A Practical Guide to Mechanical Ventilation

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Edited by Jonathon D. Truwit and Scott K. Epstein.
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Part I
Noninvasive ventilation

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1.1 Introduction to noninvasive ventilation

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1.1.1 Case presentation

You are called by a 45-year-old male with amyotrophic lateral sclerosis after recently starting him on nocturnal noninvasive ventilation by a nasal mask. He stated that his symptoms of morning headache and daytime fatigue have improved slightly. However, he can only wear the nasal mask for a few hours at a time. He has an air leak from the mask which leads to dryness of his eyes. He also states that his sinuses feel "stopped up" at the end of each use. In response to this, he has tightened the straps of the nasal mask. This helped decrease the air leak, but now he has developed soreness at the bridge of his nose, and he fears that the skin will break down. What should be done to help him?

1.1.2 Introduction

Over the past twenty years, evidence for the use of noninvasive ventilation (NIV) in acute and chronic respiratory failure has led to its widespread use. In fact, for several conditions, including acute chronic obstructive pulmonary disease (COPD) exacerbations, NIV is part of the recommended patient management. However, a

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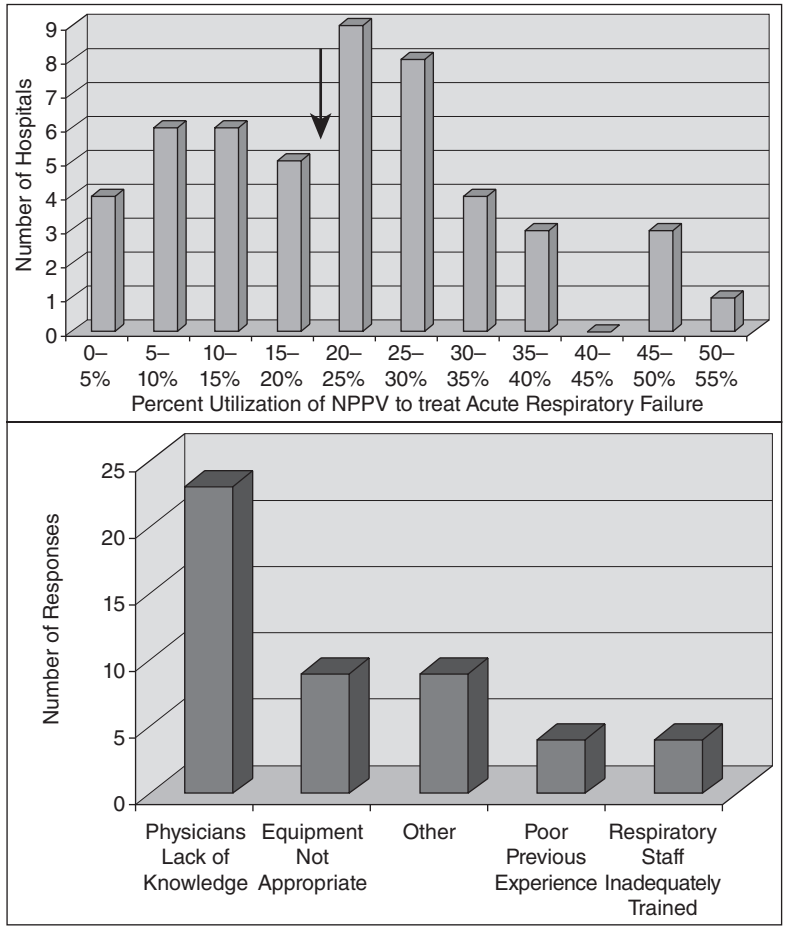

Figure 1.1.1 (Top) The use of NIV in the setting of acute respiratory failure varies widely between hospitals, with a median use of 20%. (Bottom) The most common reason for a failure to initiate NIV in the setting of acute respiratory failure is a lack of knowledge by the physician. (Reproduced with permission [1].)

survey by Maheshwari and colleagues [1] showed that NIV is underutilized in the setting of acute respiratory failure in the United States. The reason most often cited for this underutilization was "physicians lack of knowledge." (Figure 1.1.1) Surveys in the United Kingdom [2] and in Europe [3] also found that NIV was underutilized, if hospitals offered it at all. Therefore, it is hoped to increase practitioner awareness regarding the use of NIV. In this chapter, the history of NIV and the basic equipment that is used when using NIV are reviewed.

