Noninvasive Ventilation. The Essentials
Under the Auspices of the International Association of Noninvasive Mechanical Ventilation
Series Editor: Antonio M. Esquinas

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Lucia Spicuzza
Raffaele Scala *Editors*

Noninvasive Ventilation Outside Intensive Care Unit

Rationale and Practice

Springer

Noninvasive Ventilation. The Essentials

Nowadays, there is clear evidence of the consolidation of Non-invasive Ventilation (NIV) in medical practice. This Series, titled "Noninvasive Ventilation. The Essentials, is the result of extensive prior publications on this topic.

The aim of this Series is to define the current and new clinical developments in technologies such as equipment and ventilator modes and to offer practical recommendations, primarily in Intensive Care Medicine, Pulmonary, Emergency, and Sleep Medicine studies.

As a result of the previous publications, a well-experienced group of Editors and top international Editors aim to offer new books based on a multidisciplinary approach and a comprehensive overview of thematic issues in the field of Non-invasive Ventilation.

The general and main aims of this Series are as follows:

To establish a scientific reference for the clinical practice of NIV from a basic perspective of pathophysiology, clinical indications, and evidence-based concepts.

To convey the most important advances in clinical disciplines such as Intensive Care Medicine, Pneumology, Anesthesiology, Sleep Medicine, Pediatrics, Hospital and Pre-hospital Healthcare Organization in the most prevalent forms of acute and chronic respiratory failure.

To analyze the most important advances in the field of NIV technology and complementary procedures associated with NIV applications such as aerosol therapy, humidification, and airway clearance secretions required for the correct application of NIV techniques.

To serve as a valuable teaching reference for a range of healthcare professionals, including professional residents, senior consultants, and allied healthcare professionals. It will also be useful for under-graduate and post-graduate students, as well as those participating in fellowship programs.

The launch of a Series edition provides an opportunity to produce focused thematic volumes which will offer in-depth coverage of a particular topic area. This will be achieved through the involvement of internationally recognized guest editors who will work to ensure that the latest advances in NIV are analyzed comprehensively and in detail across key fields, including ICM and Emergency Medicine, as well as Pulmonary and Sleep Medicine.

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Preface

Nowadays it is evident that a large number of patients admitted in respiratory failure that require mechanical ventilation have a significant annual impact on health systems, in different terms such as costs and other health-related aspects (e.g., *complications associated with mechanical ventilation, ventilator-associated pneumonia, ICU-acquired muscle weakness*).

In this scenario, the use of noninvasive mechanical ventilation systems and nasal high-flow oxygen, which attenuate the adverse effects of invasive mechanical ventilation and its complications, is widely recommended and is supported by a very high level of clinical evidence.

The current demonstrated results of noninvasive mechanical ventilation exemplify good clinical practice and serve as a "gold standard" for patients with COPD exacerbations, cardiac pulmonary edema, immunocompromised individuals, or patients who do not require endotracheal intubation that normally are more vulnerable.

Along with this great base and proven track record, a growing application has been observed outside the critical care units, due to different situations specific to the organization and internal resources of each hospital. Recent instances of hospital collapse caused by international epidemics (H1N1, COVID-19) and other catastrophes serve as clear examples and evidence of this situation and that it can be applied in a reasonable way, and with adequate measures of equipment, monitoring, and training by appropriate personnel in a properly selected population. However, this entails an original aspect of new knowledge of NIV, especially in terms of the methodology of use, selection criteria, and establishment of new response prediction models and the organization of the health system of each hospital (e.g., *monitoring, human and material resources*). Once again, clinical reality itself leads a technique to be evaluated outside the original environment in which it was designed. This is a great scientific and health challenge for many health professionals.

In this first book on this subject, entitled Noninvasive Ventilation Outside Intensive Care Unit: Rationale and Practice, the reader can learn an analysis of how to establish and develop noninvasive mechanical ventilation as indications, methodology, and patterns of good practice, in a book structured in sections and chapters, where these flowcharts of patients with NIV outside ICU are analyzed and with this an adequate planning and hospital organization that adapts to the peculiarities of each hospital health system can be found.

The second originality of this title is that it represents the first **thematic volume** of the *Non-invasive Ventilation. The Essentials Series*, a scientific project that will analyze those classic and controversial aspects that should be well known to all health professionals who decide to start and develop a clinical practice of noninvasive ventilation, supported by an adequate scientific knowledge of all the elements that are intended to achieve clinical excellence.

May this introduction serve as a tribute and expression of gratitude to several international scientific figures who decisively contributed at the educational, human, and scientific levels in the development of this technique that we know today; they include Professors **Robert M. Kacmarek** (Boston, USA), **Jordi Mancebo** (Barcelona, Spain), and **Paolo Pelosi** (Milan, Italy).

I wish this book to be a first step ... of a long and interesting endless story.

Murcia, Spain — Antonio M. Esquinas
Catania, Italy — Lucia Spicuzza
Arezzo, Italy — Raffaele Scala

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Abbreviations

6MWT	6 Minutes walking test
ACE	Acute Care for Elders
ACE-R	Addenbrooke's Cognitive Examination
ACRF	Acute on chronic respiratory failure
AD	Advance directive
ADLs	Activity of daily living
Ads	Administrator Support in Italy or Guardian
AECOPD	Acute exacerbation COPD
AH	Absolute humidity
AHCD	Advanced health care directives
AMI	Acute myocardial infarction
ARDS	Acute respiratory distress syndrome
ARF	Acute respiratory failure
BMI	Body mass index
BNP	Brain natriuretic peptide
BPAP	Bilevel positive airway pressure
Bpm	Breaths/minute
CAM	Confusion assessment method
CAP	Community-acquired pneumonia
CCIS	Charlson comorbidity index score
CDC	Centers for Disease Control
CFS	Clinical Frailty Scale
CGA	Comprehensive Geriatric Assessment
CHF	Congestive heart failure
COPD	Chronic obstructive pulmonary disease
COT	Conventional oxygen therapy
COVID-19	Coronavirus disease 2019
CPAP	Continuous positive airway pressure
CPE	Cardiogenic pulmonary edema
CWD	Chest wall disorders
DIC	Disseminated intravascular coagulation
DMC	Decision making capacity
DNI	Do not intubate
DSM-5	Diagnostic and Statistical Manual of Mental Disorders

EACP	European Association of Palliative Care
EELV	End expiratory lung volume
EPAP	Expiratory positive airway pressure
ERS	European Respiratory Society
ETI	Endotracheal intubation
FBS	Fiberoptic bronchoscopy
FDA	Food and Drug Administration
FEV1	Forced expiratory volume in the first second
FFM	Full face mask
FiO_2	Fraction of inspired oxygen
FiO_2	Inspiratory oxygen fraction
FVC	Forced vital capacity
HACOR index	Heart rate, Acidosis, Consciousness, Oxygenation, Respiratory rate
HAT	Health Assessment Tool
HFNC	High flow nasal cannula
HMV	Home mechanical ventilation
HR	Heart rate
HRQoL	Health related quality of life
IADL	Instrumental Activity of Daily Living
IC	Informed consent
ICP	Individual care plan
ICU	Intensive care unit
ILDs	Interstitial lung disease
OLDs	Obstructive lung diseases
IMV	Invasive mechanical ventilation
IPAP	Inspiratory positive airway pressure
IPF	Interstitial pulmonary fibrosis
IRCU	Intermediate respiratory care unit
LOX	Liquid oxygen
Lpm	Litres/minute
LTOT	Long term oxygen therapy
LVEF	Left ventricular ejection fraction
MMSE	Mini-Mental State Examination
MPI	Multidimensional prognostic index
NHS	National Health Service
NIMV	Noninvasive mechanical ventilation
NIRS	Noninvasive respiratory support
NIRT	Noninvasive respiratory therapies
NIV	Noninvasive mechanical ventilation
NIV	Noninvasive ventilation
NMDs	Neuromuscular disorders
NPI	Neuropsychiatric Inventory
NPPV	Noninvasive positive pressure ventilation
OHS	Obesity hypoventilation syndrome
OSA	Obstructive sleep apnea

OTI	Orotracheal intubation
$PaCO_2$	Arterial carbon dioxide partial pressure
PAFI	PaO_2/FiO_2 ratio
PaO_2	Arterial oxygen partial pressure
PaO_2	Arterial oxygen pressure
PAP	Positive airway pressure
PCV	Pressure control ventilation
PEEP	Positive end expiratory pressure
PH	Pulmonary hypertension
POCs	Portable oxygen concentrators
Pplat	Plateau pressure
PS	Pressure support = IPAP − EPAP
P-SILI	Patient self-inflicted lung injury
PSV	Pressure support ventilation
QoL	Quality of life
RHDCU	Respiratory high-dependence care units
RICUs	Respiratory intensive care units
RIICU	Respiratory intermediate intensive care units
RMUs	Respiratory monitoring units
ROX index	(SpO_2/FiO_2)/RR ratio
RR	Respiratory rate
SAFI	SpO_2/FiO_2 ratio
SAPS II	Simplified Acute Physiology Score II
SARS-CoV-2	Severe acute respiratory syndrome coronavirus 2
SBT	Spontaneous breathing trial
SOFA	Sequential organ failure assessment
SpO_2	Oxyhemoglobin saturation
SWUs	Specialized weaning units
TV	Tidal volume
VT	Tidal volume
WC	Weaning centers

Part I

Epidemiology, Rationale and Indications of Noninvasive Ventilation Response Outside Intensive Care Unit

1 Noninvasive Mechanical Ventilation Outside Intensive Care Unit. Epidemiology

Biljana Lazovic, Radmila Dmitrovic, Isidora Simonovic, and Antonio M. Esquinas

Abstract

Noninvasive ventilation (NIV) is becoming more common in hospitals and at home around the world. The list of indications for its use is continually growing. In addition to the treatment of pulmonary conditions, it excelled in the treatment of specific cardiological conditions (ACPE), neuromuscular diseases, and even the therapy of acute respiratory disorders that occurred as a consequence of the treatment of various tumors. In this chapter, we will present epidemiological data on its application and effectiveness.

Keywords

Noninvasive ventilation · Epidemiology · Indications · Effectiveness · Prevalence · History

Noninvasive mechanical ventilation (NIV) is the delivery of ventilatory support without the use of an invasive artificial airway, endotracheal, or tracheostomy tube. According to data from the literature, the use of NIV has been increasing during the last two decades, from 2001 to 2004. It grew from 4% to 11%, primarily in European countries [1]. Acute hypercapnic respiratory failure (AHRF), arguably its most

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significant and important indication; acute exacerbation of chronic obstructive pulmonary disease (AECOPD); obesity hypoventilation syndrome (OHS); acute cardiogenic pulmonary edema (ACPE); neuromuscular disorders; and post-extubation ventilatory support are the key indications for NIV. NIV has been recommended as a palliative treatment in cancer patients to improve dyspnea. NIV is particularly useful in the treatment of AECOPD and end-stage neuromuscular disease [2]. The history of NIV could be traced back more than a century, but the modern NIV could be traced back to 1987 when Delaubier and Rideau successfully ventilated a patient with Duchenne Muscular Dystrophy [3]. Pulmonologists (52.9%) were the most likely to prescribe NIV, followed by anesthesiologists (34.3%) and, finally, other specialists (12.6%) [4]. Home ventilation with NIV can be very beneficial in chronic respiratory failure (CRF), particularly in COPD, where NIV use improves survival and reduces readmissions and exacerbations. When comparing NIV and long-term oxygen therapy, data revealed the following: mortality rates in the COPD and OHS groups were 61.3% and 21.2%, respectively; treatment durations ranged from 5.3 years in COPD patients to 11.4 years in restrictive chest wall disease patients [5]. In children with neuromuscular disease, which puts them at risk of alveolar hypoventilation, the respiratory muscles are usually spared. The most common neuromuscular diseases requiring NIV are spinal muscular atrophy and Duchenne muscular dystrophy, which are also known as collagen 6 myopathies or selenopathies and are characterized by a predominant weakness of the diaphragm [6]. According to some epidemiology data from a study conducted in North Ireland, acute neuromuscular failure, like the most common life-threatening complication in this child, had an incidence rate of approximately 2.81 (2.12 to 3.66) cases per million person-year and a mortality rate of approximately 0.26 (0.08 to 0.60) deaths per million person-years [7]. Home mechanical ventilation (HMV) improves these patients' quality of life and survival. According to certain research, the estimated prevalence of HMV is 7.3/100,000 population, and a minimal budget of roughly 168€/patient/year (504€/100,000 population) including the cost of the equipment should address the expense of HMV equipment in low-income nations [8]. Acute respiratory failure associated with cancer therapy complications is common in cancer patients. The researchers recruited 121 individuals with hematological and solid plasmas who were separated into two groups: those on IMV (56 (46.28%)) and those on NIV (65 (53.72%)). The overall mortality rate was 47.9%; however, the mortality rate for patients with hematological and solid neoplasms in acute respiratory failure was reduced in NIV patients (27.8% and 24.1% vs. 82.4% and 69.2%) [9].

Conclusion

NIV is an effective therapy option in both hospital and home settings. Because of CRF, an increasing number of patients are receiving NIV or IMV via tracheotomy to treat symptoms and improve their quality of life. Although the use of this sort of treatment is growing, particularly in Western countries, more research is needed to demonstrate its effectiveness.

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Noninvasive Mechanical Ventilation: Rationale Physiology

2

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Abstract

Noninvasive ventilation (NIV) is a type of ventilation that uses a noninvasive airway interface. and has two major modes of supplying support: bilevel positive airway pressure (BiPAP) or continuous positive airway pressure (CPAP). Since, in CPAP, pressure is constant it does not generate flow and does not increase volume, and cannot be considered a form of NIV in a strict sense (Torres et al., Cochrane Database Syst Rev (9):CD010355, 2015).

NIV will provide respiratory, neurological, muscular, and cardiovascular effects, depending on the pathophysiology of the respiratory failure.

Keywords

Noninvasive ventilation · Physiology · Cardiovascular effects · Respiratory effects · Positive pressure

Noninvasive ventilation (NIV) exerts its effects through several forms, namely, by increasing intrathoracic pressure, preventing alveolar collapse, increasing functional residual capacity and arterial oxygenation, and reducing respiratory workload and cardiac preload [1]. It is used to support gas exchange and acid–base homeostasis when the respiratory muscles are unable to maintain normal pulmonary ventilation in the face of acute or chronic respiratory dysfunction [2].

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Ventilation

Adding pressure and flow with NIV, increase tidal volume and consequently minute ventilation ($\dot{V}E$) which will translate into an increase in alveolar ventilation ($\dot{V}A$). The main purpose to increase $\dot{V}A$ is to provide O_2 and remove CO_2 [3].

PO_2 and PCO_2 in left atrium depend on $\dot{V}A$, alveolar-capillary gas transport, and ventilation perfusion matching ($\dot{V}/\dot{Q}$). Gas transport is dependent on many factors such as gradients between alveoli and venous blood or diffusing capabilities of alveolar membrane [4]. The amount of pO_2 and CO_2 in pulmonary venous blood depends on regional resistances, compliance, functional residual capacity, and delivered pattern of pressure/volume [4]. And so, the role of positive pressure is to distribute pressure/volume to units with high compliance and low resistance creating overdistention [4].

$\dot{V}/\dot{Q}$ is different for different gasses. CO_2 is very soluble in blood and its content is linearly related to PCO_2. PO_2 in pulmonary venous blood depends on regional $\dot{V}/\dot{Q}$ matching because O_2 is poorly soluble in plasma and hemoglobin is fully saturated when capillary PO_2 values are >70 mmHg [5].

Since systemic oxygen depends on hemoglobin and $\dot{V}/\dot{Q}$, raising the capillary PO_2 has little effect on blood oxygen content, and thus a lung unit with a high $\dot{V}/\dot{Q}$ ratio does not have much more oxygen to compensate for a lung unit with a low $\dot{V}/\dot{Q}$ ratio. CO_2 content depends less on $\dot{V}/\dot{Q}$ and falls steadily as $\dot{V}E$ and $\dot{V}A$ are increased with NIV [5].

Ventilatory Muscles

Respiratory failure occurs through two mecanimais, either muscle fatigue from muscle overload or reduced ventilatory drive to protect muscles from fatigue [6].

Ventilatory muscle capability is determined by strength and endurance properties and these can be diminished in critically ill patients as a consequence of lung hyperinflation or diaphragm flattening putting the muscle in a mechanical disadvantage [6]. Diaphragm is the most important ventilatory muscle with the potential to shift blood from other skeletal muscles [7]. In patients with high resistive loads like chronic obstructive pulmonary disease (COPD) or high elastic loads (interstitial lung disease) the required inspiratory pressures can be substantial requiring higher minute ventilation and increased tidal volume [7]. There is robust evidence that NIV decreases work of breathing, improves gas exchange, and relieves dyspnea in acute and chronic respiratory failure [7]. Reduces the number of patient efforts for a certain tidal volume, the muscle load during an interactive assisted breath, reverses fatigue, decreases oxygen consumption, increases oxygen delivery to other organs, and decreases lactic acidosis [7]. NIV improves respiratory muscle performance by supporting and resting respiratory muscles during periods of ventilation, and this increases patient mobility and endurance. The level of pressure support is probably the most important variable determining respiratory muscle unloading [7].

Ventilatory Control

Neurons in the brainstem, known as ventilatory control center (VCC), control the ventilatory pattern. They receive inputs from chemoreceptors (PO_2, PCO_2, and pH) located in great vessels and the fourth ventricle of the brain and mechanoreceptors in thorax and ventilatory muscles, and as a consequence, provide response to maintain adequate gas exchange with the minimal muscle load, generating the respiratory rhythm [8].

By providing adequate gas exchange and unloading muscle work hypoxemia and acidosis will be compensated and it will decrease the intensity and frequency of the VCC output. With the unloading of muscles, mechanical inputs to VCC will change which leaves to reduction of intensity and timing depending on the type of load being sensed by the VCC [9].

Overventilation and overdistention are sensed by mechanoreceptors, which often cause a shortening of neural inspiratory time and activation of expiratory muscles and so the unloading of these muscles may reset the VCC to a more normal $PaCO_2$ [9].

NIV affects the VCC by improving gas exchange, reducing muscle loads, and reducing dyspnea which contributes to a more normal ventilatory pattern.

Alveolar Recruitment

Parenchymal lung injury with alveolar inflammation, flooding, and collapse, cause $\dot{V}/\dot{Q}$ mismatching and shunts. In many of these diseases, substantial numbers of collapsed/atelectatic alveoli can be recruited with NIV [10].

PEEP is generally produced by expiratory circuit valves or continuous flow provided during the expiratory phase. It can also be produced as a consequence of short expiratory times in lung units with long expiratory times [10].

The applied PEEP can recruit and keep collapsed alveoli open increasing functional residual capacity and pulmonary congestion. These recruited alveoli improve $V/\dot{Q}$ mismatching and gas exchange and are not exposed to the risk of injury from the shear stress of repeated opening and closing during ventilatory cycle. It also prevents surfactant breakdown in collapsing alveoli and thus improves lung compliance [11].

Continuous positive airway pressure (CPAP)/PEEP decreases the gradient pressure across pulmonary capillaries, probably resulting in decreased extravascular lung water [11].

Upper Airway

NIV has been also used during sleep in patients with obstructive sleep apnea (OSA), COPD, overlap syndrome (COPD and OSA), neuromuscular disorders, and obesity-hypoventilation syndrome (OHS). They are characterized by episodes of partial or

complete obstruction of the upper airway during sleep and interrupting or reducing airflow [12].

This leads to arousal and/or oxyhemoglobin desaturation, followed by transient awakening that causes the restoration of upper airway permeability producing fragmented and poorly repairing sleep with impact on health, making it an independent risk factor for hypertension, heart failure, heart attack, cardiovascular events and arrhythmias [12].

Within the upper airway, the pharynx, and particularly the oropharynx and hypopharynx, is the region where obstructive events occur more often [12].

The role of NIV is to increase the air pressure in the pharynx, forcing the soft palate to move forwards against the tongue. The underlying physiologic principle is that the positive upper-airway pressure literally splints open the collapsed upper-airway structures during sleep [13].

Strong evidence exists that noninvasive ventilation has significant advantages in improving sleep quality, daytime wakefulness, cognitive function, and quality of life [14].

Cardiovascular

Application of intrathoracic pressure can have profound effects on cardiovascular function, Such as producing decreased venous return (VR), decreased left ventricle (LV) afterload, decreased work of breathing and oxygen consumption, and effects on pulmonary vascular resistance (right ventricle (RV) afterload) [13].

Changes in pleural pressure in the respiratory cycle will be transmitted to the heart causing changes in systemic VR (preload to RV and LV) and systemic arterial outflow (LV afterload). Negative pleural pressure swings will decrease or be absent with the application of positive inspiratory pressure when respiratory muscles are unloaded and PEEP/CPAP increased pleural pressure during expiration [15].

During systole, NIV increases intrathoracic pressure and reduces VR, decreasing the right and left ventricular preload while in diastole, increases the pericardial pressure and decreases afterload [13].

It also causes a decrease in the heart rate secondary to lung inflation and resultant increased parasympathetic tone and affects other aspects specifically dyspnea and anxiety [16].

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Noninvasive Ventilation Outside the ICU and Comorbidities

3

Ebru Sulu and Birsen Ocakli

Abstract

The application of noninvasive ventilation needs only the machine. Noninvasive ventilation is a recognized treatment not only for acute hypercarbic respiratory failure but also for obesity hypoventilation syndrome, sleep-related disorders, neuromuscular diseases, and for patients with terminal diseases for palliative purposes. The comorbidities have an important impact on ventilator success. The frequent comorbidities are cardiovascular disease, diabetes mellitus and metabolic syndrome, osteoporosis, cachexia and muscle wasting, anemia, obstructive sleep apnea, gastroesophageal reflux disease, anxiety, and depression. Other parameters such as doctor's experience, patient compliance, and the machine applied have significance.

Keywords

Noninvasive ventilation · Respiratory failure · Comorbidities · Non-ICU

Noninvasive ventilation has been an important and increasingly preferred and used treatment for respiratory failure since its use for sleep apnea in the early 1980s [1]. Noninvasive ventilation is a recognized treatment not only for acute hypercarbic respiratory failure such as chronic obstructive pulmonary disease (COPD) exacerbation or cardiogenic pulmonary edema, but also for obesity hypoventilation syndrome, sleep-related disorders, neuromuscular diseases, and for patients with terminal diseases in palliative wards [2–5].

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Noninvasive ventilation needs only the machine. Noninvasive ventilation can be applied in ICU, non-ICU pulmonary wards, emergency departments, palliative care units, and even at home. The latter is known as domiciliary or long-term noninvasive ventilation. The vast majority users of domiciliary noninvasive ventilation are the patients with chronic respiratory failure due to COPD. CODP is a multifactorial disease process having genetical, environmental, and behavioral components resulting in a disease of aging. Aging, genetical, environmental, and behavioral components are the mainstays of many coexisting diseases. Martinez et al. clearly provide us clear information defining the framework and relationship between COPD and COPD-related comorbidities. Three important points lead a comorbidity to be an important comorbidity: if the morbidity is too frequent and impacts on the progression or on the mortality of the COPD, and second, sharing a common effect of one disease on the other's outcome, and third, the presence of a comorbidity directly cumulates in specific phenotypes based on common mechanisms [6].

Frequent comorbidities are cardiovascular diseases including ischemic heart diseases, congestive heart failure, arrythmias, diabetes and metabolic syndrome, osteoporosis, cachexia and muscle wasting, anemia, obstructive sleep apnea, gastroesophageal reflux disease, anxiety, and depression [7].

Also, Martinez et al. define five common pathogenic mechanisms that COPD comorbidities are clustered in. The mechanism is inflammation, asthma, ischemic heart disease, osteoporosis, musculoskeletal dysfunction, and metabolic syndrome clustered in this mechanism. The second one is apoptosis, necrosis, and degeneration, with cardiovascular, malignancies, metabolic syndrome, osteoporosis, and musculoskeletal dysfunction predominance. The third mechanism is trauma and repair mechanism with malignancies and musculoskeletal dysfunction. The thrombosis and hemorrhage mechanism are responsible for the pulmonary embolism, ischemic heart disease, and cerebrovascular disease. And the fourth mechanism is an unknown mechanism in which depression and chronic renal failure are counted in [6]. Besides this complex mutual pathophysiology of comorbidities and COPD, in literature, comorbidities are classified according to presence or absence of pulmonary involvement. The comorbidity is classified as comorbidome, if the comorbidity is an extrapulmonary disorder and pulmorbidome, referring to pulmonary disorders. Asthma, hyperinflation, impairment in diffusion capacity, emphysema, sleep-apnea, previous tuberculosis, and bronchiectasis are the examples of pulmonary comorbidities [8].

Each of the aforementioned comorbidities affecting on the mortality and management of these comorbidities, drug interactions, and experts' recommendations are all studied well in literatures and should be managed according to disease-specific guidelines [6, 7, 9, 10].

Then, we should ponder on which coexisting chronic diseases are most crucial in COPD mortality. Divo et al. studied 79 comorbidities and risk of mortality in patients with COPD. Of those, 12 comorbidities are found to increase the risk of death. They developed a bubble graphic representation of comorbidome, indicating prevalence higher than 10% and strength of association to mortality. Congestive heart failure, pulmonary fibrosis, coronary arterial disease, lung cancer, anxiety,

atrial fibrillation, breast cancer, pancreatic cancer, esophageal cancer, diabetes mellitus with neuropathy, liver cirrhosis, and gastric duodenal ulcers are the 12 mentioned comorbidome and all these comorbidities have negative impact on 4 years of survival [11].

The comorbidities have an important affect on ventilator success. In fact, other parameters such as doctor's experience, patient compliance, and the machine applied have significance. The machine-related comorbidities are complications due to ventilator settings, such as gastroesophageal reflux disease and aspiration pneumonia, or pneumothorax. In patients with bulbar syndrome due to stroke or cardiovascular disease, cough-assisted devices may be used to prevent cough-related gastric distension, reflux, and aspiration pneumonia. In scoliotic patients with decreased lung capacity due to old age, the ventilatory settings must be adjusted. The machine pressure settings also must be checked in patients with pneumonia by increasing the positive end expiratory pressure to ensure an increment in alveolar recruitment and oxygenation or in patients with exacerbation of COPD by increasing inspiratory positive airway pressure or pressure support. In patients with tachycardia, paleness, and decreased tissue oxygenation, anemia should be checked. We should keep in mind the use of noninvasive ventilation in postoperative, especially after cardiac, pulmonary, and upper abdominal surgery patients with COPD, obstructive sleep apnea, and heart failure. Aspiration pneumonia due to mask administration and difficulty in secretion management in the patients with older ages, agitated and confused and cachexic patients are few examples for patient related comorbidities. These are the less-remembered comorbidities. The dentures removal may lead to airflow leakage, but vice versa, the usage may lead to obstruction of airflow depending on the patient's facial anatomy. In these patients with a maximum inspiratory positive airway pressure of <20 mmHg, nasal prongs are well tolerated. Sinusitis is not infrequent and responsible for the patient's incompliance. In these situations, humidifiers and mask change from nasal to oronasal one should be kept in mind. Facial bruises are also mask-related complications.

The metabolic comorbidities such as diabetes mellitus and hypertension should be controlled mutinously. The diabetic patients who underwent noninvasive ventilation are in risk of hypoglycemia and the hypertensive patients are in risk of hypotension due to decrement in venous return to right atrium. Obesity, the other metabolic comorbidity, is positively affected by noninvasive ventilation, leading to losing weight, which needs decrements in pressure values in ventilatory settings, especially in patients with sleep-related disease and obesity hypoventilation syndrome [12].

The role of comorbidities is crucial in acute and chronic settings. The chronic consequences of comorbidities are seen in domiciliary noninvasive ventilated patients. In literature, the effects of comorbidities on noninvasive ventilation outcome are investigated partially. Scala et al. aimed to evaluate the prevalence and the impact of both chronic and acute non-respiratory comorbidities on the prognosis of COPD patients with acute hypercarbic respiratory failure undergoing noninvasive ventilation. This is the first study in literature. They found that the presence of acute and chronic comorbidities negatively impacts noninvasive ventilation success [13].

In 2014, Pacilli et al. studied the effects of comorbidities and causes of respiratory failure on noninvasive ventilation outcome during an episode of acute hypercapnic respiratory failure in COPD, and they showed that pneumonia comorbidity presence and nutritional status of the patient determine the noninvasive ventilation outcomes [4].

As a conclusion, comorbidity influences not only the general health status of the patient, but also the disease prognosis, affecting directly the noninvasive ventilation. Thus, with the early diagnosis of COPD, one should be evaluated about the presence of comorbidities. As the disease progresses into respiratory failure requiring noninvasive ventilation, the comorbidities negatively affect noninvasive success or the mortality. The patient should be evaluated according to comorbidities not only during the initial stages of the diseases, but also during the later stages requiring noninvasive ventilation, and noninvasive ventilation settings should be adjusted according to patient tolerance and overlapping diseases.

Conclusion

Noninvasive ventilation has been an important and increasingly preferred and used treatment for respiratory failure. The noninvasive ventilation can be applied in ICU, non-ICU pulmonary wards, emergency departments, palliative care units, and even at home. Vast majority users of domiciliary noninvasive ventilation are the patients with chronic respiratory failure due to COPD. The comorbidities have an important impact on ventilator success. The frequent comorbidities are cardiovascular disease, diabetes and metabolic syndrome, osteoporosis, cachexia and muscle wasting, anemia, obstructive sleep apnea, gastroesophageal reflux disease, anxiety, and depression.

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Acute Respiratory Failure. Basic Concepts for Noninvasive Ventilation Approach

4

Daniela Cardoso

Abstract

Respiratory failure occurs when the respiratory system cannot adequately provide oxygen to the body or sufficiently remove carbon dioxide from the cells, resulting in inadequate gas exchange. It usually presents with dyspnoea, increased breathing work or impaired mental status, and abnormal arterial blood gas levels. There are two different groups recognized: Type 1 or hypoxemic respiratory failure, that results from lung diseases, causing oxygenation impairment and type 2 or hypercapnic respiratory failure, that results from pump failure, resulting in hypoventilation and hypercapnia. A thorough understanding of its physiopathology is crucial to this disorder management.

Keywords

Respiratory failure · Hypoxemia · Hypercapnia · Diagnosis · Clinical

Definition

Respiratory failure is defined as the inability of the respiratory system to maintain appropriate gas exchange between the environment and the body, that is, when there is inadequate oxygen delivery to the cells and a deficient carbon dioxide removal from the cells [1–4]. The normal partial pressure levels of oxygen and carbon dioxide in arterial blood, PaO_2 and $PaCO_2$ respectively, are not precise. PaO_2 varies inversely with age: by the age of 39, the lower limit is close to 80 mmHg and diminishes gradually close to 70 mmHg from the fifth decade of life. $PaCO_2$ is invariably

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abnormal when it is over 45–50 mmHg. Both vary depending on the altitude and the metabolic needs [5].

Respiratory failure is conventionally determined in a previously normal individual, by a PaO_2 lower than 60 mmHg (hypoxemia), a $PaCO_2$ higher than 45 mmHg (hypercapnia), or both [2, 4].

These cut-off values are not rigid, and the "line" for adequate gas exchange is more difficult to establish for individuals with pre-existing lung disease. In chronic obstructive pulmonary disease (COPD) patients, for example, it is not unusual to find $PaCO_2$ over 45 mmHg or PaO_2 under 60 mmHg in stability. In these chronic conditions, the acid-base balance is achieved with the buffering effect of the urinary system, allowing pH normalization. According to the blood gas criteria only, these patients are in respiratory failure; however, homeostasis is assured. In these cases, acute respiratory failure is defined as a significant change from the patient's baseline gas exchange status [4].

Clinical Manifestations

Specific manifestations of respiratory failure are directly associated with the respiratory system and are usually easily identified. Dyspnoea, wheezing, cyanosis (of the lips and tongue), tachypnoea or hypopnea, decreased ventilatory movements amplitude, paradoxical diaphragm movement, Kussmaul and Cheyne-Stokes breath, and abnormal pulmonary auscultation are some of the most frequent signs and symptoms [5].

Some of these manifestations, like cyanosis, may appear late and translate serious illness [5].

On the other hand, nonspecific signs of the respiratory failure may delay its recognition [1, 5]:

1. Hypoxemia may manifest only by a change in the state of consciousness (confusion, drowsiness, coma), seizures, myoclonus, tachycardia, or hypotension.
2. Hypercapnia may cause changes in the central nervous system (headaches, lentification, lethargy, drowsiness, anxiety, confusion, psychosis, coma), neuromuscular dysfunction (weakness, hyporeflexia, tremor, seizures), or cardiovascular changes (tachycardia, hypertension).

In the presence of respiratory acidosis, arrhythmias, hemodynamic instability, or marked change of conscience state may occur [5].

Diagnosis

The diagnosis of acute respiratory failure begins with the suspicion of its existence, based on anamnesis and physical examination of the patient. The confirmation is based on the arterial blood gas analysis (ABG), which is the gold standard exam [2, 3, 5].

ABG measures the pH, PaO_2, and $PaCO_2$. A derivative of the Hasselbach equation calculates the serum bicarbonate (HCO_3) and base deficit or excess. Its interpretation helps understanding whether the abnormalities are acute or chronic, if the primary disorder is respiratory or metabolic and also the degree and severity of the abnormalities [5–8].

There are different ways to interpret ABG results, but the Romanski method is one of the simplest ones. The first step is to look at the pH and evaluate the presence of acidaemia (pH < 7.35) or alkalemia (pH > 7.45). Second, evaluate the $PaCO_2$ and the HCO_3, which are the respiratory and metabolic components of acid-base balance, respectively, to determine the origin of the disturbance. A $PaCO_2$ > 40 mmHg with a pH < 7.4 indicates a respiratory acidosis, while $PaCO_2$ < 40 mmHg and pH > 7.4 indicates a respiratory alkalosis. Next, search for evidence of compensation for the primary imbalance, seeking for the value of $PaCO_2$ or HCO_3 that is not consistent with the pH. Lastly, assess the PaO_2 to find abnormalities in oxygenation [6–8].

Classification

Respiratory failure is conveniently classified into two different categories based on the gas exchange abnormalities pattern: Type 1 or hypoxemic respiratory failure and type 2 or hypercapnic respiratory failure:

- Type 1 respiratory failure occurs when the respiratory system is not able to provide adequate oxygen to the body, leading to hypoxemia, this being the major problem. The patient's $PaCO_2$ is normal or even low. This can result from alveolar hypoventilation, low atmospheric fraction of inspired oxygen, diffusion defect, ventilation/perfusion mismatch, or right-to-left shunt [1, 3, 5].
- Type 2 respiratory failure occurs when the respiratory system is unable to sufficiently remove carbon dioxide from the body, leading to hypercapnia. This results from the inability to ventilate, from respiratory pump failure or increased carbon dioxide production. In this second category, hypercapnia is present, and, in acute cases, the pH is low with absent or incomplete metabolic compensation for the respiratory acidosis. Generally, PaO_2 is decreased, not only because hypoventilation changes alveolar oxygen pressure (PAO_2), but also because it is frequently associated with other causes of hypoxemia [1–3, 5].

Hypoxemic respiratory failure is the most frequent one and arises when the disease is severe enough to interfere with gas exchanges, while the patient can maintain a

good ventilation. In some situations, both types of respiratory failure may coexist in the same patient, for example, in a COPD exacerbation, or when there is muscle fatigue in severe pneumonia, pulmonary oedema, or asthma crisis, with hypercapnia appearing as the disease progresses, being a sign of severity in these situations [4, 5].

Physiopathology and Aetiology

The respiratory system consists of two main components [2, 4, 5]:

1. The lung parenchyma, responsible for gas exchanging, consisting of alveolar units.
2. The respiratory pump, responsible for the ventilation, includes the entire ventilatory device: central and peripheral nervous system, chest wall, and respiratory muscles.

Both parts of the system are vital. In general, alveolar diseases usually lead to hypoxemia due to oxygenation failure, causing hypoxemic, or type 1 respiratory failure, while failure of the pump results in hypoventilation and V/Q imbalance, causing hypercapnic or type 2 respiratory failure [2, 4, 5].

Type 1 Respiratory Failure

Hypoxemic respiratory failure is mainly caused by diseases that affect the alveolar units, responsible for the gas exchange. The possible pathophysiological mechanisms involved are ventilation/perfusion mismatch, increased shunt, diffusion impairment, and low fraction of inspired oxygen [1, 2, 5].

Gas exchange in alveoli allows the elimination of carbon dioxide and oxygenation of mixed venous blood and depends on the balance between alveolar ventilation (V) and perfusion (Q). In a normal individual, V is slightly lower than Q and the relation between them (V/Q) is near 0.8 [5].

The efficacy of gas exchange can be assessed by calculating the alveolar-arterial oxygen gradient ($P[A\text{-}a]O_2$), which measures the difference between the pressure of oxygen in the alveoli and in the adjacent capillary artery. This parameter is useful to find the mechanism that causes hypoxemia [5].

The alveolar oxygen pressure (PAO_2) depends on the inspired fraction of oxygen (FiO_2), atmospheric pressure (Pb), water vapor pressure (PH_2O), carbon dioxide alveolar pressure ($PACO_2$) and on the respiratory quotient (R = CO_2 produced/O_2 consumed), and is determined by the alveolar gas equation [3, 5]:

$$PAO_2 = FiO_2 \times \left[Pb - PH_2O\right] - PACO_2 / R$$

The PaO_2 is always lower than PAO_2 because of the physiological imbalance between V/Q and the presence of small right-left shunts in the bronchial circulation

and little pulmonary arteriovenous anastomoses. Normal P[A-a]O_2 is 7–14 mmHg and increases with age, being close to 30 mmHg in the seventh decade of life [5].

1. Ventilation/perfusion mismatch is the most frequent cause of hypoxemia and in this case, P[A-a]O_2 gradient is increased [2, 3, 5].
   (a) When perfusion is excessive to ventilation, the V/Q ratio decreases. This is associated with airway changes that determine inadequate ventilation of well-perfused alveoli such as pneumonia, atelectasis, or any other alveolar filling process like alveolar haemorrhage or pulmonary oedema [3, 5].
   (b) When ventilation is excessive to perfusion, the V/Q ratio is greater than one. In areas with compromised perfusion, the impact on gas exchange is not so pronounced. The most frequent cause is pulmonary emphysema, where decreased perfusion is caused by alveolar walls destruction, supplanting the ventilation deficit. V/Q also increases when hypoxemia causes a reactive increase ventilation and vasoconstriction (exacerbation of COPD or asthma). The extreme of this situation corresponds to the dead space (V./Q. = ∞, non-infused ventilated alveoli), which happens, for example, in pulmonary embolism [3, 5].
2. Right-to-left shunt may be seen as the extreme of the V/Q imbalance, when V/Q equalizes zero, due to non-ventilated perfused alveoli. This situation may have an anatomical origin (pulmonary arteriovenous malformations or cardiac septal defect) or may be physiological (complete atelectasis, severe pneumonia, or pulmonary oedema) [1–3, 5].
3. Diffusion defects occur with structural changes of the alveolar membrane such as decreased surface area by alveolar walls destruction (emphysema) or increased thickness of the membrane found in interstitial lung diseases. In these situations, hypercapnia does not occur, as carbon dioxide diffuses more readily across the alveolar-capillary membrane than oxygen. The limitation of gases diffusion through the alveolar-capillary membrane is a less important mechanism of hypoxemia at rest, but assumes increasing importance during exercise [2, 3, 5].
4. Low atmospheric pressure (Pb) or low fraction of inspired oxygen (FiO_2) are uncommon mechanisms of respiratory failure, which causes hypoxemia by PAO_2 decrease, as the alveolar gas equation demonstrates. In either situation, the P[A-a] O_2 gradient remains normal. It can occur with high altitudes or decrease accumulation of other gases [3, 5].

Hypoxaemia resulting from ventilation/perfusion imbalance or diffusion abnormalities can easily be corrected by supplementing inspired oxygen, but when induced by increased pure shunt, even very high concentrations of FiO_2 cannot correct hypoxaemia since the alveoli do not participate in gas exchanges [2].

Type 2 Respiratory Failure

Hypercapnic respiratory failure is primarily caused by diseases that affect the normal functioning of the respiratory pump, through mechanisms of hypoventilation and V/Q imbalance, leading to hypercapnia [2, 3, 5].

Hypoventilation happens when alveolar gas movement is insufficient to remove carbon dioxide from the blood, conditioning an increase of $PaCO_2$ and a decrease of $PACO_2$. The alveolar gas equation demonstrates that an increase in $PaCO_2$ causes a decrease in the PAO_2, compromising the oxygenation and causing hypoxemia. In this situation, the P[A-a] O_2 gradient is normal, as PAO_2 and PaO_2 decrease in equal magnitudes [2–5].

Usually, hypoventilation does not occur isolated, as it is frequently associated with other disturbances that limit oxygenation (e.g. ventilation-perfusion mismatch), which accentuates the hypoxemia [4, 5].

There are three major causes of pump failure:

1. Inadequate activation from the central nervous system (CNS), resulting in insufficient central respiratory drive for the demand or as a reflective modified output of the centres to prevent respiratory muscle injury and avoid fatigue. This impairment may be temporary (e.g. anaesthesia or drug overdose) or permanent (e.g. medulla diseases, brain neoplasm, stroke, central sleep apnoea) [2, 3, 5].
2. Chest wall mechanical defect caused by the impairment of peripheral nervous system or neuromuscular junctions are responsible for the motor output coming from the CNS. Disorders affecting any component of this pathway cause insufficient inflation of the ribcage, preventing the generation of sub-atmospheric pressure, which is essential for the air flowing into the lungs. Hypoventilation appears because of the additional work of the inspiratory muscles imposed by the displace of a noncompliant chest wall. Some examples of these diseases are flail chest, kyphoscoliosis, hyperinflation, diaphragmatic paralysis, neuromuscular diseases (e.g. Guillain-Barre syndrome, myasthenia gravis, amyotrophic lateral sclerosis, multiple sclerosis, poliomyelitis, myopathies, or polymyositis) [2, 3, 5].
3. Fatigue of the inspiratory muscles is caused by excessive inspiratory load, preventing adequate pleural pressure generation despite appropriate central drive and intact chest wall. This may occur in a variety of clinical entities that result in an imbalance between respiratory muscle energy supplies and demands. No matter what the causes are, it is well known that fatigue is characterized by loss of force output, leading to inability of the respiratory muscles to develop adequate pressure during tidal breathing, with consequent decreases in tidal volume and minute ventilation leading to hypercapnia [2, 3, 5].

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Noninvasive Mechanical Ventilation in Do-Not-Intubation Order

5

David Noivo and Rita Ferro

Abstract

Acute respiratory failure (ARF) is a common reason for intensive care unit (ICU) admission. While invasive mechanical ventilation (IMV) is a cornerstone of supportive treatment for ARF, there are patients who receive a do-not-intubate (DNI) order. Variability in DNI rates may reflect the characteristics of patients, families, physicians and hospitals. Performing noninvasive ventilation (NIV) in patients with DNI orders can have a curative or a palliative purpose. Many crucial uncertainties remain regarding this topic. Additional research is warranted, particularly in patients receiving palliative care.

Keywords

Do-not-intubate · Noninvasive ventilation · Acute respiratory failure · Intensive care unit · Palliative care

Do-not-intubate (DNI), do-not-resuscitate (DNR) and comfort measures only (CMO) orders have different meanings and must be discussed separately for each patient [1]. DNI means the patient does not qualify or does not wish to be ventilated invasively (this comprises situations such as inability to protect the airway, acute

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respiratory failure (ARF) and need for general anaesthesia), while DNR means that a patient is not a candidate to initiate advanced life support interventions (intubation, chest compressions, etc.) [1]. A CMO order implies stopping all life-prolonging treatments such as antibiotics, dialysis, surgery, etc. [2]. These decisions can have important implications for each patient considering that patients with DNI order have up to five times greater hospital mortality than those without DNI order [2].

Invasive mechanical ventilation (IMV) is the hallmark of the treatment of ARF [2]. The decision to proceed or withhold this procedure can have direct impact on the outcome of the patient [2]. A DNI order should be made with the patient (if possible), their family and the multidisciplinary team [3]. The patient and their family should be thoroughly informed, and their priorities must be considered, the option to extend life or to prioritize comfort should be given [3]. A DNI order can be decided according to:

1. The patient's personal preference for no intubation.
2. Physician's clinical opinion that invasive mechanical ventilation does not offer therapeutical benefit.
3. Lack of available resources.

This decision should be written in the patient's records and can be reassessed when the patient's diagnosis, prognosis, or goals of medical treatment change [2].

Performing noninvasive ventilation (NIV) in patients with DNI order has become more common [4]. In these cases, NIV can be used for either curative or palliative purposes [2].

Patients with DNI order who undergo NIV for curative purposes seem to have a substantial survival rate with no significant decline in quality of life on day 90 versus baseline [5]. In the acute setting, survival tends to be better in the treatment and management of dyspnoea in chronic obstructive pulmonary disease (COPD) and pulmonary oedema compared to infectious disease and malignancy [6]. Symptoms such as anxiety, depression or post-traumatic stress disorder do not seem to be higher in patients with DNI orders who undergo NIV [5].

