have to start fitting different sizes, and I think their enthusiasm for NIV has improved. Probably in centers that are just starting an NIV program the full-face mask is a little easier to use. I guess the potential down side is that the art of fitting the other types of masks may be lost or not developed, so with patients for whom the full-face mask doesn't work, the RT might be slower to find a good fit with an oronasal mask.

We rarely use nasal masks, but I saw one case where nasal mask proved useful, in a young patient with asthma, who was about 19 years old, who came from the pediatric hospital. He wanted

a nasal mask and we gave him one. Our practice for administering bronchodilators to patients with obstructive lung disease is to let the patient settle for a while on NIV and then take it off and deliver nebulized medication. After doing this a few times with this young fellow, and having him almost decompensate, we realized his mouth was available to inhale aerosol, and we used a puffer. So there is that potential with a nasal mask in some people who are very dependent on the ventilator to use a puffer with an Aero-Chamber to administer bronchodilator. We haven't adopted this as a practice, but it is one advantage of a nasal mask.

Nava: About the full-face mask: I agree with you that it is easy to set and to use, but there are 2 problems. The first is that we start NIV with an oronasal mask before the full-face mask, so most of the people are con-

fident with oronasal mask, and so we see full-face mask as a last resort if the patient is not adapting to any other mask. The other issue is that the full-face mask is quite expensive, and it's single-use, so you want to reserve it for patients who are pretty sick. I've found, personally—this is totally anecdotal and there is very little evidence—that full-face masks work pretty well in comatose patients, in whom the sensorium is blunted. Very active patients do not find full-face mask very comfortable.

Concerning the nasal mask, my group found in a recent survey that nasal masks were mainly used in the medical ward in the pulmonology department. So I think we need to look at the data, because we may think that the use of nasal mask is reserved for patients with very mild COPD exacerbation, with pH between 7.30 and 7.35. They're not really really sick, so probably they can stand nasal mask

better than oronasal mask, and the amount of leaks is probably not important.

Hill: Regarding mask dead space, I think the term “dead space” is a bit misleading, because we’re usually talking about mask *volume*. The full-face mask is a good example of how an NIV interface can have a very large mask volume, and yet the effective dead space really isn’t that great. You referred to that as dynamic dead space. Shouldn’t we be more careful about using the term “dead space” with regard to masks?

Nava: Yes, but again it is a matter of terminology, because most of the studies refer only to dead space. I think dynamic dead space is better.

Kacmarek: I think the problem is when you discuss dead space you’re talking about a specific volume of gas. When you look at the functioning of a mask on a patient, especially if there is leak, you’re clearly going to have tracking of gas flow that essentially eliminates some of that gas volume from equilibrating, and the impact is different than gas moving through connecting tubing, in which mixing is complete. With NIV masks you may have large portions of the mask volume essentially isolated, particularly the more rapid the rate. So, conceptually, I think it’s reasonable to suspect that a mask with a bigger in vitro dead space would have greater difficulty eliminating CO₂ than a mask with less dead space, but the larger dead space might not affect P_{CO₂} during clinical application.

Hill: The Respironics PerforMax full-face mask is smaller than Respironics’ Total full-face mask and larger than a standard oronasal mask. PerforMax seals over the eyebrows and extends to the chin, and it resembles a scuba diving mask. That design might have advantages over currently avail-

able masks, for some patients. Do you have any experience with it?

Nava: We tried it, and, anecdotally, patient-ventilator interaction looked good. When the ventilator is properly set, the trigger delay and the shape of the flow and pressure all worked fine, as expected. So it may be a good alternative. But, again, that mask is new, so we need to be cautious. I would say that, theoretically, it could be fine, and from the physiologic point of view that I tried, it was good, but it needs to be evaluated clinically.

Hess: Regarding Sean Keenan’s point about the delivery of aerosols: Stefano’s [Nava] work and work we’ve done in our laboratory showed that aerosols can be effectively delivered during NIV, with either a nebulizer or a metered-dose inhaler and spacer.¹

Regarding rebreathing—and we addressed this in some of our work with the helmet a few years ago²—with interfaces for NIV, rebreathing is not so much a conventional dead space, where you think about it as an extension of the anatomic dead space. It’s an issue of the flow through the interface. So it’s more like clearing CO₂ from a submarine than clearing CO₂ from an extension of the anatomic dead space.

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Nava: I agree.

Epstein: The studies that have compared the various interfaces have been very small. There have to be numerous confounders, the most important of which is the physiognomy of the patient’s face. How reliable are these

kinds of analyses? Is this still more art than science in this aspect of NIV?

Nava: Yes, I think this issue of interface is more art than science so far, just because people’s faces are so different. Individualization is a big issue.

Mehta: I want to raise a practical issue that the trials don’t capture. At Mount Sinai Hospital our protocol stipulates that if NIV is started on the ward, it has to be via nasal mask, not oronasal mask, because of the potential issue of vomiting and aspiration. Even though the incidence of that is very low, there is a concern that if the patient becomes comatose, he would be unable to remove the mask in the event of vomiting. Do you have any comments about that?

Nava: That is what I also said. It came out in our survey that when I applied NIV outside the ICU, there was a lot of space for nasal ventilation, but usually those patients are not really sick. Again, it’s about timing. If you want to prevent further deterioration, you may use a nasal mask in a not-very-sick patient, but when worse comes to worst, I think you need to use oronasal mask.

Mehta: I agree. Most patient in acute respiratory distress are mouth breathers, and with nasal mask, mouth leak can be a substantial problem. As you mentioned, the chin strap is not very effective, so an oronasal mask is the best option.

Kacmarek: Regarding masks used outside the ICU, we do NIV starts outside the ICU, we use oronasal mask in over 95% of NIV starts with acutely ill patients, and we have not had a problem with gastric distension or vomiting. It has been a non-issue. I think the frequency of that complication is exaggerated. It may be because in the vast majority of patients we also limit peak inspira-

tory pressure to about 20 cm H₂O, and in most patients I don't think you need a pressure that high. So we have not restricted the use of oronasal masks to the ICU only.

Hill: Bob, what about the use of hand restraints on patients with full-face masks?

Kacmarek: We should not be restraining patients on NIV. This is supposed to be a consensual therapy, and tying the patient's hands implies lack of consent. We fight with this issue all the time, as I'm

sure many of you do. It does happen to patients in the emergency department who are semi-comatose when NIV is first applied, but it should only be short-term. Once the patient is alert then restraints are inappropriate, I think. Also, if the patient runs into problems, restraints would prevent him from removing the mask. With every patient receiving NIV via oronasal mask, even if it's only for nocturnal CPAP, we add a ventilator-disconnect alarm that is integrated into the nurse-call system and is annunciated at the nursing station and in the hallway.

Nava: In Devlin's survey¹ in North America, 24% of the ICU patients undergoing NIV were restrained. In Europe it's probably the only ethical concern we have about the use of NIV. We need to have written permission from a relative unless the patient has a severe psychiatric disease, in which case the psychiatrist can come to the bedside and grant the permission. It's a complicated issue.

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