1.1.3 History

Noninvasive positive pressure ventilation was first used in the 1930s when Barach used continuous positive airway pressure to successfully treat acute pulmonary edema [4]. In the 1940s, the use of intermittent positive pressure breathing (IPPB) became popular and was continued through the early 1980s [5]. IPPB was usually delivered via a mouthpiece and was used to assist with the delivery of nebulized medications for patients with obstructive lung disease. As such, it was used to deliver positive pressure breaths for only about an hour a day, broken into 3–4 intervals. A prospective, randomized, controlled trial sponsored by the National Institutes of Health (NIH) did not show any benefit to using IPPB over nebulized treatments alone in patients with COPD (IPPB trial group). Thereafter, its use slowly declined. Of note, the relatively short course of daily IPPB likely contributed to the poor study results [5]. The use of nocturnal NIV dates back to the 1960s, when patients with neuromuscular disease used either simple mouthpieces or oronasal masks as their interface [5]. While popular at certain centers, the general difficulty using these interfaces prevented widespread use at that time. The use of NIV did not become widespread until the mid-1980s, when the nasal mask was proven an effective means of delivering NIV to patients with obstructive sleep apnea while enhancing comfort and adherence [6]. Since that time, the use of NIV has gained acceptance as a treatment for both acute and chronic respiratory failure in a variety of conditions.

As noninvasive positive pressure ventilation has gained increasing acceptance, the use of noninvasive negative pressure ventilation has declined. The iron lung was invented by Philip Drinker in 1928, improved by JH Emerson in 1931, and was commonly used to treat respiratory failure from acute poliomyelitis through the 1950s [5]. The polio epidemic also led to the creation of the rocking bed, which used gravity to create diaphragmatic movement and create tidal volumes. In addition, the pneumobelt was created around this time. The pneumobelt is strapped around the abdomen, and a rubber bladder inflates to compress the abdomen and assist with diaphragmatic movement. While all of these methods have been used in recent years, they are no longer readily available in most hospitals or from supply companies. Because of its simple design, portability, and relative comfort to the patient, noninvasive positive pressure equipment has largely replaced the iron lung, the rocking bed, and the pneumobelt. Therefore, in the remainder of this text, the discussion of noninvasive ventilation (NIV) will be limited to the use of noninvasive positive pressure ventilation.

1.1.4 Different modes of noninvasive ventilation

1.1.4.1 Selecting a mode

Noninvasive ventilators, like intensive care mechanical ventilators, are controlled by either setting the volume desired for each breath (volume mode) or by setting a pressure that will be delivered to the airway to assist with breathing (pressure mode). Changes in volume and pressure are directly proportional and are linked by lung

and chest wall compliance ($C = \Delta V/\Delta P$). When a volume mode is used, the tidal volume provided by the ventilator will be fixed. If the compliance of the lungs is very low, then a high amount of pressure will be needed to deliver that volume. If there is a leak in the system, then the actual tidal volume delivered to the lungs may be lower than prescribed, as the machine cannot know how much air is delivered to the patient and how much is lost. Alternatively, if a pressure mode is used, the pressure will be fixed and the tidal volume will vary with compliance. The same pressure may generate adequate volumes in a patient with highly compliant lungs but would generate inadequate tidal volumes in a patient with poor chest wall compliance. If there is a leak in the system while in pressure mode, the machine will compensate for the leak until the set pressure is reached, so the patient may receive the same tidal volume regardless of whether or not a leak is present.

NIV also offers the options of being spontaneous, controlled, or a combination (assist-control or spontaneous times mode). If the ventilator is on a spontaneous mode, it will react to a preset patient trigger and will then support the breath. If the patient is apneic, then the ventilator will not deliver any breaths. Alternatively, if the patient is on a controlled mode, then the ventilator will initiate a breath at a time specified by the operator, not the patient. If the patient initiates a breath between ventilator breaths, the ventilator will not support that breath. With combined modes, a respiratory rate is usually set below the patient's spontaneous respiratory rate. If the patient's respiratory rate drops below the specified rate, the ventilator will initiate breaths at this specified rate. If the patient is breathing above the set rate, then each breath will be initiated by the patient and supported by the ventilator.