The decision to perform NIV for palliative purposes is still controversial, some authors argue that the burden of NIV may outweigh the potential benefits and could merely extend the dying process without providing an acceptable quality of life in survivors or an acceptable quality of death in non-survivors [6]. Nonetheless, it has been used successfully and some studies show benefit in reducing dyspnoea and opioid requirement when compared to standard oxygen therapy in COPD patients [5, 7]. Long-term NIV can be effective in the treatment of chronic respiratory failure and management of dyspnoea due to neuromuscular and restrictive diseases [8]. The provision of inspiratory and expiratory aid by NIV can help reduce the inspiratory burden diminishing the sensation of dyspnoea, which correlates strongly with inspiratory load [7].

Given that you assure that NIV is explained thoroughly to the patient and that its withdrawal is possible at any time, NIV is generally accepted [7]. Even the quality of sleep can improve [7]. Aside from symptoms relieve, NIV in palliative care might

be used to provide additional time to finalize personal affairs and allow the comunication with the loved ones [3].

A recent meta-analysis conducted in the United States (10,755 patients, 27 manuscripts) found that the overall rate of DNI order was 27%, increasing in elderly patients [9]. According to this review, one in four patients with ARF had a DNI order and this rate increased over time—9% in 2000–2004 to 32% in 2015–2019 [9].

In this point, Wilson and colleagues provided the first meta-analysis exploring the outcomes of NIV in patients with ARF who have DNI or CMO orders [6]. In patients with DNI order (2020 patients, 27 manuscripts), the overall survival was 56% at hospital discharge and 32% at 1 year [6]. Survival was comparable for patients treated in a hospital ward versus an intensive care unit (ICU) [6].

A prospective study developed in a university-affiliated hospital in Western Europe demonstrate a DNI order in one-third of all patients admitted to the emergency room who received NIV (243 patients) [4]. Importantly, in patients under palliative care, who represent 40% of all patients with DNI order, NIV was discontinued in more than 50% due to no improvement in symptoms [4].

A DNI decision is highly variable and individual, depending on age, prognosis, baseline health, wishes for patient and family and comorbidities [3]. Many crucial uncertainties remain regarding NIV in DNI order [2] . Additional research on this topic is warranted, particularly in patients receiving palliative care [2].

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Equipment for Noninvasive Mechanical Ventilation

6

Luigi Panza

Abstract

Noninvasive ventilation consists of the application of a ventilator to the patient's airways without recourse to orotracheal intubation or tracheostomy and therefore requires a range of devices that guarantee mechanical ventilatory support to the spontaneous pulmonary breathing. Two different types of systems are defined, namely closed and opened, depending on the type of circuit and mask used. Mechanical noninvasive ventilator delivers gas flow through pressured or volumed algorithms as well as in the intensive care unit but often are easier to manage. The importance of a good ventilation is often driven by specialized teamwork by clinicians, nursery, and trained personnel. Communicating and receiving feedback from the patient who needs to undergo a NIV session, if possible, increases compliance and improves the outcome of care significantly. Technical aspects of devices with detailed references to interfaces, management, and prevention of ventilation side effects are reported.

Keywords

Noninvasive ventilation · Interfaces · Humidifier · Anti-rebreathing

Noninvasive mechanical ventilation (NIV) has a long tradition for the treatment of chronic respiratory failure and more recently has also been applied in acute respiratory failure. The choice of ventilator type and setting should depend on the patient's condition, on the expertise of attending staff, therapeutic requirements, and on the

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location of care [1]. Equipment for NIV consists of a group of devices that provide connection between a ventilator and patient airways without the requirement of intubation.

The main tools required for this type of ventilation are:

1. ventilator machines,
2. masks also called *interfaces,*
3. tubes or *limbs,*
4. anti-microbial filters,
5. gas humidifier systems (if necessary),
6. anti-rebreathing valves (if necessary).

The main criteria of classification for non invasive ventilation are based on the system used for exhale gases (in particular CO_2): Closed/double circuit or Open/single circuit [2].

Closed or "Double-Tube" Circuit (Fig. 6.1)

A double-way tube has one for delivering pressurized air (direct *to* the patient) and the other one for exhalation of expired volumes and CO_2 (derived *from* the patient) connected with a mask. Advantages of this system is to measure the exact expired air as important feedback for real-time evaluation of ventilation. This circuit can be applied only with a mask without any rebreathing systems that is called non-vented mask.

The effective compliance of the respiratory circuit is a combination of the tubing compliance and gas compressibility. Some ventilators provide automatic compensation for circuit compliance and resistances after a calibration manoeuvre. Others have the option of choosing between adult and paediatric circuit configurations.

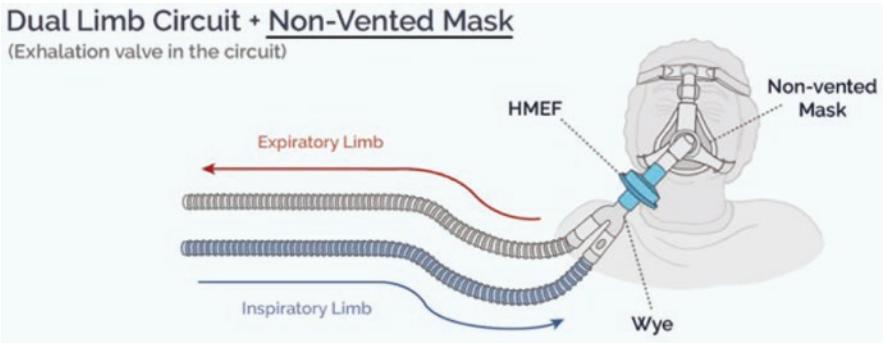

Fig. 6.1 Double-tube circuit: one expiratory limb, one inspiratory limb, a non-vented mask, HMEF heat and moisture exchanging filter (see after)

Although double-limb respiratory circuits usually measure inspiratory and expiratory tidal volume (VT), they can also be equipped with a proximal flow sensor that can be used either as a simple monitoring tool or to control some of the ventilator functions.

Opened or "Leaked" Circuit (Fig. 6.2)

Includes a single-way tube, generally associated with a non-vented mask with no-rebreathing tools for CO_2 called *whispers, plateau-valves,* or just a vented mask (Fig. 6.3). This system is easier and cheaper but associated to lower accuracy in measuring expiratory volumes (home-care ventilators) and less efficacy in exhalation of CO_2.

Masks used for noninvasive ventilation are, as mentioned above, vented or non-vented. Vented masks have integrated holes in the frame or a swivel elbow to remove CO_2 and prevent rebreathing. Non-vented masks are totally closed and need a

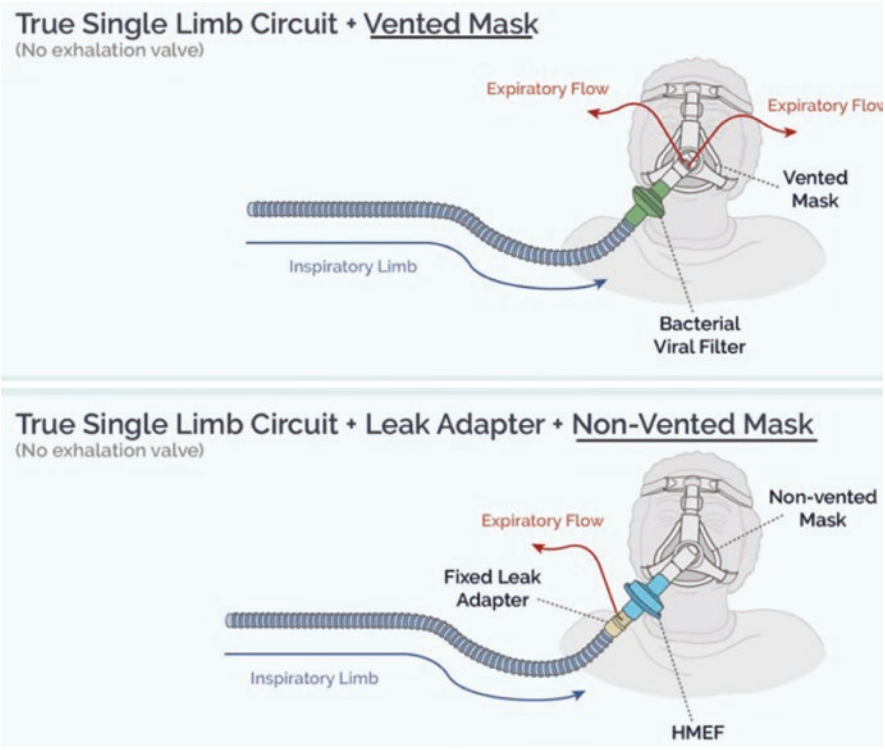

Fig. 6.2 Leaked circuits: *above* a single tube *to the patient*, an anti-microbial filter type HME, a vented-mask able to exhale CO_2 through holes or flaps integrated, *below* a single tube, a leak valve for expiration and CO_2 exhalation, an anti-microbial filter type HME, and a non-vented mask

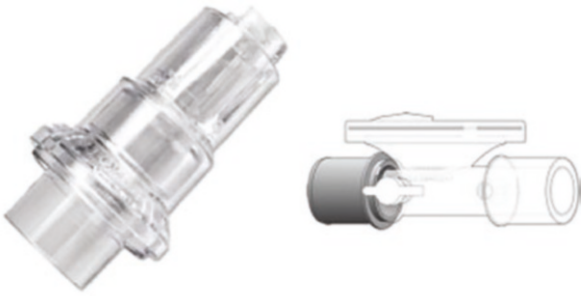

Fig. 6.3 On the left is a whisper valve, on the right a plateau-valve with a flat superior opened chamber for exhalation of expired volumes and removal of CO_2

separate option for CO_2 removal from the circuit as whispers or anti-rebreathing adding valves, as shown in the following panel (Fig. 6.3).

Different Modes of Ventilation

Ventilators can be categorised also on the way that the ventilator is set to deliver gas flow and how it changes between respiration cycle in ***pressured-cycled*** and ***volume-cycled*** machines.

- **Pressure-cycled** machines deliver a predetermined pressure and the volume delivered will depend upon the impedance to inflation. If there is a leak in the circuit, flow will increase to compensate, but if there is airway obstruction, VT will be reduced.
- **Volume-cycled** machines deliver a fixed tidal or minute volume and will generate a pressure sufficient to achieve this. If the impedance to inflation is high, pressure will be increased, and the targeted VT will be delivered. However, if there is a leak, there will be no increase in flow rate to compensate, a lower pressure will be generated, and the delivered VT will fall (Fig. 6.4).

Both systems of ventilation deliver air in response to a given trigger timed by the machine based on changing *flow* or *pressure* in the system driven by the patient's breath.

Mechanical ventilation can be *controlled* (**C mode**) in which the machine determines respiratory frequency, *assisted* (**A mode**) if the machine improves the patient's spontaneous breaths rate, or a combination of the two (**A/C mode**) that has the advantages of the timed mode but allows augmentation of extra spontaneous efforts that may occur with irregular breathing patterns that may be seen at sleep onset or during rapid eye movement sleep (REM). The A/C mode is called also

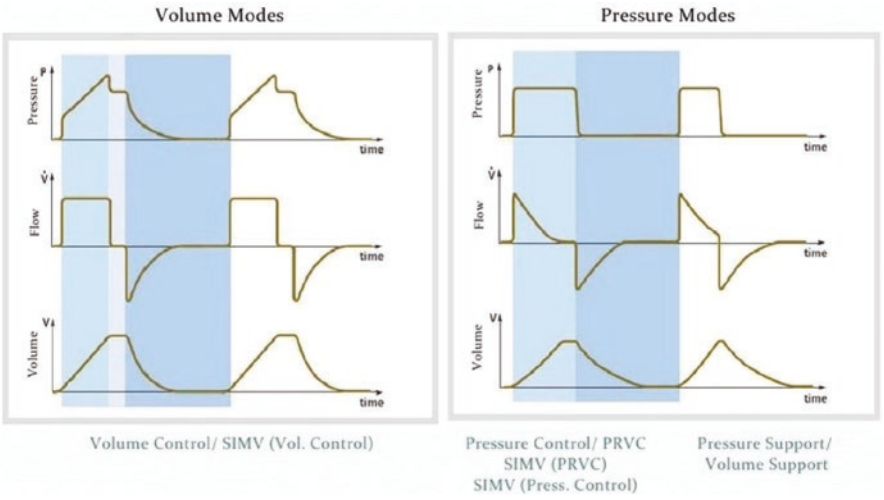

Fig. 6.4 Examples and differences of waveforms between volume-based and pressure-based ventilation modes

spontaneous/timed (**S/T mode**) in pressure-cycled machines. The proportion of breaths which are assisted and those which are controlled will depend upon the backup rate that is set. The backup rate is usually set at slightly below the spontaneous patient's breathing rate.

Critical Care Ventilators Vs. Portable (Home) Ventilators

Ventilators for ICU are manufactured to a high technical specification, are used in the invasive ventilation setting, and benefit from elaborate monitoring but are expensive. The elaborate alarms may be counter-productive since they frequently indicate very minor air leaks that are common during NIV and not of clinical significance.

Furthermore, the circuit is often heavy, which may be a problem during NIV. The simpler, smaller, and less expensive portable ventilators, which were initially designed to be used for home mechanical ventilation, can also be used in the hospital outside of ICU.

The principal limitation to the use of home ventilators is the lack of direct monitoring of pressure, volume, and flow provided by these devices. The evaluation of patient/ventilator asynchrony is more difficult without visualisation of flow and pressure waveforms, and key features, especially during the first period of ventilation when it is important to assess the patient/ventilator interaction, respiratory mechanics, and the expired VT.

Role and Importance of Interfaces

The number and types of interfaces have constantly increased, and new types are in development for variable ventilation-acquired issues. There is no perfect interface, and its choice requires careful evaluation of distinct factors like anatomic patient's features, ventilation settings, type, and time of onset of the disease for which NIV is applied.

Today, oronasal masks are the most used, followed by nasal masks and helmets. Every effort should be made to minimize air leaks, maximize patient comfort, and optimize patient-ventilator interaction. Technological issues to consider when choosing interface include *dead space* (anatomic 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 (HH) provides better CO_2 clearance and lower work of breathing than does heat-and-moisture exchanger, because HH adds less dead space [3].

During noninvasive ventilation, the patient's comfort is important to obtain optimal efficiency of the treatment. Mask fit and care are needed to prevent skin damage and air leaks that can dramatically reduce patient tolerance and the efficacy of NIV session.

Interfaces are normally secured with a head frame, headgear, or straps with velcro, clips, or hooks. Main types commonly used in NIV are divided into the following categories with specific features.

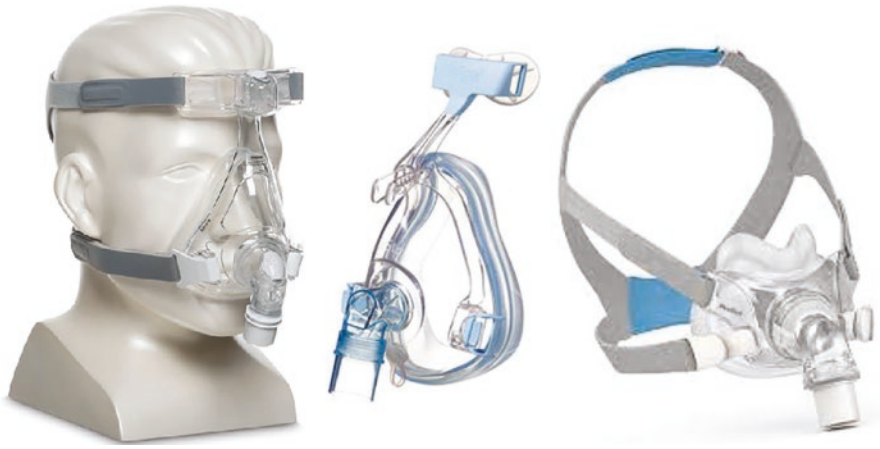

Fig. 6.5 Different types of oro-nasal masks

Fig. 6.6 Different types of nasal interfaces and supports

Fig. 6.7 Types of full-face masks

Oro-Nasal Masks

The oronasal masks (Fig. 6.5). Specifics: covers mouth and nose. Sub-types of oronasal masks have an addition of intra-nasal pillows. Are available as vented or non-vented. Largely used in routine hospital setting, are easy to apply by trained personnel, relatively low costs with fine resistance, and good quality of ventilation if tolerated. Disadvantages are generally low tolerance in long-time ventilation course by the patients, with high risks of decubitus ulcers of nose and around the mouth.

Nasal Masks and Nasal Pillows

Nasal masks and nasal pillows (Fig. 6.6). Specifics: covers only nose. Largely routine used for sleep breathing disorders and home-based ventilation (Obstructive Sleep Apnoea and/or Obesity Hypoventilation Syndrome) but not indicated in case of closed circuits for in-hospital courses of NIV. Available as vented or non-vented

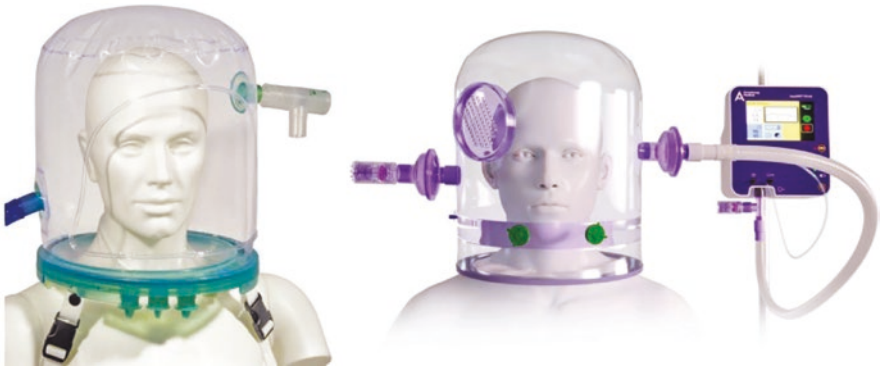

Fig. 6.8 Different types of helmets

mask. Good tolerance by patients at cost of less quality of ventilation efficacy if compared with oronasal. Nasal pillows are usually more comfortable because are applied directly on nostrils.

Total Face or Full-Face Masks

Full face masks (Fig. 6.7). Specifics: covers the whole facial profile including eyes, fitting on the forehead and the chin. Available as vented or non-vented mask in hospital setting, especially in case of edentulous patients and emergency settings. Ventilation efficacy is provided if well fitted with minor risks of facial decubitus if compared to oro-nasal. Disadvantages are potential ocular injuries (as corneal ulcers, conjunctivitis) in long-term ventilation [4].

Helmets

Helmets (Fig. 6.8). Specifics: plastic helmet that can be inflated with air/oxygen variable mixture. Patient's head is inserted in the interface and fixed closely around the neck. Generally, gas inflation and CO_2 outflow are delivered in two diverse ways: (a) an inflating tube and an expiration valve for CO_2 or (b) with two different tubes, one for inflated mixed gas and one for exhaled CO_2 and expired volume.

Sometimes helmet is wrongly considered a type of ventilation because is used for delivering continuous positive pressured ventilation (CPAP), but it is a type of interface that can be used in other ventilation settings mode (Bilevel-NIV mode). Advantages of helmets: better tolerated and allows a satisfactory interaction of the patient with the environment; its fixation system provides a good seal without major compression at contact points, thus minimising skin lesions. It can be applied to any patient regardless of the facial contour, edentulism, or facial trauma, causes less interference with speech, allows cough, and a specific connector placed in the

Fig. 6.9 Components of mouthpieces

plastic ring of the helmet can be used to allow the passage of a straw, thus allowing the patient to drink or to be fed a liquid diet. Disadvantages are perceived sensation of high-intensity noise and cold due to high flow of oxygen delivered, and sense of claustrophobia.

Mouthpieces

Mouthpieces (Fig. 6.9). Specifics: one-way tube device linked directly to the mouth of the patient. The patient receives respiratory support through a mouthpiece supported by a flexible arm kept near the lips. He must be cooperative and have sufficient muscular strength to seal their lips around the mouthpiece. Respiratory support is triggered when the patients place their lips in the mouthpiece, creating a small inspiratory pressure or a sip. Some ventilators have a mouthpiece dedicated mode and a very sensitive trigger, which allows the patient to demand respiratory support with minimal effort. Angled mouthpiece, the most frequently of 15 or 22 mm, is most commonly used, as it is easier for the patient to grasp. Adverse events of mouthpiece have been described, such as increased salivation, orthodontic problems, gastric distention caused by swallowed air, and nose leaks. In case of nose leaks, nasal clips may be used.

Fig. 6.10 Different types of humidification, on the left HME filters and on the right HH system (see text)

Role of Gas Conditioning During NIV

NIV is usually delivered through a nasal or oro-nasal mask so the inspired gas passes through the upper airway where it is conditioned. Like during spontaneous breathing, patients under NIV require adequate humidification and heating of the inspired air. NIV delivers inspired air at high flow rates, which may overwhelm the usual airway humidification mechanisms. Inadequate gas conditioning has been associated with anatomical and functional deterioration of nasal mucosa and tolerance to NIV. Several parameters, mostly technical aspects of NIV, contribute to inefficient gas conditioning.

Factors affecting airway humidity during NIV include inspiratory flow, inspiratory oxygen fraction, leaks, type of ventilator, interface used, temperature and pressure of inhaled gas, and type of humidifier [5]. Two distinct types of humidification tools are commonly used: heat and moisture exchanger filters (HME) and active HH system, as showed in Fig. 6.10.

HME are cheaper, used in ICU and able to reduce circuit condensation, do not require electricity but are associated with increased dead space, and can improve airway resistance in cases of heavy secretion and respiratory tract bleeding. HH system are more efficient in reducing relative and absolute humidity, has no impact on dead space ventilation or on CO_2 retention but requires electricity, and not too-extreme environmental room temperature. There is no uniform recommendation on preferred devices of humidification depending on clinical scenarios.

Role of Equipment Before Starting NIV

It is important to be aware of which interface and circuit is used. Therefore, prior to the start of NIV, the method of carbon dioxide removal should be identified, its patency assured, and compatibility of circuit and interface checked. Choice of interface is a major determinant of NIV success or failure.

Main aspects to consider when choosing the interface are:

1. Technical compatibility between ventilator and circuit. In most cases, ventilator calibration and ventilation mode setting are largely depending on the circuit used.
2. Safety especially on risks of throwing up and inhalation (a relative contraindication to start NIV).
3. Fitness of the interface. A well-fitted vented mask in a controlled leak circuit will provide most accuracy in ventilation than unfit non-vented mask in a closed circuit.
4. Overall setting in which NIV is started and devices availability (respiratory well-trained department or emergency room).

Role and Importance Before and After NIV Placement

The first few hours of acute NIV are crucial, and time spent fitting the mask and building the patient's confidence is well invested. Having a mask strapped immediately over the face can be very frightening for a breathless patient in acute respiratory failure, particularly if the person is naïve to NIV. A careful explanation of what will happen and why NIV is used as well as a description of the sensation the patient is likely to experience can help to facilitate the treatment.

Initiating NIV with lower pressures while holding the mask or having the patient hold the mask in place and not attaching the straps until the patient is ready to tolerate it can also help the patient to acclimatise. Once the patient can tolerate the mask, it can be secured with the head straps.

Prevention and Management of Mask-Related Side Effects

During NIV courses clinicians and respiratory nursing teams should avoid short and long-term issues associated to treatment. *Air leaking* around the mask represents the major limit because is associated with poor tolerance by patients and can cause a significant drop in the delivered intra-alveolar pressure, reduce VTs, and lead to asynchrony of ventilator-patient system. In these cases, reassessment, replacement, and fit of interface model according to the patient's guidance is mandatory.

Improving *mask pressure* could be effective but it has been demonstrated harmful on long-term ventilation courses to skin, noise, and mucosal lesions. Long-time application of high pressure on the skin can cause ulcers around the nose, decubitus on the nasal bridge, and pressure lesions around the cheeks.

Fig. 6.11 On the left skin pressure ulcers around the mouth, on the chin, and nasal bridge of a ventilated patient, on the right examples of foams, gel, and hydrocolloids pads that relief pressure on the tissues

Skin-protective strategies include ensuring the skin is clean and dry, as well as regular pressure relief, use of special mask cushions, and application of dressings to the skin to redistribute pressure and reduce friction. Ideal in long-term NIV usage are masks with hydrogel cushions or double spring air-filled cushions, or a combination of both. A rotation of two distinct types of interfaces, for example oro-nasal and full-face, can provide a regular relief on pressure on the tissues.

The routine use of additional protective coverings applied to areas with the highest pressure reduces the occurrence of pressure ulcers. Pads of foam, hydrocolloids, or gel distribute the pressure, reduce friction, and small air leaks at the same time (Fig. 6.11).

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Options Noninvasive Ventilator Support Outside Intensive Care Unit

7

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Abstract

The first-line treatment for respiratory failure is supplemental oxygen. Conventional supplemental oxygen is usually not humidified and although bubble humidifiers are frequently used the humidity of the gas remains low. High-flow nasal cannula (HFNC) have been gaining a lot of attention as an alternative means of oxygen therapy and respiratory support for critical patients. The heated and humidified air by the active humidifier has apparent beneficial physiological effects. The clinical benefits include ameliorated oxygenation; improved ventilation perfusion matching; reduced work of breathing; decreased airways resistance; and the balancing of intrinsic positive end-expiratory pressure (PEEP). Continuous Positive Airway Pressure [CPAP] is a method of ventilatory assistance that involves the application of a constant positive pressure to the patient's airways through a dedicated circuit and interface. CPAP has proven to be useful and effective only for hypoxemic respiratory failure (type 1 respiratory failure), while in the presence of a type 2 respiratory failure (hypercapnic), it is necessary to search for other solutions (e.g., noninvasive mechanical ventilation). Noninvasive mechanical ventilation (NIV) is an extensively used technique for

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acute respiratory failure (ARF). Application of NIV covers the management of ARF in patients with chronic obstructive pulmonary disease (COPD) exacerbation or acute cardiogenic pulmonary edema (CPE) which is now considered a first-line method of ventilatory support. Using NIV over invasive mechanical ventilation (IMV) in a variety of settings has proven to have many advantages. Thanks to its advantages and to the increase of evidence produced in the last years, with validation provided by different societies across the globe, NIV is now extensively and successfully used in the critical setting, inside and outside Intensive Care Units (ICUs) for different types of ARF and patients.

Keywords

Noninvasive mechanical ventilation (NIV) · Continuous positive airway pressure High-flow nasal cannula · Oxygen therapy · Helmet

Introduction

Respiratory failure is a condition in which the respiratory system fails one or both of its gas exchange functions: oxygenation of mixed venous blood and/or elimination of carbon dioxide (CO_2). Diagnosis of respiratory failure is not clinical but based on arterial gas analysis being defined by a $PaO_2 < 60$ mmHg (7.9 kPa) and/or $PaCO_2 > 45$ mmHg (5.9 kPa). Respiratory failure due to lung diseases leads to hypoxemia with normocapnia or even hypocapnia (type 1 respiratory failure).

Mechanisms responsible for hypoxemic respiratory failure are:

1. Ventilatory/perfusion (V/Q) ratio imbalance.
2. Shunt.
3. Diffusion Impairment.
4. Hypoventilation.

Hypoxemia is a condition in which oxygen is not available in a sufficient quantity to maintain adequate homeostasis in the different districts of the organism. Hypoxemia is a common finding in subjects with respiratory diseases, chronic obstructive pulmonary disease (COPD), and interstitial lung diseases (ILDs), particularly those with a more advanced disease. In some individuals, hypoxemia can be sufficiently severe to occur at rest and is associated with dyspnea, worsening of neurocognitive function, pulmonary hypertension (PH), and mortality [1–3]. Severe resting hypoxemia has been defined as a $PaO_2 < 55$ mmHg (7.3 kPa) or a $PaO_2 < 59$ mmHg (7.9 kPa) plus one of the following: edema, hematocrit >55%, or P pulmonale on ECG.

Failure of the pump results in alveolar hypoventilation and hypercapnia with parallel hypoxemia (type 2 respiratory failure). Neuromuscular diseases, Central Nervous System (CNS) depression (drugs, CNS diseases) muscle malfunctions, and chest wall abnormalities determine a pump failure which in turn may cause

hypercapnic respiratory failure. The therapeutic potential of supplemental oxygen was first described by Haldane in 1917 [2]. Since then, a multitude of reports have examined the role of oxygen therapy in respiratory patients.

Long-term oxygen therapy (LTOT) can be delivered through a combination of stationary equipment (e.g., stationary oxygen concentrators and liquid reservoirs) and ambulatory oxygen equipment (e.g., compressed-oxygen cylinders, portable oxygen concentrators [POCs], and liquid oxygen [LOX] canister).

Below is shown the current terminology for the oxygen therapy.

Ambulatory oxygen	Oxygen delivered during exercise or activities of daily living
Continuous-flow oxygen	When oxygen is delivered at a constant flow rate, regardless of the respiratory rate
Pulse-dose oxygen	Is defined as oxygen delivered during inspiration and quantity of oxygen administered is influenced by the respiratory rate
Long-term oxygen	Refers to supplemental oxygen for at least 15 h/d for a period of years, and in most cases for the remainder of the patient's life
Nocturnal oxygen	Is defined when oxygen is delivered during sleep time only
Palliative oxygen	When oxygen is given with the purpose to relieve dyspnea
Portable oxygen	Oxygen delivered through systems that can be carried or pulled by patients and allow them to leave their home
Short-term oxygen	Oxygen provided temporarily, during a period of severe hypoxemia

Long-Term Oxygen Therapy in COPD

Hypoxemia in COPD is a common finding especially in patients with advanced disease due to a decreased diffusion capacity and a worsening V /Q mismatch. A multitude of reports has shown a clear benefit for LTOT in COPD patients with hypoxemia. Two pivotal studies published in the 1980s demonstrated a significant decrease in mortality risk in patients undergoing LTOT compared with control subjects.

Nocturnal oxygen therapy trial (NOTT) study indicates a significant decrease in 2-year mortality risk in individuals prescribed with LTOT (24 h/d) compared with control subjects prescribed only nocturnal oxygen, while the Medical Research Council (MRC) study [4] found a 5-year mortality-risk reduction in individuals undergoing LTOT versus no oxygen.

While a subgroup analysis showed that LTOT compared with nocturnal oxygen improved survival in patients with a higher $PaCO_2$, lower arterial pH, lower Forced Vital Capacity (FVC), more severe nocturnal hypoxemia, a not significant difference in mortality, was found between continuous versus nocturnal oxygen in subjects with higher baseline Pulmonary Artery Pressure (PAP) and higher Pulmonary Vascular Resistance (PVR).

Also, the MRC study did not show mortality benefits according to baseline pulmonary hemodynamic characteristics [5]. Therefore, it is not possible to draw any clear conclusion on the effects of LTOT in patients with concomitant PH especially in the subset of patients with early pulmonary hemodynamic impairment.

Importantly the analysis of LTOT effects on hospitalizations rate and length of stay did not show a clear benefit in patients undergoing oxygen therapy.

The effects of LTOT on COPD patients who have moderate chronic resting hypoxemia (SpO_2 89–93%) are not clear while the costs seem to overwhelm the benefit.

Importantly ambulatory oxygen is suggested in adults with severe exertional room air hypoxemia because improves exercise capacity and may improve breathlessness during exercise testing [6].

Long-Term Oxygen Therapy in ILDs

ILDs are characterized by scarring and fibrosis of lung tissue which usually determine hypoxemia. Respiratory failure and hypoxemia in ILDs patients are due to a combination of ventilation/perfusion mismatch, shunt, and impairment of diffusion.

When present, severe resting hypoxemia often contributes to disabling and distressing breathlessness, which is common in ILD. Apart from lung transplantation, supplemental oxygen is the only treatment that improves hypoxemia that persists despite optimal medical management of the underlying disease [7].

Oxygen therapy is commonly prescribed for ILD patients who exhibit hypoxemia at rest and/or during exertion with the aim of reducing dyspnoea, increasing physical capacity, ameliorating quality of life (QoL), preventing secondary PH and right heart failure, and increasing survival. The mechanisms by which supplemental oxygen improves dyspnoea in ILD patients are not well established but could be due to a reduction of the respiratory drive and changes in breathing pattern. A reduction in dyspnoea using oxygen at rest has been demonstrated in patients hospitalized because of an exacerbation. However, it is not clear whether these results could be extended to individuals with stable disease and the only randomized trial to assess 6-Minutes Walking Test (6MWT) did not show significant improvements in this outcome.

International guidelines currently make a strong recommendation in favor of LTOT for people with interstitial pulmonary fibrosis (IPF) and BTS guidelines on home oxygen use suggests a higher threshold of 60 mmHg (8.0 kPa) for those who have concomitant PH.

The guidelines acknowledge the lack of studies supporting a survival benefit from LTOT, relying on indirect evidence from trials that include patients with obstructive lung disease. Studies that compared patients using LTOT and those without LTOT were unable to identify benefits for survival or QoL, however because of the degree of hypoxemia experienced by many people with advanced ILD, along with established clinical practices for oxygen prescription, it is likely that LTOT will continue to be used widely in these individuals.

Exertional hypoxemia is a hallmark of ILD, occurring in more than half of patients evaluated at a tertiary ILD service and in over 80% of patients with an FVC

of 50% of that predicted. The magnitude of exertional hypoxemia is generally greater in people with ILD than in people with COPD. People with ILD who desaturate to an $SpO_2 < 88\%$ on a 6MWT have a fourfold greater risk of death than those who do not, after adjusting for age, sex, smoking, respiratory function, and resting saturation. Exertional desaturation is an independent predictor of PH, which is itself a strong predictor of mortality. Greater exertional desaturation is strongly associated with reduced physical activity. These data provide a strong rationale for treatment of exertional hypoxemia in ILD to improve daily functioning and long-term outcomes.

Future trials of oxygen therapy in ILD should evaluate whether the acute improvements in exercise capacity can be translated into improved daily physical activity and better Health-Related Quality of Life (HRQoL) [3, 8].

High-Flow Nasal Cannula

The first-line treatment for hypoxemic respiratory failure is supplemental oxygen. During spontaneous breathing, inspired air passes through the upper (nose and pharynx) and lower (larynx, trachea, and bronchi) airways becoming warm and humidified up to body temperature and fully saturated with water vapor. Conventional supplemental oxygen is usually not humidified when administered at low flow and although bubble humidifiers are frequently used the humidity of the gas remains low [9]. Poor tolerance and compliance to oxygen therapy is often due to the complaint of patients regarding dry nose, throat, and pain while receiving cold and dry Conventional Oxygen Therapy (COT). It has been shown that breathing dry air results in excessive water loss by the nasal mucosa, which may reduce nasal mucociliary clearance rate and slowing of ciliary beating [10].

Although each individual appears to select one particular pattern at rest steady-state among the infinite number of possible combinations of ventilatory variables and airflow profile in patients in acute respiratory failure (ARF), the required inspiratory flow is higher than his usual with flow rates up to 120 L/min. COT can deliver oxygen at only a maximum of 15 L/min causing a substantial difference between demand and delivery. The expected fraction of inspired oxygen (FiO_2) is therefore inconstant and generally lower than expected [11–14].

High-flow nasal cannulas (HFNC) have been gaining a lot of attention as an alternative means of oxygen therapy and respiratory support for critical patients. With a FiO_2 which can range between 0.21 and 1.0 at up to 80 L/min flow, the heated and humidified air by the active humidifier has apparent beneficial physiological effects.

The clinical benefits are numerous, including improved oxygenation; improved ventilation perfusion matching; reduced work of breathing; reduced airways resistance; and the balancing of intrinsic positive end-expiratory pressure (PEEP).

To which extent HFNC contributes to these effects is still to be determined.

Humidification

As an open system with constant flow, HFNC is able to deliver a constant amount of vapor. During spontaneous breathing, however, tidal volume (TV) and inspiratory flow varies and, if HFNC flow is less than patient inspiratory flow, the patient will inspire atmospheric air.

The effects on the respiratory system of breathing dry gasses have been well established in the past. Lowering the absolute humidity (AH) of air induces a decrease in the transport capacity of airway mucus which appears to be dependent on the change of spinability (rheological property) that occurs in the mucus [15, 16]. Breathing dry air produces an acute reduction of extravascular water of the loose connective tissue of the airways and an increase in the maximum response to histamine [17].

In asthmatic patients, there is an enhanced bronchoconstrictor response to the activation of nasal cold receptors, particularly when rhinitis is present.

Therefore cold COT may elicit symptomatic bronchoconstriction. The nasal obstruction present in sleep apnea in obese patients is predominantly inflammatory in origin and the use of heated and humidified air decreases nasal inflammation and resistance to airflow. During noninvasive mechanical ventilation (NIV) and mechanical ventilation dry air frequently creates inspissated secretions and the occurence of fatal mucous plugs or direct tube occlusion is possible [18, 19].

Humidification is influenced by many factors, and only when HFNC flow is higher than the inspiratory flow of a patient with optimally positioned nasal prongs is it reasonable to expect that the patient is inspiring well-conditioned gas. Although HFNC devices usually incorporate a heated humidifier into the mechanical ventilation system, the capability of such systems to create adequate vapor for high flow remains unclear. With a flow of 60 L/min the AH was lower at 60 L/min than at 40 L/min. Therefore when applied at very high flow rates the humidification may be less than adequate [20, 21].

Interface

The nasal prongs of HFNC are a major strong point for the high successful rate in their use. Although NIV has been the mainstay for respiratory failure due to its ability to directly support patient ventilation, the different interfaces have since the beginning caused many issues. Oronasal masks, nasal masks, and hoods are most commonly used for NIV. Oronasal masks are usually tried first because they ensure the effects of NIV better than other interfaces. Unfortunately, many patients find it hard to tolerate due to the lack of comfort and skin lesions which frequently develop. It is also associated with a relatively high incidence of air leakage [22]. Also, skin lesions at the nose induced by long-term use of this device may result in frequent treatment interruptions and discontinuation pressure ulcers ranging from 15 to 100% [23, 24].

Since the HFNC is an open system, air leaks are not a problem and tight fixes are not an issue. Therefore, nasal traumas and ulcers are less frequent.

Because of the difficulties of managing NIV over long periods, HFNC is a promising alternative to NIV for do-not-intubate (DNI) patients. Peters et al. applied HFNC to 50 DNI patients with hypoxemic respiratory distress who were admitted to a medical intensive care unit (ICU); They excluded patients with $PaCO_2 > 65$ mm Hg and pH < 7.28. The primary end point was the need for escalation to NIV. Authors observed that 82% of subjects were maintained on HFNC without further need of ventilatory support demonstrating that HFNC can provide adequate oxygenation for patients with hypoxemic respiratory failure and may be an alternative to NIV for DNI patients [25].

PEEP, FiO_2, and Ventilatory Support

Despite the HFNC being an open system, the high flow rates from the nasal cannula offer resistance against the expiratory flow during expiration increasing pharyngeal pressure. Mouth opening or closing significantly influences positive pharyngeal pressure. This is in contrast to the FiO_2 which instead is not affected.

Parke et al. measured nasopharyngeal pressure in post-cardiac surgery subjects: Nasopharyngeal pressure at 35 L/min flow, during HFNC, increased to 2.7 ± 1.04 cmH_2O with the mouth closed and 1.2 ± 0.76 cmH_2O with the mouth open, but with the face mask, it remained at around zero. The mean nasopharyngeal pressure generated ranged from 1.54 to 5.34 cmH_2O. This variability may be due to the wide differences in nare size among the study population and variability in leak around the outside of the nasal cannula. A decrease in the amount of leak may create an increased resistance to expiration resulting in higher nasopharyngeal pressure [26].

Recently, Parke et al. measured End Expiratory Lung Volume (EELV) at up to 100 L/min of HFNC in healthy volunteers. Airway pressure and EELV increased linearly with increased gas flow [27].

As already discussed previously, both TV and inspiratory flow vary breath by breath and during each breath determining a difference between inspiratory flow and the supplementary oxygen flow. Therefore the assumption that all the delivered oxygen is inspired is not true especially in mask ventilation due to the presence of holes in the mask to prevent rebreathing of CO_2. Generally, the inspired FiO_2 is lower than estimated during closed-mouthed breathing via face mask and higher with open-mouthed breathing. Also, with nasal cannula, the inspired FiO_2 is lower than calculated.

HFNC overcome the problem by delivering oxygen at very high flow rates tendentially matching the inspiratory flow of the patient. Ritchie et al. found that during nose breathing at rest >30 L/min, measured FiO_2 was close to delivered FiO_2 [28].

HFNC being an open system neither push nor pull gas into the lungs therefore it does not increase TV and minute ventilation.

Clinical Applications

Pre-Intubation Oxygenation

Intubation can be associated with many complications especially in the ICU and in severely hypoxemic patients. Oxygenation can be delivered both by COT or NIV and during laryngoscopy; however, the mask must be removed. HFNC can be positioned before and may remain in place during laryngoscopy without interfering with the maneuver. This allows oxygenation during the apneic phase of intubation which can be critical in severely hypoxemic patients. In clinical trials comparing non-rebreathing bag reservoir face mask and HFNC on pre- and peri-procedure oxygenation during tracheal intubation of ICU subjects, Miguel-Montanes et al. found that with the non-rebreathing bag reservoir face mask, the median lowest SpO_2 during intubation was 94%, whereas with HFNC it was 100%. The incidence of severe hypoxemia (SpO_2 < 80%) was significantly reduced with HFNC (14% vs. 2%) [29].

Post-Extubation

Re-intubation is associated with prolonged recovery in both ICU and hospital, and with greater mortality. Hernandez et al. compared the effects of HFNC and NIV on re-intubation and post-extubation in high-risk patients. They found that among high-risk adults who have undergone extubation, HFNC therapy was not inferior to NIV for preventing re-intubation and post-extubation respiratory failure. HFNC-conditioned oxygen therapy offered advantages for these patients such as warm and humidified air with better management of secretions and was better tolerated [30].

Sleep Apnea

The deleterious effects of obstructive sleep apnea (OSA) are well established (collapse of the upper airways with hypoxemia, over-activation of the sympathetic system, cardiovascular and neurocognitive dysfunctions). Although continuous positive airway pressure (CPAP) has been the gold standard for many years and is an effective treatment, adherence remains an issue and is many times suboptimal. McGinley et al. found that HFNC for OSA alleviated upper airway obstruction in children and adults and HFNC reduced arousals and apnea-hypopnea index ratings. Among acute stroke patients, disordered breathing during sleep is common and is associated with poor prognosis and neurologic worsening. HFNC (18 L/min) was well-tolerated and decreased ratings both for apnea and oxygen desaturation and ultimately quality of sleep was better [31, 32].

Hypoxemic Respiratory Failure

The most common noninvasive respiratory treatment in AHRF is COT, which increases the FiO_2, using simple interfaces such as facemasks with or without reservoirs, nasal prongs, or Venturi masks. Failure may occur due to ineffective matching of the patient's ventilatory needs due to altered respiratory mechanics, unreliable FiO_2 delivery which is normally suboptimal, and lack of humidification with the already discussed negative effects.

By providing airflows as high as 60–80 L/min, HFNC is more likely to match the high inspiratory demands of dyspneic patients with AHRF, and is able to achieve an FiO_2 as high as 100%, while also providing a low level of PEEP in the upper airways, facilitating alveolar recruitment.

Comparing HFNC to COT, mortality in the short term was similar. Intubation rates were decreased when applying HFNC in AHRF as so was escalation to NIV. Patient's dyspnea, discomfort, and respiratory rates were lower. For these reasons, the ERS clinical practice guidelines suggest the use of HFNC over COT in AHRF with a moderate level of certainty [33].

Investigating the efficiency, safety, and outcome of HFNC in ICU subjects with ARF, Sztrymf et al. replaced about 15 L/min oxygen flow via face mask with HFNC 49 ± 9 L/min. This reduced dyspnea, breathing frequency, and heart rate, and improved thoraco-abdominal synchrony and SpO_2 and supraclavicular retraction [34].

While NIV is frequently used to treat AHRF, breaks from NIV are necessary for many practical reasons including speaking, feeding, discomfort, and patient's tolerance due to mask pressure. It is also useful to take breaks to ascertain readiness for weaning from NIV. Although COT is frequently used during these breaks HFNC may be a more effective alternative due to the humidification and more reliability in maintaining optimal FiO_2 delivery and matching patient's respiratory efforts.

Hypercapnic Respiratory Failure

Official ERS/ATS guidelines recommend the use of NIV for patients with COPD or acute hypercapnic acidotic respiratory failure (pH $\leq$7.35) prior to intubation unless the clinical situation is already too critical. NIV increases the ventilatory support thereby decreasing fatigue and dyspnea. A frequent issue is intolerance due to mask pressure on the face, skin lesions, and mask leaks which may lead to failure. HFNC is well tolerated and although it does not provide active ventilatory support it increases TV to some extent in COPD patients [35].

HFNC has a rationale (i.e., positive pressure, reduced dead space, CO_2 washout, oxygenation, comfort, and tolerance) for use in hypercapnic exacerbation of COPD and make it an alternative to NIV for acute-on-chronic hypercapnic respiratory

failure of mild to moderate severity degree of respiratory acidosis. However, its role in acute hypercapnic respiratory failure is not yet well established and the ERS guidelines suggest a first trial of NIV to understand the severity and response of the patient and then the use of HFNC in patients who cannot tolerate NIV or in breaks from NIV with respect to COT.