It is also important to specify whether or not a pressure gradient is applied between inspiration and expiration. Two popular modes of noninvasive ventilation, continuous positive airway pressure (NIV-CPAP) and pressure support (NIV-PS), are pressure modes. However, NIV-CPAP gives a continuous pressure throughout the respiratory cycle. NIV-PS gives additional support during inspiration and a continuous (but lower) pressure during expiration. In the NIV-PS mode, with a BiPAP machine, the inspiratory support is termed the IPAP (inspiratory positive airway pressure), while the expiratory support is termed the EPAP (expiratory positive airway pressure), and the difference between IPAP and EPAP is the amount of pressure support provided. Airway pressures can be regulated by a mechanical ventilator in the PS mode or a BiPAP machine.

With the exception of patients with central sleep apnea, NIV is usually started with a spontaneous mode of breathing. This allows the patient to control the respiratory rate, inspiratory time, and expiratory time. In pressure modes such as NIV-CPAP and NIV-PS, flow (Q) will depend on the set pressures, the patient's respiratory drive, the airway resistance, and the presence or absence of a leak. This can be understood through the equation $Q = \Delta P/R$, where ΔP is the pressure gradient between airway and alveoli as developed by the patient (negative pleural pressure) and ventilator (positive airway pressure) and R is airway resistance.

1.1.4.2 Ventilator triggering

In spontaneously triggered breaths, the ventilator can be triggered by either a change in pressure or by a change in flow. Some ventilators have a preset trigger, while some allow the sensitivity of the trigger to be changed by the operator. If the sensitivity of a ventilator requires a large drop in pressure or change in flow at the airway, then significant effort will be expended by the patient prior to ventilator support, thus increasing the patient's work of breathing. At the other extreme, if the ventilator trigger sensor is responsive to very small changes in pressure or flow then frequent triggering of the ventilator by air leaks and attendant breath stacking may result. Because flow triggering is more sensitive than pressure triggering, it reduces the work of breathing in spontaneous modes and has become the standard method of triggering on newer ventilator models [7, 8].

1.1.4.3 Ventilator cycling

In addition to selecting the proper mode and inspiratory trigger sensitivity, the cycling between inspiration and expiration should be assessed when starting NIV. The trigger for stopping ventilator assistance during inspiration can be either a decrease in flow to a percentage of the maximal flow rate (usually 25% of the maximal rate) or a set flow rate [9]. Some ventilators allow adjustment of this trigger, while others are preset. If the flow rate for breath delivery cessation is too high then the breath will be stopped early. Too low an inspiratory flow rate cut off will result in prolongation of the inspiratory time and increased expiratory work of breathing. This later scenario can be problematic in patients with COPD, who rely of a prolonged expiratory time to prevent auto-PEEP (positive end-expiratory pressure). Therefore, in COPD, a high flow threshold (25–40% of the maximal pressure) should be selected [9].

1.1.4.4 Proportional assist ventilation (PAV)

PAV is a newer mode of ventilation that attempts to assist each breath in proportion to the effort that the patient is able to make. It utilizes an in-line pneumotachograph to continuously track a patient's inspiratory flow. The ventilator can make quick adjustments to the patient's respiratory effort. Therefore, the operator is able to control the proportion of ventilation that is assisted to better closely meet the patient's needs [5]. While small studies have indicated that PAV is more comfortable than NIV-PS [10], this has not yet translated into clinical outcomes. Of the few small studies that have compared PAV with NIV-PS, no significant improvements in hypercapnia [11] or inspiratory muscle unloading [12] were found with PAV.

1.1.4.5 Ventilator type

In the setting of acute respiratory failure, management with NIV requires close monitoring and usually requires care in an intensive care unit or a "step-down" unit.

Portable ventilators were initially designed for home use in patients with chronic respiratory failure. As the applicability of NIV expanded to include certain patient populations with acute respiratory failure, it was recognized that these portable ventilators had shortcomings in the acute setting. These early generation portable ventilators had limited pressure generating capacities (25–35 cm H_2O), lacked oxygen blenders to deliver a high fraction of inspired oxygen (FiO_2), lacked waveform display to assist with ventilator management, and did not have the alarms of an intensive care ventilator [5]. In addition, portable ventilators often have one circuit for both inspiratory and expiratory gases. When the flow through the system is slow, there is a potential for rebreathing carbon dioxide, which can increase the time required to correct hypercapnia [13]. Therefore, intensive care ventilators became the standard for delivering NIV in patients with acute respiratory failure. In 2001, a French survey found that intensive care ventilators were used for NIV in 76% of the cases involving acute respiratory failure [3].

More recent portable ventilators have corrected many of these problems. Current portable ventilators have oxygen blenders and can deliver high FiO_2, they can deliver higher pressures, have improved alarms, and several have waveform analysis. Also, while many still use a single circuit for inspiratory and expiratory gases, setting the EPAP at 4 cm H_2O or greater generally prevents rebreathing [9]. In addition, a small leak (which is usually present in NIV) helps to avoid rebreathing. Portable ventilators have been shown to compensate for leaks better than intensive care ventilators, allowing for improved patient triggering and decreased dysynchrony [14]. However, intensive care ventilators still deliver more accurate FiO_2, have better alarms (which are not always needed with NIV), and have separate tubing for inspiratory and expiratory gases to allow for less opportunity of rebreathing exhaled gas [15]. Therefore, selection must take the patient into consideration. The clinician must also be aware of interventions for potential problems when applying NIV (Table 1.1.1). If the patient is very hypoxemic, an intensive care ventilator may still be preferred to allow more accurate FiO_2. However, in most other settings, newer portable ventilators may improve synchrony and comfort.

1.1.5 Interface

Interfaces are the devices that connect a ventilator circuit to the face. The type of interface used to deliver NIV can have a large influence on patient comfort, adherence with NIV, and efficacy of NIV. The traditional interfaces used to administer NIV are the nasal mask and the orofacial mask (Figure 1.1.2). In the acute setting, either the nasal or the oronasal mask can deliver NIV from either a portable ventilator or a critical care ventilator. Another option is the nasal pillows device. Patients with chronic respiratory failure requiring long-term NIV during the day (in addition to the night) may use the simple mouthpiece or the mouthpiece with lip seal. Recently, the helmet device has been used, although its use is mostly confined to research purposes at present. The choice of which interface to use for a patient requires knowledge of the advantages and disadvantages of each.

Table 1.1.1 Common problems in NIV, problems that may lead to their occurrence, and how to correct the problem.

Problem	Potential cause	Corrective measure
1. Inspiratory trigger failure	Air leak	Adjust mask or change type
	Autocycling	Adjust trigger sensitivity
	Increased work of breathing	Adjust trigger sensitivity or change to a flow trigger if pressure trigger used
2. Inadequate pressurization	Pressure rise time too long	Reduction of pressure rise time
	Pressure support too low	Increase inspiratory pressure
3. Failure to cycle into expiration	Air leak leading to "inspiratory hang up"	Adjust mask or consider switch from nasal to face mask
	High end-inspiratory flow	Increase end-inspiratory flow threshold and set time limit for inspiration
4. CO_2 rebreathing	Single circuit with no true exhalation valve	Use two lines and use non-rebreathe valve
	High respiratory rate	Lower respiratory rate
	No PEEP	Add PEEP to wash out (lavage) mask
	Large mask dead space	Reduce dead space with padding

Reproduced with permission [9].