Other Conditions

In acute heart failure, CPAP remains the most frequent form of oxygenation due to the higher PEEP values which may be applied. HFNC has been used in symptomatic decompensated heart failure to relieve dyspnea and increase oxygenation with promising results. Moriyama et al. reported successful oxygenation in a patient with life-threatening pulmonary edema [36].

HFNC is easy to use in endoscopic procedures due to its ability to provide consistent FiO_2 values, high rates of airflow, and importantly minimal interference of endoscopic devices inserted via different routes. HFNC creates a PEEP to prevent variations in the expiratory flow. Killen et al. used HFNC during fiberoptic bronchoscopy (FBS) procedures and found that HFNC could prevent hypoxemia and reduce the number of interruptions during the FBS procedure in patients with underlying chronic respiratory diseases which were at risk for severe desaturation. The HFNC technique combined with propofol sedation could be safe for performing bronchoscopy in the ICU [37].

Contraindications

To date, absolute contraindications are absent.

Continuous Positive Airway Pressure (CPAP)

CPAP is a method of ventilatory assistance that involves the application of a constant positive pressure to the patient's airways through a dedicated circuit and interface.

It must be underlined that the patient is entirely responsible for respiratory work and therefore CPAP can be used only when we judge the patient's ability to cope with this effort without too much difficulty [38]; it follows that a subject with ARF and associated clinical signs of respiratory fatigue is not a good candidate for CPAP.

CPAP has proven to be useful and effective only for hypoxemic respiratory failure (type 1 respiratory failure), while in the presence of a type 2 respiratory failure (hypercapnic), it is necessary to search for other solutions (e.g., NIV).

Indications hypoxemic respiratory failure from various causes, which generally share the feature of a reduction in functional residual capacity (FRC).

The most frequent clinical conditions for the application of CPAP are acute cardiogenic pulmonary edema (CPE) on a hypertensive basis [39], severe pneumonia, early stages of ARDS, and respiratory failure due to SARS-CoV2 pneumonia [40].

Equipment An oxygen source, a system capable of generating the gas flow, a circuit suitable with the patient interface.

- Source of oxygen: usually, in hospitalized patients, the centralized pressure oxygen system is used; alternatively, a common oxygen cylinder can be used, with the limit that often the CPAP needs high oxygen flows and therefore the capacity of the cylinder can be an important limitation.
- Flow generator: the most effective system is the one that uses a high-performance flow generator that consists of a double oxygen flowmeter that works by exploiting the Venturi effect; alternatively, normal flow meters for COT can be used.
- Circuit: normally is used a monotube circuit that conveys the mixture of gases from the oxygen source and through the flow generator to the patient.
- Interface: the best method involves the use of a CPAP helmet, alternatively CPAP masks can also be used.

Settings The parameters to be set are the pressure inside the circuit, the main flow, and the secondary flow.

- Pressure: it is configurated simply by adjusting the PEEP valve mounted on the helmet. Normally pressure range from a minimum of 5 cmH_2O to a maximum varying between 10 and 15 cmH_2O.
- Main flow: it is regulated through the rotameter of the flow generator and must guarantee a total flow inside the helmet of at least 30 L/min to avoid rebreathing of the exhaled air by the patient.
- Usually, tables provided by the manufacturer of the flow generator can be used to know which value to set the knob of the rotameter.
- Secondary flow: it is used to regulate the FiO_2 and therefore guarantee the arrival inside the helmet of the amount of oxygen that the operator deems necessary; usually the FiO_2 used is at least 50%; the provided adjustment tables allow to select the most appropriate value on the rotameter of the secondary flow.

Example of a CPAP setting (Tables 7.1, 7.2 and 7.3).

- PEEP valve adjusted to 10 cmH_2O.
- Main flow 15 L/min.
- Secondary flow 15 L/min.

With these settings, we will apply a CPAP with 10 cmH_2O pressure, a FiO_2 of 50%, and total flow in the helmet of 80 L/min (see Table 7.3).

Table 7.1 PEEP valve 5 cmH_2O

	Supplemental O_2 (L/min)										
Main O_2 (L/min)	0	2	6	10	14	18	22	26	30	max	
6	34	34	34	33	33	33	33	33	34	34	Fl (L/min)
	40	45	56	67	78	89	92	93	95	96	FiO_2 (%)
10	65	64	63	62	62	62	62	61	62	60	Fl (L/min)
	36	38	43	48	53	60	65	71	76	92	FiO_2 (%)
14	106	103	103	102	102	102	101	101	101	101	Fl (L/min)
	33	34	37	40	44	47	50	54	57	79	FiO_2 (%)
18	130	130	130	129	129	129	130	130	130	131	Fl (L/min)
	33	34	36	38	41	44	46	48	51	66	FiO_2 (%)
22	152	152	152	152	153	153	153	154	153	152	Fl (L/min)
	33	34	35	38	40	42	44	46	48	65	FiO_2 (%)
26	181	181	182	183	181	181	181	183	183	179	Fl (L/min)
	33	34	36	37	39	41	43	45	46	62	FiO_2 (%)

Table 7.2 PEEP valve 7.5 cmH_2O

	Supplemental O_2 (L/min)										
Main O_2 (L/min)	0	2	6	10	14	18	22	26	30	max	
6	20	23	22	22	21	20	20	19	19	19	Fl (L/min)
	100	100	100	100	100	100	100	100	100	100	FiO_2 (%)
10	60	59	58	58	58	57	57	57	56	53	Fl (L/min)
	38	41	47	53	60	66	72	79	85	97	FiO_2 (%)
14	88	86	87	86	85	85	85	85	84	82	Fl (L/min)
	35	36	40	44	48	52	56	60	64	93	FiO_2 (%)
18	118	118	118	117	117	117	117	116	116	120	Fl (L/min)
	35	36	38	40	43	46	49	52	54	77	FiO_2 (%)
22	142	142	143	142	143	143	142	142	142	141	Fl (L/min)
	34	35	36	39	41	43	46	48	50	70	FiO_2 (%)
26	165	165	165	166	166	165	166	166	165	165	Fl (L/min)
	34	35	36	38	40	42	44	46	48	65	FiO_2 (%)

Table 7.3 PEEP valve 10 cmH_2O

	Supplemental O_2 (L/min)										
Main O_2 (L/min)	0	2	6	10	14	18	22	26	30	max	
6	–	–	–	–	–	–	–	–	–	–	Fl (L/min)
	–	–	–	–	–	–	–	–	–	–	FiO_2 (%)
10	36	36	35	35	35	34	34	33	33	32	FL (L/min)
	43	48	59	71	82	92	94	95	96	100	FiO_2 (%)
14	82	81	81	80	80	80	79	79	79	76	Fl (L/min)
	36	38	42	46	50	55	59	64	68	95	FiO_2 (%)
18	113	112	111	111	111	112	112	112	112	114	Fl (L/min)
	35	36	38	41	45	47	50	53	56	82	FiO_2 (%)
22	136	138	137	137	137	138	138	140	139	137	Fl (L/min)
	34	35	38	40	42	45	47	50	52	72	FiO_2 (%)
26	159	159	160	160	160	161	160	160	160	158	Fl (L/min)
	35	36	37	39	41	44	46	47	49	66	FiO_2 (%)

Troubleshooting During CPAP

Excessive Noise Inside the Helmet It is a normal scenario during the high flow of air/oxygen conveyed in the helmet to produce noise; it can be attenuated very effectively by interposing filters both on the opening of the T tube of the generator, before the circuit (Fig. 7.1) and at the entry and exit points of the helmet (Fig. 7.2). Alternatively, the patient can put plugs in the auditory meatus.

Loss of Pressure (Helmet "Deflated") If for various reasons there is a pressure drop in the circuit, the anti-suffocation valve in the helmet porthole (Fig. 7.2) opens as a safety mechanism; the helmet at this point is deflated and the patient breathes at zero pressure level; the risk is a rapid desaturation with the obvious consequences involved.

To prevent this event, it is necessary to be sure that the helmet is correctly positioned during its assembling and also to remember that the collar varies in size and the helmet packaging usually has a meter to measure the circumference of the patient's neck in order to choose the most appropriate helmet size.

During the setting of flow through the high-performance generator, it is recommended to provide an overall flow in the circuit, and therefore in the helmet, greater

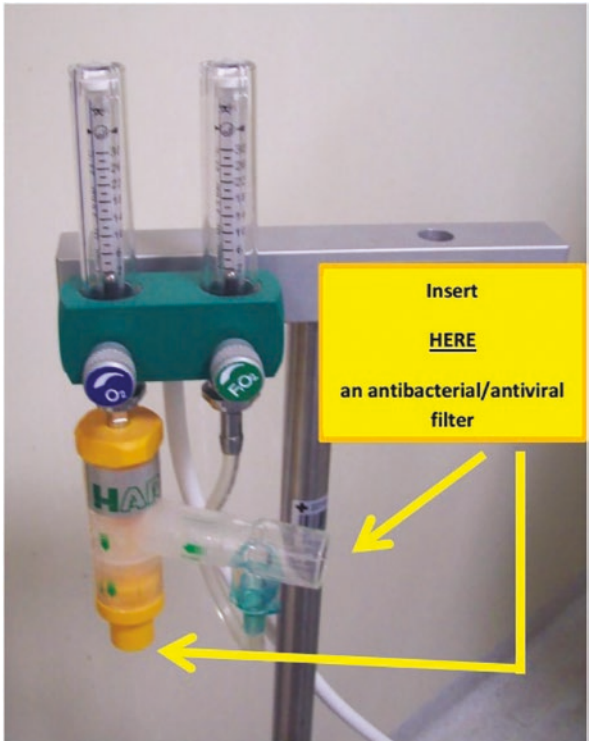

Fig. 7.1 Flow generator for CPAP

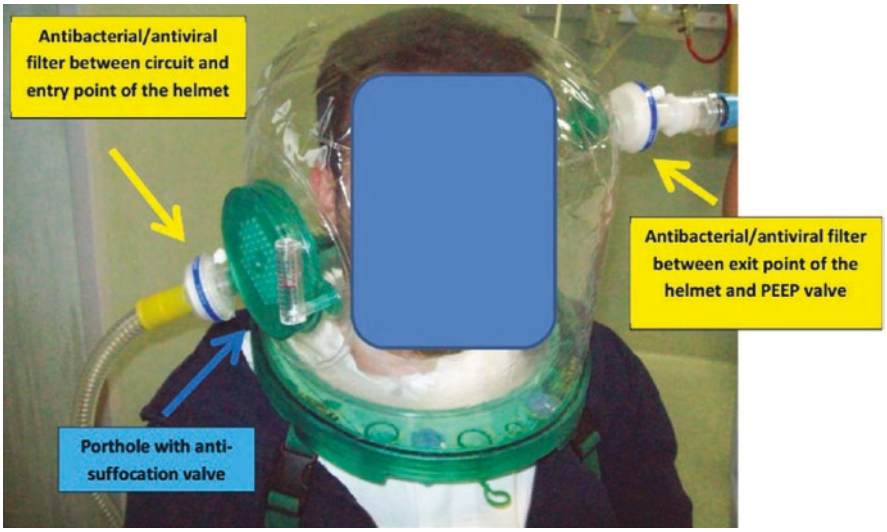

Fig. 7.2 Equipment for CPAP

than 60 L /min; the high flow helps to limit the possibility that small and perhaps transient pressure losses in the circuit will end with the opening of the anti-suffocation valve with the consequences previously described.

During the choice of the suitable flow, please refer to the tables above, remembering that the total flow in the circuit is regulated by the knob of the main flow.

Unstable Pressure in the Helmet It may happen that the spring pressure gauge usually present in the helmet measures an unstable pressure, in particular, there may be a pressure drop during inhalation and an increase in pressure during exhalation; this phenomenon is linked in part to the patient's ventilation activity and involves a continuous change in pressure inside the helmet; therefore, the patient is not subjected to continuous pressure with a reduction in the effectiveness of therapy.

The problem can be mitigated and often solved by increasing the total flow of air/oxygen in the helmet, thus increasing the main flow on the generator.

Noninvasive Mechanical Ventilation

Introduction

NIV is an extensively used technique for ARF deriving from different etiologies; the term refers to the administration of ventilatory support without using an invasive artificial airway (without bypassing the upper airway) and over the past two decades has become a widespread fundamental tool in the management of respiratory failure supported by an increasing body of evidence [40, 41].

Application of NIV covers the management of ARF in patients with COPD exacerbation or acute CPE, which is now considered a first-line method of ventilatory support, but its use has been extended in the past years in a variety of situations such as hypoxemic respiratory failure, the prevention of post-extubation ARF, palliative care, ARF due to chest trauma and as a tool for weaning patients from invasive mechanical ventilation (IMV) [40–45].

Using NIV over IMV in a variety of settings has proven to have many advantages such as the reduction of complications deriving from endotracheal intubation with better comfort for patients and also maintaining intact the patients' respiratory drive; NIV may also be used as the only method for providing ventilatory support in patients who are not candidates for or decline IMV.

Thanks to its advantages and to the increase of evidence produced in the last years, with validation provided by different societies across the globe, NIV is now extensively and successfully used in the critical setting, inside and outside ICUs for different types of ARF and patients.

Options for Noninvasive Ventilator Support: The Role of NIV

Considering NIV as an option for the ventilatory support in ARF patients, it is important to underline the main differences this technique presents from other methods such as CPAP, a well-established ventilatory support technique, and high-flow nasal cannula oxygen (HFNCO), a more recent method of delivering oxygen therapy.

HFNCO delivers a highly heated and humidified flow of an oxygen-enriched fresh gas through nasal cannulas or even tracheostomy opening (T-HF) at a certain flow rate (up to 60 L/min) and FiO_2. HFNCO provides ventilatory support due to the reduction of inspiratory nasopharyngeal resistance to the airflow and generating a flow-dependent positive airway pressure; the high flow of fresh gasses is also responsible for a dead space washout of CO_2.

HFNCO does not provide support in terms of positive pressure during the inspiratory phase so is not to be considered a ventilation technique and cannot be applied in patients who are not spontaneously breathing.

CPAP delivers a constant pressure greater than atmospheric pressure throughout the respiratory cycle during spontaneous respiration, both during inspiration and exhalation phase the level of pressure delivered is the same, therefore CPAP does not provide assistance during inspiration and requires an intact respiratory drive from the patient.

NIV provides a pressure during the inspiratory phase that is greater than the pressure applied during exhalation therefore providing ventilatory support.

Ventilatory support provided by NIV has proven to reduce the neuromuscular drive and inspiratory muscle effort unloading respiratory muscles from work and directly intervening on the respiratory pump failure from which derives type 2 ARF; in type 1 ARF the main issue is lung failure or gas exchange failure, on which ventilatory support provided by NIV has been proven to improve oxygenation without directly operating on the mechanism responsible for hypoxemia [42, 44, 46, 47].

Interfaces

Interface is a system used to connect the patient to the ventilator tubing, allowing to deliver pressurized gas to the airway.

There are different interfaces available which differ for face covering (nasal, oronasal, whole face, or helmet) (Fig. 7.3) and straps systems used to hold the interface in place.

The selection of the most adequate interface system is an important moment in the setup of ventilatory therapy and can determine success or failure of NIV.

Generally, full face mask (FFM) is the preferable interface as in AHRF predominates a mouth breathing pattern, a valid alternative is the helmet with the disadvantage of less effective triggering.

Nasal and oronasal masks are preferable interfaces for the chronic patient and domiciliary ventilation support [40, 41, 48].

Fig. 7.3 Different types of interface

Indications for NIV

Acute Hypercapnic Respiratory Failure Due to a COPD Exacerbation

Acute exacerbations of chronic obstructive pulmonary disease (AECOPD) are described as a sudden worsening in respiratory function and symptoms in patients with COPD, and it's a typical type of acute-on-chronic respiratory failure.

NIV applies in different clinical settings for ARF due to AECOPD.

NIV can be used in patient with mild respiratory acidosis to prevent clinical deterioration to a point when intubation and IMV are needed (Table 7.4).

NIV demonstrated to reduce dyspnea, rate of intubation and ICU admission, respiratory and nonrespiratory infectious complications, hospital length of stay, and even mortality [40–42].

In the COPD patient the external application of PEEP and PSV can offset the auto-PEEP reducing the work of breathing and interrupting the vicious cycle of dynamic hyperinflation thank to the reduction of the RR with a positive effect on expiratory time.

Patients with mild Respiratory acidosis with pH between 7.25 and 7.35, in the absence of a metabolic cause for acidosis is the group of patients with the strongest evidence for NIV use.

Even if there is no sufficient evidence to establish an absolute threshold value of pH or $PaCO_2$ to use as indication for IMV rather than NIV, a pH of 7.25 is conventionally used as inferior limit to consider IMV and pH <7.15 as indication for ETI and IMV.

Table 7.4 Indications for ETI and IMV

– Depressed consciousness
– Respiratory arrest/peri-arrest or gasping
– Respiratory distress with escalating RR
– Persisting pH <7.15
– Worsening acidosis with deterioration of pH value despite NIV
– Developing hemodynamic instability with signs of low cardiac output

Table 7.5 Contraindications for NIV

Absolute contraindications
– Coma/depressed consciousness
– Respiratory arrest/peri-arrest or gasping
– Hemodynamic instability
– Severe facial deformities
– Facial burns
– Fixed upper-airway obstruction
Relative contraindications
– pH < 7.15 (7.25)
– GCS < 8
– Confusion/agitation or non-cooperative patient
– Cognitive impairment
– Vomiting
– Pneumothorax (should be drained before initiation of NIV)
Note: Old age alone is not a contraindication for NIV

Anyway, severe acidosis alone is not a contraindication for NIV, unless the patient is rapidly deteriorating, thereby a trial of NIV could be attempted in selected patients with prompt intervention if ETI is needed, so that the use of NIV does not delay escalation to IMV when appropriate (Table 7.5).

Conventionally criteria for defining NIV failure are persisting or worsening acidosis or/and escalation of respiratory distress/ increasing RR.

Commonest reasons for NIV failure generally rely on mask leak and asynchrony between patient and ventilator.

Patients with ARF who are hypercapnic but are not acidotic in the setting of AECOPD do not benefit from the use of NIV, NIV appears to not reduce the need for ETI and mortality and the main focus should be medical and oxygen therapy [40, 41].

Finally, NIV can also be used as ventilatory support in patients who refuse or who are not candidates for IMV.

Acute Respiratory Failure Due to Cardiogenic Pulmonary Edema

Both NIV and CPAP have proven to be effective therapies in CPE, improving dyspnea, and reducing the rate of intubation and mortality [41].

During CPE the alveolar flooding due to high capillary pressure drastically reduce the compliance of the respiratory system escalating the effort of the respiratory muscles and with an increment of the ventricular afterload.

In this situation, the application of a PEEP through NIV or CPAP demonstrated to reduce the respiratory effort, improving respiratory mechanics, and decreasing left ventricular afterload and, thereby, left ventricular work.

Despite both techniques demonstrated to be effective, CPAP should be preferred in this clinical setting.

Hypoxemic ARF or De Novo ARF

De Novo ARF is defined as a Respiratory failure without a prior chronic respiratory disease; such ARF occurs without being an exacerbation of a previous COPD or restrictive syndrome and is generally a type 1 respiratory failure in which the main feature is clinical hypoxemia.

The pathophysiologic mechanism underlying hypoxemia may be:

– Shunt.
– Ventilation/Perfusion Mismatch.
– Impaired diffusion.

* Hypoventilation generally causes a type 2 ARF with hypercapnia as main clinical feature.

Clinical presentation includes:

(a) PaO_2/FiO_2 Ratio < 300.
(b) Dyspnea/Tachypnea (RR > 30 breaths per min).
(c) $PaCO_2 \leq 45$ mmHg.
(d) Absence of previous chronic respiratory disease.

The effect of NIV in this type of ARF not deriving from respiratory pump failure is less clear since ventilatory support provided by NIV does not intervene directly on the cause of respiratory failure such as in type 2 ARF [44, 46, 47].

In hypoxemic ARF NIV lacks of efficacy in reducing the work of breathing; Moreover the pressure dissipated to inflate the lungs in patients with hypoxemia, whose inspiratory demand is very high, and larges TVs resulting from this inflation, could generate high transpulmonary pressures and exacerbate lung injury. Indeed lung injury is possible not only in invasively ventilated patients but also during NIV and in spontaneously breathing patients under certain circumstances as there is evidence that spontaneous ventilation induce harm similar to VILI when there is severe lung injury, an effect known as patient self-induced lung injury (PSILI) [49].

The high pressures required are also responsible for air leakage, gastric insufflation, and also patient intolerance.

Anyway, the main risk associated with NIV to treat De Novo ARF is none of the above but is to delay a needed intubation.

Considering pros and cons of the use of NIV in this clinical setting it is possible to offer a NIV trial to patients with hypoxemic ARF only if they're carefully selected, strictly monitored, and managed by an expert team, and only if ETI and IMV could be promptly provided if needed.

Acute Asthma

The use of NIV for the treatment of acute asthma is controversial [40, 41].

Acute asthma presents with a sudden and reversable episode of bronchoconstriction leading to an increased airway resistance and mechanical load that generates hyperinflation, increased respiratory muscles work, and induce dyspnea.

The combination of increased respiratory effort and reduced efficiency in respiratory muscle contraction generated by hyperinflation conduct to the exhaustion of the respiratory muscle pump, leading to hypoventilation and hypercapnia in the late evolution of the most severe cases of acute asthma.

Episodes of acute severe asthma requiring escalation of medical assistance to an intensive setting are quite uncommon and ETI with IMV in those cases has proven to be effective, is associated with low mortality rate, and is generally the treatment of choice.

Despite performing a trial of NIV in this clinical setting could be theoretically useful, as NIV could reduce respiratory muscles work improving ventilation and lowering dyspnea with some studies also showing a decrease in the rate of ETI, such practice should be carefully applied considering the risk of bronchospasm exacerbation, patients' deterioration and application of high inflation pressures and inspired oxygen fraction, leading to NIV failure in short periods of time.

Anyway, when addressing acute asthma, the vault stone of the management should be considered medical therapy rather than ventilation support.

ARF in Immunocompromised Patients

Respiratory failure represents the main reason of ICU admission of the immunocompromised patient.

NIV is considered the first-line treatment for managing mild to moderate episodes of ARF in this subgroup of patients. Anyway, it must be considered that monitoring in an intensive setting and prompt availability of IMV when needed are mandatory [40, 41].

Postoperative ARF

Postoperative ARF (PRF) can be defined as pulmonary gas exchange impairment after a surgical procedure and as a result of the changes induced by anesthesia and surgery (respiratory failure secondary to cardiac dysfunction is generally excluded from this definition) and appears within a few days after surgery, with a time frame between 1 and 7 days and a median time of 48 hours, but possibly also in a late frame up to 30 days after surgery.

His severity varies from transient hypoxemia and ARDS and can be classified as mild, moderate, or severe relying on PaO_2/FiO_2 Ratio.

Mechanism responsible for this condition includes the airway closure and atelectasis induced by the reduction of muscle tones after general anesthesia, conducting to ventilation-perfusion mismatch and shunts, and the surgical manipulation of structures near the diaphragm during thoracic and upper abdomen surgery.

Others include hypoventilation due to residual anesthesia, postoperative residual curarization (PORC), lung edema or bronchospasm/laryngospasm.

In case of PRF, the risk for other complications, such as postoperative pneumonia, increases.

In general, could be said that the pathogenesis of PRF is multifactorial.

Both CPAP and NIV intervene to counter the pathophysiological mechanisms of PRF, so in this clinical setting, NIV is useful to improve lung aeration and gas exchange, reducing the amount of atelectasis, postoperative complication, and reducing the rate of ETI [40, 41, 50].

Post-Extubation Respiratory Failure

Considering post-extubation respiratory failure different considerations should be made between two clinical situations for which NIV could be used to prevent post-extubation respiratory failure and avoid re-intubation (Preventive NIV):

1. Unplanned extubation regarding at-risk or non-at-risk patients.
2. Planned extubation in patients at high risk of post-extubation respiratory failure.

While in the former situation the use of NIV seems to not produce a significant difference in re-intubation rate, for the latter, NIV not only prevents re-intubation risk when applied immediately after planned extubation, but also seems to reduce the development of post-extubation respiratory failure and mortality [40, 41].

Patients at risk of post-extubation respiratory failure are not easy to identify since there is no agreement on which criteria should be used to define such patients. Anyway, generally patients aged >65 years with underlying cardiac or respiratory disease are considered at high risk and should be addressed with a planning for extubation and considered for a NIV support immediately after.

On the other hand, no evidence supports the use of NIV on the group of patients that already had developed respiratory failure after extubation (Rescue NIV) thus its role is only preventive.

Since respiratory failure develops NIV has no benefit on re-intubation rate and could be detrimental if its use delays a needed intubation.

Chest Trauma-Induced ARF

Posttraumatic ARF results from the involvement of the thoracopulmonary system after a traumatic event. The main pathophysiological mechanism causing ARF relies on the restrictive defect originating from pulmonary contusion, with reduction in compliance and FRC, and from the involvement of respiratory muscles and chest wall conducting to respiratory pump impairment, which contributes also to pain deriving from trauma.

Both CPAP and NIV could be useful in this clinical setting if pain is well controlled and hypoxemia is not severe. Anyway, caution must be used, strict monitoring is mandatory, and the hypothesis of a novel development of pneumothorax and/or pneumomediastinum must always be considered in rapidly deteriorating patients [40, 41, 45, 51].

Cystic Fibrosis and Non-CF Bronchiectasis

Acute exacerbation of bronchiectasis generally presents as recurrent episodes of hypercapnic respiratory failure, frequently precipitated by infections, interspersed with periods of relatively good health status.

In this clinical setting, NIV is considered as the treatment of choice when a ventilatory support is needed and should be started following the same criteria as for AECOPD [40, 41].

Obesity Hypoventilation Syndrome (Pickwickian Syndrome)

Obesity hypoventilation syndrome (OHS) is defined as a combination of obesity (body mass index $\geq$30 kg/m^2), daytime hypercapnia ($\geq$45 mmHg), and sleep-disordered breathing, after ruling out other disorders that may cause alveolar hypoventilation.

The exact cause of OHS is not known, but mechanisms such as obesity-related changes in the respiratory system, alterations in respiratory drive, and breathing abnormalities during sleep can be responsible for this condition.

The obese patient is also subjected to the effect of body mass on the thoracopulmonary system which is associated with a restrictive lung ventilatory defect.

Patients diagnosed with OHS generally require long-term domiciliary support (CPAP), and many of them anyway experience at least one episode of exacerbation presenting as an acute-on-chronic respiratory failure (type 2 hypercapnic ARF).

These episodes could be anticipated by the need to change respiratory setting for domiciliary ventilation, with increasing pressures needed to deliver adequate breaths, especially during sleep. Consider High IPAP and EPAP settings as IPAP >30 cmH_2O and EPAP >8 cmH_2O.

Another common cause of ventilatory support failure is fluid retention and subsequently fluid overload, and presence of excessive secretions.

Indications for NIV in the obese patient with OHS should be the same as used for AECOPD and includes pH <7.35 and $PaCO_2$ > 45 mmHg (Respiratory acidosis), if they're anamnesis comprises daytime somnolence or sleep-disordered breathing or right heart failure and they are hypercapnic, NIV could be indicated even in the absence of acidosis [40, 41].

Neuromuscular Disease

Respiratory impairment with evolution to terminal respiratory failure is part of disease progression in many cases of neuromuscular diseases (NMD).

NMD include those deriving from muscular dystrophies, those deriving from a motoneuron disease such as amyotrophic lateral sclerosis (ALS), and those deriving from metabolic disorders, as for acid maltase deficiency.

A complete discussion about every NMD and their clinical features is beyond the purpose of this text.

Anyway, considering respiratory impairment as a major clinical feature of NMDs, NIV plays a central role in the management of these conditions [40, 41, 43].

An important clinical feature regarding patients with NMD is that any elevation of $PaCO_2$ may herald an impending episode of acute failure, thereby NIV support should be considered even without respiratory acidosis in those patients who are hypercapnic with shortness of breath/tachypnea (RR > 20 breaths per min) or acutely unwell, before they develop acidosis.

Treating a restrictive condition, ventilation initial setting should target low-pressure support (but patients with chest wall deformity may require higher levels of PS), inspiratory/expiratory time ratio (IE Ratio) 1:1, low PEEP, and low trigger setting, preferentially flow triggered ventilation and pressure support setting.

Controlled ventilation should be considered if triggering results are ineffective.

Recovery from acute episodes of respiratory failure in patient with NMD is generally slower than in AECOPD and requires a slower process of weaning from NIV when not escalating to invasive form of assistance.

Weaning from Invasive Mechanical Ventilation

NIV is an effective tool that could be used during weaning from IVM in selected patients that have been intubated and ventilated with a diagnosis of hypercapnic ARF [40, 41].

In this group of patients, NIV could improve breathing patterns reducing respiratory effort while maintaining adequate gas exchange during the weaning phase.

Before deescalating from IMV to NIV a switch from controlled to assisted IMV should be made as soon as the patient recovery allows and readiness for weaning should be assessed daily.

End of Life

During the end of life, in a terminal condition setting, dyspnea is one of the main symptoms, worsening progressively as death approaches.

The control of such symptoms is challenging, but at the same time necessary to relieve patient's suffering during the last moments of his life.

NIV is a precious resource in this setting for patients who cannot or do not want to benefit from an escalation of therapy involving ETI and IMV (for which NIV can be considered the "ceiling" of treatment), as it may alleviate dyspnea and prolong life for a sufficient period of time, potentially allowing the patient to carry out personal tasks and realize end-of-life- desires [40, 41, 52].

Sedation is generally associated with ventilatory palliation, as it is fundamental to relieve pain, and opioids are the most frequent choice; anyway, when using sedatives during NIV in this setting, attention must be paid to the risk of oversedation, as it could frustrate the application of such therapy.

We can identify 3 types of NIV usage in this setting, as defined by the Society of Critical Care Medicine:

- Type 1 Patients: NIV is a life support with no limitation of therapy.
- Type 2 Patients: NIV as salvage therapy but patient has decided to forego intubation.
- Type 3 Patients: NIV as symptom alleviation.

Contraindications for NIV

Discontinuation of NIV

Before starting to wean from NIV the sustaining cause of ARF must be addressed and treated.

Also, fluid management has to be optimized with a strategy directed to avoid and eventually treat fluid overload.

Criteria used to guide the discontinuation of NIV are

- Normalization of pH > 7.35.
- Normalization of $PaCO_2$ < 48 mmHg (6.5 kPa).
- PaO_2/FiO_2 Ratio > 200 mmHg (27 kPa).
- FiO_2 < 0.5.
- PEEP <10 cmH_2O.

Good clinical practice is to alternate periods of NIV with periods of self-ventilation.

During the weaning from NIV periods of self-ventilation should be prolonged to the point which NIV is only used overnight.

Setting on ventilator should also consist in reduction of pressure support and backup rate, relying more on the patient effort than on the ventilator work, as a criterion for patient capacity of autonomous ventilation.

If the patient is stable and parameters adequately controlled during spontaneous breathing, NIV withdrawal could be performed safely.

Noninvasive Ventilation Failure

Common causes of NIV failure are the followings:

- Patient-ventilator asynchrony.
- Excessive air leak.
- Copious secretions.

Regarding Patient-ventilator asynchrony, some of the most common causes are:

- Trigger failure: Ineffective triggering could derive from inadequate respiratory muscle activation by the patient or elevated iPEEP requiring excessive effort to trigger a breath.
- More common during sleep, when respiratory drive is reduced and more likely in long-time hypercapnic patients.
- Auto-Trigger: The ventilator delivers breaths inappropriately.
- Caused by manipulation of tubing, patient movements, including coughing, swallowing, or during suctioning.
- Facilitated when the trigger sensitivity setting is too high
- Inappropriate setting of ventilation.
- Inadequate Pressure support or an excessive delay in delivering the breath after triggering are common causes of "air hunger" during NIV.

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Part II

Patterns Response, Complications, Safety, Supervision and Quality Indicators for NIMV Outside ICU

8 Response, Complications, Safety, Supervision, and Quality Indicators for NIMV Outside ICU. Risk Factors for Failure

José Terán-Tinedo, María Churruca Arróspide, Miguel Lorente, Miguel Suarez, and Pedro Landete

Abstract

Noninvasive respiratory therapies have experienced significant growth in recent years, especially positive airway pressure or high-flow oxygen therapy. The usefulness of this respiratory support has been demonstrated in chronic obstructive pulmonary disease exacerbation, obesity hypoventilation syndrome, acute pulmonary edema, or acute hypoxemic respiratory failure due to infectious pneumonia. However, the failure of these therapies may increase mortality due to delayed invasive mechanical ventilation; therefore, it is essential to identify risk factors for failure.

Briefly, persistence of high respiratory rate, poor improvement in gas exchange, severity assessed by scales such as SAPS II, HACOR, or low ROX index, and presence of comorbidities or intolerance to the device are presented as predictors of failure of noninvasive respiratory therapies.

Keywords

NIRT · CPAP · HFNC · NIV · ROX index · HACOR · Failure

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Introduction

The use of noninvasive respiratory therapies (NIRT) with close and continuous monitoring is considered the mainstay of treatment of acute respiratory failure (ARF) outside intensive care units (ICU). The effectiveness of these therapies has been closely related to the pathology treated. For example, noninvasive mechanical ventilation (NIV) has been proven useful in hypercapnic respiratory failure secondary to exacerbation of chronic obstructive pulmonary disease (COPD) or in obesity hypoventilation syndrome (OHS) [1, 2], as well as continuous positive airway pressure (CPAP) in hypoxemic respiratory failure in cardiogenic pulmonary edema (CPE) [3] or more recently in patients diagnosed with COVID-19 pneumonia [4]. Moreover, oxygen therapy with a high-flow nasal cannula (HFNC) appears superior to other NIRTs for treating pneumonia of other etiologies [5].

NIRT failure is defined as the need for orotracheal intubation or death following treatment [6]. Patient selection and the initiation of the therapy in the appropriate setting are both keys to success in the management of patients with ARF [7, 8]. Hence, it is paramount to identify early risk factors of NIRT failure as this could avoid complications of delayed intubation and improve survival in patients with respiratory failure [9, 10]. In the following chapter, we will carefully review the most important risk factors of NIRT failure, divided into HFNC and positive airway pressure NIV, or CPAP.

Risk Factors for HFNC Failure

Initially developed for pediatric patients, HFNC has been studied in many different adult populations and conditions [11]. Risks and benefits may vary in various settings (hypoxemic and hypercapnic ARF, post-operative and post-extubation ARF, coronavirus disease 2019 [COVID-19] pneumonia [12]. HFNC should be initiated in the appropriate environment with staff trained to closely monitor the patient's clinical evolution and prepared to recognize early signs of failure [13].

Several studies have attempted to describe factors associated with higher risk of intubation in patients treated with HFNC. Although none of them has been tested prospectively, some clinical and oxygenation variables have been related to HFNC outcomes and considered as risk factors for failure and subsequent need for mechanical ventilation (MV) [14]. For instance, variables as lower SpO_2, PaO_2, and PaO_2/FiO_2 ratio and persisting thoraco-abdominal asynchrony or high respiratory rate (>30 breaths/min) after the beginning of HFNC were significantly related to secondary intubation and invasive MV and therefore considered as early indicators of treatment failure [15, 16]. History of intubation and absence of oxygenation improvement defined as the need for higher flow and FiO_2 levels, can help to distinguish HFNC failure subjects from the cases that can a priori succeed [17]. But, assessing respiratory parameters is not the only way for predicting response to HFNC therapy. Factors such as need for vasopressors or the addition of another organ failure (renal failure) to the clinical course are also decisive factors of HFNC

success [18]. Frat et al. found recently no respiratory variable associated with intubation in patients receiving HFNC support, being tachycardia assessed 1 h after HFNC initiation as the only predictor of intubation statistically significant [19]. Another observational study published in 2015 examined the use of HFNC in 45 severely hypoxemic subjects (whereof 82% were pneumonia cases), of whom only 40% required secondary intubation and were thus classified as having failed HFNC. The presence of additional organ failure, mainly hemodynamic or neurological, in a patient with respiratory distress, was yet again associated with a higher HFNC failure rate. Therefore, this condition should guide the clinical choice toward another form of ventilatory support, more likely invasive MV [20]. With this regard, sequential organ failure assessment (SOFA) score can be a useful tool for identifying the subjects with a higher intubation requirement when elevated [11]. A cohort of 30 patients diagnosed with COVID-19 pneumonia, identified male sex, BMI > 30, immunosuppression and having higher inflammatory markers, SOFA scores, and lactate levels as key features associated with HFNC treatment failure [21]. Moreover, bacterial coinfections, HTA, and chronic kidney disease could also be useful to predict worse outcomes in these patients with COVID-19 pneumonia and ARF [22] (Table 8.1).

However, most of these variables previously listed were analyzed in small samples and heterogeneous populations of ARF patients. Generally, indexes are helpful tools used to guide clinical decisions, particularly in critically ill patients in order to assess organ failure and systemic dysfunction [14].

Recently, Duan et al. validated a scoring system which can predict patients that would be at risk of NIV failure in a cohort of 449 patients. The HACOR score is a useful tool based on five items easily assessed in clinical practice (HACOR: heart rate, acidosis, consciousness – defined by the Glasgow Coma Scale score, oxygenation, and respiratory rate) that can serve, as the ROX index, as a rapid approach for predicting HFNC failure measured at the first hour of initiation of the therapy. Results around 5.5–6 were established as the cutoff point with a higher sensitivity

Table 8.1 Risk factors of HFNC failure

Risk factors of HFNC failure	
Respiratory variables	Non-respiratory variables
Absence of oxygenation improvement (SpO_2, PaO_2, and PaO_2/FiO_2 ratio)	Male sex
Thoraco-abdominal asynchrony	BMI >30
Respiratory rate (> 30 breaths/min)	HTA
ROX index	Immunosuppression
HACOR score	Tachycardia
	Higher inflammatory markers
	Bacterial coinfection in viral pneumonia
	Additional organ failure (renal, hemodynamic, neurological): – SOFA score – Need for vasopressors

and specificity, with a good diagnostic accuracy of patients that had a higher risk of intubation and hospital mortality [23].

The ROX index was first introduced and lately validated by Roca et al. around 2016 and 2019, respectively [14, 24]. Defined as the ratio of SpO_2/FiO_2 to respiratory rate (breaths/min), it has been proposed as a prediction tool that accurately identifies the need of intubation and MV in patients diagnosed with pneumonia and ARF treated with HFNC [14]. In the numerator are placed the variables with a positive association with HFNC success whereas in the denominator are placed those variables that had an inverse relation with HFNC success [24]. It was calculated from the measured respiratory variables assessing respiratory failure (respiratory rate and SpO_2/FiO_2 ratio). Considering that the power of a single variable to predict HFNC failure is low, the ROX index intends to gain an additive effect (better predictor of treatment success than SpO_2/F_iO_2 or respiratory rate alone) that might increase its capacity to discriminate between patients who would succeed on HFNC and those who would not [14, 24].

Among the elements of the index, SpO_2/FiO_2 has the utmost relevance [24]. Patients with acute respiratory distress syndrome (ARDS) diagnosed by the SpO_2/FiO_2 ratio have very similar demographic and comorbidity features and outcomes compared with those diagnosed by PaO_2/FiO_2 ratio in terms of length of hospital stay, length of MV, and hospital mortality rates. Thus, it has been revealed that it accurately correlates with PaO_2/FiO_2 representing a useful and noninvasive tool to assess hypoxemia and monitor respiratory function in critically ill patients [25].

When analyzed, ROX index demonstrated the best prediction accuracy after 12 h of HFNC therapy. Using the ROC curve, the best cutoff point for the index at 12 h was estimated to be 4.88, with a sensitivity of 70.1%, a specificity of 72.4%, a positive predictive value of 89.4%, and a negative predictive value of 42% [14]. Therefore, ROX index values greater than 4.88 at 2, 6, and 12 h is related to success of HFNC, while values less than 3.85 are associated with HFNC failure and poor outcomes including mortality. If the value is between 3.85 and 4.88, the index should be recalculated every 1–2 h [11]. Hence, it is a dynamic and easy index that helps predicting outcome (success and risk of failure) of HFNC treatment of patients with ARF due to pneumonia and contributes to clinical decision process of critically ill patients treated with HFNC [24]. An important limitation should be taken into account regarding this index: as it was tested only in patients diagnosed with pneumonia-related ARF, it may not necessarily be generalizable to patients with ARF from other etiologies [14]. In this context, until the COVID-19 outbreak in 2020, little data were published describing the utility of the ROX index to lead the use of HFNC as a respiratory support therapy in viral pneumonia. A recent retrospective observational study of 393 subjects with laboratory-confirmed COVID-19 acknowledged that ROX index assessed at device initiation, at 2 h and 12 h after device initiation worked better than other respiratory variables accurately diagnosing severe outcome and matched adequately with previous validation studies of the ROX index for predicting failure of HFNC and risk of intubation in subjects with non-COVID-19 pneumonia [26]. A meta-analysis confirmed these results, with a high sensitivity (0.70) and specificity (0.79) for predicting HFNC failure in

COVID-19 patients (as we previously said, lower ROX index predicts higher mortality risk). Based on the studies included, the optimal cutoff value may be around 5 of ROX index within 24 h of admission with a maximum diagnostic accuracy observed when measured close to 6 h after the initiation of the therapy [27].

Finally, one question remains unanswered: should we intubate when ROX index is below 4.88 or wait until all the intubation criteria are met? [14]. In the Roca et al. prospective study, patients who failed on HFNC and were intubated after more than 12 h of HFNC presented an increased risk of death [24]. Moreover, a retrospective observational study recently evaluated the effect on patient outcomes of the timing of intubation after failure of HFNC. They predetermined HFNC failure criteria as hypoxemic respiratory failure with the patient failing to maintain a $SpO_2 > 90\%$ despite receiving the maximal FiO_2 permitted by the HFNC, hypercapnic respiratory failure with pH < 7,30, signs of respiratory distress with a high respiration rate (>35 breaths per min), uncontrolled metabolic acidosis, hemodynamic instability and need for airway protection because of deterioration of neurologic status [28]. Nevertheless, most of them are themselves intubation criteria and therefore poor predictors for early decision to intubate [19]. They concluded that patients intubated within 48 h of HFNC support had lower ICU mortality (39 vs. 67%; $P = 0.001$) than those intubated later. Similar results were found with regard to extubation and ventilator weaning success and ventilator-free days [13, 28]. These results may be founded on inspiratory efforts that can lead to volutrauma and self-induced lung injury (large swings in transpulmonary pressure) [29] and the fact that prolonged HFNC can induce respiratory muscle fatigue and cardiac dysfunction, which can in turn conduct to poor hospital outcomes. The study did not reach to describe patient's features that could allow to anticipate late HFNC failure and by that improve clinical outcomes [28]. Needless to say, clinical judgment and establishing predefined intubation criteria are important aspects to quality of care and must be always taken into account [14].

It is therefore of utmost importance to reach protocols and methods including signs and factors associated with potential failure of HFNC therapy in patients with acute hypoxemic respiratory failure [13]. Constant monitoring and experienced assessment of patient response to treatment are paramount [24]. The ROX index has demonstrated a high sensitivity in identifying patients likely to succeed on HFNC and assessing patient's clinical evolution and recognizing early signs of failure in order to avoid delayed intubation [13, 29].

Risk Factors for PAP Failure (NIV/CPAP)

Related to Time to Failure

According to previous studies, NIV failure can be classified considering the moment of disease worsening:

1. Immediate failure (<1 h): may account for up to 15% of failures. Among the main causes, we can identify device intolerance, psychomotor agitation and/or confusion due to hypercapnic encephalopathy, ineffective cough with poor secretion management, and patient-ventilator asynchrony [6].
2. Early failure (1 to 48 h): about 65% of failures occur in this period. In patients with hypoxemic respiratory failure, particularly in those with ARDS or community-acquired pneumonia (CAP), a $PaO_2/FiO_2 < 150$ on admission or persistently low after 1 h from the start of NIV should be considered an important risk factor [30, 31]. Additionally, the association with sepsis or multiorgan failure increases the rate of NIV failure.

   In subjects with hypercapnic respiratory failure, the most studied field has been COPD. In this regard, about 60% of patients with a pH <7.25 presented therapy failure [32]. Likewise, the persistence of a pH <7.25 after 1 h of NIV was considered an independent factor for failure [33].

   In both types of respiratory failure, increased respiratory rate (RR) 1 h after initiation of NIV is considered a risk factor. Specifically, RR >25 in patients with ARDS or RR > 30 in patients with COPD should be used as a warning sign of eventual endotracheal intubation [6].
3. Late failure (>48 h): about 15% of NIV failures are included. It tends to be observed in patients with infectious complications such as nosocomial pneumonia or secondary to delirium or sleep/wake disturbances [6].

Associated with the Type of Disease

ARDS

As previously mentioned, PaO_2/FiO_2 is an important feature when assessing the effectiveness of NIV since the risk of intubation increases concerning the severity levels of ARDS [34]. Thille et al. [35] reported an orotracheal intubation rate of 31% in mild ARDS (PaO_2/FiO_2 <300 and >200), 62% in moderate ($PaO_2/FiO_2 < 200$ and >100) and 84% in severe ($PaO_2/FiO_2 < 100$) with a mortality of 32% in moderate/severe cases vs. 19% in mild cases. In that sense, in a sub-study of the LUNG SAFE Study, Bellani et al. reported in patients with a $PaO_2/FiO_2 < 150$, mortality of 36.2% in the NIV group compared with 24.7% in the IMV group [36].