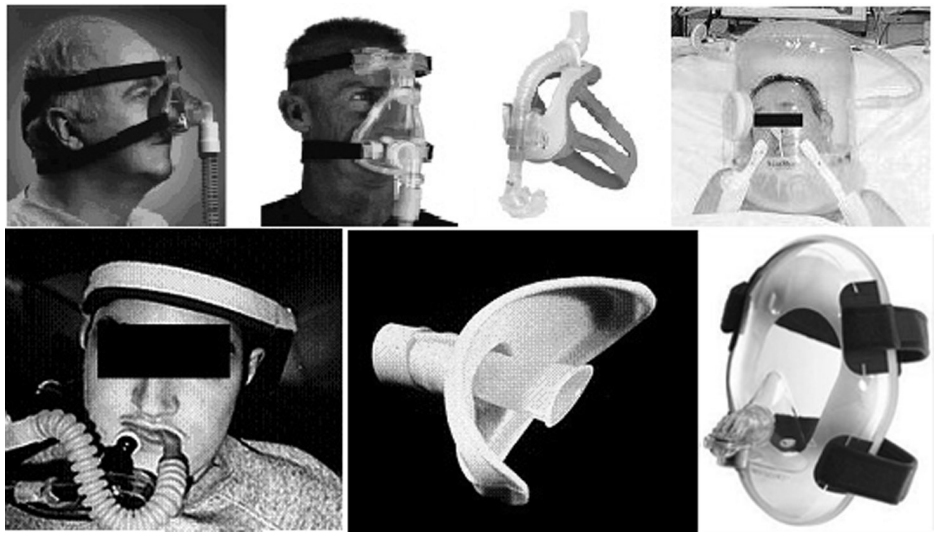

Figure 1.1.2 Common interfaces used to deliver NIV. Top far left: Nasal mask. Top left: Oronasal mask. Top right: Nasal pillows. Top far right: Helmet system. Bottom left: Simple mouthpiece. Bottom right: Mouthpiece with lip seal.

1.1.5.1 Nasal mask and oronasal mask

The nasal mask was the first method for delivering NIV. A comparison between advantages and disadvantages of oronasal and nasal masks is outlined in Table 1.1.2. The nasal mask permits easier expectoration of secretions, liquid consumption and has less respiratory dead space than the oronasal mask. Furthermore, the nasal mask is less claustrophobic than the oronasal mask and patients can talk much easier with a nasal interface. The orofacial mask is more likely to be associated with skin ulceration during prolonged use [16]. However, the nasal mask is very difficult to use in patients with acute respiratory failure (ARF). Patients in ARF are mouth breathers, and this creates a large leak when attempting NIV with a nasal mask. Chin straps and other devices created to decrease the amount of mouth breathing are relatively contraindicated, as the patient is often dependent on this additional ventilation.

Growing evidence supports the common clinical practice of using oronasal interface over a nasal mask in patients with ARF. The oronasal mask provides more rapid improvement in hypercapnia and minute ventilation [17, 18]. Recently, a prospective, randomized, controlled trial compared the utility of the oronasal mask with the nasal mask in patients with ARF [19]. While no difference in rates of intubation or death were noted, most patients (75%) in the nasal mask group were changed to an oronasal mask within six hours due to mouth breathing and the resultant air leak. This study supports the use of the oronasal mask as the standard interface in patients with ARF. However, the duration of continuous oronasal mask use should be limited to decrease the rate of skin ulceration and the time a patient has without oral nutrition. As patients improve, intermittent oronasal mask use or a transition to a nasal mask to enhance comfort and compliance should be considered.

Table 1.1.2 A comparison of the advantages and disadvantages of nasal and oronasal masks.

Clinical aspect	Oronasal mask	Nasal mask
Mouth leak and mouth breathing	+	–
Influence of dental status	+	–
Airway pressure	+	–
Dead space	–	+
Communication	–	+
Eating, drinking	–	+
Expectoration	–	+
Risk of aspiration	–	+
Risk of aerophagia	–	+
Claustrophobia	–	+
Comfort	–	+

A plus indicates superiority of one interface over the other with respect to that clinical aspect.
Reproduced with permission [9].

In the setting of chronic respiratory failure, the oronasal mask is infrequently used. The nasal mask is the preferred interface with nocturnal NIV. The majority of studies in patients using nocturnal NIV have used the nasal mask as the interface, and it is generally well tolerated. However, nasal masks are prone to air leaks. If the mask–face seal pressure is >2 cm H_2O, then a leak is generally avoided [20]. While ventilators made for NIV generally compensate for air leaks and maintain pressure and allow effective triggering, air leaks can still affect the patient's comfort. Air leaks cause a decrease in the absolute humidity of the system, increase patient–ventilator asynchrony, lead to decreased FiO_2, and can lead to irritation of the eyes and dry mouth [14].

Often, the presence of a leak is a sign that the nasal mask is not sized or fitted properly. Nasal masks that are too large often require excessive tightening to prevent air leaks. If one or two fingers cannot be placed inside the straps (usually Velcro), they are probably too tight [21]. Over time, if the mask remains too tight (greater than skin capillary pressure), skin breakdown can occur on the bridge of the nose, sometimes leading to ulceration. In certain populations, such as the immunocompromised, this can be particularly concerning. There are several ways to prevent skin breakdown in patients using nasal masks. Firstly, maintain the lowest mask–face seal pressure that avoids significant leak. Because this pressure is not routinely measured in clinical practice, an experienced practitioner should frequently monitor the mask fit and assess for signs of skin breakdown. Wound care tools (gauze or duoderm) can create padding to prevent injury, but the interface should also be addressed if it is uncomfortable. If the mask has been sized improperly, the correct mask should be supplied immediately. Also, a forehead spacer (Figure 1.1.3) can be used to relieve pressure from the bridge of the nose. Once skin breakdown has developed, the interface should be changed if at all possible. For example, transition from a nasal mask to a full face mask or nasal pillows system may relieve areas with skin breakdown.

When using NIV to treat chronic respiratory failure, humidification has the benefits of decreasing the work of breathing while providing comfort and increasing

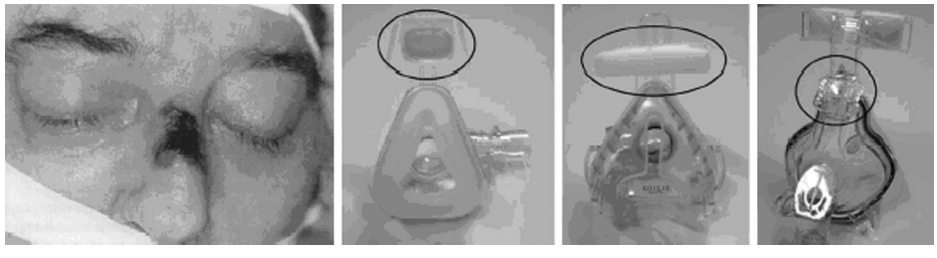

Figure 1.1.3 On the far left, a patient with skin breakdown from a nasal mask. The next three pictures show different forehead spacers that can be used to relieve pressure from the bridge of the nose and prevent skin breakdown.

adherence with NIV [22]. The circuit of the ventilator can be changed to provide heated humidity in certain patients who continue to be "mouth breathers" and are unable to effectively humidify the gases while in their upper airway. However, heated humidifiers should not be routinely used, as most patients do well without their use and they are expensive. A chin strap can be used to prevent mouth breathing in patients using nasal masks. The chin strap can be effective in reducing air leak and hypercapnia in selective patients, although it is not always effective [23].

1.1.5.2 Nasal pillows

Nasal pillows are an alternative to nasal masks for the chronic use of nocturnal NIV. Nasal pillows are two soft plastic plugs that fit into the nares and seal with the help of positive pressure [15]. In patients with obstructive sleep apnea, nasal pillows provided less air leak and better sleep quality compared with the nasal mask [24]. Nasal pillows can also be used for NIV in patients with claustrophobia, who may find this interface less confining compared with nasal masks, oronasal masks, or the helmet. While there is little research comparing nasal pillows to nasal masks in populations other than sleep apnea, they are readily available in clinical practice and commonly used to deliver chronic NIV.

1.1.5.3 Full face mask

Development of a new interface has caused difficulty with current nomenclature. Previously, the oronasal mask had also been called the full face mask. However, with the development of an interface that covers the entire face (Figure 1.1.1), the term full face mask now refers to this interface. The oronasal mask should therefore only be called by this name. The full face mask was developed to decrease skin breakdown, air leaks, and the sense of claustrophobia created in some who use the nasal or oronasal masks [20]. It has been used in patients with acute respiratory failure who could not tolerate oronasal or nasal interfaces. The full face mask was found to significantly improve gas exchange and often prevent intubation in this population [25, 26]. Therefore, if available, it should be considered in those who are candidates for NIV but cannot use an oronasal or nasal mask.