Although the use of NIV is not contraindicated in ARDS, it must be performed with great caution, particularly considering respiratory support alternatives. In the RCT by Frat et al. [5], an intubation rate of 50% was reported in the NIV group compared to 38% in the HFNC group, although without significant differences ($p = 0.18$). However, in a post hoc analysis when stratifying according to PaO_2/FiO_2 of 200, an intubation rate of 58% was observed in NIV vs. 35% in HFNC. Regarding mortality, a hazard ratio of 2.5 was evident in NIV compared with HFNC.

The etiology could influence NIV failure. In a study conducted in ICUs in China, patients were divided according to whether ARDS was pulmonary or extrapulmonary in origin. It was noted that patients with pulmonary ARDS (97% secondary to

pneumonia) had a failure rate of 55% vs. 28% in extrapulmonary ARDS with dramatically higher mortality, 47% vs. 14%, respectively [37].

About COVID-19, PAP via CPAP could offer good results. In the RECOVERY-RS RCT, Perkins et al. [4] compared CPAP and HFNC with conventional oxygen therapy, to assess the outcomes of a composite endpoint of orotracheal intubation or 30-day mortality. They reported a CPAP failure rate of 36.3% vs. 44.4.% for conventional oxygen therapy ($p = 0.03$). Although assessing risk factors for CPAP failure was not raised as a primary or secondary objective, age (>50 years), symptom days before initiating therapy (<7 days), and obesity (BMI >35) could be associated with a higher failure rate, although studies focused on answering these questions are needed.

COPD

Despite the widespread use of NIV, the failure rate in COPD is around 15%–24%, with increased mortality associated with delayed identification of failure [38]. In an observational study of 1809 patients with COPD exacerbation and hypercapnic respiratory failure treated with NIV, Nicolini et al. [39] reported an increased intubation rate related to the presence of at least 1 comorbidity (OR 1. 06, CI 1.03–1.1, $p < 0.01$) and severity on admission according to Simplified Acute Physiology Score II (SAPS II) of 34 ± 4 (OR 1.007, CI 1.003–1.01, $p < 0.001$). They also reported that improvement in pH after 1 h of NIV (pH at admission 7.22 ± 0.05, $p < 0.03$, pH at 1 h 7.28 ± 0.06, $p < 0.001$) was associated with a higher probability of success.

Other studies have reported COPD severity, heart rate (HR), or level of consciousness as predictors of therapy outcomes. Duan et al. assessed 14 variables recorded at the bedside on admission and after 1 h of NIV. After multivariate analysis, only HR, acidosis, level of consciousness, oxygenation, and RF were presented as independent variables. The HACOR score was developed, demonstrating in the validation phase that a score of more than 5 was associated with NIV failure of 50%. In these patients, early intubation (<48 h) was associated with reduced mortality [40].

Finally, chronic colonization of the lower airway by gram-negative bacilli such as *Pseudomonas aeruginosa* has been associated with increased failure of NIV in COPD patients (OR 5.6, CI 1.4–22.4, $p = 0.016$) [41].

OHS

The failure rate is variable, ranging from 2 to 60% depending on the study setting. In a review by Nicolini et al. [42], it was observed that a higher APACHE II severity scale score, the presence of comorbidities, and the use of home ventilation were associated with greater NIV failure. Similarly, the existence of pneumonia, high respiratory rate, low $PaCO_2$, bicarbonate, and level of consciousness were associated with worse outcomes. Finally, the need for high pressures in ventilator settings

and the occurrence of new respiratory failure after an adequate initial response were considered predictors of failure.

CPE

Although many patients respond adequately to PAP, up to 15% may require endotracheal intubation secondary to severe respiratory distress [43]. Luo et al. [44] demonstrated in patients with myocardial infarction (AMI), that a Killip class IV was associated with increased failure of NIV, probably related to hemodynamic instability (OR 28.56, CI 2.17–375.73, p = 0.011). Similarly, patients with a left ventricular ejection fraction (LVEF) <30% (OR 9.54, CI 1.01–90.55, p = 0.05), brain natriuretic peptide (BNP) >3350 pg/mL (OR 39.63, CI 3.92–400.79, p = 0.002), and water balance >400 mL in the first 24 h (OR 13.19, CI 1.18–147.70, p = 0.036), presented a higher rate of NIV failure.

In a retrospective study with 1138 patients, it was observed that patients with hypocapnia had an orotracheal intubation rate of 15.4% compared with 8.6% and 10.7% of patients with eucapnia and hypercapnia, respectively (p = 0.02). Similarly, mortality was higher in patients with hypocapnia (18.7%) vs. eucapnia (10.2%) and hypercapnia (14.8%) (p = 0.02) [45].

CAP

The presence of cardiac or respiratory comorbidity could influence the likelihood of succeeding of NIV. In this regard, Carrillo et al. reported a failure rate of 25.6% in patients with previous cardiorespiratory pathology compared with 46.6% in "de novo" ARF [46].

In a retrospective study of 130 patients with CAP treated with NIV, Nicolini et al. observed a failure rate of 20% [47]. They divided patients with failure according to their history of cardiac or respiratory disease. In those without this kind of background, failure of NIV was associated with higher CURB-65 (1.22 ± 0.52 vs. 1.8 ± 0.45; p = 0.03) and SAPS-II (19.13 ± 8.62 vs. 32 ± 9.38; p = 0.006) scores, greater extent of chest radiograph findings and lower PaO_2/FiO_2 (121.4 ± 45.99 vs. 199.7 ± 43.34; p = 0.001). Failure in patients with previous cardiorespiratory disease was associated with the elder, $PaCO_2$, bicarbonate, and worse level of consciousness at admission. Multivariate analysis of both groups showed that a HR >108 (OR 12.7, CI 2.6–69.4, p = 0.002) after 1 h of NIV, an alveolo-arterial oxygen index (A-aDO2) >131 (OR 214, CI 19. 4–12,051, p = <0.001) after 24 h and an OPRAVIL X-ray score > 11 (OR 14.1, CI 2.5–92.1, p = 0.003) were associated with a higher intubation rate.

Neuromuscular Diseases and CWD

Among the neuromuscular diseases, ALS has the highest rate of failure of NIV. It has been reported that the success of therapy is related to the presence of hypercapnia and orthopnea, with worse results in patients with moderate or severe bulbar symptoms [48]. In some patients, the involvement of the velolingual or buccal musculature can cause leaks due to seal failure, even though the pressures in many cases are low. Additionally, increased pharyngeal pressure due to glottic closure or the entry of air into the esophagus or stomach can limit the effectiveness of ventilation [49].

In a study by Martí et al. [50] with patients with CWD, it was observed that the presence of more comorbidity, increased residual volume, and low FEV1 was related to higher mortality of patients on home MV; however, it is necessary to identify risk factors for NIV in patients with ARF.

Associated with the Ventilation Itself

As previously discussed, device intolerance and patient-ventilator asynchrony can result in immediate NIV failure. Equally important are ventilator selection and ventilator settings according to the patient's situation and underlying disease. In this regard, the presence of leaks may condition the effectiveness of therapy. Mild-to-moderate leaks are adequately compensated by NIV ventilators, with worse results in intensive care ventilators in NIV mode [51]. However, the magnitude of leaks correlates with more ineffective efforts and cycling delays that worsen tolerance and decrease the success of NIV [52].

On the other hand, Carteaux et al. [53] reported that tidal volumes greater than 9.5 mL/kg were associated with higher rates of NIV failure in patients with moderate-to-severe hypoxemic ARF. In this sense, it is essential to adjust the ventilator settings with the aim of reducing these volumes.

Finally, inefficient humidification can develop dry and thick respiratory secretions with airway obstruction that worsen compliance to NIV, as has been demonstrated in patients with COVID-19 [54].

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9 Safety Recommendations for Noninvasive Ventilation Outside Intensive Care Unit

Abhijit S. Nair and Yogesh Manhas

Abstract

There are certain indications for which noninvasive ventilation (NIV) can be initiated outside the intensive care unit (ICU). However, there should be a clear policy for such admissions based on the clinical condition which includes hemodynamic stability, consciousness, pH from a blood gas, and the indication for NIV. The location where NIV is started should have continuous monitoring of hemodynamics, consciousness, oxygenation, respiratory rate, and acid-base status. The nursing staff involved should be trained in managing patients with NIV and also proficient in basic troubleshooting of the ventilators. The nursing staff needs to be instructed regarding when to raise an alarm or inform the ICU outreach team in case they anticipate a failure of NIV requiring ICU admission of these patients for further management and if necessary, invasive ventilation.

Keywords

Noninvasive ventilation · Intensive care unit · Chronic obstructive pulmonary disease · Positive end-expiratory pressure · Arterial blood gas · Adult respiratory distress syndrome

Over the years, the safety and efficacy of noninvasive ventilation (NIV) have been established in many acute conditions. The several waves of the COVID-19 pandemic saw an exponential increase in the use of NIV in many patients with COVID-19 acute respiratory distress syndrome (ARDS). Although this topic is

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debatable, in hospitals with limitations in the intensive care unit (ICU) beds and healthcare workers (i.e., a low nurse-to-patient ratio required in managing a pandemic), the use of NIV and high-flow nasal cannula (HFNC) in the wards was the only practical alternative. The growing body of evidence that has accumulated over the years has made the clinicians understand the importance of early initiation of NIV from the emergency room itself. In several situations, such proactive NIV initiation could prevent endotracheal intubation and thus could reduce the length of stay (LOS) in the ICU, and in the hospital, and thus could have better outcomes. Studies have proved that when NIV is initiated in indicated patients in the emergency room, before shifting to the ICU for definitive care, the overall in-hospital mortality and number of ICU days are reduced [1].

Robertis et al. suggested that having wards with patients with NIV is possible with proper training and continuous monitoring, and is safe, and cost-effective [2]. Almost two decades ago, in the year 2000, Plant et al. conducted a multicentre, randomized-controlled study to investigate the early use of NIV for patients with acute exacerbation of COPD initiated in general respiratory wards [3]. The trial was also called YONIV or Yorkshire Noninvasive Ventilation Trial. The study involved 236 comparable patients out of which 118 patients received standard therapy and 118 patients in another arm were initiated on NIV. The authors concluded that the early use of NIV for mildly and moderately acidotic patients with COPD in the general ward setting led to rapid improvement of physiological variables, a reduction in the need for invasive mechanical ventilation, and an overall reduction in in-hospital mortality.

Approximately two decades later, Faqihi et al. published a multicentre, retrospective, cohort study involving patients with AHRF unrelated to COPD in which they investigated the outcomes and failures with ward-based NIV in these patients [4]. The authors concluded that ward NIV was feasible with better outcomes in patients with a pH between 7.15–7.25 and not less than a pH of 7.15. Older patients with obesity-induced AHRF and patients with underlying pneumonia experienced adverse events which included extended LOS and mortality.

Cabrini et al. conducted an international survey comprising 175 questionnaires with respondents from 51 countries [5]. Sixty-six present respondents reported the use of NIV in general wards and found it to be safe and effective. For the success of outside ICU NIV, there needs to be stringent policies and protocols in place with a careful selection of patients who could benefit from such an approach [6]. Cabrini et al. achieved a success rate of 77.5% while managing patients with NIV in the wards led by the medical emergency team [7]. They reported that 10.1% were intubated and the remaining 12.4% of patients who died had ‘do not attempt resuscitation’ orders.

In a narrative review of current practices and outcomes from the United Kingdom, Trethewey et al. concluded that patients with AHRF due to acute exacerbation of COPD can be managed in the ward, with trained nursing staff, continuous monitoring, and a definitive and documented plan of escalation of management in adverse situations [8]. In another observational study by Farha et al., the authors concluded that NIV was successfully implemented in the wards for several indications and the success rate was comparable to the NIV initiated in an ICU setting [9].

The reason for NIV in the wards could be the nonavailability of beds in the ICU, overall acceptable general condition (pH more than 7.15, hemodynamically stable, conscious, and well oriented), to reduce nosocomial infection in these patients, single organ

affected who could be otherwise managed appropriately in the wards, 'do not intubate' patients. Having well-trained nursing staff round the clock, availability of respiratory therapists for troubleshooting in the wards, and immediate access to resuscitation and endotracheal intubation is essential for the success of NIV in the wards [10, 11].

Following are the prerequisites in the ward where the clinician should agree for initiating NIV. There should be central oxygen and medical air supply along with a wall-mounted suction. All the beds should have a multipara monitor capable enough to monitor heart rate, blood pressure (noninvasive/invasive), ECG, oxygen saturation with a pulse oximeter, respiratory rate, and end-tidal carbon dioxide (Co_2) in a few monitors, although this is optional.

Essential Monitoring During NIV

The selection of the patients who can be managed with NIV in the ward has to be decided with precision. Once admitted, the parameters that need to be monitored frequently initially are heart rate, blood pressure, oxygen saturation, electrocardiography (ECG), respiratory rate, patient comfort, synchrony to the NIV interface, alertness, and sensorium (Glasgow Coma Scale). Some patients need sedo-analgesia for tolerating NIV. Although the medication can be as per institutional protocol or the clinician's choice, sedation scores need to be monitored and drug titration needs to be done accordingly [12].

Having an adequate seal with an NIV mask is very important because, in presence of leaks due to improper fit, the ventilator will not be able to deliver the set pressure support and positive end-expiratory pressure (PEEP). This will thus not benefit the patient and in turn, could give a false indication pointing towards NIV failure.

Clinical Parameters

Gas Exchange Monitoring

Monitoring oxygen saturation with a pulse oximeter with a continuous display of plethysmograph waveform is essential for all patients. Arterial blood gas (ABG) analysis is important to understand the acid-base status, oxygenation, ventilation, and also to plan the settings of NIV. The frequency of ABG needs to be individualized based on the patient's clinical condition. In case frequent ABGs are necessary, it is recommended to have an indwelling arterial catheter placed under aseptic precautions and local anesthetic infiltration. The care of the arterial line should be as per the policies in the ICU.

End-tidal CO_2 monitoring is essentially important with invasive ventilation but if available, a side-stream monitoring could be useful and provide continuous monitoring in borderline patients. Defilippis et al. suggested monitoring the trend of the pCO_2-$ETCO_2$ gradient can be very informative in patients with NIV. A progressive reduction of the pCO_2-$ETCO_2$ gradient is suggestive of clinical improvement and effectiveness of NIV [13]. Having a side-stream $ETCO_2$ module in a general ward wall-mounted is unlikely. In such situations, whenever possible, trans-cutaneous

monitoring of CO_2 can be useful, especially in patients who are severely hypercapnic and needs NIV settings to be adjusted to optimize CO_2 [14]. In a study by Georges et al., the authors demonstrated that the use of transcutaneous CO_2 reliably detected inappropriate NIV without requiring frequent ABGs in patients treated with NIV for various respiratory ailments [15].

Ventilatory Parameters Monitoring

It is recommended to use a ventilator for providing NIV which can give certain important information that can aid in identifying the effectiveness of NIV and also help in planning appropriate settings. The parameters that should essentially be available on the ventilator used for NIV are respiratory rate, tidal volume (inspired and expired), minute ventilation, inspiratory:expiratory (I:E) ratio, and the fraction of inspired oxygen (FiO_2), inspiratory time, and trigger sensitivity.

Once the settings are done and the interface is connected to the patient, the parameter which needs to be seen first is the tidal volume generated. The person initiating NIV should be aware of the range of desirable tidal volume for that particular patient. Once an appropriate seal is established, the pressure support or the inspiratory positive airway pressure should be adjusted to the desired tidal volume [16]. Having flow and pressure waveforms, and leaks/leak compensation can be an added advantage. As NIV is usually required for an extended duration of time, it is desirable to have a humidifier incorporated to deliver humidified gas.

Monitoring Cardiac Function and Stability

Although NIV can be initiated in the wards, patient selection is important because a certain population of them could be susceptible to adverse hemodynamic consequences due to NIV. Underlying cardiovascular condition, or pneumonia could predispose to hypotension due to increased intrathoracic pressure impairing venous return of right ventricle, increased pulmonary vascular resistance leading to increased right ventricular afterload, increased central venous pressure, and decreased left ventricular preload. Although the above-mentioned vicious cycle is detrimental in hypovolemic patients and patients with restrictive cardiomyopathy, it could be beneficial in patients who present with congestive heart failure and fluid overload of any etiology [17, 18]. Although not necessary every time, having a baseline 2D echocardiography could give a lot of information about the heart function which could help in planning ventilatory settings [19].

Availability of Essential Investigations

The ward should be equipped with a portable radiograph machine which could be used whenever an acute deterioration is suspected, to rule out barotrauma, fluid

overload, aspiration pneumonia, and worsening of underlying pathology. An ABG machine should be nearby to access the acid-base status whenever necessary. Having a portable ultrasound machine around can be of great use, albeit not mandatory. It could be used for vascular access (venous or arterial line), for performing lung ultrasound, inferior vena cava assessment, 2-dimensional echocardiography, and evaluation of diaphragmatic function.

Scoring Systems Useful During NIV

Duan et al. described the heart rate, acidosis, consciousness, oxygenation, and respiratory rate (HACOR) score [20]. This scale comprises heart rate (H), acidosis based on pH (A), consciousness based on the Glasgow Coma Scale (C), oxygenation (O), and respiratory rate (R), all of which are monitored regularly or can be noted quickly (Table 9.1). In their experience with 449 patients with AHRF, the authors found that the failure rate with NIV was 47.8 and 39.4% in the test and validation cohorts. After analysis, the authors concluded that a HACOR score of more than 5 had a very high risk of NIV failure and would require early intubation. They studied this score further and later collected data from 500 COPD patients [21]. The HACOR score was noted at 1–2 h of NIV. The authors concluded that HACOR scores demonstrated good predictive power for NIV failure in patients with COPD, and predicted early NIV failure in less than 48 h.

Later, the score was validated in AHRF seen in non-COPD patients, COVID-19 patients, and patients with high-flow nasal oxygenation. The verdict was that the HACOR score at various time frames (but less than 6 h) could predict NIV failure. These patients need close monitoring and decision needs to be taken for invasive ventilation [22–24]. As HACOR is an easy scoring to perform and interpret, it can be used in patients admitted with NIV outside ICU. The staff involved should be instructed to inform the concerned team if the score is more than 5. Thus, based on the score, and based on the overall clinical picture, a decision for shifting to ICU can be taken.

Any patient requiring NIV for his/her clinical condition requires an ICU bed. But due to the limited number of ICU beds in any given hospital, NIV can be initiated in the ward in select patients with due diligence. Having a clear algorithm to initiate NIV in the ward ensures that patient safety is not compromised. A proposed algorithm is shown in Fig. 9.1. Any patient in need of NIV should be assessed by the

Table 9.1 showing various components of HACOR score and the points allotted to various values of the components

Heart rate	Points	pH	Points	GCS	Points	P/F ratio	Points	RR/min	Points
≤120	0	≥7.35	0	15	0	≥201	0	≤30	0
≥121	1	7.30–7.34	2	13–14	2	176–200	2	31–35	1
		7.25–7.29	3	11–12	5	151–175	3	36–40	2
		<7.25	4	≤10	10	126–150	4	41–45	3
						101–125	5	≥46	4
						≤100	6		

GCS glasgow coma scale, *P/F ratio* PaO_2/FiO_2 ratio, *RR* respiratory rate

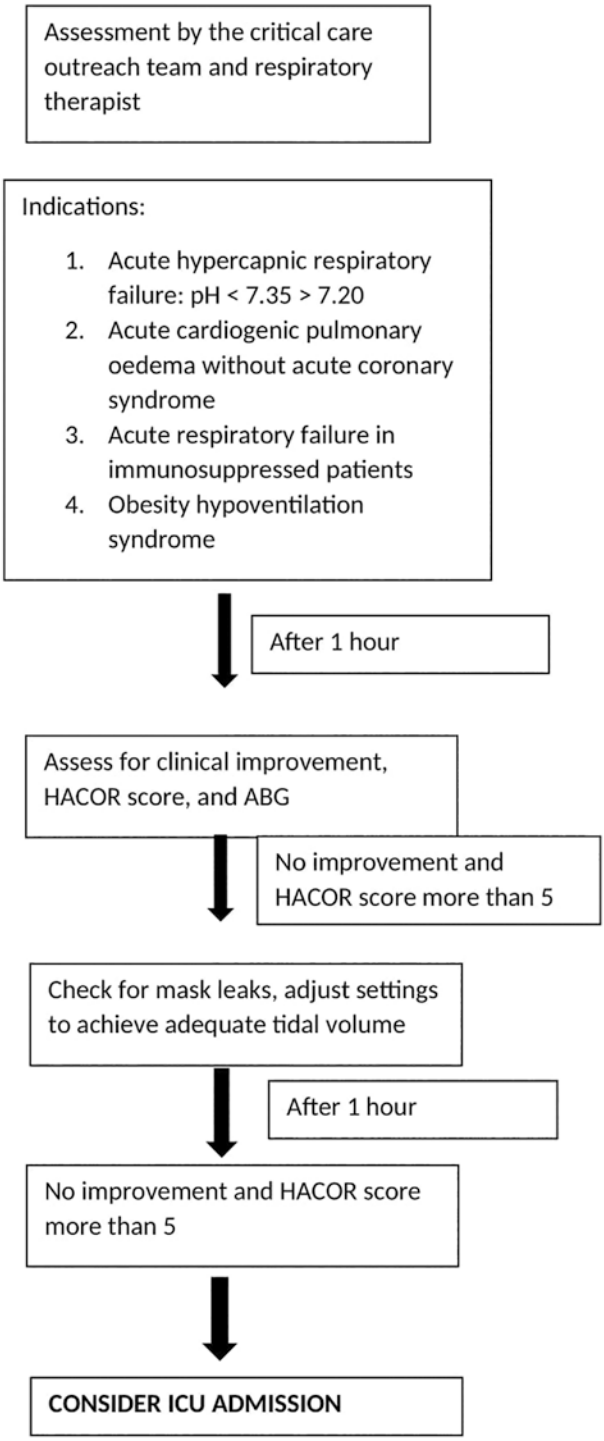

Fig. 9.1 Assessment by the critical care outreach team and respiratory therapist

critical care outreach team along with a respiratory therapist who shall assess for indications and feasibility of NIV in the ward. Nursing staff in the ward must have basic minimum training in managing NIV with a focus on monitoring patients on NIV, interpretation of ABG, identifying treatment failure to raise alarm, patient-ventilator interface, and troubleshooting.

Important Points to Remember While Using NIV

NIV can be applied either via an open single-limb circuit or a closed double-limb circuit which is ventilator specific. An open single-limb circuit requires a vented mask with a built-in exhalation port or a non-vented mask and an additional exhalation valve in the circuit to allow CO_2 removal. A closed double-limb circuit is used with a non-vented mask and has an exhalation port for CO_2 removal within the system. It is essential to be aware of which circuit is used when the mask is chosen. The wrong combination, for example, a non-vented mask in an open single-limb system and no exhalation port in the system, can be fatal. Also, an exhalation port should never be obstructed intentionally (e.g., taping up the holes in the mask) to reduce leakage [25–27].

Conclusion

NIV is a time-tested ventilatory modality that can be safely offered to indicated patients in the wards. For the success of this initiative, there should be round-the-clock trained nursing staff available who are trained in managing ICU patients and can handle ventilators that provide NIV. The prerequisites are a carefully selected patient, a fully-equipped ward with oxygen, air, and suction, availability of various airway gadgets and adjuncts, a facility for continuous monitoring, and having a protocol or an algorithm in place. These patients need to be monitored meticulously as they are on the verge of invasive ventilation and could need ICU transfer. Therefore, having a definitive, documented plan of escalation based on clinical criteria is essential with all essential monitoring that is required and relevant investigations like ABG as necessary once it is decided to shift these patients to the ward. In this regard, hospitals can have regular focused NIV workshops for ward nurses. It is also important that the nurse-patient ratio is kept at not more than 1:3 where ward NIV is offered.

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Noninvasive Ventilation Outside ICU. Registration, Supervision, and Policies

10

Zühal Karakurt and Gül Erdal Dönmez

Abstract

The purpose of this chapter is to define the clinical condition of the patient with respiratory failure, the basic monitoring and observation for safe follow-up, the definition of competent personnel, and the elements that can form the basis of international health policies in the application of noninvasive mechanical ventilation (NIMV) outside of the intensive care unit (ICU). In this book, you will find a comprehensive list of the necessary conditions for patient selection and follow-up. In general, the goal of respiratory failure should be to provide the patient with the most appropriate respiratory support that local resources permit. When invasive mechanical ventilation (IMV) is required, it is essential to act immediately. Except for the NIMV palliative care, and end-stage unit, IMV application opportunities should be included in all NIMV applications outside the ICU.

Keywords

Noninvasive ventilation · Outside ICU · Registration · Supervision · Policies · Response, complications, safety, supervision, quality indicators

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Noninvasive Ventilation Outside ICU. Registration, Supervision, and Policies

The locations outside of the intensive care unit (ICU) where NIMV will be utilized are listed below. The readers can find the related chapters for detailed understanding.

Models of Noninvasive Mechanical Ventilation (NIMV) Units

1. NIMV in the Emergency Room.
2. NIMV in Step Down Units.
3. NIMV in High Dependency Critical Units.
4. NIMV in Conventional Respiratory Ward.
5. NIMV in Respiratory İntermediate Care Units.
6. NIMV in Internal Medicine Ward.
7. NIMV in the Perioperative Medicine.
8. NIMV in the Endoscopic Wards (bronchoscopy, gastrointestinal, transesophageal echocardiography).
9. NIMV in Specialized Weaning Center.
10. NIMV in Geriatric Wards.
11. NIMV in Hematology Oncology Departments.
12. NIMV Palliative Care and End-Stage Unit.
13. NIMV in Respiratory Rehabilitation Unit.
14. NIMV During İntrahospital Transport.
15. Models of NIMV in Pandemics Conditions.
16. Models of NIMV in Bioterrorism and Other Catastrophic Conditions.
17. NIMV Outside ICU in Low-Income Countries.

The NIMV application guidelines for patients with acute respiratory failure are updated considering recent technology and literature regarding the patients to whom it will be applied [1].

"A suitable patient for NIMV" as itself is insufficient for NIMV administration. Additionally, it is required to specify where NIMV will be implemented "for patient safety." Over time, NIMV application site models can be established. The application site of NIMV should be determined by analyzing the causes of respiratory failure and the general patient features. In "decision support systems" and hospital information management systems, defining the causes of acute and chronic respiratory failure such as reversible causes, irreversible end-stage diseases, very elderly patients, and the need for respiratory support after short-term interventions will guide physicians and healthcare professionals. In the arrangement of these algorithms, NIMV application places may be titled Emergency Unit, ward, pre- and postoperative places, and specialized unit for end-stage patients (palliative care units), accordingly, based on the country's health support capabilities.

Physicians and other health care workers should get training on the application of NIMV and the identification of appropriate patients at periodic intervals considering technology advancements and changing health circumstances, such as pandemics. Repetition of the trainings on how to administer and monitor NIMV at home, in the ambulance, in the Emergency Unit, and in the units where NIMV will be administered to patients with respiratory failure will highlight the beneficial elements of the practice (Fig. 10.1). Health Policymakers can be persuaded that NIMV in hospitals and outside the hospital settings, such as ambulances and the home, can reduce the need for ICUs. With early NIMV-oxygen support, and other medical treatments such as antibiotics and bronchodilators, it is possible to prevent irreversible organ damage and reduce the length of hospitalization days and mortality [2].

Partially novel is the use of NIMV outside of the ICU for critically ill patients with respiratory insufficiency. Team training is necessary for initiating respiratory failure at home and in the ambulance with the support of NIMV during the patient's admission to the hospital. Assessing the patient's acute and chronic health status is essential for evaluating the patient. The effective treatment decision will be guided by the evaluation of clinical patient data in an electronic environment and telemedicine applications.

Registration of step-down unit, intermediate ICU, or Level 2 ICU are well defined worldwide, and the follow-up patients with NIMV besides invasive mechanical ventilation (IMV) [3–5].

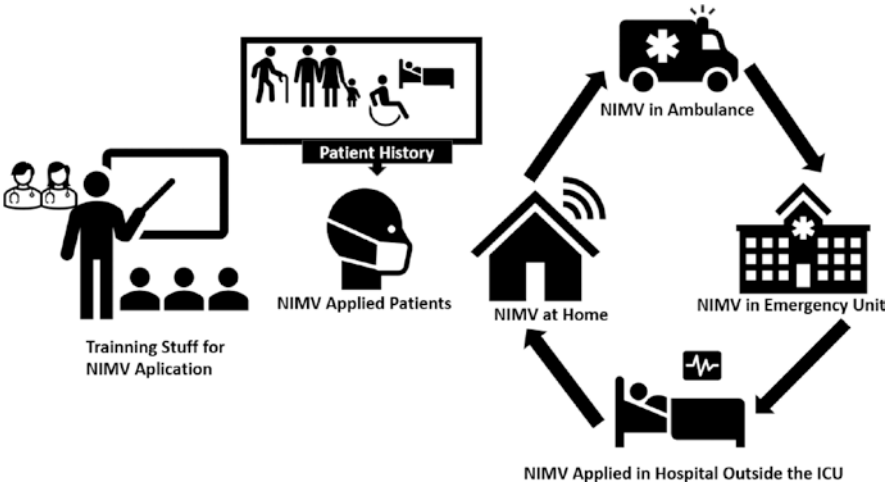

Fig. 10.1 Noninvasive mechanical ventilation (NIMV) outside of the intensive care unit (ICU) requires staff training (physicians, nurses, and other caregivers). Following a suitable patient history, the NIMV application should be initiated as soon as possible (at home, during hospital transfer, in the emergency unit, and in the hospital ward)

NIMV Applied Place/Unit Other Than ICU. Each Please Should Be Defined

1. Place definitions: They are units where medical conditions that may pose a life-threatening risk are closely monitored, have invasive and noninvasive monitoring methods, can provide basic supportive treatments and initial stabilization, can be configured within pertinent clinics as needed, and can transfer patients to advanced intensive care services as needed.
2. Required device and monitoring: At least 4 beds (ideal 10 to 12 beds) and 1 bed to 1 monitor system; having orotracheal intubation, invasive mechanical ventilation, thoracentesis, respiratory drug administration, defibrillation, blood gas interpretation, ECG interpretation, cardiopulmonary resuscitation, arterial catheterization, installing a feeding tube facility.
3. Appropriateness of Patients for NIMV: Patients with respiratory failure with various clinical conditions which are under control of treatment.
4. Staff: Physicians, nurse, and other health care workers should be defined and request some certificate for NIMV application. The nurse must be available 7/24 in the NIMV applied unit and the physician must be existing in hospital.

It may be essential to supervise the established centers at regular intervals twice a year and to re-register them every 2 years. Following technology advancements, it may be necessary to reorganize the equipment of NIMV-applied units other than the ICU. It should be conveyed to health policymakers that the establishment of such units will reduce the unnecessary use of ICU, that rapid respiratory support can be initiated at home and applied to patients who can continue in the ambulance until they reach the hospital, that patients are hospitalized in ICU or end-stage palliative care units based on their underlying diseases, and that hospital- country facilities will be utilized effectively in hospitalization for those patients. Health policymakers should encourage NIMV implementation units other than ICU and provide reimbursement for each NIMV implementation model's units and staff. Unlike simple hospital wards, these units contain severely ill patients with respiratory failure, are supplied with NIMV devices, monitors, and other medical equipment, and have highly trained personnel available 24 h a day, 7 days a week. Different NIMV application units for different patients with respiratory failure, which will improve the quality of health services by placing the patient first, will be the units that enable the ICUs to be used more efficiently.

In future, when different NIMV model units are actively and extensively used over the world, the number of ICU beds will be sufficient even if the population continues to rise, and the acute problems of most patients will be resolved in these units before the need for ICUs arises.

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Noninvasive Mechanical Ventilation Outside Intensive Care Unit. Quality Indicators

11

Didem Sözütek Akkoyun and Dilek Özcengiz

Abstract

There is an increment of the noninvasive mechanical ventılatıon; outsıde with a great clinical impact on clinical practice. However, there are a few criteria which are the important determinants that determine the quality indicators and their relationship with the outcome. We know that they can have an important clinical impact**.**

Keywords

Noninvasive mechanical ventilation · Outside: Intensive care unit: Quality indicators · Outcome

Introductıon

Noninvasive mechanical ventilation (NIV) involves the delivery of oxygen into the lungs via positive pressure without the need for endotracheal intubation. It is used in both acute and chronic respiratory failure and is also effective in treating various chronic respiratory diseases such as obesity hypoventilation syndrome, obstructive sleep apnoea, respiratory failure secondary to neuromuscular disease, and restrictive thoracic disorders but requires careful monitoring and titration to ensure its success and avoid complications.

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The British Thoracic Society (BTS) has recently produced an NIV Quality Standard. Its purpose is to provide a set of specific, concise statements to act as markers of high-quality, cost-effective patient care. There have been 6 quality statements each describing a standard of care for the provision of acute NIV [1].

Quality Statements

Acute NIV should be offered to all patients who meet evidence-based criteria. Hospitals must ensure there is adequate capacity to provide NIV to all eligible patients.

1. According to the latest guidelines for acute respiratory failure (ARF), NIV carries a strong recommendation for the following in the setting of ARF [2].
2. NIV for acute or acute-on-chronic respiratory acidosis secondary to Chronic obstructive pulmonary disease (COPD) exacerbation where pH $\leq$ 7.35.
3. NIV is the prevention of endotracheal intubation and mechanical ventilation in a patient that is not immediately deteriorating.
4. NIV for cardiogenic pulmonary oedema.

Conditional recommendation for the following in the setting of ARF:

1. Early NIV for immunocompromised patients with ARF.
2. Postoperative ARF.
3. As palliation to dyspnoeic patients in the setting of terminal cancer or other terminal conditions.
4. Chest trauma patients with ARF.
5. Prevention of post-extubation respiratory failure in high-risk patients.

Acute NIV reduces mortality by 50% and shortens hospital length of stay when used to treat COPD exacerbations complicated by acute hypercapnic respiratory failure (AHRF). In addition, NIV has been effective in treating various chronic respiratory diseases. These diseases include obesity hypoventilation syndrome, obstructive sleep apnoea, respiratory failure secondary to neuromuscular disease, and restrictive thoracic disorders [3, 4].

This quality statement means for healthcare professionals: Should ensure that patients with a clinical need for NIV are reviewed by a specialist healthcare professional with the necessary NIV competence to make the decision to start acute NIV.

Training and Maintenance of Competencies

All staff who prescribe, initiate or make changes to acute NIV treatment should have evidence of training and maintenance of competencies appropriate for their role.

Acute NIV is an effective treatment provided it is delivered correctly. Effective acute NIV treatment can be delivered by a range of specialist healthcare professionals (e.g., nurse, physiotherapist, and doctor) provided that they are competent to deliver the aspect of treatment they are responsible for [5].

Staff responsible for the clinical decision to start acute NIV and practical application including starting and adjusting treatment according to practical and theoretical knowledge. All must demonstrate evidence of training.

This quality statement means for healthcare professionals Who are involved in any aspect of delivering acute NIV should have evidence of training in the theory and practice of NIV, commensurate with their role.

Specified Clinical Areas

Acute NIV should only be carried out in specified clinical areas designated for the delivery of acute NIV.

Patients treated with acute NIV should be considered at high risk of death; national averages for in-hospital mortality exceed 30%. Use of acute NIV in non-specialised areas is associated with poorer outcomes [6].

Acute NIV should only be used in clinical areas eqıipped with continuous pulse oximetry, continuous ECG monitoring for all patients with clinical indication, oxygen supply, and blood gas analyser within or adjacent to the areas. All ventilators used to deliver acute NIV should be designed for this purpose. There should be sufficient quantity of masks and ventilators to meet expected demand for NIV. Suitable areas may include emergency departments, acute medical units, respiratory wards, high-dependency units, and critical care.

This quality statement means for healthcare professionals to ensure that patients treated with NIV are cared for in an appropriate clinical area.

When to Start NIV?

Patients who meet evidence-based criteria for acute NIV should start NIV within 60 min of the blood gas result associated with the clinical decision to provide NIV and within 120 min of hospital arrival for patients who present acutely.

NIV treatment is often delayed and this can be detrimental to patient outcomes. Whilst a time-limited trial of standard medical therapy (e.g., controlled oxygen and drugs) may be appropriate provided the patient is not in extremis, acute NIV should not be delayed. Clinical deterioration due to treatment delay may result in worsening acidaemia. For pre-NIV blood gas measurements, worsening acidaemia is associated with an increase in mortality. Therefore, prompt initiation of treatment defines this as within 60 min of the decision-making after blood gas result.

This quality statement means for healthcare professionals to ensure that they are adequately trained in the recognition of AHRF via clinical and blood gas parameters and understand the evidence-based criteria for treatment with NIV.

Escalation Plan

All patients should have a documented escalation plan before starting treatment with acute NIV. Clinical progress should be reviewed by a healthcare professional with appropriate training and competence within 4 h and by a consultant with training and competence in acute NIV within 14 h of starting acute NIV.

Careful clinical review is essential for successful patient outcomes. As a minimum, all patients treated with acute NIV should be reviewed by a healthcare professional within 4 h of starting acute NIV. A consultant with expertise in acute NIV should review the patient and initial escalation decision within 14 h of admission and daily until NIV treatment stops. Changes to the escalation plan should be made on the basis of review by a clinician with appropriate expertise and include critical care review if required.

This quality statement means for healthcare professionals to ensure that only appropriately trained specialists make clinical decisions for patients treated with NIV.

Measurements

All patients treated with acute NIV should have blood gas analysis performed within 2 h of starting acute NIV; failure of these blood gas measurements to improve should trigger specialist healthcare professional review within 30 min.

Patients receiving acute NIV were often not monitored closely enough in the first 24 h, potentially leading to delayed recognition of deterioration or NIV failure There have been recommended continuous monitoring of pulse oximetry for the first 24 h or until the resolution of acidosis. In addition to continuous monitoring of oxygen saturations and measurement of respiratory rate, blood gas sampling is used to assess the response to acute NIV. Routine analysis 1 h after starting treatment with NIV with additional sampling at 4 h and in the event of clinical deterioration [7]. Studies show that improvements in pH and $PaCO_2$ values, and a reduction in respiratory rate after 2 h of NIV are strong predictors of treatment success [8].

This quality statement means for healthcare professionals to ensure that the response to NIV is assessed early.

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Part III

Flow Chart in Noninvasive Ventilation Outside ICU

Noninvasive Mechanical Ventilation Outside Intensive Care Unit. Emergency Department Organization

12

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Abstract

Noninvasive ventilation (NIV) is an increasingly used technique in emergency and critical care services. It can be applied in both type I and type II acute respiratory failure. By applying this technique, we manage to control hypoxemia and hypercapnia, with the potential to reduce severe complications that can be lifethreatening for the patient, with fewer adverse effects. In recent years, its use in terminal patients or those with Do Not Intubate (DNI) orders has also gained strength, trying to provide optimal patient comfort and understanding the limits of therapeutic effort. Its use is based on evidence, and criteria are established to indicate its initiation. In the emergency department, the use of CPAP, BiPAP, and HFNC to palliate, stabilize, and even transfer patients is essential, according to the pathologies studied. NIV is applicable in pneumonias, COPD, pulmonary edema, near-drowning syndrome, excessive mucus secretions in patients on artificial ventilation, immunosuppressed patients and palliative patients. During the process of mechanical ventilation, it is important to monitor clinical parameters, gasometrical parameters, hemodynamics and ventilation parameters, an indication for its change, if necessary. Finally, for pandemics such as the one generated by SarS-CoV-2, it is the first respiratory support we can use with trained personnel.

Keywords

Noninvasive ventilation (NIV) · Acute respiratory failure · Hypoxemia Hypercapnia · Terminal patients · Do Not Intubate (DNI)

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Noninvasive Ventilation. Principles in Emergency Medicine

Acute respiratory failure (ARF) is defined as failure of respiratory function, oxygenation, and carbon dioxide release. This results in decreased arterial partial pressure of oxygen (PaO_2) or hypoxemia and/or increased arterial partial pressure of carbon dioxide ($PaCO_2$) or hypercapnia. The establishment period of the ARF is concise, it can be minutes or hours, without giving time for the compensatory mechanisms to be established [1]. Noninvasive mechanical ventilation (NIMV) in type I or type II ARF applied in the emergency department acts in such a way that it improves gas exchange alterations and reduces signs of respiratory effort: dyspnea, accessory respiratory muscle activity, decreased respiratory rate, thus being able to achieve a rapid stabilization of the patient. NIMV is any process that is responsible for covering the flow of a patient, it is any form of ventilatory support that does not use orotracheal intubation (OI), nor any other device that creates artificial ventilation can be used as support ventilation in patients with ARF [2–4]. The principles on which we base ourselves to choose this treatment are:

- The presence of a pathology that responds well to treatment with NIMV.
- The absence of contraindications to its use.
- Patient preferences.
- The use of NIMV compared to the use of the invasive modality reduces many complications that can be life-threatening for the patient. With NIMV it is possible to correct hypoxemia more effectively than with conventional oxygen therapy since it improves the ventilation of the lung fields, and we achieve the so-called alveolar recruitment to improve gas exchange. This allows us to obtain an improvement in respiratory dynamics, with a decrease in respiratory work. The breathing effort increases hypoxemia and hypercapnia, which translates into an increase in lactic acidosis [1].

Indications and Contraindications

Clinical criteria for initiation of NIMV have one or more of the following indications. Moderate-severe dyspnea, with signs of labored breathing or use of accessory muscles

- Tachypnea.
- Blood gas criteria (if available, do not delay NIMV while waiting for the result of a blood gas) [5].
- Need for a fraction of inspired oxygen (FiO_2) greater than 0.4 to achieve adequate oxygenation (88–92% in patients at risk of hypercapnia and greater than 92% in the rest of the patients).
- Acute ventilatory failure (pH < 7.35 with $PaCO_2$ > 45 mmHg, PaO_2/FiO_2 (PaFi) <300 mmHg).

Contraindications of NIMV [5]

Absolute

- Need to isolate airway/cardiorespiratory arrest.
- Obstruction/severe anatomical alteration in the upper airway.
- Poor control of secretions/high risk of aspiration.
- Threatening hemoptysis.
- Impossibility of adapting any type of interface.
- Rejection/lack of patient collaboration.

Relative

- Uncontrollable hemodynamic instability/shock.
- Decreased level of consciousness (ECG < 8).
- Unresolved pneumothorax.
- Uncontrollable vomiting.
- Uncontrollable hematemesis/epistaxis.
- Pregnancy.
- Severe hypoxemia (PaO_2/FIO_2 < 150 mmHg), hypercapnia ($PaCO_2$ > 70 mmHg), acidemia (pH < 7.15).
- Recent surgery (2 weeks) of the upper airway-upper digestive tract.
- Lack of knowledge of the technique.

Clinical Application in the Emergency Department

NIMV is a technique increasingly used in emergency services, both hospital and outpatient. The main pathologies where we use it are (Table 12.1):

- With more scientific evidence:
  - Acute pulmonary edema (APO) (hypoxemic syndrome or AKI type I).
  - COPD (hypercapnic syndrome or type II ARF).
  - Pneumonia in immunosuppressed patients.
- With less scientific evidence:
  - In patients with a significant respiratory effort but there is an order not to intubate.
  - CO poisoning.
  - near-drowning syndrome,
  - Acute non-cardiogenic pulmonary edema.
  - In patients with restrictive patterns due to underlying diseases such as pulmonary fibrosis, kyphoscoliosis.
  - In patients with asthma.
  - As an aid to weaning in intubated patients.

Table 12.1 Indications for NIMV according to the type of pathology

INDICATIONS FOR NIMV ACCORDING TO TYPE OF PATHOLOGY		
INDICATION	EVIDENCE LEVEL	RECOMMENDATION GRADE
Severe exacerbation of COPD	A	1
Acute Pulmonary Edema	A	1
Immunocompromised patient	B	2
Extubation in patients with COPD or high risk of AKI	B	2
ARF in the postoperative period of abdominal surgery and pulmonary resection	C	2
exacerbated asthma		NR
Community-acquired pneumonia		NR
Bronchoscopy in patients with hypoxemia		NR

NR no recommendation, *COPD* chronic obstructive pulmonary disease, *ARF* acute respiratory failure. Image taken from: Indications, contraindications, advantages, and disadvantages of noninvasive ventilation [4]

Pressure-limited NIMV is the most suitable for acute processes, providing more comfort to the patient. In this mode, pressure is the dependent variable, and the volume will depend on lung mechanics and the value of the pressure programmed in the respirator. We divide NIMV into two main modes: continuous positive airway pressure (CPAP) and double pressure level (BiPAP):

- **Double pressure level (BiPAP):** the ventilator supplies a positive pressure during inspiration (IPAP/PS + PEEP) and maintains another during expiration (EPAP/CPAP/PEEP)
- **Continuous positive airway pressure (CPAP):** increases functional residual capacity and opens collapsed or poorly ventilated alveoli, decreases LV transmural pressure, its main indication is to correct hypoxemia (e.g., EAP), although it also reduces the work of breathing in patients with COPD. The most used pressures are between 5 and 12 cmH_2O [6].