1.1.5.4 Helmet

The helmet has been created as an alternative interface to deliver NIV. It is comprised of a plastic helmet attached to a soft collar (Figure 1.1.1) which fits around the neck. It has been proposed primarily to treat acute respiratory failure as an alternative to the oronasal mask. Because the helmet does not contact the head, it has the advantage of providing increased comfort and longer use compared with the oronasal mask [27]. However, the helmet's large size yields a large dead space, which has raised concerns regarding the ability of the helmet to correct hypercapnic

respiratory failure. In fact, when compared with the oronasal mask in patients with acute respiratory failure, the helmet has a smaller reduction in carbon dioxide levels compared with the oronasal mask, and this may have contributed to NIV failure [28]. Patients using the helmet also have a longer delay to trigger inspiration compared with the face mask, but this can be offset by increasing the PEEP and pressure support [29]. While the helmet is tolerated well in patients with acute respiratory failure, the patient and the ventilator settings require careful monitoring while it is in use [30]. At present, the helmet is not available for use in the United States.

1.1.6 Case presentation revisited

It was suspected that the initial nasal mask was too large. Large masks often create air leaks that irritate the conjunctiva. When attempts are made to decrease the air leak by tightening the straps, the extra pressure can cause pressure sores over the nasal bridge. The sensation of feeling "stopped up" could result from the leak as well. When leaks are large, the absolute humidity in the system is decreased, which can lead to dry nasal secretions and sinus pressure. This sensation could also be from the transmission of positive pressure to the sinuses, which can frequently cause sinus pain.

The oxygen supply company was contacted, and it was requested that the patient be fitted with a smaller mask. Gauze padding under the new mask was used for a couple of weeks, so that the nasal bridge would not be irritated. To improve patient tolerance, both airway pressure settings, IPAP and EPAP, were decreased by 3–5 cm H_2O and later returned to original set pressures. In addition, we added a nasal corticosteroid to decrease inflammation and permit easier breathing. With these changes, the patient reported resolution of the initial problems, and was able to wear a nasal mask without difficulty. It would have been acceptable to transition the patient to nasal pillows, as this device would likely have corrected the eye pain and prevented skin breakdown. However, the problems with the sinuses would still require attention.

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1.2 Physiology of noninvasive ventilation

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1.2.1 Case presentation

A 55-year-old with post-polio syndrome presents to clinic for further evaluation. He has developed morning headaches and some mild dyspnea. An arterial blood gas reads 7.35/55/70, with SaO_2 of 94%. After a lengthy discussion, he agrees to start nocturnal noninvasive ventilation with pressure support (NIV-PS) with a nasal interface. The discussion raises several questions. How can chronic nocturnal hypercapnia progress to daytime hypercapnia? How long should one try nocturnal NIV before improvement in daytime hypercapnia is seen? What is the best way to follow response to therapy over time?

1.2.2 Introduction

Noninvasive ventilation has several theoretical advantages over endotracheal intubation or tracheotomy, and several studies suggest that gas exchange is very similar to these more invasive methods of mechanical ventilation. In the acute setting, despite a clinician's best attempt, some patients require endotracheal intubation

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following unsuccessful noninvasive ventilation. In this chapter, the physiology behind the most common problems leading to failure of NIV in patients with acute respiratory failure is discussed, including mask leaks and ventilator asynchrony. When noninvasive ventilation is used chronically, patients often have difficulty tolerating the interface due to upper respiratory tract complaints. The physiology of the upper airway in reference to NIV is also discussed. Additionally, when used chronically, NIV and its pressure settings can be difficult for physicians to titrate. As different diseases have different physiologic explanations for improved gas exchange with NIV, it is important to review this physiology.

1.2.3 Patient–ventilator interaction in acute respiratory failure

There are several problems that can lead to ineffective noninvasive ventilation or intolerance to noninvasive ventilation. In Chapter 1.1 the problem of carbon dioxide rebreathing and mask leaks were discussed. Problems with patient–ventilator interaction are another common reason for patient discomfort, ineffective noninvasive ventilation, and discontinuation of mechanical ventilation. Inspiratory triggering asynchrony may occur due to ineffective ventilator triggering during patient inspiration or due to decreased rate of inspiratory pressure rise during the inspiratory cycle [1, 2]. Expiratory triggering asynchrony can occur if there is ineffective termination of a mechanically delivered breath or if expiratory positive airway pressure is ineffectively delivered. In cases of asynchrony due to ineffective triggering, there is a phase shift between the patient's neural signaling and the ventilator's response [1]. This leads to increased work of breathing and patient discomfort. An example of patient–ventilator asynchrony is shown in Figure 1.2.1.