BiPAP, compared to CPAP, can improve vital signs more quickly, being more effective in reducing the work of breathing. High-flow therapy via nasal cannula (HFNCT) should be highlighted; some authors consider it noninvasive therapy, which provides humidified oxygen mixed with ambient air. It allows to reach FiO_2 between 0.21 and 1 and can reach up to a flow of 60 lpm. It manages to reduce the anatomical dead space since it generates a positive pressure at the end of expiration and increases alveolar recruitment, lung compliance, and tidal volume. All this leads to a decrease in the effort of breathing [1]. Among its multiple indications is the transition from invasive mechanical ventilation (IMV) to noninvasive, treatment of decompensated heart failure and its benefits have recently been seen in COPD patients with a mild-moderate exacerbation (pH between 7.30 and 7.35 and pCO_2 <55–60) [7].

There are different interfaces to connect to the different ventilators in NIMV. In the emergency department, the most used is the oronasal or oropharyngeal mask, since it is the most effective in acute pathology. However, it prevents the patient from speaking, eating, or coughing, so its tolerability is limited [1].

In hypoxemic or type I respiratory failure (e.g., heart failure, APO, pneumonia, SarS-CoV-2 infection) with RR greater than 28–32 rpm, with use of accessory muscles, O_2Sat<90%, moderate-severe dyspnea, medical treatment would be indicated together with the use of NIMV.

- Suspected hypercapnia or chronic respiratory disease: use of NIMV in BiPAP mode.
  - We started with IPAP 10–12 cmH_2O and EPAP 5–8 cmH_2O,
  - Fast ramp at the start,
  - Rescue respiratory rate (RR) at 12–15 rpm,
  - I:E ratio 1:1–2.
  - Minimum FiO_2 is necessary to achieve a saturation of around 88–90%.
  - It is necessary to re-evaluate at 60 min to assess the clinical and/or gasometric improvement. One of the best indicators of clinical improvement is a reduction in respiratory rate. If we do not see improvement, assess OI, or change the ventilation mode. See Annex I.
  - Without suspicion of chronic disease or hypercapnia: the use of CPAP and HFNC would be indicated.
  - In CPAP mode:

We started with an EPAP of 5 and a minimum FiO_2 to achieve saturation of around 92%.
We will increase the EPAP 2 by 2 cmH_2O until effective values, ideally between 7 and 10 cmH_2O.
If there is no improvement after 60 min, increase EPAP and be careful with values greater than 15–20 cmH_2O. If despite this there is no improvement, assess OI.

- As for HFNCT, start with flows around 50–60 bpm and, as always, use the minimum FiO_2 necessary to maintain saturation around 92%.
- If the patient has an order not to OI or intolerance to NIMV, it is recommended to take breaks from it with cycles of HFNC and rotational therapy.
- In case of an acute hypercapnic or type II respiratory failure (e.g., COPD exacerbation (gold standard)) with a RR greater than 25 rpm, with the use of accessory muscles, $O_2Sat<90\%$, moderate-severe dyspnea, a Ph between 7.25 and 7.35 and a pCO_2 >45 mmHg, medical treatment would be indicated along with the use of NIMV.
- NIMV in BiPAP mode:
  IPAP 10–12 cmH_2O.
  EPAP between 4 and 5 cmH_2O,
  Target expiratory tidal volume 6–8 mL/kg of ideal weight.
  Starts with medium-fast ramp.
  Safety FR 12–15.
  I:E ratio 1:3–4.
  FiO_2 is necessary to maintain a saturation between 88 and 90%.

- In the case of moderate COPD exacerbation (pH 7.30–7.35 and pCO_2 between 45 and 55 mmHg), HFNC can be started with a flow of 60 lpm and a minimum FiO_2 to maintain oxygen saturation between 88 and 90 %. This therapy can also be used when there is intolerance to NIMV as rotational therapy. See Annex II.

Monitoring and Surveillance

When faced with a patient to whom NIMV has been applied, it is necessary to conduct control and follow-up to verify that it is being effective (Table 12.2). The best indicator for monitoring NIMV is the decrease in respiratory rate and the decrease in dyspnea or the patient's feeling of anxiety:

- Clinical monitoring: check that the patient adapts well to the interface and to the ventilator, check for leaks, control of dyspnea, decrease in diaphoresis and/or signs of hypoxemia-hypercapnia (e.g., cyanosis), decrease in tachypnea, respiratory work, the use of accessory muscles, improvement of the level of consciousness, control of possible complications such as skin lesions due to interface pressure, conjunctivitis, gastric distension, nausea, etc.

Table 12.2 Monitoring and surveillance in NIMV

		Start	1 h	2 h	4 h	6 h
Gasometric results	pH					
	PaO_2					
	$PaCO_2$					
	HCO_3					
	PAFI					
	SAFI					
	FiO_2					
Hemodynamic monitoring	HR					
	SAP					
	ADT					
Respiratory monitoring	RF					
	O_2Sat					
	Musculature accessory (Y/N)					
	Paradoxical breathing (Y/N)					
Ventilator monitoring	PEEP/EPAP					
	PS/IPAP					
	TV					
	Trigger					
Neurological monitoring	Glasgow					
	Tolerance					

- Blood gas monitoring:
  - Arterial blood gas analysis is essential at the beginning of ventilation and in the first hour since it will verify the evolution of ventilation. The following controls will be conducted at the discretion of the physician with venous blood gases. According to the literature, it would be indicated at 60–120 min, at 4–6 h, and at 12 and 24 h.
  - oxygen saturation,
  - expiratory capnography: can offer a wide gradient with respect to arterial pCO_2 due to alterations in the patient's ventilation-perfusion relationship and leaks.
- Hemodynamic monitoring: respiratory rate, continuous electrocardiographic, and blood pressure [8].

NIMV Application in the Palliative Patient in the Emergency

When we work in an emergency service, it is common for many of our patients to be elderly patients, patients with multiple pathologies, fragile elderly patients, or patients who, whether they fulfill these characteristics, are being followed up by the palliative care unit. One of the great challenges in medicine is knowing when to limit therapeutic effort and prioritize patient comfort.

Dyspnea is one of the most common symptoms faced by patients near the end of life. Traditionally, the treatment of dyspnea in palliative patients has been based on opiates, benzodiazepines, and conventional oxygen therapy. NIMV has recently been proposed as an effective tool for the treatment of dyspnea in palliative patients [1]. Four cases have been described in which this therapeutic alternative could be useful:

1. A palliative situation with potentially curable superimposed pathology.
2. A palliative situation without curative intent, relief of symptoms.
3. A palliative situation pending decisions.
4. A palliative situation waiting to say goodbye to family or friends.

However, this therapeutic alternative has a series of limitations, one must be cautious when using it, as it can pointlessly prolong the moment of death, cause inconvenience and discomfort, create false expectations for the patient and relatives, as well as being able to limit the communication and intimacy at the end of life [9].

Likewise, the effectiveness of HFNCT has been described as a useful treatment option in patients with a no-intubation or no-resuscitation order, compared with others such as NIMV, the use of opiates, and conventional oxygen therapy presenting better tolerability and fewer adverse effects [10].

Noninvasive Therapy in SARS-COV-2 Infection in the Emergency

In the SarS-Cov-2 infection, it is a respiratory infection in which we can use NIT as an adjuvant treatment to the doctor.

The first therapeutic step would be a conventional oxygen therapy, followed by HFNC (starting with high flows, 60 lpm, and maximum FiO_2 of 1). The next step is NIMV, and the last is IMV that requires OI (Fig. 12.1) [11].

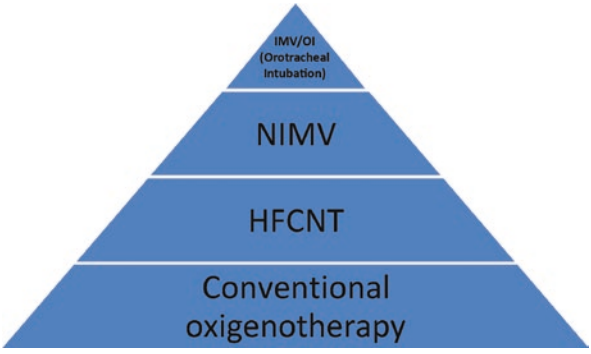


Fig. 12.1 Therapeutic steps of ventilation in the SarS-Cov-2 infection

Criteria for Starting Ventilatory Support in ARF Secondary to Covid-19 (Fig. 12.2) [11]

– Clinical criteria.
  Moderate-to-severe dyspnea with signs of labored breathing and use of accessory muscles and paradoxical abdominal movement.
  Tachypnea >30 rpm.
– Gasometric criteria.
  PAFI<200 (or need $FiO_2 > 0.4$ to maintain $O_2Sat > 92\%$).
  pH < 7.35 with $pCO_2 > 45$ mmHg.

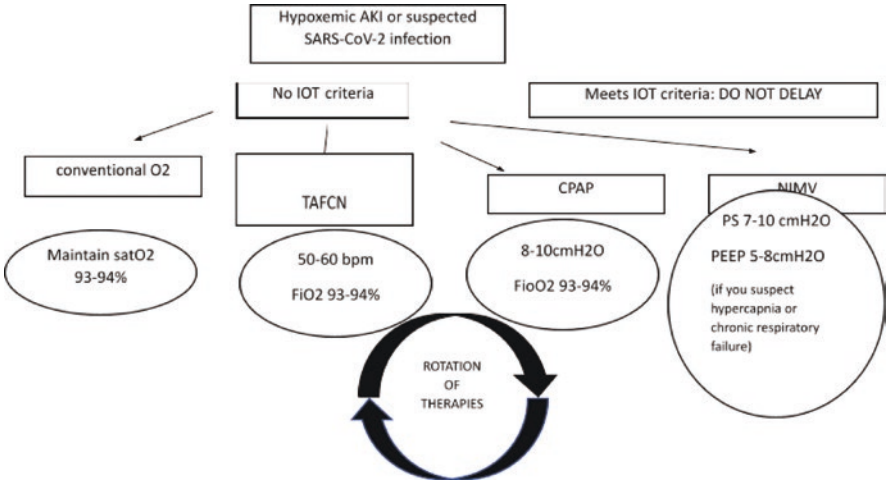
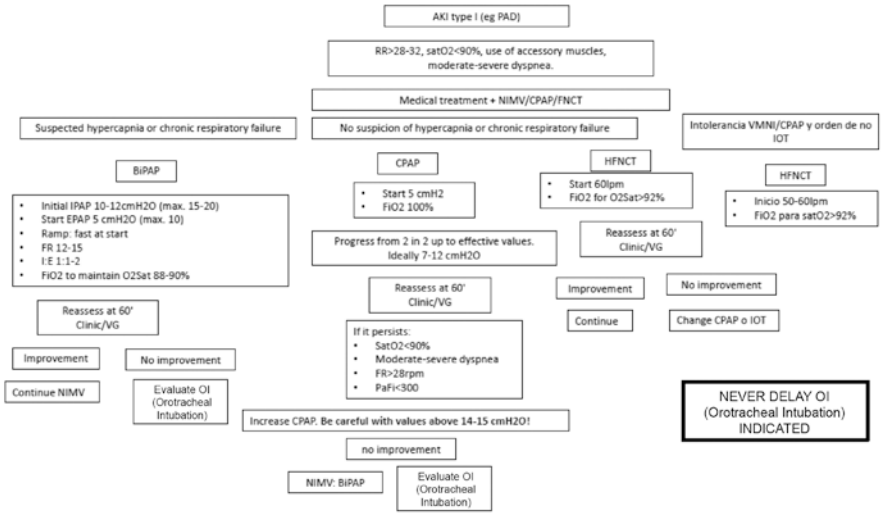


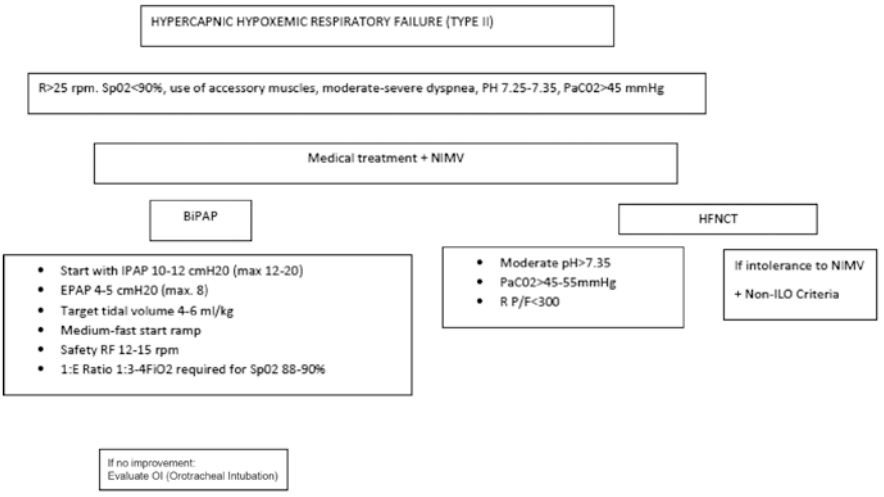
Fig. 12.2 Criteria for starting ventilatory support in ARF secondary to covid-19

Annexes

Annex I: Acute Respiratory Failure Type I



Annex II: Acute Respiratory Failure Type II



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13 Noninvasive Mechanical Ventilation: Discharge Planning's from Intensive Care to Hospital Wards. Key Concepts

Diana Amorim

Abstract

The introduction of noninvasive ventilation (NIV) outside the intensive care unit (ICU) is increasing, essentially due to resource-limited health care systems. However, not all patients can be transferred to a common ward and some stability situations must be met. It is important to choose the proper moment for the transference and have qualified personnel to supervise these patients in the ward. This chapter summarizes the discharge plan of a patient on NIV from ICU to a medical ward.

Keywords

Intensive care unit · Ward · Noninvasive ventilation

Noninvasive Ventilation Outside of Critical Care

Different hospitals have different care wards for patients receiving noninvasive ventilation (NIV). The clinical area in which a patient should stay is debatable and may be influenced by several factors, like the clinical status (Acute Physiology and Chronic Health Evaluation (APACHE) II score, respiratory rate and level of consciousness, the patient's progress over time, and presence of comorbidities), the hospital practice and the availability of beds [1]. Patients with more severe acidosis, hemodynamically unstable, decreased level of consciousness, several comorbidities, poor ventilator synchronization or who are persistently dyspneic despite efforts

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to optimize their ventilator settings should be managed in a higher dependency unit such as the intensive care unit (ICU).

When a patient had started NIV in ICU, it is important to choose the time to start the transfer to a medical ward, according to the stability of the patient [2]. There are several studies in literature that identify facilitators and barriers to a successful ICU discharge. It is important to remind that NIV patients have to be managed by experienced staff from different areas: doctors, nurses, respiratory physiotherapists, nutritionists, speech therapists, etc. [2, 3]. Some of the facilitators are [4].

1. Education/training of providers;
2. Provider-provider communication;
3. Critical care transition programs (e.g., outreach, liaison nurse);
4. Collaboration between ICU and ward;
5. Written documentation for providers;
6. Knowledge/experience of provider;
7. Multidisciplinary team;
8. Provider empathy to patient and family.

There is little literature that clearly defines when patients should be transferred to a common ward, but at least the following conditions must be fulfilled: acidosis resolution, hemodynamic stability, preserved consciousness, ability to protect airways [2, 3].

The Transport Between ICU and Hospital Wards

Successful intra-hospital transport requires effective communication, appropriate staff and planning, and adequate equipment, such as ventilators and monitoring systems [5]. In addition to the ventilator, all the equipment must be assessed and confirmed (oxygen, batteries, filters, ventilator circuitry) as well as emergency equipment [5]. The most appropriate health professional should be chosen, considering the patient's clinical status. The professional must be familiar with transfer routes, prepare the material for transport, and be capable of reviewing the patient's monitoring and treatment parameters to coordinate with ward staff to receive the patient [2]. Staff must be present at the reception so they can review the protocol of patient monitoring and treatment parameters.

In patients who have to be transferred on NIV, ideally, the transport to a different hospital section should not exceed 10–15 min [5].

Wards That Receive Patients Under NIV

NIV may be safely applied in medical wards with success if monitoring capabilities and personnel resources are available [6]. There are some conditions that must be fulfilled when a patient is transferred to a certain ward [2, 3].

The patient should be clinically stable for a period of at least 2 h with no change in ventilatory parameters (except for reduced FiO_2);

1. When possible, the patient should be transferred to a stable physical unit with proper equipment and trained professionals;
2. In the new ward, NIV patients must be supervised 24 h a day by trained staff (doctors, nurses, physiotherapists), so they can:
   (a) Monitor patient clinical status (hemodynamic status, level of consciousness, skin color, and capillary refill);
   (b) Adjust the mask and leaks, ask about pain or discomfort, be aware of complications (increased dyspnea, abdominal distension, vomiting).
   (c) Check alarms (limits, sound level, and the appropriate response to each type of alarm);
   (d) Monitor pressures, frequency respiratory, and volumes;
3. The professionals involved must have adequate knowledge about the ventilators and other equipments, like the various noninvasive interfaces/devices for access to the airway, and the basic elements for monitoring the efficacy of NIV. They should also have skills in managing secretions.

In summary, some patients may properly undergo NIV in a medical ward after staying in the ICU, but certain criteria must be met so that transport and stay in the ward are safe.

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Noninvasive Mechanical Ventilation: Discharge Planning's from Intensive Care to Hospital Wards

14

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Abstract

Respiratory failure is a common disorder that requires intensive care unit (ICU) admission. Noninvasive ventilation (NIV) is a treatment modality for respiratory failure. Although the most substantial scientific data supports the usage of NIV in the ICU, NIV therapy can also be performed in hospital wards, emergency services, and at home as a long-term therapy. Effective ICU admission and discharge processes are needed to minimize morbidity, mortality, and ICU readmissions and improve family and patient satisfaction, cost-efficacy, and availability of ICU beds. The decisions to admit patients to ICU or discharge them to the ward should be established according to patients' disease severity, need for close monitoring, location capabilities, and staff experiences.

Keywords

Respiratory failure · Noninvasive ventilation · Intensive care unit · Respiratory support · Wards

Noninvasive Mechanical Ventilation: Discharge Planning's from Intensive Care to Hospital Wards

Respiratory failure is a common condition requiring intensive care unit (ICU) admission. Patients with acute respiratory failure are always very fragile, with potentially high mortality risk. Mechanical ventilation is a well-established

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treatment modality for patients with respiratory failure of various etiologies. Noninvasive ventilation (NIV) is used as first-line therapy in patients with chronic obstructive pulmonary disease (COPD) and cardiogenic pulmonary edema. NIV therapy can be delivered as initial respiratory support therapy as well as the following weaning from invasive mechanical ventilation. Although the benefits of NIV therapy were observed in patients with acute hypoxemic respiratory failure, those patients were often associated with poor outcomes compared with hypercapnic respiratory failure. The delay in recognizing the deterioration under NIV, progression of respiratory failure, or new-onset complications may result in devastating and fatal consequences [1–4].

The most substantial scientific data supports the usage of NIV in the ICU. Thanks to the medical staff's increased experience, developments in treating sicker patients with comorbidities, and utilizing respiratory support therapy, a dramatic increase is shown in NIV usage out of the ICU [5]. In many countries, three levels of facilities exist in which NIV therapy could be applied: the ICUs, respiratory intermediate care units, and the general wards.

Although most of the literature demonstrated that treatment with NIV decreases mortality in ICU [6], the limited number of ICU beds is the primary factor precluding the admission of patients. Additionally, prolonged or redundant ICU stay could be related to some harmful patient outcomes, including ICU-acquired infections, invasive procedures-related complications, and psychological problems such as anxiety or delirium [6–8]. Effective ICU admission and discharge processes are needed to reduce morbidity, mortality, and ICU readmissions and improve family and patient satisfaction, cost-efficacy, and availability of ICU beds [9]. ICU should be chosen as a location for NIV therapy only for severely ill patients with a high risk of NIV failure: severe respiratory acidosis, hemodynamically instability, seriously impaired level of consciousness, and multi-organ failure [10]. Furthermore, patients who no longer need intensive care support should be discharged from the ICU with a reasonable approach.

Recommendations on where and how to properly deliver NIV therapy are also not clear in the guidelines [11]. The decisions to admit patients to ICU or discharge them to the wards should be established according to the patient's disease severity, need for close monitoring, location capabilities, and staff experiences [12]. Support with appropriate personnel knowledgeable and experienced in using NIV is critical to its success. Suitable usage of NIV often stands upon bedside experts providing a comfortable interface with minimal leaks, appropriate initial settings, and patient relief with a follow-up that includes frequent check-ins and altered settings, if needed [10].

After the episode of acute respiratory failure, it is essential to consider seeking answers to the questions of how, where and how NIV therapy should be applied, and what is the most appropriate care that will allow the most significant independence, function, and quality of life for those patients [13].

Patient's Clinical Features

After ICU management, patients should meet the respiratory and hemodynamical stability criteria for deciding to discharge to wards. They should have a secure airway or be stabilized on a regimen of NIV. Patients should not have severe episodic dyspnea or desaturations, and oxygenation requirements should be met effortlessly without high supplementary oxygen concentrations or elevated levels of positive end-expiratory pressure. Respiratory secretions should be manageable outside of the ICU environment, and variations in airway resistance should be minimal. In addition, the patient should not be undergoing frequent ventilator setting changes other than for weaning and should not require sophisticated ventilator modes [3, 10, 14]. Discharge from ICU should be postponed if the patient has the criteria for risk of failure in NIV treatment which were determined in previous studies, including advanced age (>40 years), low Glasgow coma scale (<11), tachypnea (>35 breaths/min), low pH (<7.25), severe disease (Acute Physiology and Chronic Health Evaluation score > 29), agitation, excessive secretions, poor tolerance, poor adherence to therapy, low PaO_2/FiO_2, failure to improve oxygenation within the first hour of NIV therapy [2, 4, 15]. Also, scoring systems to predict NIV failure, such as HACOR score [16], Midland NIV score [17], and NIVO score [18], can be used to identify patients at risk for NIV failure.

Types of Respiratory Failure

Previous data reveals that NIV therapy can be safely applied in the wards to patients with COPD acute exacerbation with mild to moderate respiratory acidosis [19–23]. On the other hand, the success of NIV treatment in hypoxemic respiratory failure and de-novo respiratory failure is controversial. An association between severe hypoxemia ($PaO_2/FiO_2 < 150$) and NIV failure has been found in previous studies [10]. The significant concern is that applying NIV out of ICU may delay intubation and the initiation of invasive mechanical ventilation in those patients with acute respiratory distress [24]. In addition, many NIV devices used in wards cannot provide the high oxygen fractions that intensive care–type devices can provide. For this reason, ICU discharge may be delayed for patients whose oxygen demand is still high/variable during the day [1, 10].

Ward Facilities

A standardized NIV therapy protocol should be developed; nursing and medical staff undergo formal NIV educational courses and training regularly. Clinicians responsible for managing NIV therapy should be aware of the capabilities of available devices based on modes, leak-compensation abilities, trigger/cycle settings, and monitoring capabilities. Nurses and medical staff should be capable of monitoring patients under NIV therapy, minimizing air leaks with an appropriate interface,

and recognizing the alarm system of NIV devices [11]. Intermittent arterial blood gases and continuous oxygen saturation measurements should be obtainable. The patient and their family/caregivers need to learn skills about care. General medical equipment such as appropriate beds and wheelchairs should be provided, or their acquisition facilitated [10]. Improving staff training and introducing standardized protocols could help make NIV safer and more common when applied in general wards [3].

To summarize, there is no consensus for making decisions on the criteria for discharge towards from an ICU. The decision must be individualized based on patients, staff, and logical conditions. Clinicians should be aware of biases based on their medical opinions, family requests, or insufficient resources during ICU discharge decisions. Judgments on the most suitable non-ICU setting must be made on a patient basis. Still, regardless of the chosen site, several criteria for patient stability must be fulfilled to ensure that discharge to an alternative location is safe, logistically possible, and cost-saving.

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15 Noninvasive Ventilation Outside Intensive Care Unit. Prevention Readmission. Key Practical Approach

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Abstract

Intensive care unit (ICU) readmission is associated with poorer outcomes, including higher mortality rate. Respiratory conditions are among the most common causes of ICU readmission. Several risk factors have been identified, such as older age, comorbidities, and higher severity scores. Preventing ICU readmission is of the utmost importance.

Keywords

Intensive care unit · Readmission · Noninvasive ventilation · Acute hypercapnic respiratory failure

Introduction

The classic main indications for acute noninvasive ventilation (NIV) are acute hypercapnic respiratory failure (AHRF) leading to respiratory acidemia in chronic obstructive pulmonary disease (COPD) exacerbation and obesity hypoventilation syndrome (OHS) and acute hypoxemic respiratory failure due to cardiogenic

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pulmonary edema [1–3]. For patients with neuromuscular disorders (NMD) and chest wall deformities (CWD), as well as OHS, a trial of NIV should be initiated when presenting with hypercapnia even without acidosis [1, 3]. Failure of optimized NIV is an indication of invasive mechanical ventilation [1–3].

Risk Factors for ICU Readmission

According to published data, Intensive care unit (ICU) general readmission rates vary between 4% and 14% [4–6]. Respiratory conditions, such as pneumonia, COPD, and respiratory distress after aspiration, are among the most common causes of ICU readmission [4–7].

Several risk factors for ICU readmission have been identified. The most recurrent ones are older age, higher number of comorbidities, higher severity scores at initial admission and at ICU discharge, delay in initial ICU admission, longer length of stay in initial ICU, and discharge during night shift [4–8]. Rosenberg and Watts (2000) [4] identified unstable vital signs (especially respiratory rate and heart rate) and poor lung function at the time of ICU discharge as the most consistent predictors of ICU readmission [4]. Tam et al. (2014) [6] pointed out positive fluid balance in the 48 h pre-discharge and increased sputum quantity on discharge as risk factors for preventable ICU readmission [6]. In a recent review, Morgan et al. (2020) [5] reflected on the impact of increased ICU census pressuring into faster discharge and leading to higher likelihood of ICU readmission [5]. COPD patients with AHRF who survived after treatment with NIV have an elevated risk of readmission and life-threatening events (AHRF requiring assisted ventilation) [9]. During a 1-year follow-up of a group of 110 patients, Chu et al. (2004) [9] registered around 80% readmissions for respiratory diagnoses and around 63% life-threatening events [9]. A low Katz Activities of Daily Living score (0–4) before admission and > 21 days in hospital in the previous year were also found to be independent risk factors for readmission [9]. Furthermore, a low Body Mass Index, a high Acute Physiology and Chronic Health Evaluation (APACHE) II score, and use of home oxygen before admission were identified as independent risk factors for recurrent life-threatening events [9].

Predicting ICU Readmission

When considering discharging a patient from the ICU, risk stratification scores can be useful in the decision-making process [10]. The Stability and Workload Index for Transfer (SWIFT) score was designed to predict the risk of ICU readmission [5, 11]. It evaluates the original source of current ICU admission, total ICU length of stay, last measured PaO_2/FiO_2 ratio (during current ICU admission), Glasgow Coma Scale at time of ICU discharge, and last arterial $PaCO_2$ [11]. A SWIFT score > 15 identifies patients at risk of ICU readmission [11]. The SWIFT score was considered a more precise predictor of readmission than the day of discharge APACHE III score [5, 11].

Two more practical tools are the Modified Early Warning Score (MEWS) and the National Early Warning Score (NEWS) [10, 12, 13]. Both evaluate systolic blood pressure, heart rate, respiratory rate, temperature, and level of consciousness [12, 13]. The NEWS also considers oxygen saturation and any oxygen supplement [12]. A NEWS before ICU discharge >7 is an independent predictor of clinical deterioration within 24 h of transfer [10, 12]. In such high-risk patients, ICU discharge should be postponed [12]. Patients with a MEWS = 0 before ICU discharge present lower risk of early readmission, with a negative predictive value of 99.7%, boosting clinician's confidence in transferring the patient [13].

The PEARL score was validated to stratify the 90-day risk of readmission or death after hospitalization for acute exacerbation of COPD [14]. It includes previous admissions (≥ 2), extended Medical Research Council dyspnea score, age (≥ 80), right-sided heart failure, and left-sided heart failure. It was considered superior to other predictive models (ADO, BODEX, CODEX, DOSE, and LACE scores) [14].

Strategies for Preventing Readmission

ICU readmission is associated with poorer outcomes, including higher mortality rate, longer hospital length of stay, and higher likelihood of being discharged to a post-acute care facility [4–8]. The European Respiratory Society/American Thoracic Society guidelines on NIV for acute respiratory failure recommend the use of NIV to facilitate weaning from mechanical ventilation in patients with AHRF [2]. This strategy was associated with lower incidence of ventilator-associated pneumonia and lower ICU and hospital length of stay [2, 3]. As mentioned before, respiratory conditions are among the most common causes of ICU readmission and initial ICU length of stay is a risk factor for ICU readmission [4–8]. The Cochrane Review by Burns et al. (2013) [15] pointed out a significant benefit of weaning to NIV in terms of not only overall mortality reduction, but also in rates of reintubation and tracheostomy [15]. The pooled estimate of 10 studies supported a significant reduction in reintubation rate (RR 0.65, 95% CI 0.44 to 0.97) [15]. These benefits were greater in COPD patients, but also positive in other mixed populations [15]. More importantly, estimates from 16 trials demonstrated a positive effect of NIV weaning on mortality and ventilator-associated pneumonia without an increased risk of weaning failure or reintubation [15]. Weaning of NIV may also be an issue of debate. Sellares et al. (2017) [16] compared NIV direct discontinuation (after 4 h of tolerated unassisted breathing) versus prolongation of nocturnal NIV in COPD patients without previous domiciliary NIV admitted for AHRF [16] They observed no differences in AHRF relapse, hospital stay or 6-month hospital readmission [16]. Furthermore, prolongation of nocturnal NIV led to longer length of stay in an intermediate respiratory care unit [16].

The following interventions have been proven to reduce readmission rate for acute exacerbation of COPD: antibiotics initiated in the first 2 days of hospital admission; short course of systemic corticosteroids; maintenance therapy with a combination of inhaled corticosteroids and long-acting β-agonists; domiciliary

NIV; pulmonary rehabilitation; nutritional supplementation of malnourished patients; adherence to treatment; and patient education [14]. The role of long-term oxygen therapy in preventing readmissions is not yet clear [14].

Following an exacerbation with AHRF, some patients will benefit from long-term home NIV [1, 17–21]. This is true for: COPD patients presenting with persistent hypercapnia ($PaCO_2$ > 53 mmHg) 2 to 4 weeks after resolution of respiratory acidemia; COPD patients who have had two or more episodes of AHRF treated with acute NIV within 1 year; most OHS patients; NMD and CWD patients [1, 17–21].

For COPD patients with persistent hypercapnia after an acute exacerbation, long-term home NIV plus long-term oxygen therapy (versus long-term oxygen therapy alone) has been shown to prolong time to readmission or death within 12 months [17].

Unstable COPD patients with recurrent episodes of AHRF have experienced fewer AHRF episodes and readmissions after initiation of long-term home NIV [18]. On the other hand, for stable COPD patients with chronic hypercapnia, the pooled estimate of 13 studies supported some (although little) benefits of long-term home NIV on mortality and admissions [19]. Nevertheless, NIV significantly improved dyspnea, exercise capacity, and quality of life [19]. Assisted coughing techniques and secretion mobilization techniques are an essential part of respiratory care for NMD patients [22].

Effective secretion clearance aims to prevent atelectasis, pneumonia, acute respiratory failure, and ultimately hospitalization [22]. For patients admitted with acute decompensated heart failure, congestion relief with diuretic therapy, optimal medical therapy initiated before discharge, and treatment of comorbidities were associated with a lower risk of 30-day readmission [23].

Finally, all patients who received acute NIV for AHRF should be evaluated by a specialist within 2 to 6 weeks after discharge [1]. COPD patients who had a follow-up meeting with a pulmonologist within 30 days of discharge registered lower risk of rehospitalization within 90 days of discharge. [24] The British Thoracic Society COPD discharge care bundle recommends a follow-up call within 72 h of discharge. [14] For patients admitted with acute decompensated heart failure, the European Society of Cardiology recommends a follow-up visit within 1 to 2 weeks after discharge, as retrospective studies showed lower 30-day readmissions rates with this approach [23].

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Noninvasive Mechanical Ventilation in the Emergency Room. Clinical Indication and Organization

16

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Abstract

Noninvasive mechanical ventilation is increasingly being considered an emergency treatment outside of intensive care units such as emergency department (ED), high-dependency unit (HDU), and wards for patients with acute respiratory failure. The two types of noninvasive ventilation (NIV) are bi-level positive pressure and continuous positive pressure. These pressures deliver high pressure and help to reduce the workload of the patient, which will avoid intubation and reduce the hospital stay. There is so much evidence for the effectiveness of this treatment for patients with acute exacerbations of chronic obstructive pulmonary diseases and acute cardiogenic pulmonary edema. Other conditions included in this chapter are asthma and community-acquired pneumonia. The main criteria for initiating these therapies are based on blood gas values and the clinical symptoms of patients. The successful outcomes of NIV are based on the appropriate selection of patients, interfaces, and pressures.

Keywords

Noninvasive positive pressure ventilation · Acute exacerbation of COPD · Bi-level positive pressure · Continues positive pressure · Acute cardiogenic pulmonary edema · Emergency department

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Introduction

Noninvasive ventilation (NIV) delivers positive pressure ventilation through the patient's upper airway by means of a mask without the use of an invasive artificial airway (endotracheal tube or tracheostomy). NIV is an indispensable equipment that can be provided in several locations outside the ICU, including the high-dependency units (HDUs), respiratory wards, and the emergency departments (EDs) for patients with ARF [1, 2].

The use of NIV is associated with decreased rates of intubation and its related complications [3–6]. Traditionally, all forms of ventilatory assistance have been managed in intensive care units (ICUs) where personnel, knowledge, skills, and monitoring capability amply exceed those of a general ward. Now, however, with the shortage of intensive care beds and the growing ease of application, NIV is frequently started outside the ICU not only in the ED under the indications and direct management of the duty anesthesiologist, but also in general wards with scant monitoring facilities and usually inadequate medical or nursing knowledge and skills [7]. The use of NIV requires knowledge of appropriate patient selection, modes of delivery, selection of the correct amount of positive pressure, and appropriate methods of monitoring the patient [2].

Indications

The NIV support used outside of ICUs is based on patient's diagnosis, and clinical and blood gas criteria. The main indications of noninvasive mechanical ventilators are the following:

Acute Exacerbation of COPD

Patients with chronic obstructive pulmonary disease (COPD) have an expiratory airflow limitation owing to the collapse of small and medium-sized airways. When patients have acute exacerbation of COPD, they have difficulty with gas exchange and therefore retain carbon dioxide. The standard treatment for acute exacerbation of COPD consisted of the administration of bronchodilators, systemic corticosteroids, supplemental oxygen, and antibiotics [2].

For patients with acute exacerbation of COPD, NIV is one of the most effective treatments to improve patient outcome [2]. Several studies have shown improvement due to early application of NIV for COPD exacerbations such as decreased hospital stay, decreased complications, improvements in pH, respiratory rate, and partial pressure of carbon dioxide in arterial blood ($PaCO_2$) [8]. Recent guidelines on the use of NIV support the use of BiPAP for patients with COPD and pH of less than 7.35 [9].

Acute Cardiogenic Pulmonary Edema

In patients with or without existing cardiomyopathy, increased left ventricular end-diastolic pressures cause the left atrium to pump against an increased load. As the atrium becomes overwhelmed, an increased hydrostatics pressure gradient is created within the pulmonary arterial and venous systems. Eventually, the pulmonary interstitium becomes overloaded, resulting in alveolar collapse and widening of the area reserved for diffusion of gases. Therapy for acute cardiogenic pulmonary edema (ACPE) is aimed at reducing cardiac preload, reducing afterload, removing excess volume, and recruiting areas of lung with V/Q mismatch [2]. Studies by S. Ursella et al. have shown that both continuous positive airway pressure (CPAP) and noninvasive positive -pressure ventilation (NPPV) gained important roles in the treatment of several forms of hypoxemic acute respiratory failure like ACPE and it is shown that both CPAP and NPPV significantly decreased the need for endotracheal intubation, and CPAP significantly decreases mortality when compared to standard medical treatment [10]. So, based on this study, CPAP should be considered the preferred intervention in patients with cardiogenic pulmonary edema in outside ICUs especially in the ED room.

Asthma Exacerbations

Asthma is a disease marked by the pathologic triad of airflow obstruction, mucus hypersecretion, and bronchoconstriction. Exacerbation of asthma can be caused by infection, medication nonadherence, environmental allergens, and exposure to smoke. The treatment includes administration of inhaled bronchodilators and systemic corticosteroids. Additional therapies that can be considered in exacerbation of asthma include intramuscular bronchodilators, magnesium sulphate, helium-oxygen admixture, and NIV [2].

In NIV treatment, the benefits observed are the improvement of gas exchange, decreased P_aCO_2, and rapid improvement in vital signs within first 2 h in exacerbation of asthma patients [11].

Community: Acquired Pneumonia

The use of NIV reduced the intubation rate, ICU stay, and mortality rate in patients with severe community-acquired pneumonia (CAP). The studies produced mixed results on NIV for the patients with CAP, so the results from other studies have demonstrated less favorable results, causing confusion about the role of NIV in patients with respiratory failure from CAP. Current guidelines do not recommend the use of NIV in CAP; however, it can be used when non-COPD patients with pneumonia are treated with NIV [2, 11].

Patient Selection Criteria

The selection of appropriate patients for the need of noninvasive mechanical ventilation in outside of ICUs is based on the clinical signs and blood gas criteria. The clinical signs and symptoms include distress, tachypnea (RR > 24 breath/min), use of accessory muscles, and paradoxical breathing [12]. Blood gas criteria includes pH less than 7.35 and $PaCO_2$ greater than 45 mmHg or PaO_2/FiO_2 less than 200 [11].

Exclusion Criteria

Exclusion criteria includes certain patients who have been at increased risk of failure and complications such as respiratory arrest or the need for immediate intubation, hemodynamic instability, inability to protect the airway, excessive secretion, agitated and confused patients, facial deformities, or conditions that prevent mask from fitting, uncooperative or unmotivated patients, brain injury with unstable respiratory drive [11].

NIV Outside the Intensive Care Unit

Mainly portable BiPAP or CPAP machines are used in outside of the ICUs. It can be an easily operated machine that helps a patient with COPD to breathe. This machine pressurizes the air to a higher level than the air in the room, and so it helps a patient to take in oxygen and exhale carbon dioxide. The BiPAP can be useful for a patient with both hypercapnic and hypoxic respiratory failure because it can take some load off a patient's breathing muscles and heart, allowing them to breathe more easily.

The CPAP machines are highly recommended for a patient with ACPE and who primarily has hypoxic respiratory failure in ED or other areas such as wards and high depending units. It works by holding the airways open through continuous pressure, whether the individual is breathing in or out. This pressure prevents the upper airways from collapsing, which makes breathing easier and helps to improve the oxygen levels.

Initial setting of NIV: once a patient is selected for treatment with NIV, the respiratory therapist, Nurses must choose the mode of ventilation, the type of interface, the PEEP or CPAP level, the IPAP or PS level, and the FiO_2 (Table 16.1). The two most common interfaces are nasal mask and face masks which are used in outside of ICUs. Other types available are: Nasal pillows, full face mask, total face mask, and helmets.

Table 16.1 Initial setting of NIV

Initial setting OF NIV	
1. Choose CPAP or BiPAP modality based on indication	
2. Select interface/mask	
CPAP	*BiPAP*
3. Set CPAP 5–10 cmH_2O	Set EPAP or PEEP 5–8 cmH_2O
4. Set FiO_2 between 0.4–1.00	Set PS(7–10 cmH_2O) or IPAP (12–15 cmH_2O)
5. Titrate pressure 2 cmH_2O every 5 min to effect	Titrate pressure 2 cmH_2O every 5 min to effect
6. Titrate FiO_2 according to SaO_2 or ABG	Titrate FiO_2 according to SaO_2 or ABG

Monitoring

Monitoring for NIV patients should include regular assessment of respiratory mechanics, hemodynamic and neurologic status by respiratory therapist or trained personnel. Thus implies:

1. Patient tolerance and comfort. Clinically, improvement in patient comfort is indicated by a decrease in respiratory rate (RR), reduced inspiratory muscle activity, and synchronization with ventilator. If these indicators are absent, the respiratory therapist must take steps to ensure the patient's comfort, such as refitting or changing the mask to reduce air leakage, encouraging and coaching the patient in the proper breathing pattern, or adjusting ventilator settings [13].
2. Oxygenation and heart rate are monitored continuously.
3. FiO_2 is adjusted to maintain SpO_2 above 90%.
4. Arterial blood gases after 1 h of NIV and at least every 2 h. If pH and $PaCO_2$ have shown improvement, intubation can be avoided. However, the $PaCO_2$ may take longer to decrease in some patient, particularly those with chronic hypercapnia.
5. NIV will be terminated and switched to invasive mechanical ventilation if the patient's level of consciousness, hemodynamic instability, or pH, $PaCO_2$ and PaO_2 continue to worsen within an hour.

Key Messages

- NIV can be used outside of ICUs in selected patients with respiratory failure.
- NIV can reduce the rate of intubation and its related complications.
- Selection of NIV is based on patient clinical conditions and blood gas criteria. The acute exacerbation of COPD and acute cardiac pulmonary edema are most common indications of NIV used in outside of ICU.
- Continue monitoring the respiratory mechanics, hemodynamic, and neurologic status of the patients in the first 30–90 min after initiation of NIV.

- Selection of appropriate interfaces and mode of ventilator are required for the success of NIV.

Conclusion

Nowadays, NPPV is widely used outside of ICUs. Applying the NPPV requires appropriate knowledge of patient selection, modes of delivery, selection of the correct amount of positive pressure, and appropriate methods of monitoring the patient. However, the respiratory therapist or trained staff has to continue monitoring the respiratory status, hemodynamic and neurologic status of the patients with NIV, so early intervention and appropriate patient selection and therapy are the keys to its benefits.

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Noninvasive Ventilation in Step-Down Units Organization

17

Huriye Berk Takir and Ayşegül Berk

Abstract

When the demand for intensive care unit (ICU) beds is greater than their availability, clinicians should be aware of patients who really need or benefit from ICU. Step-down units are good options for suitable noninvasive mechanical ventilation (NIV) patients who can be treated successfully with less personnel and sources.

Keywords

Step-down unit · Noninvasive mechanical ventilation · Mortality · Length of stay

Step-down unit was initially defined as a patient-care organization for monitoring and nursing care for cardiac patients who are not stable enough for discharge to the ward but no longer require full intensive care [1, 2]. Step-down unit is also called as high dependency unit, transitional unit, respiratory intermediate unit, Level 2 care, and progressive care unit since first definition in 1968 by Gotsman MS, Schrire V [1]. There is still great heterogeneity and each definition includes diverse severity of patients in some means.

The increase in the elderly population with multiple serious comorbidities has triggered a great surge in the need for intensive care beds. To expand the number of ICU beds is very expensive. Because it means not only the equipment but also more specialized medical personnel, human resources, and supplies. When the demand

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for ICU is greater than their availability, to optimize utilization of ICU beds, clinicians should be aware of patients who really need or benefit from ICU and are also stable enough to discharge from ICU as soon as the readiness is accrued. Discharging the right patient at the right time reduces length of stay and readmissions, but early discharge is associated with increased mortality [3–5]. Like weaning invasive mechanical ventilation, 'weaning from ICU' should have objective criteria to identify suitable patients and time. Recently Maike Hiller et al. published an expert consensus, a total of 28 discharge criteria for adult ICU patients including respiratory, cardiovascular, central nervous, and urogenital systems. And there are also criteria concerned with pain, fluid loss and drainages, medication and nutrition, patient diagnosis, prognosis and preferences, and lastly four institution-specific criteria [6]. Respiratory and cardiovascular system criteria are mostly concerned with maintaining airway, effective cough, respiratory rate (RR) ($10 \leq RR \leq 30$ (pm)), heart rate (HR) ($50 \leq HR \leq 110$ (bpm)), mean arterial pressure ($60 < MAP \leq 110$ mmHg), bleeding, and need for low-dose vasoactive. Most of these criteria end with the 'patient's individual baseline value is met', 'adequately handled', or 'available required technology/staff capabilities' in the receiving unit. We believe each center should define its own discharging criteria according to matching patients' needs and step-down unit/ward capabilities.

Step-down units are good options for suitable patients who can be treated successfully with less personnel and sources.

The ratio of nurse-to-patient number and ability to provide specific organ failure determine step-down unit constitutively. Patients requiring invasive mechanical ventilation or dialysis should be followed in a level 3 intensive care unit (ICU). Patients with respiratory failure requiring noninvasive mechanical ventilation (NIV) but not multiorgan failure can be treated successfully in step-down units.

Besides the patient's characteristics and monitoring needs, the risk of NIV failure is important for the decision of where to administer NIV (Table 17.1). For example, patients with acute respiratory failure on chronic respiratory failure due to Chronic obstructive pulmonary disease (COPD) and/or pulmonary edema are good candidates for step-down units because NIV success is quite well in this population. Patients who have various risk factors of NIV failure are better treated in ICU. Also, the capabilities of the unit should be adequate both in terms of medical personnel skills and technology.

Patients who do not require ICU-level monitoring but do require close observation that cannot be provided in a general ward can be treated successfully in step-down units. However. capabilities differ between hospitals. Therefore, clinicians' awareness of the equipment and personnel skills of different units in the hospital, and thus the correct selection of the NIV application site, are associated with NIV's success outside the ICU.

NIV patients should be monitored regularly at least for respiratory, consciousness, and hemodynamic parameters by trained personnel 24 h a day. Arterial blood gases should be evaluated after the first 1 h with clinical signs of tachypnea, dyspnea, and usage of accessory respiratory muscles. Hemodynamic assessment can be monitored noninvasively every 10 min initially. It is also necessary to follow skin perfusion (cyanotic, cold, etc.). ECG monitoring at least second lead should be

Table 17.1 Risk factors for NIV failure in patients with acute respiratory failure (adapted from [9])

Hypercapnic Respiratory Failure	Hypoxemic Respiratory Failure
Poor neurologic score (Glasgow Coma Score < 11)	Diagnosis of ARDS or pneumonia
Tachypnea (>35 breaths/min)	Age > 40 years
pH < 7.25	Hypotension (systolic blood pressure < 90 mmHg)
APACHE score > 29	Metabolic acidosis (pH <7.25)
Asynchronous breathing	Low oxygenation index (PaO_2/FIO_2)
Edentulous	Simplified Acute Physiology Score II >34
Excessive air leak	Failure to improve oxygenation within first hour of NIV (PaO_2/FIO_2 < 175 mmHg)
Agitation	
Excessive secretions	
Poor tolerance	
Poor adherence to therapy	
No initial improvement within first 2 h of NIV:	
No improvement in pH	
Persistent tachypnea	
Persistent hypercapnia	
APACHE: Acute physiology and chronic health evaluation, ARDS: Acute respiratory distress syndrome FIO_2:Fraction of inspired oxygen, NIV: Noninvasive ventilation PaO_2: Partial arterial pressure of oxygen	
[10, 11, 12]	[13, 14, 15]

available [7]. It is crucial to have necessary medical equipment such as oximeters, ECGs, blood pressure monitors, and intubation tools for prompt and effective interventions. A step-down unit should provide at least a nurse-to-patient ratio of 1:2.5 to 1:4 per shift and medical personnel available 24 h a day [8].

Continuous noninvasive monitoring, expertise in NIV implementation, and expert medical personnel are necessary to establish urgent endotracheal intubation in case of NIV failure or acute deterioration in patient's status. The expert team consists of mainly anesthesiologists or critical care specialists for both selecting suitable patients and applying/monitoring NIV. Pulmonologists should also be capable of following NIV patients outside the ICU as long as training is completed. Respiratory mechanics and gas exchange mechanisms physiopathology of respiratory failure, are already included in the most basic training of pulmonologists.

Conclusion

Step-down units are good options for treatment of suitable patients with NIV who do not need ICU monitoring. Thus, ICU beds can be available for more patients who really benefit. Clinicians are responsible for selecting the right patient where to apply NIV safely and successfully. This can be provided by awareness of the capabilities of different units in the hospital.

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Noninvasive Mechanical Ventilation in High-Dependency Units

18

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Abstract

Noninvasive ventilation (NIV) is a mode of oxygen delivery that reduces or eliminates the need for invasive mechanical ventilation and involves the use of external masks that are attached to a system producing positive pressure ventilation. NIV in the acute setting is commonly used to treat patients with acute hypoxic and/or hypercapnic respiratory failure secondary to underlying conditions such as chronic obstructive pulmonary disease (COPD) exacerbations, cardiogenic pulmonary edema, respiratory muscle weakness like neuromuscular disorders, and other disorders resulting in acute hypoxic respiratory failure. High-dependency units (HDU) or step-down units are specialized units that serve as intermediary units to general wards and intensive care units (ICUs). They have facilities to provide a higher level of care compared to general wards. These units are increasingly being utilized to manage patients requiring NIV in the hospital. Protocols, adequate training, and role-appropriate education of nursing staff, doctors, physical therapists, and respiratory therapists staffing the unit are necessary to ensure the successful management of these patients on the unit.

Keywords

Noninvasive ventilation · Positive pressure ventilation · Respiratory failure · High-dependency units · Step-down units

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Introduction

Noninvasive ventilation (NIV) is a commonly used mode of oxygen delivery that reduces or eliminates the need for invasive mechanical ventilation (IMV). It is used to reduce the work of breathing and improves gas exchange without the need to IMV. The most used types of NIV are positive pressure ventilators which include continuous positive airway pressure (CPAP) and bilevel positive airway pressure (BiPAP). Rarely used types like negative pressure ventilation will not be discussed in this chapter. Careful selection of the patients that can benefit from this mode of ventilation is important as not all patients are appropriate candidates. NIV in the acute setting is most used to treat patients with acute hypoxic and/or hypercapnic respiratory failure in such conditions as chronic obstructive pulmonary disease exacerbations, worsening of chronic respiratory failure in chronic obstructive pulmonary disease (COPD), cardiogenic pulmonary edema, respiratory muscle weakness like neuromuscular disorders. NIV is also useful in decreasing the risk for nosocomial infections like ventilator-associated pneumonia (VAP), shorter lengths of intensive care unit (ICU) stays, and lowering mortality, especially in chronic hypercapnic respiratory failure from COPD, when compared to invasive modes of ventilation such as endotracheal intubation [1]. Increasing numbers of patients requiring NIV are managed on high-dependency units (HDUs) or step-down units. These units have nursing and respiratory staffing required to monitor and manage these patients. HDUs also provide a separate space to house these patients that free up ICU beds that are in high demand. In this chapter, we will discuss the application of NIV in HDU outside of the ICU.

NIV Outside the ICU

Although NIV can be initiated in the emergency department, general wards, HDUs, or ICUs, patients with acute respiratory failure on NIV should be managed in either in an HDU or ICU. The main limitation of managing these patients in the ICU is bed availability in the ICU. HDUs or step-down units are specialized units that serve as intermediary units to general wards and ICUs and have facilities to provide a higher level of care compared to general wards. They are designed for patients that may not meet the criteria for management in an ICU. HDUs offer capabilities for continuous pulse oximetry, electrocardiography, heart rate, blood pressure, and many times include pressure discontinuation alarms that alert staff when ventilation is interrupted or discontinued. They also have physician, nursing, and respiratory therapist staffing required to manage these patients. The nurse-to-patient ratio is lower compared to the same ration on the medical wards. Although HDUs offer many benefits in housing patients with acute respiratory failure, majority of literature supporting NIV use is in patients that are in the ICU [2–4]. Decision of monitoring a patient in a non-critical care unit like an HDU should be made based on factors like acuity of respiratory failure, severity of clinical condition including impairment of consciousness, duration of time the

patient can survive off NIV, patient's adherence to NIV, patient's ability to call for help, and likelihood of complications [3]. Patients with less severe conditions can be safely managed on HDUs. ICU is generally recommended for those patients with a high risk of NIV failure, or hemodynamic instability. Most often patients with chronic conditions like sleep apnea that only require CPAP could be admitted to the medical surgical regional units rather than monitored or telemetry-capable units. Data suggests that managing such patients in an HDU rather than an ICU is a cost-effective strategy.

Types of NIV

BiPAP is generally preferred over CPAP as the difference in inspiratory and expiratory pressures aids in improving the vital capacity in the lungs. Ideally, initiation of NIV should be performed in a monitored setting to allow individualized titration of settings. There are multiple types of NIV interfaces available. Oronasal masks are generally first line. Other options include nasal masks, nasal pillows, total face masks, and helmet masks. Oronasal masks may cause posterior displacement of the tongue in some patients and paradoxically cause further obstruction. In these patients or those with claustrophobia, nasal masks or nasal pillows can be considered. Mouthpiece or sip ventilators may be used to delay tracheostomy in patients with neuromuscular disorders with gradually progressive respiratory failure and provide an alternative to NIV during the day.

Monitoring NIV

Monitoring with pulse oximetry and capnography should be performed to monitor for adequate treatment. Clinical assessment of the patient includes evaluation of the patient's tolerance, mask fit, mental status, accessory muscle use, vital signs especially pulse oximetry and respiratory rate, and synchronicity with the machine. Laboratory testing such as periodic arterial blood gas may be performed and is recommended 1–2 h after initiation of NIV to assess if the treatment demonstrated improvement [5]. This can be used to guide the escalation of treatment if an invasive modality is to be considered. Oxygen saturations (SpO_2) and end-tidal CO_2/pCO_2 are useful for assessing baseline respiratory status and ongoing continuous SpO_2 monitoring is recommended for 24 h after initiation of NIV [5]. These measurements may be important in determining the need for invasive ventilation if no improvement is observed with NIV. Capnography seems to be the most sensitive indicator of respiratory impairment. Explicit protocols of the indications for initiation of NIV should be in place for on-call medical staff. Protocols for alerting doctors and escalating care in the case of a change in clinical status and/or vital signs should also be in place. The success of running such a unit is ensured by adequate training and role-appropriate education of nursing staff, doctors, physical therapists, and respiratory therapists staffing the unit.

Indications for Initiation of NIV

Broadly, indications for initiation of NIV include acute or chronic hypoxic and/or hypercapnic respiratory failure. Common conditions include chronic obstructive pulmonary disease exacerbations, cardiogenic pulmonary edema, acute respiratory muscle weakness like neuromuscular disorders, bronchial asthma exacerbation, pneumonia, and other causes of acute hypoxic respiratory failure. NIV should not be used to substitute or delay endotracheal intubation in patients that evidently require it. Certain factors and prognosticators like modified HACOR score can be used to evaluate risk of NIV failure in these patients [6]. These can aid in selecting candidates for the trial of NIV. More specific criteria for initiation of NIV for conditions are discussed below.

Contraindications for Initiation of NIV

Initiation of NIV is not recommended in patients that have altered mental status, copious secretions, active emesis including hematemesis, and severe hypoxemia [7]. Bulbar dysfunction is an absolute contraindication for NIV due to the increased risk of aspiration, as patients with weak bulbar muscles cannot adequately protect their lower airways or clear secretions. Upper airway obstruction, poor compliance, inadequate cough, and inability to achieve a satisfactory interface are additional contraindications. As with other diseases, NIV should not be used to delay invasive ventilation in patients that require it.

Contraindications to NIV:

- Bulbar dysfunction.
- Vomiting.
- Upper airway obstruction.
- Poor compliance.
- Agitation/confusion.
- Inadequate cough.
- Recent upper gastrointestinal surgery.
- Bowel obstruction.
- Inability to obtain proper interface (facial deformities, burns, trauma).
- Hemodynamic instability.

NIV in COPD Exacerbation

The use of NIV in COPD exacerbation is well established. It is now recommended as a part of many international guidelines on the management of acute hypercapnic respiratory failure in COPD. Better outcomes have been demonstrated in these patients compared to those managed with IMV which is likely due to the high complication rate associated with invasive ventilation [3]. These patients are generally

monitored in HDUs as they require trained staff with appropriate nurse-to-patient ratios. Arterial blood gases are used to monitor acidosis and arterial pCO_2 content and guide the titration of NIV. Positive benefits of NIV in COPD exacerbation have been demonstrated in patients with respiratory acidosis (pH <7.35) [7]. We can discontinue NIV once acidosis and hypercapnia have resolved [7].

NIV in Cardiogenic Pulmonary Edema

NIV has been used in cardiogenic pulmonary edema causing hypoxia. The mechanism of action is due to reduction of pulmonary edema by reducing venous return and hence left ventricular filling pressure [8]. NIV in these patients reduces the need for endotracheal intubation and improves mortality. In a large RCT conducted on patients in ARF, oxygen delivery done via NIV reduced respiratory distress and dyspnea than oxygen therapy via nasal cannula [9]. These patients should also be managed in HDU, especially those with significant respiratory distress.

NIV in Neuromuscular Disorders

Neuromuscular diseases (NMD) can broadly be categorized into diseases of the cerebral cortex, brainstem, spinal cord, motor nerves, neuromuscular junction, and muscles based on pathogenesis. Common NMD that can lead to life-threatening respiratory effects include multiple sclerosis, amyotrophic lateral sclerosis, Guillain-Barre syndrome, myasthenia gravis, and toxins. Neuromuscular disorders are important indications for ventilation in the critical care unit. The main cause of respiratory impairment in neuromuscular disorders is hypoventilation due to respiratory muscle weakness. NIV has been proven to be a life-prolonging tool in patients with chronic respiratory insufficiency caused by NMD. The role of noninvasive mechanical ventilation in NMD patients extends to facilitation of extubation and includes benefits like shortening ICU and hospital stay and improving survival. A few studies have demonstrated that NIV use post-extubation can reduce the risk of extubation failure in NMD patients. Respiratory insufficiency can manifest in an acute, chronic, acute on chronic, or progressive manner. Clinical features manifest secondary to inadequate ventilation, ineffective cough, and bulbar dysfunction. This is usually used along with a mechanical insufflator-exsufflator to promote cough and airway clearance, and open atelectic lungs. NIV has been shown to improve hypercapnia, hypoxia, improve physical activity, and quality of life in patients with NMD. For patients in earlier stages of respiratory failure like nocturnal hypoventilation, intermittent NIV can be used in controlling hypercarbia allowing daytime independence.

Neuromuscular disorders are one of the most common indications for NIV. Use of NIV in patients with NMD is a level 3 recommendation based on systematic reviews of case-control studies for treatment of acute respiratory failure [8]. Multiple criteria can be used to determine if NIV is indicated in a patient. Presence of forced

Table 18.1 Pulmonary function test criteria to determine if NIV is indicated in a patient with neuromuscular disorders

Measure	Value
Forced vital capacity (FVC)	<50% of predicted
Vital capacity (VC)	<15–20 mL/kg or < 60% of predicted or < 1 L
Mean inspiratory pressure (MIP)	<−60 cm H_2O
Mean expiratory pressure (MEP)	<40 cm H_2O
Sniff nasal inspiratory pressure (SNIP)	<40 cm H_2O

vital capacity < 50% of predicted, vital capacity <15–20 mL/kg, < 60% of predicted, or < 1 L, MIP < -60 cm H_2O, MEP <40 cm H_2O, or SNIP <40 cm H_2O serve as indications for use of NIV [10] (Table 18.1). Randomized controlled trials demonstrate improvement in survival and quality of life in patients with amyotrophic lateral sclerosis without bulbar symptoms [11].

Conclusion

HDUs are good options outside the ICU for safely managing patients requiring NIV in an acute setting. Continuous telemetry services, ventilatory alarms, and appropriate nurse-to-patient ratios are present in these units. In addition, clear protocols and training of a multidisciplinary care team are key in ensuring the safety of patients and provide a cost- and resource-effective way of management.

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Part IV

Models of Noninvasive Mechanical Ventilation Units Outside ICU

Noninvasive Mechanical Ventilation in Conventional Respiratory Ward

19

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Abstract

Acute respiratory failure is a very common cause of in-hospital emergencies (Cabrini et al., Minerva Anestesiol 76(1):71, 2010). As the number of patients requiring ventilator treatment is increasing, hospitals face a lack of beds in intensive care units (Kim et al., Int J Environ Res Public Health 18:2877, 2021). Due to the development of medical devices and improvement in medical equipment quality, the early start of noninvasive ventilation programs has improved patients' survival rates and performance (Kim et al., Int J Environ Res Public Health 18:2877, 2021). All services, including conventional respiratory wards (CRWs), must establish local protocols to follow and monitor these patients to reduce the risk of unsafe use of NIMV (Cabrini et al., Minerva Anestesiol 76(1):71, 2010).

Keywords

Noninvasive mechanical ventilation · Conventional respiratory ward · Respiratory care · Non-intensive care unit ward

Introduction

Noninvasive mechanical ventilation (NIMV) is a highly effective intervention, both in acute and chronic settings [1–3]. NIMV recommendations are increasing and even include the possibility to palliate patients [1, 4]. Nevertheless, it is still

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underused or started later than recommended, especially among less experienced teams with this kind of intervention [5, 6].

Starting NIMV in a conventional respiratory ward (CRW) has both its advantages and disadvantages. The clinician should weigh them to decide the best location to start NIMV and to optimize the efficacy and avoid harm to patients. Each hospital should have a specific, designated area staffed by personnel with appropriate experience [7, 8].

Quite often, some patients successfully start NIMV at other locations (e.g., emergency department, general intensive care unit (ICU)) and are then transferred to a general respiratory ward. In this situation, appropriate monitoring, weaning, and the decision to start home mechanical ventilation (HMV) at discharge should be made.

Despite the clinical setting or location, the key to a successful NIMV intervention relies on good education and communication within the multidisciplinary team where everyone fully understands the indications, benefits, and concerns associated with NIMV [7, 9, 10].

Fundamentally, 4 topics about NIMV in the CRW will be covered: location characteristics; starting and managing NIMV in acute settings; starting and managing NIMV in chronic settings; NIMV in palliative settings.

Conventional Respiratory Wards' Characteristics

CRW is one of many locations in a hospital where NIMV can be started acutely. Depending on the pathology and the patient's clinical status, one location may be more suitable than the other since each location has its characteristics. It should be noted that CRWs differ considerably from hospital to hospital: some have nursing staff with NIMV experience while many others don't, and not all of them have central telemetry [5]. Compared to respiratory high-dependency care units (RHDCU) and ICUs, CRWs have a higher availability of beds and lower costs for NIMV therapy. Nevertheless, CRWs offer fewer monitoring capabilities, a lower nurse/patient ratio, and staff with lower NIMV skills and experience [10]. This can lead to a higher risk of delayed recognition of NIMV failure, especially if there are other unstable patients in the ward [11]. All these characteristics make it a more suitable location for low-risk patients.

The CRW is also a location to start and titrate NIMV in chronic respiratory failure (CRF). It is usually not the first choice, because it is an unfamiliar environment for the patient and caregivers may not be able to stay, especially through the COVID-19 pandemic. Although time-consuming, especially for the patient, CRWs offer the possibility to titrate ventilation accurately with sufficient time for NIMV adaptation and problem-solving [10]. Given these characteristics, it may be a more appropriate location if a prompt adaptation to NIMV is warranted.

The advantages and disadvantages of starting NIMV at CRW, both in acute and chronic settings, are summarized in Tables 19.1 and 19.2.

Table 19.1 Summary of advantages and disadvantages of starting NIMV at a CRW in acute settings

Advantages	Disadvantages
Higher availability of beds	Less monitoring capabilities
Lower costs for NIMV therapy	Lower nurse/patient ratio
Appropriate for low-risk patients	Staff with lower NIMV skills and experience
Appropriate for COPD patients with mild or moderate acidemia	Higher risk of delayed recognition of NIMV failure

Adapted from: [10, 12, 13]
COPD chronic obstructive pulmonary disease, *CRW* conventional respiratory ward, *NIMV*, noninvasive mechanical ventilation

Table 19.2 Summary of advantages and disadvantages of starting NIMV at a CRW in chronic settings

Advantages	Disadvantages
Titration is quicker and more accurate	Unfamiliar environment for the patient
Higher monitoring capabilities	Caregivers may not be able to stay
More opportunities for patient and caregiver education	Titration is time-consuming
More time to adapt to the therapy	Higher costs for chronic NIMV therapy
Problem-solving is quicker	Dependent on beds availability
Appropriate if a prompt adaptation to NIMV is warranted	

Adapted from: [10, 12, 13]
CRW conventional respiratory ward, *NIMV* noninvasive mechanical ventilation

Starting and Managing NIMV in Acute Settings

The decision to initiate and manage NIMV in acute settings at a CRW must be carefully made, always considering this location's advantages and limitations, as previously stated.

There is no definitive guidance as to where NIMV should be started and monitored. Since CRWs' capabilities widely differ, a universal recommendation cannot be done [5, 12]. This should be judged based on many factors, such as the patient's need for monitoring, and illness severity, but also the unit's monitoring capabilities and staff experience [12, 14].

Nevertheless, low-risk patients are suitable to initiate and manage NIMV at a CRW. On the contrary, high-risk patients are at a greater risk of NIMV failure, and delayed endotracheal intubation (ETI) increases mortality risk [15, 16]. These patients would be more appropriately managed at an RHDCU or ICU.

Identification of low-risk and high-risk patients is a critical step to deciding where to start and manage NIMV.

Responsiveness to NIMV

Some patients are more responsive to NIMV than others. Hypoxemic ARF or hypercapnic ARF occurring in patients without pre-existent cardiorespiratory diseases are less likely to respond to NIMV [14, 17]. Furthermore, the NIMV failure rate in patients with pneumonia, asthma, or ARDS is high [17, 18]. In these patients, a higher care level should be considered, unless there has been a clear decision to limit life-sustaining treatments.

On the other hand, hypercapnic ARF with pre-existent respiratory disorders or acute-on-CRF is very responsive to NIMV [17, 19]. Usually, management at a CRW is appropriate in such cases.

NIMV Failure Predictors

NIMV failure predictors should be carefully evaluated and identified in every patient, both in hypercapnic and hypoxemic ARF. Some predictors can be identified before NMVI initiation, while others only afterward. The evidence on NIMV success and failure predictors in hypoxemic ARF is more limited, while in hypercapnic ARF the available data is wider.

Since hypoxemic ARF is already less responsive to NIMV [14, 17], if any failure predictor is identified, management at a CRW should be avoided. If a patient admitted at a CRW is in this condition and NIMV is started, a prompt transfer to higher care levels must be ensured. The updated HACOR score can be used to predict NIMV failure with high predictive power in patients with hypoxemic ARF [20].

In most cases of hypercapnic ARF, especially with pre-existent respiratory disorders or in case of acute-on-CRF, starting and managing NIMV at a CRW is usually suitable, if adequate monitoring and revaluation are guaranteed. There is evidence that the early use of NIMV in chronic obstructive pulmonary disease (COPD) patients with mild or moderate acidaemia in general wards resulted in fewer intubations and decreased mortality [11, 21, 22]. The noninvasive ventilation outcomes (NIVO) score can be used to predict in-hospital mortality in exacerbations of COPD requiring assisted ventilation, aiding treatment escalation decisions [23].

Patients at a higher risk of NIMV failure (i.e., with multiple risk factors, described in Tables 19.3 and 19.4) should be closely monitored [12, 13, 25]. If not already at an RHDCU or ICU, their medical team must be aware that such a patient is at a CRW and might need quick escalation in the level of care in case of NIMV failure.

Most cases of early NIMV failure (occurring between 1–48 h) are due to the persistence of an increased respiratory rate, poor arterial blood gases (ABGs) and an inability to swiftly correct them, and increased illness severity [24].

Table 19.3 Summary of predictors of NIMV failure in hypercapnic ARF

Before starting ventilation	After starting ventilation
Low BMI	No improvement within 2 h of NIMV in pH, RR, $PaCO_2$, APACHE II score
Severe respiratory acidosis (pH <7.25)	Inability to correct gas exchange (pH <7.25)
RR >35 breaths/min	Inability to co-ordinate with NIMV
Severe altered level of consciousness (i.e., Kelly–Matthay score > 3, GCS <12)	Poor compliance to NIMV and/or agitation not manageable with cautious sedation
Severe acute illness (i.e., high APACHE II scores >29)	Inability to minimize leak
Poor nutritional status	The burden of secretion is not manageable
Poor pre-morbid condition (i.e., ADL score < 2)	Late clinical–physiological worsening after an initial successful response to NIMV
Community-acquired pneumonia	
Excessive secretions	
Airway colonization with non-fermenting gram-negative bacilli (e.g., *Pseudomonas aeruginosa*)	

Adapted from: [10, 24]
ADL activities of daily living, *APACHE* acute physiology and chronic health evaluation, *BMI* body mass index, *GCS* Glasgow coma scale, *NIMV* noninvasive mechanical ventilation, *$PaCO_2$* partial pressure of carbon dioxide in arterial blood, *RR* respiratory rate

Table 19.4 Summary of predictors of NIMV failure in hypoxemic ARF

Before starting ventilation	After starting ventilation
Moderate–severe ARDS (P/F < 200)	Failure to improve oxygenation within the first hour of NIMV (P/F < 150)
Increased RR (>25 breaths/min)	Increase in radiographic infiltrates within the first 24 h
Age > 40 years	
Shock (i.e., systolic blood pressure < 90 mmHg despite vasopressors)	
Multiple acute organ insufficiency	
Metabolic acidosis with pH <7.25	
Severe acute illness (i.e., SAPS II >34)	
Pneumonia	

Adapted from: [10, 24]
ARDS acute respiratory distress syndrome, *RR* respiratory rate, *SAPS* simplified acute physiology score

Monitoring NIMV

Monitoring is mandatory, not only to evaluate the efficacy of NIMV but also to identify therapy failure [10, 14, 26]. The RHDCU or ICU offers complete monitoring capabilities, a high nurse/patient ratio, and experienced staff. Nevertheless, the shortage of beds causes many NIMV interventions to be carried out in a CRW and/

or emergency department [11]. Monitoring capabilities at a CRW are less advanced and may vary among hospitals. The intensity of monitoring should be primarily guided by the risk of NIMV failure, but also the severity of ARF [10].

Essential monitoring can be done at any CRW [10] and it includes:

1. Clinical evaluation, including heart rate, pulse oximetry, and breathing frequency continuous recording.
2. Complications evaluation.
3. Patient-ventilator desynchronization evaluation.
4. Air leakage and tidal volume evaluation.
5. Patient comfort evaluation.
6. ABGs 1–4 h after NIMV initiation and 1 h after changing ventilator settings.

If any failure predictor during NIMV monitoring is identified (see Tables 19.3 and 19.4), such a patient might need a quick escalation of care level.

High-risk patients will need more advanced monitoring [10, 14, 26]. Nevertheless, invasive monitoring through arterial lines is not available at CRWs. Transcutaneous PCO_2 measurement, although advisable, is also rarely available at CRWs. The frequency of clinical reassessment will not be as high as in an RHDCU or ICU, so problem-solving, ventilator settings adjustments, and NIMV failure recognition might be delayed in a CRW.

Local protocols to follow and monitor these patients must be established to reduce the risk of unsafe use of NIMV [27]. Trethewey and colleagues suggested an inpatient referral pathway for acute NIMV use in hypercapnic ARF [21] and Brad and colleagues developed a local protocol in their hospital [28].

Starting and Managing NIMV in Chronic Settings

CRW is one of many locations where NIMV can be started in chronic settings. It is the most complete location for monitoring and titrating NIMV, but it also has its disadvantages, as previously stated.

Unlike starting acute NIMV, which is a temporary treatment, starting chronic NIMV might be a complex process and it might take some time for the patient to accept and adapt to it [29].

The most important factor to consider regarding where to start chronic NIMV is the patient's preference [29, 30]. Preparing patients and caregivers and giving them as much information and choice as possible are essential factors to ensure the success of the therapy. Other important factors are also the hospital's capabilities, the patient's characteristics, and the adaptation time. Some hospitals may not have an outpatient department or the possibility of an overnight stay. The only available locations in such scenery would only be at a CRW or the patient's home.

Generally, patients with a chronically stable condition prefer to initiate NIMV at home or in an outpatient setting, since this has less impact on their work and home life. In patients needing a prompt adaptation to NIMV, like in rapidly progressive diseases, starting NIMV at a CRW or as an overnight stay is usually more suitable.

There are also some exceptional circumstances to consider. If a patient presenting with acute-on-CRF is hospitalized, starting chronic NIMV, if indicated, after adequate treatment and patient stabilization at a CRW, might be a good strategy. Similarly, if a patient presenting with ARF is hospitalized, and develops CRF with an indication for chronic NIMV, starting this therapy at a CRW during hospitalization might also be a good strategy.

Monitoring

Monitoring capabilities for chronic NIMV at a CRW are the same as with acute NIMV.

Since continuous monitoring and ABGs are immediately available, a quick NIMV titration is possible. Generally, at the start, the pressures are kept low, helping with compliance, and then increased to achieve a therapeutic effect [31]. Titration overnight is possible at a CRW, while at home it may take several weeks or months.

Comfort issues, more commonly with the interface and the drying effects of NIMV, are also swiftly solved. Any excessive air leakage and patient-ventilator desynchronizations are more readily recognized and solved at a CRW. The patient's and caregiver's ability to independently manage NIMV therapy is also monitored.

In some hospitals, it is possible to use polysomnography (PSG) to adjust ventilatory settings. It is expensive, not available in all centers, and its use in COPD and obesity hypoventilation syndrome does not lead to more improvement in gas exchange [31, 32]. Nevertheless, it might have a role in the titration and follow-up of HMV in patients who are difficult to initiate on NIMV, in whom concomitant sleep-related disturbances are noticed, and in patients in whom goals are not met [30].

After starting chronic NIMV at a CRW, the therapy is theoretically fully optimized and ready to use at home. If NIMV is started at home, it can take several weeks or even months to accomplish a full optimization. Nevertheless, a study suggests that there is an equivalent outcome regarding the improvement in ventilatory failure and compliance, whether patients were initiated as outpatients or as inpatients [33].

Regardless of the location, adequate education and training of the patient and caregiver by staff who are fully competent in NIMV are the key points for NIMV success [12].

NIMV in Palliative Settings

With the aging of the population worldwide, the diagnosis of neoplasms and other diseases in terminal stages became more frequent, leading to approaches that previously would not be possible [4].

NIMV can be used to palliate symptoms in "do-not-intubate"/"do-not-resuscitate" (DNI/DNR) patients, with end-stage cardiac, pulmonary, and neoplastic diseases presenting with ARF [1]. Since these patients have no criteria for RHDCU or ICU

admission, a CRW is usually a more suitable location to manage such patients. We must keep in mind that the use of NIMV in palliative settings aims to improve the quality of life and alleviate the symptoms of patients [34]. That being said, the patient's comfort must be the priority. If an intervention, including NIMV, is compromising the patient's comfort or inadequately prolonging the patient's life, it is most appropriate to stop it.

Discussion

Choosing the right timing, type of patient with respiratory failure, and adequate setting to start NIMV increases the chances of therapeutic success [8].

An unjustified delay of early NIMV treatment outside the ICU or while waiting for an ICU bed can lead to inadequate ventilatory support, missing a "window of opportunity" with potentially severe consequences that can be avoided [27].

In a chronic context, the use of NIMV may reduce the risk of readmission and life-threatening events, including death improving survival and quality of life in stable patients [35, 36]. As there are more and more patients with lung diseases that lead to CRF, there is a greater need to initiate NIMV. Given the type of patients, this adaptation can be carried out in a ward allowing an early and supervised transition to home [37].

Proper education and training of staff delivering NIMV therapy are critical [12]. Whether it is in the context of acute or chronic NIMV use, all services, including CRWs, must establish local protocols to follow and monitor these patients to reduce the risk of unsafe use of NIMV [27].

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Noninvasive Mechanical Ventilation in Respiratory Intermediate Care Units

20

Rita Costa

Abstract

Noninvasive mechanical ventilation is widely used in respiratory intermediate care units. In this chapter, we will review the latest evidence related to the use of noninvasive mechanical ventilation in patients that presented acute respiratory failure in widely numerous pathologies like chronic obstructive pulmonary disease exacerbations, cardiogenic pulmonary edema, postoperative lung cancer patients, chest trauma patients, and COVID-19 positive patients.

Keywords

Noninvasive mechanical ventilation · Acute respiratory failure · Acute hypercapnic respiratory · Clinical application · Mortality rate

Noninvasive mechanical ventilation (NIV) is a method of ventilatory assistance through a noninvasive interface instead of an endotracheal tube or tracheostomy [1]. It is commonly used in respiratory intermediate care units for acute respiratory failure (ARF) in multiple pathologies [2]. The COVID-19 pandemic recently forced a change in health care resources and new questions about NIV emerged. The purpose of this chapter is to review the indications of NIV in respiratory intermediate care, including the novelties related and nonrelated to the COVID-19 pandemic.

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Chronic obstructive pulmonary disease (COPD) is one of the main causes of morbidity and mortality globally [3]. Exacerbation has a negative impact on patient's everyday activities and quality of life [4], increases mortality, and is one of the main reasons for hospitalization in these patients. We can identify patients at risk of acute respiratory acidosis through the initial evaluation of respiratory rate, chest and abdominal wall movements, and a sample of arterial blood, and the improvement in pH or/and respiratory rate is also a favorable prognostic factor in NIV treatment [2].

NIV could be part of the treatment of COPD patients with acute hypercapnic respiratory failure/respiratory acidemia to prevent or substitute invasive mechanical ventilation [2]. These patients need close monitored because rapid deterioration with worsening pH and respiratory rate cloud leads to endotracheal intubation and invasive ventilation [2, 5]. It is essential that trained professionals in NIV with updated knowledge were part of the teams in respiratory intermediate care not only for adjusted the settings according to the patient's responses but also to choose the right interface. Adequate equipment and staffing numbers are also essential for the success of NIV treatment [5]. According to the Official ERS/ATS clinical practice guidelines [2], NIV cloud be used in patients who are not candidates for invasive mechanical ventilation or refused it for palliation goals because it can improve symptoms like breathlessness [6].

The use of NIV in these patients and other high-risk patients (like patients with end-stage disease) could be the reason in everyday clinical practice including in respiratory intermediate care, the benefit of NIV is not always substantial like in the randomized controlled trials (RCTs) [5].

In patients with hypercapnia (arterial partial pressure of carbon dioxide [$PaCO_2$] >6 kPa [45 mm Hg]) in the absence of acidosis, there is no robust evidence that NIV reduces the mortality rate or other substantial benefits [2]. However, there is an indication for treatment with NIV in patients with hypercapnia and a pH of <7·35 caused by a COPD exacerbation [2, 7]. Less severe acidosis is associated with a better prognosis [5]. Although this clear indication of acute respiratory acidosis, Roberts et al. [8] reported that 11% of patients with pure metabolic acidosis received NIV treatment.

Pneumonia is a major reason for exacerbations in COPD patients, although there is a lack of indications of NIV in these specific patients, except for the small study (n = 56) of Confalonieri et al. [9] that reported improved 2-month survival and a significant reduction in endotracheal intubation. NIV is also recommended in patients with ARF due to obesity, neuromuscular disease, and chest wall deformity [5].

ARF can occur in patients without previous pulmonary disease. The effectiveness of NIV in patients with acute hypoxemic respiratory failure without COPD is a very debated topic because there are controversial results. Besides the uncertainty of the benefits for these patients, there are remaining doubts about potential harm, for example, the risk of delaying needed intubation [2, 5, 10]. In the current literature, there is no formal recommendation but there is an attempt to predict NIV failure in hypoxemic patients [5, 11].

Cardiogenic pulmonary edema is a common and serious cause of ARF. Despite the initial concern, there is no evidence that NIV is associated with increased myocardial infarction risk [12], but the Official ERS/ATS clinical practice guidelines [2] do not make any recommendations in patients with acute coronary syndrome or cardiogenic shock. Grays et al. [13] reported that patients improve faster after NIV, but it has no effect on short-term mortality. However, a meta-analysis suggested that both continuous positive airway (CPAP) and bilevel NIV pressure should be used in patients with cardiogenic pulmonary edema due to a reduction in intubation and mortality rate.

Decreases in lung volume, diaphragm dysfunction, and post-operative pain are important concerns after lung resection. Auriant et al. [14] demonstrated that NIV can be used during the post-operative period of lung cancer resection due to decreasing intubation and hospital mortality rate. More studies are necessary for this specific population.

Chest trauma patients represent a heterogeneous group since lesions cloud have different degrees of severity. That illustrates why it is so difficult to make a universal indication in these groups. However, an NIV trial could be used after the pain is controlled and if patients do not have severe hypoxemia [2].

COVID-19 was declared a pandemic by the World Health Organization (WHO) on March 11th, so rapidly doctors all around the world had to fight an unowned disease without solid evidence-based guidelines. There are some studies that try to evaluate NIV in COVID-19 patients but due to different resources in different countries (some patients received NIV due to lack of ventilation), diverse backgrounds, and different staff and facilities organizations, the results were conflicting [15]. There were some concerns about the safety for health care professionals due to aerosols so some authors [16, 17] did not recommend NIV until the patients are cleared of COVID-19 however the risk of nosocomial transmission of COVID-19 is low with NIV [18]. Forrest et al. [19] show that hypoxemic patients with COVID-19 NIV had lower mortality and morbidity than mechanical ventilation patients. There is still doubt about a true cause and effect and results from RCTs are awaited [18].

There is no doubt that NIV should and could be used in the respiratory intermediate care units with significant benefits for the patients when specific indications are fulfilled. Patients need close monitored, so trained staff is essential for the success of NIV in these units.

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Noninvasive Mechanical Ventilation in Conventional Hospitalization Ward of Internal Medicine

21

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Abstract

Noninvasive mechanical ventilation and, more recently, high-flow oxygen therapy using nasal cannulas (HFNC), are increasingly used in patients with acute respiratory failure. Since its beginning in intensive care units, it has been progressively extended to other hospitalization areas, adapting to the peculiarities of each center. In small hospitals, the performance of these techniques in conventional wards is increasingly frequent in the absence of free intensive care beds and even the lack of these units. This chapter reviews the requirements and makes recommendations for the management of devices and patients with ventilatory support in conventional medical hospitalization wards of a polyvalent internal medicine service.

Keywords

Internal medicine · Conventional hospital ward · Noninvasive mechanical ventilation · High-flow oxygen therapy

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Introduction

Acute respiratory failure is a frequent cause of admission to the emergency department and a reason for admission to the medical services on a large number of occasions, ending in many cases in the intensive care unit (ICU) with intubation and connection to mechanical ventilation or death without this possibility in cases where this option is not appropriate due to the advanced disease, the accompanying pathology or the patient's will. Between arrival at the emergency department and intubation, there are diverse levels of therapeutic and monitoring needs that should be adapted to the reality of each center.

In recent years, noninvasive mechanical ventilation (NIV) and, more recently, high-flow oxygen therapy using nasal cannulae (HFNC), have been increasingly used in patients with acute respiratory failure to avoid tracheal intubation and the appearance of associated complications. Conceptually, the aim is to provide ventilatory support without airway intubation, to reduce the work of breathing (improving dyspnea), and increase alveolar ventilation (improving pH and increasing oxygenation).

There are currently numerous studies demonstrating that NIV is an effective therapeutic method in exacerbation in patients with chronic obstructive pulmonary disease (COPD), as it allows rapid symptomatic and physiological improvement, and reduces the need for intubation, mortality, and hospital stay. Based on this evidence, expert consensus groups recommend NIV as the method of first choice in selected patients with COPD exacerbations. The same can be said for the treatment of respiratory failure or acute cardiogenic pulmonary edema, as well as in numerous causes of acute respiratory failure, both hypoxemic and hypercapnic, including post-extubation treatment of ICU patients or palliative therapies in patients who do not undergo endotracheal intubation. The most recent clinical guidelines postulates attempting NIV before invasive ventilation whenever the clinical situation allows it (it should never delay an indicated intubation) [1].

Any discussion concerning the location of an NIV unit should be based on the peculiar characteristics of each hospital. Emergency departments, intensive care, intermediate care, respiratory care, or conventional hospitalization wards vary in their composition, characteristics, or their very existence from one center to another, even at similar levels of care complexity, so extrapolating the results of one or another study to our usual reality should be done with a certain degree of caution.

Since the early 2000s, there have been studies on the needs and location of respiratory care in patients requiring NIV outside their initial intensive care setting [2]. When considering the organization of this care in a conventional hospital ward, it is necessary to consider the characteristics of the hospital in which it is to be performed. A tertiary-level hospital with the physical presence of all the specialties is not the same as a lower-level hospital where the common and most important nexus when planning respiratory care is the existence of a system of continuous care that lacks some medical specialties and often lacks ICUs, with such care being grouped in a single group of physicians from different specialties of the health center to which are added to a greater or lesser extent other physicians contracted exclusively

for such continuous care. This reality is also condemned to its perpetuation by economic criteria and staff size. This reality, which is common in most regional hospitals, is what we refer to in this chapter when talking about internal medicine wards.

HFNC lacks relevant studies on its management in conventional wards; however, the greater simplicity of the device, its better tolerance, and the lower nursing workload in terms of specific care of the technique make this a promising option at least for initial episodes or in milder cases. The current COVID-19 pandemic has served to increase its awareness and, in the context of the lack of intensive care beds, there are several published experiences in unmonitored medical wards [3, 4].

To establish noninvasive ventilation therapies in a conventional hospital ward, we consider that several requirements are necessary:

1. Selection of the type of patients, both the pathology to be treated and the characteristics of these patients, including the point of limitation of therapeutic effort and the moment of referral to other units.
2. A single space for these patients within the same ward.
3. Determine monitoring needs.
4. Staffing needs based on the maximum number of therapies that can be administered simultaneously and 24 h a day, and the need for minimum training and knowledge.
5. Equipment needs and characteristics.
6. Elaboration of protocols for each of these aspects to standardize the activity at any time of the day.

Patient Selection

First, we must select those pathologies and patients with the best response to NIV techniques and, especially, those cases where the indication for transfer to the ICU is not assessed or making it noticeably clear when this will take place, for which it is necessary to protocolize these aspects with the reference ICU. Most studies on the success or failure of ventilations have been done in COPD exacerbations, establishing criteria for the probability of success or failure of NIV [5].

Among the potentially subsidiary pathologies to initiate therapy in the medical ward, we could recommend:

Decompensated COPD with pH less than 7.35 but greater than 7.25–7.30, conscious and without other important comorbidities.

Heart failure with criteria for respiratory failure of non-ischemic or non-valvular cause (tachyarrhythmia, decompensation of chronic heart failure) [6].

All potential indications for NIV or CPAP in patients who are not candidates for admission to the ICU (due to age criteria or accompanying pathologies) [7].

As we have mentioned, most studies refer to COPD exacerbation, and among them, some present results in general hospital wards, but always depending on the experience of the medical and nursing staff. Even tables of risk of NIV failure are established [5] based on parameters at the beginning and 2 h after initiation of NIV, in

general, patients with a level of consciousness above 11 on the Glasgow Consciousness Scale (GCS), pH greater than 7.30, respiratory frequency less than 35/min and level of severity measured by the APACHE II scale <29 are established as the safest group to manage on the ward; globally, the pH value is the best related to the need for intubation. Patients with pH <7.25 and especially with low level of consciousness (GCS < 11) or APACHE greater than 29 should be managed in ICU if they are candidates, the rest will be managed based on experience and availability of resources (intermediate care or conventional ward beds). More recent studies manage the exacerbation of COPD patients in conventional wards with Ph above 7.16 [8].

Experience with HFNC is much less, but by extension, it would be developed as a previous or complementary step to NIV. Initially, it emerged for the treatment of hypoxemic respiratory failure, starting as an alternative to NIV in case of intolerance to it in the immediate treatment of respiratory distress (respiratory rate > 25/mn and saturation < 90%) and in heart failure [6], but good experience is turning this technique into the first alternative for ventilatory support treatment in the centers that have it. In the rest of the pathologies, there is less experience in its use outside the ward, but we always count on those who are not candidates for ICU, and based on experiences accumulated during the current pandemic [3, 4] using scales of response to treatment such as the ROX index [9], we can include patients who are candidates for ICU by early detection of the failure of the technique to refer them to intensive care. In the case of COPD, it is still restricted to NIV breaks, weaning, or intolerance of the patients we are managing on the ward.

There are multiple published experiences with NIV management on conventional floors [10]. In a survey carried out in 2015 in units of different countries, 60% of the centers performed NIV in conventional floors, and the conclusion was that this activity was in clear progression [11]. However, other works of the same time decreased this percentage to 20% of NIV [12]. Probably the recent pandemic has contributed to a better knowledge and generalization of NIV and especially of HFNC which has been developed in most medical floors due to the precariousness of intensive care beds.

Location

Early studies have already established the need for a unique location within the hospital, to facilitate the training of the same nursing staff who would be more accustomed to handling these patients and devices [2].

Patients with NIV established in the ED and who are to be admitted, or who are admitted to another hospital ward and who are considered candidates for NIV without being transferred to the ICU, should be admitted or, if necessary, transferred to an area on a single floor, where all the noninvasive ventilatory therapies will be concentrated. Preference should be given to the floor where respiratory patients are usually admitted, and they should be located as close as possible to the nursing control.

There should be a protocol for action if the floor is full; this may include exchanging patients with other floors, transferring to them those without noninvasive therapy, and exchanging them for those who require it.

The maximum number of simultaneous treatments should also be specified, given that it is recommended that the same nurse should not carry more than four patients with NIV at least at the beginning of the technique and what to do if they are all in operation and some more are needed (referral to another center, collaboration with other services—emergency department) [2].

Equipment and consumables should be stored in a single area, preferably on the same floor where these patients are admitted.

Monitoring

Monitoring may vary according to resources; ideally, continuous noninvasive monitoring of electrocardiographic recording and oxygen saturation with frequently programmed blood pressure would be required, although some expert recommendations consider saturation and continuous echocardiography to be essential [13]. In practice, there are studies with all viable options. The minimum is a continuous or very frequent recording of saturation and heart rate during the first 2 h and an hourly blood pressure measurement also during the first hours. Monitoring should be adapted to the type of patient rather than to the technique; it is not the same to monitor a patient with limited therapeutic effort as a potential candidate for invasive measures in whom the diagnosis of failure of the technique should be made without delay to move on to the next phase.

It is desirable to prepare a form that records the agreed data at the established frequency, including at least respiratory rate, pulse oximetry saturation, heart rate, and blood pressure together with ventilatory mode (NIV or HFCN, device parameters, and FiO_2).