While not often used in clinical practice, the pressure time product (PTP) is a common indicator of the work of breathing in clinical research. The pressure time product is the product of the average inspiratory pressure (starting from the onset of effort) and the duration of inspiration: PTP = Pavg × Ti. The PTP was developed to account for energy expenditures during the dynamic and isometric phases of respiration, whereas other measures of work of breathing require a change in the volume (thus accounting for only the dynamic phase) [37]. Therefore, the PTP should more directly measure the total energy (in addition to the total work) of breathing than other means of measuring work of breathing. Thus, the PTP often allows for comparisons of work of breathing with different modes, amounts of leak, and so on. Much of the research on the effect of patient–ventilator interaction on work of breathing has used the PTP.

There are several different factors that can lead to asynchrony in noninvasive ventilation. The presence of a leak, the type of interface, the mode of noninvasive ventilation, and the method of triggering the ventilator to stop inspiration have all been identified as causes for asynchrony.

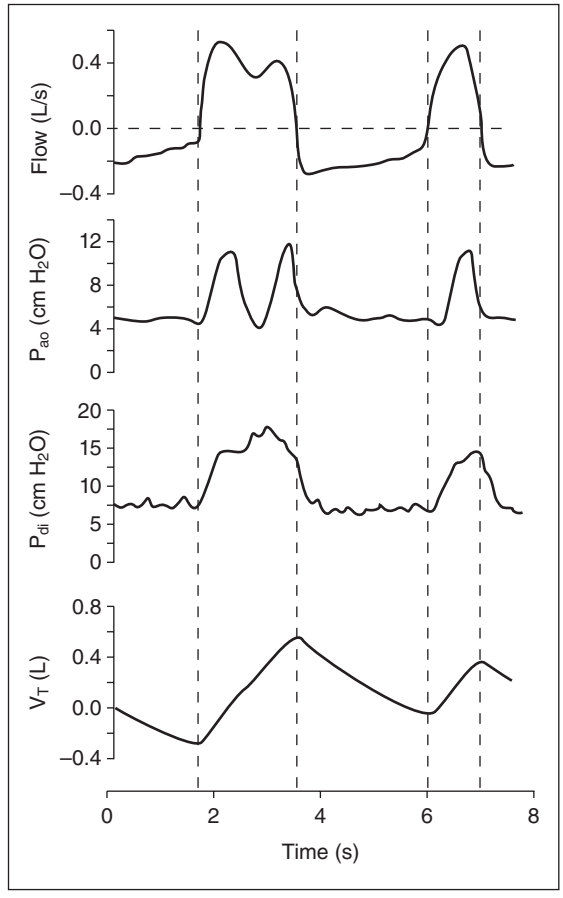

Figure 1.2.1 Patient–ventilator asynchrony. In the first patient breath (between seconds 2 and 4), there is an initial positive airway pressure (Pao), indicating effective noninvasive ventilation. This is preceded by a downward reflection in the Pao, indicating patient effort on top of ventilator effort. This resulted in a transient decrease in airflow and prolonged total inspiratory time compared with the second breath. (Reproduced with permission [7].)

1.2.3.1 Asynchrony and air leak

The presence of a leak is the most common cause of asynchrony [2]. This may present as an inability of the ventilator to trigger inspiration. A leak causes faulty inspiratory triggering by delaying inspiratory triggering, by decreasing ventilator sensitivity, or both. A leak may also prevent effective transition from inspiration to expiration. As the end of inspiration is recognized by the ventilator as inspiratory flow decay to a certain threshold, and a leak can prevent recognition of this decay, a leak can prevent the "cycling off" of inspiration and lead to asynchrony. During inspiration, if a leak prevents adequate transmission of pressure from the ventilator