The combination of clinical and blood gas data at the beginning and after the first few hours of ventilation allows us to calculate the probability of success or failure of NIV to anticipate this and assess the patient's transfer if intubation is imminent [5]. In the case of high-flow oxygen therapy, there are validated indexes that combine different parameters of the constants and are associated with the risk of failure or success of therapy such as the ROX index based on saturation, respiratory rate, and FiO2 [9] .

Monitoring should include visual surveillance of the patient; this is difficult in conventional wards, with separate rooms and outside the visual control of nursing. In our case, we have made up for this deficit with the installation of video surveillance cameras connected to a central monitor installed in the nursing control room. This monitoring is not expensive and adds a considerable plus of safety in the management of these techniques in these patients.

Staff

We recommend no more than four noninvasive therapy patients per nurse, these ratios are described in intermediate care units with patients with other needs and more complex, but the care is the same so we continue to recommend no more than four patients per nurse regardless of being able to take on more patients with normal characteristics of the floor. In our experience, it is good to establish policies of reinforcement of nursing staff for these situations [2, 14].

Both medical and nursing staff need to be familiar with the fundamentals of NIV, the handling of devices and interfaces, and the solution of the usual problems of this technique. Such personnel must be present and available 24 h a day, every day. Given that most hospitals have pooled on-call personnel of various specialties and with different degrees of knowledge of NIV, it is necessary to establish a strategy for training personnel [2] or support teams [15].

It is advisable to create an "NIV team" in the morning hours that will oversee controlling the indications and management as well as the time to discontinue the technique in a regulated manner. It will be made up of personnel with experience in the management of NIV and will also be responsible for the maintenance and care of the equipment, assessing the need for consumables, establishing training needs and organizing training activities, collaborating at all times with the physicians responsible for the patients when they are not part of the team (e.g., heart failure can be assessed by their cardiologist or internist and, simultaneously, their NIV or HFCN can be assessed by the team created for this purpose). In some centers, similar teams have been described but in 24-h presence supporting the rest of the on-call team (anesthesia, emergency, ICU) [16]. The team will also oversee elaborating and updating protocols for the practical management of the ventilator and NIV.

If ICUs exist, the possibility of requesting their help in case of need should be agreed upon, even in the case of patients who cannot be referred to the ICU.

As in all unstable patients, it is necessary to establish continuity of care throughout the 24 h, structuring changes in medical and nursing shifts, by both oral and written.

Programming with ventilation or high-flow parameters will be done as nonpharmacological medical orders and it is advisable to create a standard form that includes both modes (CPAP, PS, HFCN), starting parameters, and subsequent progression.

Periodic refresher training will be scheduled for the regular staff of that floor, and the previous training needs to access it will be defined, so that there will always be staff with sufficient knowledge for the management of these patients (create a profile as that created for other specific units such as ICU or emergency).

Equipment

As far as possible, priority will be given to simplicity in the choice of equipment, as well as uniformity (i.e., we will try to have a single model of equipment and consumables). The objective is to avoid confusion since we are talking about staff and knowledge variability.

The ventilators should be simple and intuitive, we only need CPAP and PS with the possibility of a time-cycled mode for rescue ventilations (ST) for our patients. At least initially, it is not essential that they have flow or pressure curve graphs. Touch systems and large screens are preferable, and it is necessary to know the locking and unlocking systems of the device. Whether the device is for home use or only for hospital use does not seem to be important, despite some expert recommendations that advise against home use ventilators except for patients who have already used them previously; in our experience, this is not the case and, in addition, almost all ventilators have a clinical or home use mode; as long as they meet the other requirements, the use for which they are designed is irrelevant [13].

Full face oronasal or full face masks [13] with safety systems should preferably be used. We will avoid having masks with expiratory leakage simultaneously with masks without leakage, or tubing with leakage coinciding with those with leakage to avoid errors and to avoid coupling one with the other erroneously. The latest recommendations after the current pandemic recommend handling these acute patients and suspicion of infectious process, with masks without leak, intercalating an antiviral filter between mask and leak (placed this one in the tubing) or at the exit of the mentioned leak [14]. There are no differentiated experiences with one or other masks outside specific units, but it seems common sense to use masks easy to remove by the patient in case of vomiting or complications (that is why we do not recommend more complex models such as helmet type).

It would be desirable to extend this uniformity, at least of consumables, to the whole hospital, so that the patient coming from other wards or from the emergency room only needs a change of device (or not even that) and the same if the patient needs to be transferred from the ward to the ICU.

In the case of high-flow equipment, although the variability of equipment and consumables is less, it also exists, so we must establish the same strategy of single models of devices and equipment.

It is important that ventilators or HFCN equipment have an external battery that allows them to operate without connection to an electrical outlet for a period, to facilitate transfers both between services and to perform complementary studies or to avoid problems with variations in electrical supply.

Protocol

The basis for the success of noninvasive respiratory therapy in a general ward is the development of protocols that standardize the attitude of all those involved in the management of these patients (Fig. 24.1).

The protocol should include all the above aspects and be accompanied by initial guidelines for the prescription of NIV and HFCN.

First, it should describe the type of patient who is a candidate for ward therapy, both the underlying pathology and the exclusion criteria (e.g., patients with adult respiratory distress should be excluded, except for patients who are not candidates for intubation).

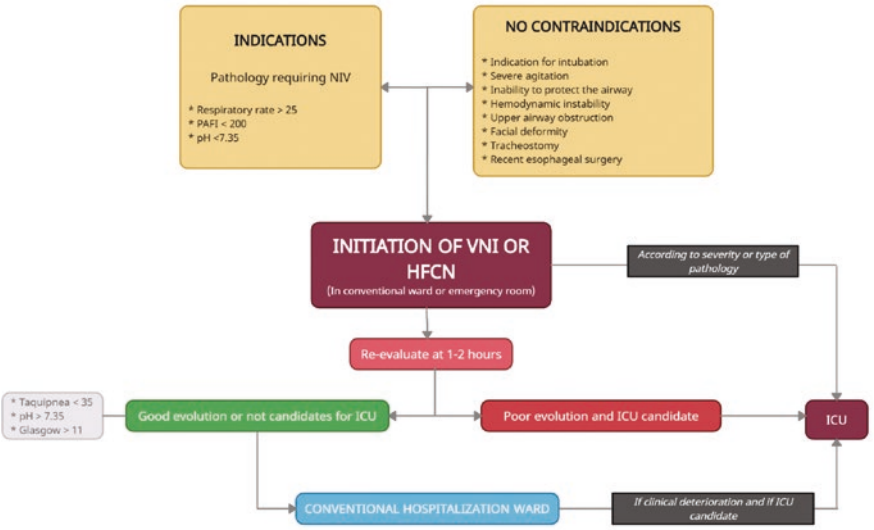

Fig. 21.1 NIV/HFCN management algorithm in conventional Internal Medicine inpatient ward

The place of admission will be shown and will consider all the cases of location, including the figure of the person who should solve those problems that deviate from the aforementioned protocol.

The functions of all the personnel should be clear: who indicates and prescribes, who makes the changes, who decides the monitoring, who conducts the assembly, the nursing care (change of lines, revision of bedsores), who is in charge of the removal and who is in charge of the cleaning. It will also reflect the person in charge of maintenance (schedule revisions, check operation) and warehouse control.

A manual for the handling of equipment, location, and assembly of interfaces, which will be deposited next to the ventilators, must be included.

Criteria and parameters for starting the technique and periodic adjustments as well as the attitude with the most frequent problems will be elaborated.

The protocol will also include the vital signs and analytics to be monitored and will establish how they will be reflected in the clinical history as well as the times and alarm signs.

It is especially important to make clear the criteria and the attitude in case of failure of the technique.

A strategy should be agreed with the ICU (of the hospital itself or the reference hospital) which should include an initial assessment of the possibility of intubation and connection to mechanical ventilation or limitation of therapeutic effort in case of deterioration (Fig. 21.1).

Conclusion

NIV and HFCN are increasingly used in patients with acute respiratory failure. Their use has been progressively extending, becoming a common resource in conventional hospitalization wards. For proper management of NIV and HFCN in conventional hospital wards, it is necessary to correctly identify the patients who can benefit the most from this therapy.

It is essential to define the location within the hospital as well as the monitoring and staffing needs. Multidisciplinary collaboration and the active participation of the nursing staff are essential for optimal development of NIV and HFCN therapy in the conventional hospitalization ward. To protocol each of the key aspects of NIV and HFCN therapy performance on the conventional ward promotes uniformity of therapy and predicts its success.

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Noninvasive Mechanical Ventilation in the Perioperative Unit

22

Ozlem Korkmaz Dilmen and Eren Fatma Akcil

Abstract

Noninvasive mechanical ventilation (NIV) is used to prevent or treat respiratory complications in the perioperative setting. NIV can be used during the induction of anesthesia to reduce the risk of hypoxemia, especially in patients with high metabolic demands such as sepsis or decreased lung volumes and lower functional residual capacities such as pregnancy and obesity as well as lung diseases. There are limited data in intraoperative use of NIV. Postoperative application of NIV prevents and treats postoperative pulmonary complications, especially in patients following abdominal, cardiac, and lung resection surgery.

Keywords

Continuous positive airway pressure · High-flow oxygen therapy · Lung functions · Noninvasive positive pressure ventilation · Perioperative medicine

Noninvasive mechanical ventilation (NIV) is used to prevent or treat respiratory complications in the perioperative setting. NIV can be used during the induction of anesthesia to reduce the risk of hypoxemia and intraoperative period as well as at the postoperative period to prevent and treat the postoperative pulmonary complications (PPCs).

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Noninvasive Respiratory Support Techniques

Noninvasive respiratory support techniques are high-flow oxygen therapy (HFOT), continuous positive airway pressure (CPAP), and noninvasive positive pressure ventilation (PSV). Interfaces are used in NIV. HFOT is performed by nasal cannula; nasal, facial mask, or helmet is used for gas delivery in CPAP and PSV. An interface that fits properly is crucial in minimizing air leaks.

HFOT is a simple system that has an air-oxygen blender connected to a flowmeter. The gas mixture is routed to a heated humidifier delivering gas conditioned at 37 °C and completely saturated with water. The physiologic effect of HFOT includes delivery of high friction of inspired oxygen (FiO_2), Positive End Expiratory Pressure (PEEP) effect, and continuous wash out of dead space flushing out CO_2 [1]. Positive pressure effect is markedly reduced when the patient opens his or her mouth. High humidity reduces the risk of epithelial cell injury and inflammation. Acute hypoxemic respiratory failure is characterized by acute hypoxemia, high respiratory rate in patients without chronic lung disease, without cardiogenic pulmonary edema and hypercapnia. HFOT is the first treatment choice in acute hypoxemic respiratory failure.

CPAP delivers constant positive airway pressure during both inspiration and expiration, therefore preventing atelectasis, and maintaining functional residual capacity (FRC). When CPAP is applied with positive inspiratory pressure, it is called PEEP. During PSV the patient's spontaneous inspiratory effort triggers inspiration once the selected airway pressure is achieved [2]. When applying PSV start with PEEP alone and then slowly increase the PSV levels to achieve a 6–10 mL/kg expiratory tidal volume, a decrease in patient's respiratory rate. The PEEP is started at 3–5 cmH_2O and increased to improve oxygenation [3]. PSV as compared with CPAP provides better physiologic response and dyspnea relief and increased oxygenation. NIV is applied at 2–4 h intervals depending on patient's clinical condition.

Absolute contraindications for the use of postoperative noninvasive ventilation are cardiac or respiratory arrest, multiple organ failure, severe agitation or encephalopathy, copious secretions, uncontrolled vomiting, inability to protect airway, severe upper gastrointestinal bleeding, facial trauma, hemodynamic instability, and unstable cardiac arrhythmia. Relative contraindications are mildly decreased level of consciousness, progressive severe respiratory failure, and uncooperative patient [3].

Use of Noninvasive Mechanical Ventilation During Induction of Anesthesia

The pathophysiology of the general anesthesia-induced atelectasis is resorption of gases, compression of alveoli, and surfactant dysfunction. Using high FiO_2 at the induction and maintenance of anesthesia results in a decrease in nitrogen concentration in alveoli and resulting in atelectasis. Therefore, we generally avoid the use of

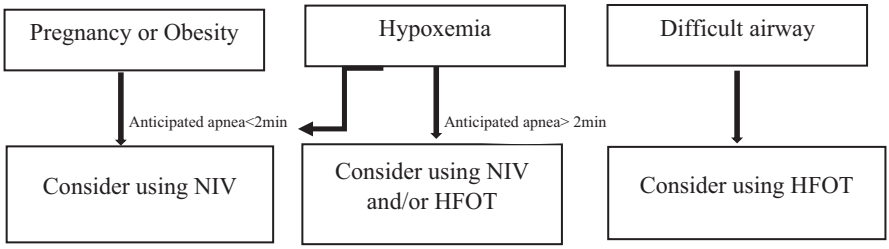

Fig. 22.1 Decision support flow chart for the use of noninvasive ventilation in preoperative setting [4] Einav S, Lakbar I and Leone M. Non-invasive respiratory support for management of the perioperative patient: A narrative review. Advances in Therapy 2021;38:1746–1756

1.0 FiO_2 at the induction of anesthesia if there is no risk of difficult intubation. On the other hand, the apnea period of the endotracheal intubation cannot be tolerated in patients with high metabolic demand such as sepsis or decreased lung volumes and lower FRC such as pregnancy and obesity as well as lung diseases [4]. Those patients need high fraction of O_2 at the induction of anesthesia to prevent hypoxemia. Recent airway management guidelines suggest use of NIV at the induction of anesthesia particularly in patients with difficult intubation and obesity [5]. Patients with full stomach or gastroparesis need rapid sequence induction of anesthesia to prevent aspiration of gastric content during endotracheal intubation. HFOT administration during rapid sequence induction reduces the risk of hypoxemia. NIV or HFOT administration is also advised in patients with preoperative hypoxemia during induction of anesthesia. Figure 22.1 shows a decision support flow chart for the use of noninvasive ventilation in a preoperative setting [4].

Intraoperative Use of Noninvasive Mechanical Ventilation

Intraoperative use of NIV has not been widely evaluated in medical literature. It is used during deep sedation in patients with no preexisting lung disease to prevent sedation-induced hypoventilation. The surgical procedures are included lower extremity surgery, hernia repair, lower abdominal and gynecological surgeries, and craniotomies under regional anesthesia or neuro-axial blocks. Upper airway obstruction may occur under deep sedation during intraoperative NIV administration. Placement of oropharyngeal or nasal airways as well as rise in PEEP up to 10 cmH_2O can resolve this problem. CPAP application may cause worsening hypoventilation in some cases. Changing the respiratory support from CPAP to BiPAP can improve ventilation [6, 7].

There are also some case reports that describe using NIV during caesarian delivery in pregnant women with respiratory failure [8]. They reported that one of those cases developed pneumonia and died after 10 days of surgery.

Postoperative Use of Noninvasive Mechanical Ventilation

Postoperative Pulmonary Complications

PPCs are an important cause of postoperative mortality and morbidity. Respiratory failure, atelectasis, hypoxemia, pneumonia, bronchospasm, and acute respiratory distress syndrome are types of PPCs [9]. The incidence of PPC ranges from 5 to 25% and cardiac surgery has the higher occurrence followed by thoracic, abdominal, and vascular surgery [9]. If the surgery site is close to the diaphragm, it increases the risk of postoperative diaphragm dysfunction and PPCs. The main reason for the PPCs is development of atelectasis [10].

Several clinical risk factors facilitate to development of perioperative atelectasis [11]:

1. Obesity-induced rise in abdominal and thoracic adipose tissue causes restriction of the chest wall and cephalad placement of the diaphragm reduces lung compliance and FRC. These pathophysiological changes result in higher risk of perioperative atelectasis development in obese than non-obese patients.
2. Intra-abdominal hypertension and pregnancy increase the risk of atelectasis by reduction in FRC and increase in pleural pressure, particularly after induction of anesthesia by loss of diaphragmatic tone.
3. Closing capacity exceeds FRC by aging that facilitates development of pulmonary atelectasis.
4. Pulmonary inflammation, edema, Chronic Obstructive Pulmonary Disease (COPD), and smoking are other pulmonary risk factors that increase the risk of atelectasis.
5. Inhaled and intravenous anesthetics except ketamine reduce the diaphragm and chest wall muscle tone, and are associated with intraoperative pulmonary atelectasis. Postoperative residual neuromuscular block is a principal factor that may facilitate PPCs. Although postoperative pain leads to modifications of respiratory functions, high-dose opioid administration may facilitate PPCs. Multimodal pain treatment is important to improve respiratory functions.
6. Laparoscopic surgeries, and cardiac and thoracic surgeries have higher risk for PPCs. Besides the type of surgery, the patient's position during surgery increases the risk of atelectasis. The Trendelenburg position, prone, and lateral decubitus positions increase the lung compression and reduce FRC.

Role of Noninvasive Ventilation in the Prevention and Treatment of Postoperative Pulmonary Complications

Maintenance of adequate oxygenation and prevention of hypoventilation in the postoperative period is of major importance when PPCs occur. Several studies showed that mortality associated with pulmonary problems is largely associated with the complications of reintubation and mechanical ventilation-induced lung

injury [3]. Noninvasive ventilation reduces work of breathing, improves alveolar ventilation, reduces left ventricular afterload with an increase of cardiac output, and reduces atelectasis. However, noninvasive ventilation should be administered only when it represents an effective treatment and not only a delay to an unavoidable intubation [10].

PSV is the first-line treatment for chronic obstructive respiratory disease patients and acute cardiogenic pulmonary edema. PSV and CPAP improve oxygenation, especially in obese patients in the postoperative period [12].

The European Society of Anesthesiology (ESA) and the European Society of Intensive Care Medicine (ESICM) have developed guidelines for the use of noninvasive respiratory support techniques in hypoxemic patients in perioperative period [13]. In the perioperative hypoxemic patient, use of PSV or CPAP is preferred to continuous oxygen therapy (COT) to improve oxygenation (Grade 1B). PSV is recommended rather than CPAP to reduce the risk of atelectasis (Grade 2C). After upper abdominal surgery, CPAP or PSV is recommended rather than COT to reduce the risk of hospital-acquired pneumonia (Grade 2A) and to prevent reintubation (Grade 2B) as well as to reduce mortality (Grade 2C). PSV or CPAP is recommended immediately for post-extubation for hypoxemic patients at risk of developing acute respiratory failure after abdominal surgery (Grade 1B). Either PSV or CPAP may be considered for prevention of further respiratory deterioration in hypoxemic patients after cardiac surgery (Grade 2B). HFOT may be considered for hypoxic patients after cardiac surgery (Grade 2C). PSV may be considered for prevention of atelectasis in hypoxemic patients after lung resection and solid organ transplantation (Grade 2C). They suggest using HFOT rather than COT in postoperative hypoxemic patients with low tolerance to other forms of NIV (Grade 2B).

Conclusion

NIV can be used during the induction of anesthesia to reduce to risk of hypoxemia, especially in patients with high metabolic demand such as sepsis or decreased lung volumes and lower FRCs such as pregnancy and obesity as well as lung diseases. There are limited data on intraoperative use of NIV. Postoperative application of NIV prevents and treats the PPCs, especially in patients following abdominal, cardiac, and lung resection surgery.

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Noninvasive Mechanical Ventilation in the Endoscopic Wards

23

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Abstract

Endoscopic procedures, such as airway, cardiovascular, and gastrointestinal procedures are the minimal invasive diagnostic and therapeutic approaches in expansion. These procedures often require sedation to ensure patient compliance and consequent success of procedure. However, they are associated with desaturation and hypoventilation, especially in patients with low pulmonary and cardiovascular reserve. Noninvasive Mechanical Ventilation (NIMV) is a safe procedure that provides ventilatory support, allowing endoscopic examinations, but avoiding the complications of Invasive Mechanical Ventilation (IMV). It requires a trained team and an environment capable of cardiopulmonary resuscitation. In recent years, interfaces have emerged that allow the insertion of endoscopic probes, with less air leak, ensuring adequate ventilatory support during the procedure. Currently, the effectiveness of using NIMV as ventilatory support in flexible bronchoscopy is supported by prospective studies and clinical trials. Although in widespread use, its use in cardiological and gastrointestinal endoscope procedures is only supported by observation studies. This type of approach may expand in the future, due to the possibility of reducing costs and complications.

Keywords

Noninvasive mechanical ventilation · Endoscopic procedures · Bronchoscopy · Transesophageal echocardiography · Esophagogastroduodenoscopy

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Introduction

Endoscopic airway, cardiac, and gastrointestinal tract procedures are performed with a diagnostic and therapeutic objective. The indications are expanding in different clinical contexts as they represent less invasive approaches compared to the surgical approach.

These procedures do not require any sedation; however, the patient's full cooperation is necessary to allow the procedure to be performed successfully and avoid possible serious complications such as vascular, gastrointestinal, and airway perforation [1]. To ensure proper collaboration and procedure success, many procedures are performed using intravenous sedation with spontaneous breathing to avoid the need for general anesthesia [1]. Sedation is associated with respiratory depression, hypoxemia, and/or hypercapnia, especially as the dose is increased, which may compromise the performance of the procedure or even lead to the necessity for ventilatory support [2, 3]. It is especially critical in patients with reduced respiratory physiological reserve [1].

Noninvasive Mechanical Ventilation (NIMV) can avoid the complications of Invasive Mechanical Ventilation (IMV), ensuring a similar degree of effectiveness in different conditions, so its use during endoscope procedures is particularly interesting [2]. Currently, it has been used as a strategy for ventilatory support and prevention of respiratory failure related to endoscopic procedures in high-risk patients [1, 4]. However, there is no evidence regarding optimal pressure settings and interface choice.

Clinical Use

NIMV can be used in different ways in patients undergoing an endoscope procedure, namely: (1) Before the procedure in order to ventilate and pre-oxygenate the patient, increasing respiratory reserve and avoiding consequences during the procedure; (2) During the procedure to prevent or treat hypoventilation and hypoxia; (3) After the procedure to improve the patient's recovery [2].

Environment and Monitoring

It is recommended that the procedure be performed in an intensive care unit, intermediate respiratory unit, or in a procedure room capable of dealing with any complications [5, 6]. It should be performed in an environment with trained personnel and equipment available for urgent endotracheal intubation. An experienced clinician should perform endoscope procedures to reduce the duration of the procedure [4].

Standard monitoring of sedated patients during NIMV for endoscopic procedures includes continuous electrocardiogram, noninvasive blood pressure measurement, pulse oximetry (SpO_2), and capnography when available [2]. In particular,

monitoring of SpO_2, capnography, and qualitative clinical signs, such as respiratory rate and thoracic excursion, may be useful for optimizing NIMV during the procedure [4].

Adaptation and Support Modality

Adaptation to NIMV is recommended within a period of 15–20 min before the endoscopic procedure [6]. Regarding ventilation modes, there are no published articles comparing the different methods. The most used is the Bi-Level Positive Airway Pressure (BiPAP) Ventilation. Expiratory Positive Airway Pressure (EPAP) and Inspiratory Positive Airway Pressure (IPAP) levels should be individualized and screened over a period, it is recommended to start IPAP 14–15 cmH2O and EPAP 5 cmH_2O. The target expiratory tidal volume (Vt) is between 8–10 mL/kg and the respiratory rate is below 25/min. Pressure titration is performed based on SpO_2, capnography, and respiratory distress. If hypoxemia, EPAP should be increased by 2 cmH_2O until reaching $SpO_2 \geq 90\%$. However, extremely high values (above 10 cmH_2O) may cause a greater risk of gastric distention and patient intolerance. If hypoxemia persists, Fraction of Inspired Oxygen (FiO_2) should be increased. If hypercapnia, the IPAP should be increased (maximum 25 cmH_2O) and the EPAP adjusted to avoid rebreathing. Signs of maladjustment include accessory muscle contraction, active expiration, failed inspiration, and low Vt [6].

FiO_2 should be increased to 100% immediately before the procedure and titrated to $SpO_2 > 95\%$ [4].

After the end of the procedure, NIMV should be maintained for 15–90 min with similar parameters [6].

If failure of NIMV develops, despite optimization of ventilatory parameters, the procedure should be discontinued immediately. If it persists or is severe after interruption of the procedure, endotracheal intubation and IMV should be performed [1].

Interface

The NIMV interfaces suitable for ventilation during the endoscopic procedure must ensure a closed system to provide positive pressure ventilation and, simultaneously, provide a place for the insertion of an endoscopic probe during the procedure [4].

Devices Coupled to Traditional Masks

Currently, there are devices that can be placed between a traditional interface and ventilator tubing that allow the introduction of endoscopic probes, such as the T-piece and elbow connector (Fig. 23.1a). Due to the large diameter of transesophageal echocardiogram probes, commercially available elbows cannot be used in Transesophageal Echocardiography (TEE) [1, 2].

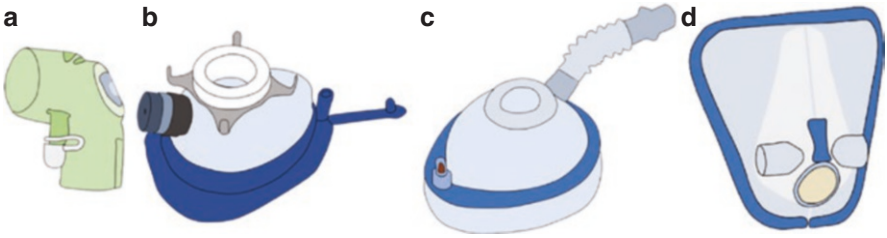

Fig. 23.1 NIMV interfaces/devices suitable for ventilation during the endoscopic procedure. (**a**) Elbow connector which allows the introduction of endoscopic probes. (**b**) *Patil-Syracuse Mask.* (**c**) *Endoscopy Mask (VBM Medizintechnik GmbH,* Germany*).* (**d**) *Janus Mask (Biomedical Srl,* Italy*)*

Maitre et al developed another strategy, using a facemask connected to a disposable continuous positive airway pressure (Boussignac-CPAP), having been evaluated in flexible bronchoscopy [12]. However, it only allows ventilation in CPAP mode [6].

Nasal Mask

The use of a nasal mask does not interfere with endoscopic tube insertion and handling of the procedure through the mouth. The major disadvantage of these devices is the difficulty in providing Positive End-Expiratory Pressure (PEEP) and support pressure, due to air leak through the mouthpiece [2, 4].

Chiner et al created a handmade system, using a membrane made of a latex glove attached to the mouthpiece with a small incision to insert the endoscopic probe through the mouth, preventing air leak [6].

Helmet

In 2003, Antonelli et al. described the use of helmet in flexible bronchoscopy. The endoscopic probe can be introduced through the larger airtight port for nasogastric tube, using tracheostomy foam dressing around the probe that crossed the helmet to prevent air leakage5. A hand enters the helmet through the patient inspection port to help positioning the probe. Once the probe was positioned correctly, the inspection port was closed [1, 2, 6].

Patil-Syracuse Mask

Currently, there are NIMV masks available that allow the insertion of an endoscopic probe [2]. The first mask available on the market was the Patil-Syracuse Mask, which has an additional port with a silicone membrane that allows the introduction of endoscopic probes (Fig. 23.1b) [1, 2].

Endoscopy Mask (VBM Medizintechnik GmbH, Germany)

The endoscopy mask is a face mask with a silicone membrane with a 5 mm hole that allows the introduction of endoscopic probes, having an independent channel to connect to ventilator tubing (Fig. 23.1c) [2].

Janus Mask (Biomedical Srl, Italy)

The Janus Mask is a full-face mask that has a hole covered by a membrane in front of the patient's mouth that allows the insertion of the endoscopic probe (Fig. 23.1d) [6]. The mask is made of two halves, so it can be placed on the patient's face during the procedure if the patient needs NIMV support, so it can be considered for elective or urgent procedures. It has the advantage of allowing flexible bronchoscopy intubation in patients with difficult airways scenario [2].

Airway Procedures

The risk of complications associated with flexible bronchoscopy in patients without comorbidity is low. However, patients with hypoxemia and/or hypercapnia are at risk of complications during and after bronchoscopy, particularly when this procedure is combined with bronchoalveolar lavage (BAL) [7]. The introduction of the bronchoscope occupies about 10% of the tracheal lumen, increasing airway resistance and, consequently, breathing effort. In addition, aspiration promotes alveolar collapse, as it reduces airway pressure at the end of expiration. BAL further exacerbates the collapse as it removes the surfactant. This causes the arterial oxygen pressure (PaO2) to decrease by 10–20 mmHg during the procedure. Due to the loss of surfactant, the pulmonary shunt can last up to 12–24 h after lavage. On the other hand, in patients with obstructive pathology, bronchoscopy can promote air trapping, increasing functional residual capacity up to 17% and auto-PEEP [6].

NIMV performs alveolar recruitment through the application of PEEP and reduces the breathing effort through the application of inspiratory support [7]. It is recommended to maintain NIMV at least 30 min after finishing the procedure to maintain alveolar recruitment [6].

The use of NIMV is supported by observational studies and randomized clinical trials, showing benefit in preventing hypoxia during and after bronchoscopy, when compared with High-Flow Nasal Cannula (HFNC) and conventional oxygen [2, 7]. Therefore, the patients who benefit most from NIMV during bronchoscopy are hypoxemic patients ($PaO_2/FiO_2 < 200$ mmHg) [7].

Some authors do not recommend performing transbronchial biopsies while undergoing NIMV due to the higher risk of pneumothorax and hemorrhage [6].

The use of periprocedural NIMV is also useful in the context of predicted or unpredicted difficult airway. It can be used in patients under sedation before

intubation by flexible bronchoscopy for pre-oxygenation and during the procedure until intubation, using a *Janus Mask* [2].

The use of NIMV in Endobronchial Ultrasound (EBUS) is promising, but so far there are no prospective studies that demonstrate its advantage.

Cardiovascular Procedures

The evidence on the use of NIMV for evaluation by TEE is limited to case reports [8–12]. It has been used in patients with reduced cardiovascular reserve in several interventional cardiovascular procedures requiring sedation and prolonged TEE, namely in transaortic valve implantation, MitraClip procedures, and left atrium appendage closure.

Gastrointestinal Procedures

Observational studies suggest benefit of using NIMV in high-risk patients during diagnostic or therapeutic endoscopic gastroenterology procedures, including esophagogastroduodenoscopy, Endoscopic Retrograde Cholangiopancreatography (ERCP), and Percutaneous Endoscopy Gastrostomy (PEG). These types of prolonged procedures, requiring sedation, increase the risk of pulmonary complications in patients with respiratory muscle weakness, Chronic Obstructive Pulmonary Disease (COPD), obesity, and heart failure, and therefore, it can be considered in these patients [1–4].

Complications and Disadvantages

Although scientific evidence supports the use of NIMV during endoscope procedures, this approach is not entirely effective or without complications. The most common cause of NIMV failure with potential need for endotracheal intubation and IMV is respiratory failure, patient intolerance with agitation/delirium, claustrophobia, and facial lesions [2, 3]. On the other hand, this strategy does not protect the airway, presenting a higher risk of aspiration and coughing, with consequent risk of injury during the procedure [1, 2].

It is also postulated that NIMV, through the inspiratory flow with positive pressures can cause gastric distention, increasing the risk of aspiration. The increased abdominal pressure generated by gastric distention can reduce the functional residual capacity and increase the breathing effort [1, 6].

Conclusion

NIMV is a safe and effective therapy that provides ventilatory support, allowing endoscopic examination, and avoiding the complications of IMV. It can be used as a strategy to prevent respiratory failure related before, during, and after endoscopic procedures in high-risk patients.

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Noninvasive Ventilation in Gastroenterology Unit

24

José Luis Sandoval Gutiérrez

Abstract

Noninvasive ventilation has ventured into other fields of medicine, and has had a great participation in diagnostic procedures in different systems and devices of the human body. Recently, the support it has had within the gastric system has been promoted, and it is important to review the future probable indications for this ventilatory modality.

Keywords

Noninvasive ventilation · Endoscopy · Gastroenterology · Hypoxemic · Hypercapnic

Since the beginning of the use of noninvasive ventilation (NIV), this technique for the use of patients with hypoxemic respiratory failure mainly, later the benefits were demonstrated in hypercapnic patients, there was a contraindication decades ago, for its use in patients with gastroenterological problems due to the possibility of aerophagia with the use of the interface, for which reason patients with recent abdominal surgery, bariatric surgery and/or digestive tract bleeding were contraindicated, this has been relativized in recent years. NIV has had an important use in the development of upper and/or lower endoscopy, as well as its importance in fiberoptic

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bronchoscopy (FOB) [1]. There are publications that show evidence of the benefits of NIV in this modality [2].

Administering supplementary oxygen using a standard nasal cannula (SNC) is the current standard of care for most patients undergoing sedation for digestive endoscopy procedures. The highest oxygen flow SNC provided is 6 L/min, inspired oxygen concentration (FiO2) in the distal airways is no more than 40%, and the problem of this situation is the limits of oxygenation [3].

Aggressive procedures and frail patients are the conditions in which NIV could be indicated more. NIV use has been reported during FOB and bronchoalveolar lavage (BAL), gastroscopy, and transesophageal echocardiography (TEE).

Flexible endoscopy (FE) is a well-established gold standard tool for the direct visualization of dynamic anomalies in the aero-esophageal tract (AET).

FE is a common medical procedure often performed under deep sedation in patients breathing spontaneously. The use of sedation improves the quality of examination and patient comfort. Hypoxemia can occur in 26–85% of cases [4] (Table 24.1).

The combination of airway obstruction by the endoscope, anesthesia-induced upper airway collapse, and respiratory depression and lung compression because of intestinal gas insufflation. Endoscopies are commonly performed worldwide in a variety of settings. Upper endoscopies (UEs) require a probe to be introduced through the mouth or a nostril. The diagnostic and therapeutic relevance of UEs grows together with their complexity (Figs. 24.1 and 24.2).

Moreover, patients' demand for comfort while undergoing these examinations leads to the widespread use of sedatives. Unfortunately, sedation increases the risk of respiratory depression associated with hypoxemia and/or hypercapnia. Sedation also carries the risk of losing the patency of the upper airways, increasing the risk of acute respiratory failure (ARF) and aspiration pneumonia [5] Table 24.2.

High-risk patients are increasingly scheduled for UEs, both for diagnostic and treatment reasons. In fact, UEs are often considered a less dangerous, second-choice treatment for patients that are not fit for surgery.

Table 24.1 Indications of NIV in endoscopic procedures

Prepare the patient before the procedure
Prevent hypoventilation or hypoxemia during the procedure
Treat ARF during the procedure
Treat ARF after procedure

NIV noninvasive ventilation, *ARF* acute respiratory failure
Information based: *Cabrini L* et al, *Minerva Anestesiol. 2013 Jun;79(6):683–94. Epub 2013 Feb 18*

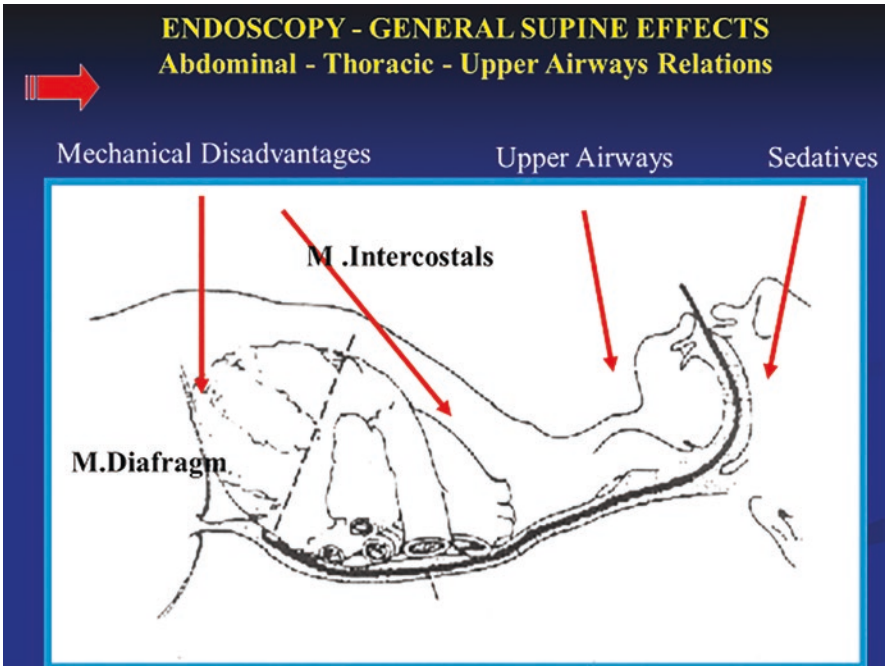

Fig. 24.1 Pathophysiology upper gastroendoscopy and relationships with respiratory compartments

The incidence of cardiac and/or respiratory complications in critically ill patients during UEs can be high [6] Table 24.3.

NIV has been evaluated as a tool to prevent or treat ARF in a wide range of settings, including outside the intensive care unit (ICU). Ventilatory support during UEs is challenging, as ventilation using traditional interfaces cannot be performed without removing the endoscopic probe.

An extremely high success rate was observed intra-procedurally during diverse types of UEs, even in patients at high risk of intraprocedural respiratory failure (hypoxemic) or sedated.

NIV is frequently applied in patients affected by amyotrophic lateral sclerosis (ALS) to support ventilation and avoid hypercapnia. Percutaneous endoscopic gastrostomy (PEG) is performed in ALS patients to avoid malnutrition and food aspiration/aspiration pneumonia.

High-flow nasal cannula (HFNC) oxygen is developed for noninvasive oxygen therapy system. It can provide heated and moist oxygen through the nasal cannula, as well as offer a much higher and predictable gas flow rate (up 60 L/min) and FiO2 (Up to 100%). HFNC could also reduce the risk of hypoxemia during sedated digestive endoscopy [7].

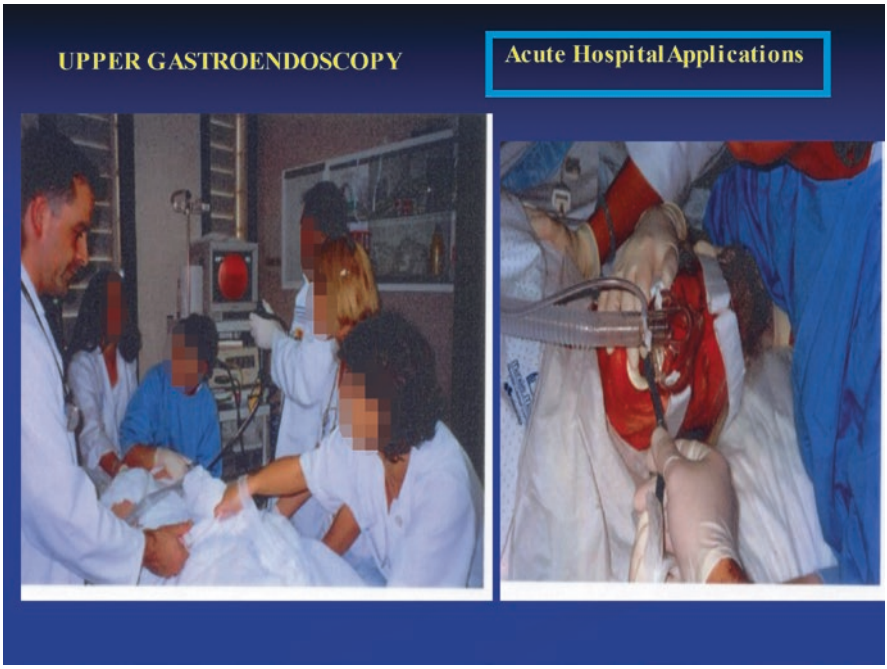

Fig. 24.2 Upper Gastroendoscopy procedure and noninvasive ventilation (courtesy Dr. Antonio Esquinas. ICU Hospital Morales Meseguer. Murcia. Spain)

Table 24.2 Risk of hypoxemia in patients in FE

Obstructive sleep apnea syndrome
>60 years
Obesity
Hypertension
Diabetes
Heart disease
High American Society of Anesthesiologist (ASA) physical status class

FE flexible endoscopy

Table 24.3 Contraindications of NIV in FE

Unprepared patient, with a full stomach
Imminent aspiration hazard
Severe hypercapnia with narcosis
Failure of technique to maintain or increase oxygenation
Impossibility to use interfaces: Naso-facial trauma, recent surgery in that anatomical area
Hemodynamic instability
Electrocardiographic instability
Impaired mental status
Refractory hypoxemia

NIV noninvasive ventilation, *FE* flexible endoscopy

Conclusions

NIV offers a great opportunity for respiratory control in patients undergoing different endoscopy modalities in the digestive system. Prospective studies are needed to observe the scope of this ventilatory mode.

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Noninvasive Ventilation in Weaning Centers. Organization

25

Giuseppe Fiorentino, Paolo Ruggeri, Anna Annunziata, and Antonio M. Esquinas

Abstract

Progresses in critical care have led to a growing number of frail patients who may access and benefit from critical care and who survive critical illness. There are an increasing number of patients with "chronic critical illness," in which life-sustaining organ support continues to be necessary after the resolution of the acute process. The imbalance between the increasing prevalence of patients with acutely decompensated respiratory disease and the shortage of ICU beds has stimulated new health solutions. Respiratory high-dependence care units (RHDCU) and specialized regional weaning centers (WC) are two health-care models with a high cost-effective profile. In this chapter, the authors reported the selection of patients that can be admitted to this unit, the specific role of these units in the health care system underlying the importance of a multidisciplinary team with specific training. A model of organization and location is proposed with a cost-efficacy profile. Finally, rethinking respiratory noninvasive support organizations outside ICU during pandemics is considered.

Keywords

Noninvasive ventilation · Prolonged mechanical ventilation · Artificial respiration · Ventilator weaning

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Introduction

Progresses in critical care have led to a growing number of frail patients who may access and benefit from critical care and who survive critical illness. Patients who necessitate prolonged invasive mechanical ventilation (IMV) (also via tracheostomy) use significant intensive care unit (ICU) resources, and many die in hospital. Weaning failure may also happen in any patient who survives a prolonged period of severe multi-organ failure, and weaning success is associated with the number of comorbidities [1]. Difficulties are more likely in patients with chronic disorders that affect breathing, such as chronic obstructive pulmonary disease (COPD) and restrictive or neuromuscular disorders (NMDs). For example, critical care-related neuropathy and muscle weakness are usual in such conditions and may provide to a significant loss of respiratory muscle function. Their catabolic metabolic status can explain this during the period of IMV [2]. Tracheostomy has a host of short- and long-term risks and problems that mirror those related with IMV. The tracheostomy tube is a foreign body and can lead to infectious and respiratory complications and impaired swallowing [3].

In the USA, the annual cost of prolonged dependence on IMV, a key feature of chronic critical illness, is estimated to be $35 billion. For this reason, weaning is a stressful time with high clinical and economic implications. Dedicated units named "Weaning Centres (WC)" seem cost-effective to care for this population [4].

Patients Selection

The causes and severity of ICU admission may differ in different countries or geographical areas, so these factors must be considered when assessing outcomes. For example, respiratory failure due to COPD exacerbation or post-surgical operation is a different condition with different outcomes.

Although the time spent on weaning attempts is high, it is often performed too late. It is strictly related to different diseases and distinct categories of patients. The usage of existing studies to compare different care models is limited by differing referral patterns, difficulties in adjusting for comorbidity and case mix, and retrospective data collection [5] Brochard L et al. proposed a classification of patients into three diverse groups according to the difficulty and length of the weaning process [6]. The simple weaning group (69% of weaning patients) includes patients who successfully pass the initial spontaneous breathing trial (SBT) and are successfully extubated on the first attempt. The prognosis in this group is good. The second group, called difficult weaning, comprises patients demanding up to three SBTs or 7 days from the first SBT to achieve successful weaning. The third group, named prolonged weaning, includes patients who require more than three SBTs or more than 7 days of weaning after the first SBT [6].

Role of the Specialized Weaning Unit

The imbalance between the increasing prevalence of patients with acutely decompensated respiratory disease and the shortage of ICU beds has stimulated new health solutions.

The Respiratory Support and Sleep Centre (Cambridge, UK) is a national specialist weaning service since 1992 and aims to discharge patients home with the best possible independence from ventilatory support [7]. The service infrastructure is consistent with current National Health Service (NHS) specialist weaning specifications. It includes a team of respiratory physicians, nurses (usually 1:2, with distinction concurring to patient necessity), and physiotherapists with a specialist interest and skills in weaning and noninvasive or invasive (via tracheostomy) home ventilation. It is also continued by hospital-wide services, comprising dietetics, speech rehabilitation, and occupational therapy [7].

The formation and expansion of respiratory high-dependence care units (RHDCU) are crucial for managing patients with tracheostomies, especially given the weaning process. It is also critical to highlight that the decannulation process includes a multidisciplinary approach between doctors, nurses, physiotherapists, and speech therapists [8]. A European Respiratory Society Consensus statement summarizes the specialized weaning unit's role compared to continued critical care [9]. Acute care units lack the required attention, personnel, and organizational structure to care for patients with persistent weaning failure. Instead, in specialized weaning units (SWUs), there are specialized teams (e.g., intensivists, pneumologists, nurses, physiologists, respiratory therapists, nutritionists, etc.) and an opposite "bridge to home" situation for such patients and their families (e.g., privacy, daytime activity, longer visiting hours and undisturbed sleep). They also relieve pressure on scarce ICU beds [8]. These units can be of two types: (1) step-down units or noninvasive respiratory care units within acute care hospitals, and (2) regional WCs that serve several acute care hospitals within the region. The preferable unit will depend on each region or country's healthcare structure and financing system. RHDCUs provide a specified quality of care for patients recovering from acute respiratory failure (ARF), with health resources and organization optimization (e.g., lower nurse-to-patient ratio). The RHDCU is an intermediate-level respiratory care setting designed to manage single-organ decompensations and to avoid the risk of the inadequate intensity of care in a lower-level care environment (e.g., ward) and the potentially wasteful provision of unnecessarily intensive care in an ICU. Moreover, the RHDCU may function as a step-down unit for post-ICU patients (for weaning and decannulation). In North America, several levels of RHDCU have been running since the 1960s [8]. In Europe, RHDCUs were set up only in the late 1980s. However, in Europe, there has been a rapid intensification in the quantity of RHDCUs, and the types of RHDCUs diverge among the European countries and within given countries, as shown in a European Respiratory Society survey [9]. This paralleled the expanding popularity of noninvasive mechanical ventilation (NIV) to treat ARF. The 68 European surveyed units were classified into three levels of care, dependent on the resources, the severity of the ARF, and the complexity of the

available interventions: respiratory monitoring units (RMUs), respiratory intermediate intensive care units (RIICUs), and respiratory intensive care units (RICUs) [9].

In agreement with these European data, there has been increasing interest in intensive care medicine in Italy. Thirty-five percent of the RHDCUs included in the European Respiratory Society survey were in Italy. The only available systematic data on the number, features, and activities of Italian RHDCUs is from a survey performed in 1997. Here it is reported the second Italian survey of RHDCUs and analyzed the changes from 1997 to 2007 [8].

Multidisciplinary Approach

For patients who have required prolonged IMV, estimating prognosis is a crucial part of clinical decision-making, including weaning unit referral. The weaning unit is only part of the continuum of care for patients who have required prolonged IMV. Underestimating final discharge home rates could lead to unnecessarily pessimistic decision-making within ICU [9].

Better outcomes were seen for patients treated in SWUs. During this time of weaning, the multi-professional team should also be seen and assessed for rehabilitation. The patient's physical, psychological, communication, and dietetic requirements should all be considered, with access to the relevant professionals as required. Early physical rehabilitation is safe and effective. These may include improvement in breathing pattern, improvement in oxygen peripheral saturation or arterial blood gases, and identifiable changes in the work of breathing with, for example, increased use of accessory muscles [10].

Interventions, Diseases, and Outcomes

Compared to the data reported for each level of care in the European RHDCU survey, the Italian RHDCUs admitted a lower percentage of patients for monitoring only. The cost/benefit ratio for effective behaviors (e.g., mechanical ventilation, weaning, and decannulation) for a patient with respiratory failure may be advantageous in an RHDCU compared to an ICU. This is true for Italian units, not only for patients successfully treated with NIV but also for tracheostomized patients. The advantages of a new model for long-term weaning, based on the integrated activity of one Italian RHDCU and one WC run by the same pulmonology team, were recently described [11].

The changes in the pattern of diseases admitted to RHDCUs may be the result of three factors:

1. NIV's increasing success and cost savings in treating COPD exacerbation in other hospital settings (e.g., general ward or emergency department) were also observed in this survey: 86% of the respondent RHDCUs described using NIV in other locations.

2. The literature and documents support the use of NIV in patients with neuromyopathies.
3. The increased use of NIV as a precautious attempt to treat de novo ARF before resorting to intubation and a high-level care setting.

The augmented complexity of the interventions implemented and the patients cured in Italian RHDCUs reproduce increasing expertise in dealing with critically ill patients. This agrees with previously published data that improved experience with NIV may progressively allow more severely ill patients to be treated without changing the NIV success rate.

The crude mortality rates found in the two Italian RHDCU surveys are like those reported for COPD exacerbations managed with NIV (10–25%). However, those data were obtained from hospital discharge sheets, which lack information about important confounders such as disease severity, comorbidities, and interventions [8, 11].

A significant element of the weaning protocols is the disposal of physiotherapy. It has been confirmed that early physiotherapy benefits critical patients in the ICU. The ERS Task Force, based on these reports, suggests that efforts to prevent or treat respiratory muscle weakness might have a role in reducing weaning failure [11].

Organization

Recently the problem of appropriate ICUs utilization has been faced by proposing two types of units:

1. "Step-up" units like respiratory intermediate care units (RICU) within acute care hospitals manage patients with ARF or acute on chronic respiratory failure (ACRF) with NIV, resulting in a significant reduction in ICU admissions and the need for IMV, with a satisfactory level of assistance. These units may provide multidisciplinary rehabilitation and serve as a bridge to home-care programs or long-term care facilities. Some of these RICUs may also be "step-down" units for difficult-to-wean patients [11].
2. Specialized regional WCs, often located within Rehabilitation Hospitals, treat difficult-to-wean patients transferred from several acute care hospitals. Dedicated WC offers specialized teams (e.g., nurses, respiratory therapists, nutritionists, psychologists, speech therapists.) and relieves pressure on scarce ICU beds at a lower cost. Variable mortality and weaning success have been reported [11].

Specific studies on the role of physiotherapy and weaning outcomes are lacking. The main expectancies from WCs are to relieve ICU beds, maintain an elevated level of nursing assistance, respond to sudden changes in patient's clinical condition, allow enough time for a multidisciplinary rehabilitative method, to take on the

role of a bridge to home care programs, or other opportunities of continuous chronic assistance.

A multidisciplinary team that takes a patient-center methodology is required for weaning to succeed. A specialist WC can better provide this than an ICU. The emphasis of such centers is on delivering a high-quality service that is available close to the patient's home. They should offer clinical, research, and educational excellence, provide rehabilitation and support home ventilation (HMV), and have high core service standards. The centers should operate a comprehensive, coordinated care pathway from inpatient to long-term outpatient follow-up and outcomes benchmarked to national and international standards.

At the Lane Fox (UK), a specialist WC, weaning and rehabilitation interventions take place during the daytime, and patients are ventilated with pressure support ventilation (PSV) in obstructive lung diseases (OLDs) or pressure control ventilation (PCV) in NMDs overnight to minimize the effects of hypoventilation REM related and maintain adequate gas exchange and allow effective daytime weaning and rehabilitation. Weaning, rehabilitation, and HMV programs are required to provide life-long support for many patients.

In patients who have failed to wean, health-related quality of life (HRQoL) is variable but can be satisfied with appropriate support. For these individuals, physicians must explain the consequences and outcomes of long-term HMV and regular follow-up, review therapy goals, and establish their wishes regarding medical interventions and continuing treatment.

In the intervention group, it was possible to discharge all patients weaned from invasive ventilation without continued NIV into home care with no ongoing respiratory care. Of the NIV patients, 85% returned to the home setting, 10% were discharged to residential care groups, and 5% to nursing homes. Since many patients in the intervention group died, and out-of-hospital care was not required for 12 months, the costs for deceased patients were projected over 1 year in the theoretical approach. Even if one looks at the total costs of weaning and theoretical care in the case of 100% 1-year survival, totaling seven million euros, one still sees a saving of 50% of the costs generated without a secondary attempt at weaning [12].

Locations

An example of an Italian RICU is the one located at University Hospital in Pisa, Italy. This 4-bed RICU is situated inside a 28-bed pulmonary ward within a Cardio-Thoracic Department, including a cardio-surgery ICU. It is worked with a 1:4 nurse-to-patient ratio, a 24-h on-duty doctor (in the night shared with the ward), and a 1:4 respiratory therapist-to-patient ratio. This RICU admits patients with ARF or ACRF to provide NIV (step-up), and to a less extent, tracheostomized difficult-to-wean patients may be transferred from the medical or surgical ICUs (step-down). According to ERS standards, it is equipped with monitoring and diagnostic facilities, including bronchoscopy and a gas analyzer. The estimated RICU daily stay cost is 900 euros compared with an ICU daily stay cost of 1500 euros. RICU

occupation is refunded on a Diseases Related Group (DRG) system basis. The integrated 6-bed WC is located inside a 14-bed pulmonary rehabilitation unit of a Rehabilitation Hospital (Auxilium Vitae) in Volterra, Italy about 70 km away from Pisa. It is staffed with a 1:6 nurse-to-patient ratio, a 24-h on-duty doctor shared with the pulmonary rehabilitation unit, and a 1:6 respiratory therapist-to-patient ratio. Psychological, speech, nutrition, and swallowing services are also available. Difficult-to-wean tracheostomized patients are admitted to the WC, either transferred from the RICU of Pisa or from ICUs of other Tuscany Hospitals to undergo either a program of progressive discontinuation from mechanical ventilation or to be discharged to a home program of long-term ventilatory assistance, if weaning from the ventilator fails. The estimated daily cost of a WC stay is 470 euros [8, 11, 12].

Pulmonologists trained in mechanical ventilation serve as primary physicians in both units, which the same person directs.

Furthermore, patients needing prolonged mechanical ventilation have high resource utilization and poor outcomes, especially the elderly, and are increasing in number. The sequential activity of units less expensive than ICUs like RICU and dedicated WC has an additive weaning success rate in difficult-to-wean patients with substantial cost savings compared with ICU.

There is significant variability in the clinical outcomes of WC in the literature. However, the comparison between studies of different centers and different periods may not be appropriate, as weaning success seems strongly related to patients' complexity and comorbidities, hospital organization and personnel expertise, availability of early physiotherapy, use of weaning protocols, patients' autonomy and families' preparation for home discharge with ventilation.

Rethinking Respiratory Noninvasive Support Outside ICU During Pandemics

The massive spread of the COVID-19 outbreak has put in crisis the surge capacity response of whole sanitary systems worldwide [13]. In particular, ICU surge capacity response has been severely stressed by enormous requests for ventilatory assistance due to hypoxemic acute respiratory distress syndrome (ARDS) COVID-19 [14]. In many countries, innovative solutions have been found to change the routine hospital organization and cope with limited resources, leading to massive task-shifting with a suspension of elective medical and surgical procedures [15]. To stabilize the respiratory condition and avoid intubation, NIV has been used outside the ICU [16]. In this context, all the strategies finalized to increase the success of NIV have been pursued. However, during the current COVID-19 pandemic, the importance of close monitoring of the patient in NIV has emerged, as, despite its clear benefits, a delay in intubation turns out to be associated with worse outcomes [17]. RHDUs set up in Western countries in the last decade are a transitional step-up or step-down between the ICU and the conventional hospital ward in terms of staffing, level of monitoring, and patient severity. RHDU should have two fundamental

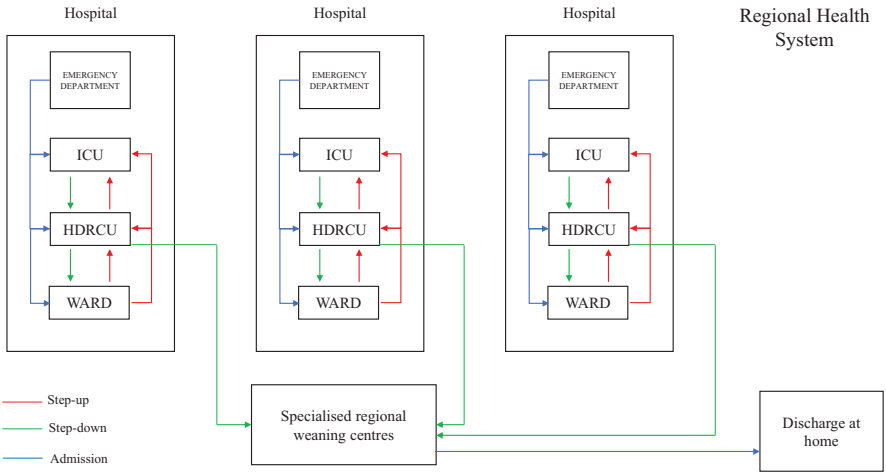

Fig. 25.1 RHDUs set up as a transitional step-up or step-down between the ICU and the conventional hospital ward in terms of staffing, level of monitoring, and patient severity

purposes during pandemics: on the one hand, to decrease the number of admissions into ICU, and on the other hand, early discharges of patients from ICU with prolonged admissions due to the need for care or laborious weaning from IMV [18]. Although this dual purpose of RHDUs has contributed to decreasing the overload of the ICUs during the pandemic, hundreds of patients admitted to hospitals have exceeded the forecasts of many hospitals. So, reorganizing the RHDCU for pandemics is necessarily focusing on the number of units needed as a function of population and on the central concept that only the expert application of noninvasive respiratory therapies can prevent intubation and ICU admission of a complex patient with ARF due to COVID-19 [19].

Moreover, early weaning from IMV represents a challenge. Compared to standard weaning, early extubation followed by immediate NIV shortened IMV duration and reduced the rate of extubation failure and reintubation [13] Also, early tracheostomy should be an efficacy weaning strategy that can be performed by a unified and experienced tracheostomy team comprising tracheostomy nurses, speech and language therapists, respiratory physiotherapists, critical care specialists, respiratory physicians, and head and neck surgeons. WCs dedicated to managing NIV and decannulation from tracheostomy are needed. **Summary details in** Fig. 25.1.

Cost-Effectiveness

Based on existing literature that included cost analysis, it has been calculated that the cost of a stay in critical care is almost double the cost in a WC. The overall cost is, of course, dependent upon the length of stay. There are no data to compare

transfer to a SWU and continued management within critical care. The reduced weaning unit budgets occur from the lower staffing ratio. RICU and WC may be cost-effective options for acute ICUs to manage difficult-to-wean patients. Several observational studies estimate lower daily costs of care for ventilator-dependent patients in WC, primarily through the reduced need for personnel, reduced costs for monitoring (e.g., noninvasive), technical equipment (e.g., portable ventilators), diagnostics, and therapeutics [12]. The cost-benefit ratio of the program necessitates future analyses.

Conclusion

NIV is a well-established therapeutic strategy in the treatment of patients with ARF and ACRF. Its use outside the ICU is an established but not uniform practice in several health care settings. Each hospital should be equipped with specific units (HRCU and WC) equipped with a multidisciplinary team that works with specific approved protocols. Organizing specific care units with specific tasks can reduce health care costs by improving outcomes for these chronic critical patients using noninvasive respiratory support techniques safely. The recent SARS-CoV2 virus pandemic has taught us that these types of units are indispensable to deal with the massive influx of patients with respiratory failure while saving ICU beds. Only trained medical staff can work within these units.

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Noninvasive Mechanical Ventilation in Geriatric Wards

26

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Abstract

Noninvasive mechanical ventilation (NIV) in elderly patients with acute respiratory failure (ARF) successfully prevents unnecessary intubation and a prolonged hospital stay and reduces hospital mortality rate acutely, especially in some conditions such as acute on chronic respiratory failure, acute heart failure, pneumonia, and prevention of post-extubation ARF. NIV is also the main management of ventilator in elderly patients with "DNI order" with cardio-pulmonary disease according to some studies even if studies in this area are still insufficient and often controversial. An emerging issue is the management of elderly patients with respiratory failure and dementia although the presence of cognitive impairment and delirium are not a barrier to the administration of NIV. Indeed, some studies have shown a better management of symptoms in very elderly hospitalized patients in a non-intensive care unit setting followed by a multidisciplinary medical staff conforming to principles of comprehensive geriatric assessment and treatment, the involvement of family caregiver and the attention to quality of life according to the principles of Acute Care for Elders (ACE) model usually used in geriatric wards.

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Introduction

Many elderly patients with acute and chronic conditions such as chronic obstructive pulmonary disease (COPD), cardiogenic pulmonary edema, chronic diseases that produce immunosuppression, neuromuscular disease without severe bulbar insufficiency, obesity hypoventilation syndrome and chest wall deformity need noninvasive mechanical ventilation (NIV) as the first-choice treatment when developing acute respiratory failure (ARF) [1]. NIV produces the same physiological effects similar to those in mechanically ventilated patients via intubation (i.e., unloading of respiratory muscles, improved gas exchange, and increased alveolar ventilation). Early application of NIV along with optimal medical therapy and oxygen support in patients with ARF, including those in old age, successfully prevents unnecessary intubation and a prolonged hospital stay and reduces hospital mortality rate, particularly in patients with hypercapnic acidosis. The main management of ventilator in elderly patients with "DNI order" with cardio-pulmonary disease is NIV according to some studies [2, 3]. NIV may also be useful in palliative care, for example in the management of elderly patients with end-stage solid tumors and acute on chronic respiratory failure [4]. Unfortunately, it is evident that the increasing aging of the population does not correspond to a greater effort in identifying specific clinical-assistance paths in the management of the last stages of life for the elderly person. Although medical treatments are technologically advanced, they do not promise any healing, they can sustain life with or without meaningful existence or with secondary support (such as feeding tubes, NIV). Hence, these medical advances have given patients and their families (delegates) an important task of choosing their treatment preference during end-of-life care. It is therefore necessary for geriatrics, and intensive and palliative care experts to work together to share specific models of care for the older patient and their families [5].

Furthermore, some studies reported that many older patients with ARF (receiving noninvasive ventilation or oxygen with a high-flow nasal cannula) have a non-intubation order (DNI) [6]. The rate of patients with a DNI order has increased in the last few years and there is high inter-study variability both in non-intubation rates (especially in advanced aging and older patient with high comorbidity) and in patient/family involvement in do-not-intubate decision-making processes. Studies in this area are still insufficient and often controversial [7]. An emerging issue is the management of elderly patient with respiratory failure and dementia althought cognitive impairment and delirium is not a barrier to administration of NIV. Some studies have shown a better management of symptoms in very elderly hospitalized patients in non-intensive care unit setting if a multidisciplinary medical staff is present. This staff must comply with the principles of comprehensive geriatric assessment (CGA),

the involvement of family caregier and the attention of quality of life [8]. The family member of older patients (with or without dementia) in critical illness can play an essential role in the decision-making process relating to treatement because of the psysicians may be difficult to know the patient's wishes and preferences. For this reason it would be important that doctors to know the legislation about informant consent or Advanced Health Care Directives (AHCD) [9]. These problems are frequent in geriatric wards, and they are always to be taken into consideration when applying NIV. NIV is often used in these contexts, and it can be facilitated by the methodological approach (typical of geriatrics) dedicated to complex elderly patients even in a context of non-intensive care. Indeed, the results of the use of NIV in elderly patients in non-geriatric care settings are often controversial. In this regard, a recent French study based on a retrospective analysis has shown that NIV use in elders admitted for acute heart failure in the emergency department was not associated with better outcome in this population regardless of their comorbidities and functional status [10]. On the other hand, clinical observations support the issue that the choice of NIV can be adequate and effective when it is adopted by a multidisciplinary medical staff in a setting where nurses and medical team, as well as being trained on the methodology of the geriatric approach, are trained in NIV protocol and where, when necessary, the involvement of the family is foreseen [11]. These characteristics make specific the geriatric model of care that we describe in this chapter.

The Models of Geriatric Care

The management of the acute elderly patient in hospital can be more due to the greater complexity characterized by the simultaneous presence of multimorbidity, polytherapy, and functional and cognitive impairment. The factors to consider in the approach to the elderly patient are essential: aging, comorbidities, use of drugs, malnutrition, cognitive impairment, and functional decline, better known as a condition of "Frailty". All these elements are part of the "comprehensive geriatric assessment" defined as a process used by healthcare practitioners to assess the status of older people to optimize health management and care [12, 13]. Frailty involves a complex interaction of biological, social, and cognitive factors that negatively impact an individual's ability to independently complete their activities of daily living (ADLs). Moreover, "Frailty" represents a greater vulnerability to an acute stressor with consequent difficulty in adapting to them. One of the most used and validated tools to evaluate fragility is the Clinical Frailty Scale (CFS) [14], which stratifies older patients into nine groups from "very fit" to "terminally ill". An increased CFS is associated with a higher risk of mortality and complications such as falls, reduced mobility, and adverse events. A recent meta-analysis shows that an elderly with high CFS values have higher hospitalization risks and higher mortality in intensive care unit (ICU) [15] and another European study showed that in critical patients over 80 years with high frailty (CFS > 5) the 30-day mortality exceeded 30% of the cases. Consecutive classes in CFS were inversely associated with short-term survival [16]. It is suggested that you can also use faster tools like FRAIL

screen (a five-item scale that evaluates fatigue, resistance, ambulation, illnesses, and loss of weight) used to detect older persons at increased risk [17]. In the older patient, it is not correct to have an approach based on the evaluation of the single disease, but it is always necessary to consider the global health status that is the result of the integration between chronic diseases and their implications in the physical, mental, and social sphere. A CGA allows to identify the strong relationship between different domains /dimensions: biological, functional, psychological, and social interactions with each other characterize the great complexity of the older patient. It is known in many studies that elderly patients had a greater chance of survival at home if they received CGA upon admission to hospital [12]. The factors to consider in the approach to the elderly patients are essentially aging, comorbidities, use of drugs, malnutrition, cognitive impairment, and functional decline better known as a condition of "frailty". All these elements are part of the "Comprehensive Geriatric Assessment" defined as a process used by healthcare practitioners to assess the status of older people in order to optimize health management and care [13, 18]. These people often have complex, multiple, and interdependent problems (multimorbidity) which make their care more challenging than in younger people, or those with just one medical problem. CGA is the core job of geriatricians although many other health professionals have not heard of it or are unaware of what it is [19]. The use of CGA improves the outcomes for people who are older and frail. From the many studies (more than 1200 under the heading "Comprehensive Geriatric Assessment" in "PubMed" from 1969 to today) the scientific community has shown that the CGA and the individual care plan (ICP) that derives from it: (a) constitutes the specific element that characterizes continuous assistance to the older patient; (b) increases diagnostic accuracy and the implementation of interventions capable of slowing down functional decline and improving the quality of life of frail elderly people; (c) allows greater appropriateness in the use of resources, a reduction in costs, and an improvement in the organization and quality of care; d) it is particularly effective when it is applied in a network of hospital and territorial services [20]. An example of a cumulative CGA tool is Multidimensional Prognostic Index (MPI) that could be used to evaluate high-risk older patients predicting the risk level (low, moderate, or severe) of all-cause mortality, especially in hospital settings. This tool (based on some crucial indicators of CGA such as nutritional status, physical activity, mobility, strength, cognition and mood, and social support) would seem to be an accurate predictor of short and long-term all-cause mortality, length of stay, and clinical evolution of older patient admitted in hospital [21]. A recent study compared the accuracy of some geriatric health indicators in predicting different outcomes such as mortality and hospitalization: one of these, in addition to CFS (or frailty index), frailty phenotype (FP), walking speed and multimorbidity, is HAT (Health Assessment Tool), a summary score including clinical diagnoses, functioning and disability [22]. HAT evaluates five characteristics: walking speed, Mini-Mental State Examination (MMSE) score, difficulties in instrumental activities of daily living (IADL), limitations in basic ADL, and list of chronic diseases obtaining a score ranging from 0 (poor health) to 10 (good health) [23].

Therefore, the clinical approach to the older patient, from admission to the hospital, should consider these variables and have the possibility to use a validated approach that assesses the frailty and all the typical aspects of the "geriatric" patient. This occurs using when it is possible, the framework of CGA which has been shown (compared with usual care) to improve the chances of persons being alive 1 year later hospitalization [12]. As there is often a mismatch between the clinicians' assessment and the patient's wishes, multidisciplinary collaboration in the decision-making process is strongly recommended especially for the old because all health-care providers who can help to improve the decision-making process for the benefit of the patient should be involved [24]. Because of multiple chronic conditions the elderly patient often uses multiple medications (polypharmacy) that expose him to a series of adverse events (indicators of frailty) such as falling, chronic disease exacerbations, and ultimately death [25]. Polypharmacy and inappropriate medication prescription among older patients frequently lead to adverse outcomes; often acute hospitalizations determine an increased risk of inappropriate prescription, the presence of polypharmacy, inadequate medication reconciliation, and a lack of care coordination [26]. Adverse events can be prevented, and geriatric care can be improved using support in medication evaluation such as the Beers Criteria for Potentially Inappropriate Medications Use in Older Adults [27] and the Screening Tool of Older Persons' potentially inappropriate Prescriptions (STOPP) and Screening Tool to Alert doctors to the Right Treatment (START) criteria [28]. Furthermore, in geriatric care, the presence of cognitive impairment is associated with an elevated risk of delirium which is the most common complication afflicting hospitalized patients aged 65 or older, even if it often remains unrecognized [29]. Delirium is associated with increased mortality, high length of stay, risk of premature institutionalization, and subsequent further cognitive decline [30].

In addition to the essential elements of the approach and methodology of geriatric intervention, the main evidence in the management of an older patient in hospital is given by the application of Acute Care for Elders (ACE), a geriatric model of care that promotes improved outcomes for hospitalized elderly trough specialized interprofessional staff and environmental adaptations [31]. Usually in the hospital frail older patients admitted for acute reasons often experience more adverse outcomes, including lengthier hospital stays, functional decline, and an elevated risk of discharge to a nursing home [32]. The ACE is a care intervention dedicated to the hospitalized older patient structured to guarantee: a) an adequate environment to promote mobility and orientation; b) a person-centered care with nursing-validated protocols for maintenance of retained abilities, sleep hygiene, mood, and cognition; c) comprehensive and ICP for returning home, facilitated by social service intervention to mobilize the family and other community resources; d) a review of the medical care to promote optimal prescribing for elderly (see Fig. 26.1).The first positive clinical trial of this model showed that admission to an ACE Unit compared to usual care in a general medical ward was associated with better maintenance of the basic activities of daily life at discharge and a lower risk of medical problems related to hospitalization. Subsequent studies have also shown mostly positive results including a meta-analysis that demonstrated favorable results towards ACE in terms of

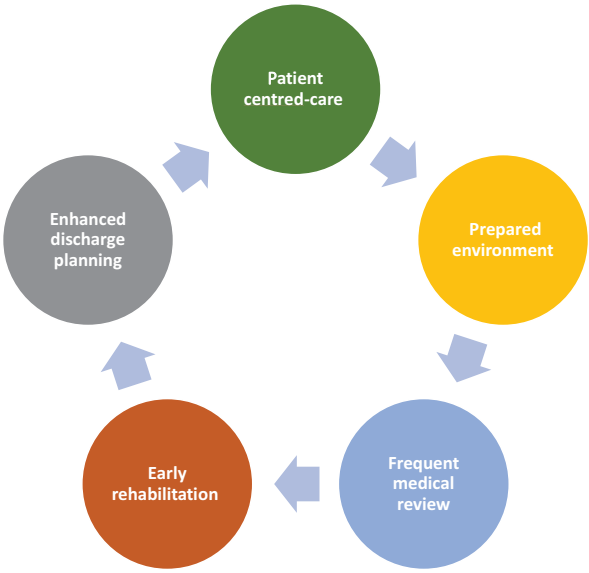

Fig. 26.1 Components of the ACE (Acute Care for Elders) model. (Adapted from R. Wong "Leading Best practice: acute care for elders' unit (ACE)-evidence and Key to successful operation, Canadian Geriatric Society, 2017)

reduction of falls, delirium and functional decline at discharge, length of hospital stay, lower hospital costs, and fewer discharges to a nursing home [33]. An important consideration concerns the problems of people of advanced age (generally very old) suffering from diseases that cannot be treated at home due to their instability. Patients dependent on the hospital differ from those with severe chronic diseases; frequently require cycles of noninvasive ventilation or intensive or semi-intensive support (nurses, doctors, availability of monitoring, diagnostics), which can only be obtained in a hospital setting and from which they draw immediate comfort and succeed to have an acceptable quality of life (e.g., they are able to have valuable interactions with family and friends). Conversely, when the response to treatment is not as fast or is not available, they are unable to live outside the hospital setting. These patients are of advanced age, always have multiple chronic conditions, and a reserve physiological insufficiency to cope with the stress of an acute illness, even a minor one: they develop pulmonary edema, exacerbations of COPD, orthostatic hypotension, myocardial ischemia, acute kidney damage, fever, falls and delirium often without identifiable precipitating factors. In the hospital (especially in a geriatric ward), they survive and live, but not at home where until recently they were necessarily candidates for death.

The Use of Noninvasive Mechanical Ventilation in Older Patients and in Geriatric Care

ARF is a common cause of hospitalization in older patients or those near the end of life. These hospitalizations are usually complicated by respiratory symptoms requiring the use of high-intensity, high-risk interventions, including invasive mechanical ventilation (IMV) and NIV. Trends in NIV over the past two decades show a substantial increase in the use of NIV whose applicability has been determined by significant reduction in mortality and intubation rates [34]. This suggests a change in the way ventilatory support is provided to patients at end of life. However, while the use of NIV in the elderly may have increased, the evidence supports this use in severe diseases remains vague. In a recent study, Sullivan et al. analyzed patterns and trends in NIV and IMV over the past 17 years in 2.5 million patients hospitalized in the last days of life. Their results show a ninefold increase in the use of NIV in older patients (a tenfold increase in patients with congestive heart failure (CHF), a fivefold increase in patients with COPD, and a ninefold increase in patients with cancer and dementia at the end of life) [35]. In a recent observational study of patients on long-term NIV, patients aged over 75 are about one-third of the treated population and the benefits are similar to those of the younger population in terms of correction of arterial blood gases and nocturnal pulse oximetry, adherence, residual respiratory events in the same diagnostic group (COPD is the most representative disease) and these data would confirm the applicability of NIV in the very older patients [36]. To date, there are many indications for NIV in the elderly and these range from acute on chronic respiratory failure to acute heart failure, de novo ARF in immunocompromised patients (e.g., pneumonia), prevention of post-extubation ARF besides DNI context and palliative care [3]. Age does not exclude benefits from NIV in a variety of settings, but these benefits may be more evident in a ward structured according to the principles of the ACE model (patient center care, prepared environment, frequent medical review, early mobilization and rehabilitation, enhanced discharge planning, and an ICP). Even though clinical guidelines clarify where NIV should be avoided, for example, in patients who are clinically unstable or agitated and those who are unable to cooperate it is likely that the geriatric approach and methodology could help improve both the efficacy and tolerability of NIV in this category of older patients. Previous studies and clinical observations had already highlighted that even if mortality was higher in the more severe patients, NIV could be effective also in patients living with dementia, indicating that barriers generally considered for these procedures may be overwhelmed in a dedicated geriatric setting. Its tolerability, success rate, and associated global mortality are comparable with those of younger adult patients [37, 38]. In particular, the increasing use of NIV in the elderly with advanced dementia and elderly with delirium is an area of concern. The patient with dementia or delirium is unable to provide this degree of collaboration and therefore needs more support and help to collaborate in care. For these reasons, an assessment of cognitive and behavioral disorders and an assessment of delirium before deciding to apply NIV is important in clinical practice. As part of the most useful tools in geriatric settings, we can cite the MMSE, the

Addenbrooke's Cognitive Examination (ACE-R), the Neuropsychiatric Inventory (NPI), and the Confusion Assessment Method (CAM). The MMSE [39] has become the most widely used tool for cognitive assessment (verbal assessment of memory and attention) in a wide range of neurological diseases but it is insensitive to frontal-executive dysfunction and visuospatial deficits. For this reason, it is preferable to use short and more accurate cognitive tests such as *ACE -R* [40] a brief cognitive test that takes about 15 min and assesses five aspects of cognition: attention/orientation (AO), memory (M), verbal fluency (F), language (L), and visuospatial abilities (VS). To evaluate behavioral symptoms, the most used test is the NPI, a scale that provides for the measurement of frequency (from 0 to 4) and severity (from 0 to 3) for each individual behavioral symptom: the score of maximum relevance of a symptom is therefore [12]. The total score of the scale is given by the sum of all the scores obtained in the individual symptoms with a maximum score of 144. A therapeutic intervention, whether it involves nondrug therapy or a drug, is considered effective if can reduce the NPI scale by at least 10 points [41].The CAM continues to be the most widely used delirium instrument worldwide. The CAM provides an algorithm based on the four core features of delirium: acute onset, fluctuating course of symptoms, inattention, and either disorganized thinking or altered level of consciousness [42]. The American Psychiatric Association's fifth edition of the Diagnostic and Statistical Manual of Mental Disorders (DSM-5) defines delirium as a syndrome characterized by an acute onset and fluctuating course of symptoms such as inattention, impaired level of consciousness and disturbance of cognition, (e.g., disorientation, memory impairment, or alteration in language) [43]. Other elements that support the diagnosis of delirium are alterations in the sleep-wake rhythm, alterations in perception (e.g., hallucinations), emotional lability, delusions, and inappropriate or unsafe behaviors [44] .The CAM algorithm has been validated in research and has high sensitivity (94–100%) and specificity (90–95%) with good interrater reliability. The CAM, a widely tool used in geriatric wards, has also been adapted for use in the ICU, emergency departments, nursing homes, and palliative care. Delirium is the most common complication afflicting hospitalized patients aged 65 or older even if it often remains unrecognized this is particularly true if the mental status at the baseline is neglected. The psychological and behavioral disturbances due to dementia are also very frequent in older people and they must be recognized and treated with both nonpharmacological and pharmacological approaches. The evaluation and knowledge of the most appropriate therapeutic interventions could also help in the application of NIV in older patients who are often excluded for these reasons. Indeed, therapeutic approach based on nonpharmacological and pharmacological strategies is essential to improve NIV adherence in this patient. Furthermore, the approach and selection of the elderly patient to undergo NIV are also very important to reduce the risk of failure of NIV. A recent study highlighted that, in frail older patients with ARF from an acute geriatric unit, CGA can help in the identification of patients at risk of NIV failure.

The tool used in this case is the MPI based on multidimensional assessment derived from a standardized CGA oriented to identification of prognosis and best management strategy in hospitalized older adults with critical illnesses (pneumonia,

acute myocardial infarction, cardiogenic pulmonary edema, acute COPD exacerbation). According to experience of several clinicians, the CGA is particularly useful and effective in the management of geriatric symptoms and syndromes, especially in situations of complexity/emergency. In this study, MPI and admission in geriatric ward may predict with good accuracy NIV failure avoiding unnecessary delay in IMV via endotracheal intubation; a higher MPI score (= 0.84) can collect useful information at hospital admission which increases the likelihood of recognizing potential NIV non-responders [45]. In times of pandemic crisis due to Covid-19 the use of multidimensional assessment tool may be useful in management of hospitalized older patients with dementia and Sars-Cov-2 virus infection which is a very common condition in a geriatric ward. Even in this situation, higher MPI can be an excellent prognostic index in clinical practice to identify elderly with dementia at greater risk of NIV failure and in-hospital mortality [46]. On the other hand, a recent study conducted in Taiwan evaluated long-term outcomes and prognostic factors in older patients with ARF receiving IMV. This retrospective study that included 7095 elderly patients showed not only that 1 year- mortality is higher in oldest-old and middle-old patients but also that this mortality, as well as age, depends on a number of risk factors that have been identified: female sex, obstructive lung disease (included COPD, asthma and bronchiectasis), neoplasm (as active cancer), sepsis, trauma, CHF, cardiac arrest and comorbidities (evaluated with CCIS (Charlson Comorbidity Index Score)). These factors have been used to develop a prognostic nomogram that can help physicians estimate 1-year mortality of elder patients in the early stage of ARF, the possible transition to NIV, and assist them in clinical decision-making [47]. In geriatric care, NIV can also be used as a palliative strategy when endotracheal ventilation is inappropriate (patients with DNI) although its effectiveness for relieving symptoms in end-of-life care is controversial [6]. Palliative ventilation can be administered to alleviate the symptoms of respiratory distress in advanced stages of diseases and to manage patients with respiratory failure who present suffering from severe dyspnea not responding to usual pharmacological strategies. However, the prescription of NIV in this context (palliative care and older patient with advanced stages of diseases) requires further studies because these patients have many problems and comorbidities that can complicate the management of ARF [48]. Some authors suggest that DNI activities on very elderly patients with respiratory failure admitted to hospital should be conducted outside the ICU. This situation could be important in reducing anxiety and depressive symptoms and in improving pain and psychological distress related to DNI and the palliative context [49] and a geriatric setting can also be helpful in achieving this goal. According to ACE model, the geriatrics ward can also be a facilitating environment to prepare these patients for discharge at home or in long-term care settings. Patients who have chronic respiratory failure and are being treated with home mechanical ventilation (HMV) usually have a poor prognosis. For this reason, health-related quality of life takes on special significance. Physical quality of life during HMV therapy is more often assessed by patients themselves as reduced, while mental and psychological quality of life is rated as good in some cases [50]. On the one hand, HMV offers the potential to significantly improve both the extent

of chronic respiratory failure and the quality of life [51] and can serve as a palliative measure in the context of monitoring dyspnea. Nava et al. have shown that NIV is more effective than oxygen therapy in reducing dyspnea in this patient group, so the NIV could play a role in patients receiving palliative care or for patients with a DNI order [52]. On the other hand, there is also the risk of unnecessarily prolonging the patient's suffering and preventing him from dying with dignity at the end of a prolonged illness [53]. Caring for older patients often poses ethical and practical challenges both before and during intensive treatments. Therefore, a selection decision-making process is necessary in the clinical path and this process includes inquiring about the patient's wishes and the expectations of family members. In the absence of advance directives (AHCD) already formulated, an "Individual Care Plan" (ICP), typical of the geriatric approach and methodology, is configured as the only adequate tool to prepare a shared path of palliative care.

Conclusive Remarks

Elderly population is growing and the incidence of ARF increases significantly for each decade of life until age 85 years, with a particularly high incidence in patients over the age of 65 years [54]. Older patients, especially with dementia, are at increased risk for ARF secondary to non-pulmonary conditions such as delirium, stroke, malnutrition, and drugs (excess of sedation, anticholinergic, or antalgic drugs), which increase pulmonary risk aspiration. The incidence rate of elderly patients admitted to hospital for ARF is high, especially if some medical conditions are present such as underlying chronic cardiopulmonary disorders, immunosuppressed diseases, neoplasms, extra-pulmonary comorbidities while triggering causes of ARF in older age are acute heart failure, acute exacerbations of COPD, severe community-acquired pneumonia, and drug-induced lung injury. NIV should be the first choice in the elderly as well as in the young when this method is required to avoid the need for IMV and prevent complications which can be higher and more frequent in older patients. Some studies and clinical observations in the past two decades showed that in elderly patients with acute hypercapnic respiratory failure NIV reduces the need for intubation and the mortality rate by improving arterial blood gasses and dyspnea. For these reasons, the NIV can be considered an alternative treatment for elderly patients at elevated risk for intubation even if there are still no specific guidelines about it. Especially clinical evidence on the use of NIV in older patients with new onset acute hypoxemic respiratory failure without a previous diagnosis of chronic respiratory disease (i.e., pneumonia or acute respiratory disease or distress syndrome) is yet to be defined. The European Respiratory Society nor the American Thoracic Society nor the geriatric scientific societies have yet produced any recommendations for the use of NIV in this category of older patients, but there are only conditional recommendations for the palliative use of NIV. The use of NIV in the seriously ill elderly should be based on careful patient selection and it should only be used if clinical evidence demonstrates favorable effects for older patients; evidence remains elusive in a recent commentary on Sullivan's

research published in JAMA magazine [55]. More research is needed in this field which is becoming emerging due to the substantial number of "critical "or "complex" elderly admitted to hospital. Although NIV can be considered an adequate therapeutic tool in the elderly population with ARF, some peculiar issues should be considered such as the environment and staff training (organized according to ACE model), patient selection (guaranteed by CGA), palliative care and "end of life" decisions (provided to older patients with a "DNI order"). These characteristics which are guaranteed in a geriatric ward (outside the ICU) could have influence in ensuring the effectiveness of NIV in improving the care outcomes of the elderly patient. Considering that the geriatrics wards as well as geriatricians are insufficient compared to the high number and care needs of elderly patients admitted to the hospital, the same argument could be applied to the general medicine wards which, as shown by a recent survey conducted in Emilia-Romagna Region, could partially compensate for this lack. However not justified in an "aging world" that requires skills and specialized training in the geriatric field both in the treatment and in the prevention of disability [56]. Indeed NIV in ARF is also effective if some conditions are guaranteed such as: a) the correct selections of older patients addressed to NIV; b) the awareness that NIV is not an alternative to IMV if this is indicated (let's remember that elderly usually receive less intensive and expensive care in hospital and in very old patients with chronic advanced respiratory diseases the label of "DNI order" is often applied); c) the knowledge that NIV may be the best treatment under certain conditions that respond to the patient's needs at a given time; d) early application and proper monitoring; and e) high standards of organization, training, quality, and safety. Some controversies and doubts remain in this context and often underlie the success of NIV in an elderly patient there are the experience and clinical judgment of the physicians and care staff. The presence of the geriatrician, an adequate organization, and the use of a tool that is still too little used, as the AHCD, can make the difference, but we need further research that goes in this direction.

> *My inspiration and my passion will always come from my older patients. One day I hope to be like them; when that day comes, I hope that my doctor will be a geriatrician.* (Hazzard WR. "I am a Geriatrician." J Am Geriatric Soc 2004;52:161).

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Models of Noninvasive Mechanical Ventilation Unit in Palliative Care and End-Stage

27

Bruno Mendes

Abstract

Dyspnea is a common consequence of progressive respiratory disease, especially at the end of life. The increasing use of noninvasive positive pressure ventilation (NPPV) has reduced the need for endotracheal ventilation in patients with acute respiratory failure (ARF). Also, NPPV use as a palliation strategy, to alleviate the symptoms of respiratory distress in dying patients, has been growing over the years. Although more studies are needed on this subject, international societies have already added the use of NPPV for palliative purposes into their guidelines. It is of major importance to optimize communication between healthcare professionals, patients and their families around the issue of when to start NPPV as palliative measure and how to withdraw it at the end of life if palliation is not achieved. This communication should start early in the course of the disease.

Keywords

Noninvasive positive pressure ventilation · Palliative · Dyspnea · Cancer · Chronic obstructive pulmonary disease · Neuromuscular disorders · Communication

Introduction

Palliative care is an approach with the goal to improve the quality of life and to alleviate the symptoms of people living with life-limiting illnesses [1] (Table 27.1). In palliative care, the intensity of breathlessness frequently worsens as death

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Table 27.1 Palliative noninvasive positive pressure ventilation overview

Palliative noninvasive positive pressure ventilation	
Primary goal of care	Palliation of symptoms
Communication with patient and family	Comfort measures and minimize adverse effects
Definition of success	Improve symptoms and maximize comfort
Definition of failure	Patient is not more comfortable with NPPV Patients is not able to communicate
Professional	Appropriately trained personnel (doctors, nurses)
Local	Ward, intensive care unit and hospice

approaches. As families expect symptom relief, many times opioids are given. Although effectively a number of undesirable side effects may occur.

Noninvasive positive pressure ventilation (NPPV) is a treatment used in selected patients with acute respiratory failure (ARF). The use of NPPV for palliative purpose in patients who have foregone endotracheal intubation is still controversial. Some authors suggested that NPPV may help to alleviate respiratory distress with relief of dyspnea in terminal disease patients and provide some additional time to allow these patients to finalize personal affairs. On the other hand, other authors believe that NPPV is still a form of life support causing discomfort and prolonging the dying process. Initially, palliative care focused on the care of end-stage cancer patients, but in recent years have included other diseases such as chronic obstructive pulmonary disease (COPD) and neuromuscular disorders (NMDs) [1, 2].

Intensive Care Unit

The transformation undergone by intensive care units (ICUs) over the years has increased survival rates among patients with severe conditions. This led to an increased number of admittances to ICU of patients with major comorbidities experiencing severe but reversible acute events during the last period of their lives [3]. Evidence has shown that among older patients and those with chronic disorders, the rate of ICU denial is high. When patients are admitted to ICU it is of major importance to establish the limits of active treatment for each patient to protect them from useless interventions that are against their wishes and that may prolong suffering [3, 4]. To prevent unreasonable therapeutic interventions in ICU it is important to create a multidisciplinary approach to patients with a strong connection between intensivists and palliative teams. Some patients may choose only to undergo a time-limited trial of NPPV to prolong life until the arrival of family members or friends.

It remains a challenge to select the group of patients with acute-on-chronic respiratory failure who are most likely to benefit from ICU admission, but NPPV appears to be especially efficient in those with hypercapnia. The question of whether general or disease-specific instruments should be used to evaluate the effects of NPPV on quality of life remains unanswered.

Although regularly performed, implementing palliative NPPV in ICU remains a controversial issue with scarce data.

Communication

Clinicians must be aware of the goals of care when NPPV is used for patients that have decided to forego endotracheal intubation. Goals for each patient must be clear for all the medical personnel in charge of the patient. Also, the patient himself and his family must understand the purpose of palliative care. A shared approach exchanging clinical information and patients' preferences is important to provide information about NPPV which is a device mostly unfamiliar to patients and families.

Misleading recommendations and adverse consequences may occur if the dialogue between the three parts is not clear (Fig. 27.1) leading to inappropriate use of medical resources, inadvertent prolongation of the dying process and intensification of the patient suffering. Some patients or family members may choose comfort/palliative measures but maintain hope for a cure and this may cause ambivalence regarding decisions of life-sustaining treatments. It is important to discuss this ambivalence and explore patients' and families' fears and questions about palliative care and the decisions that were made may change over time.

This area is still in need of improvement, and the general population must be educated about palliative care [2, 5].

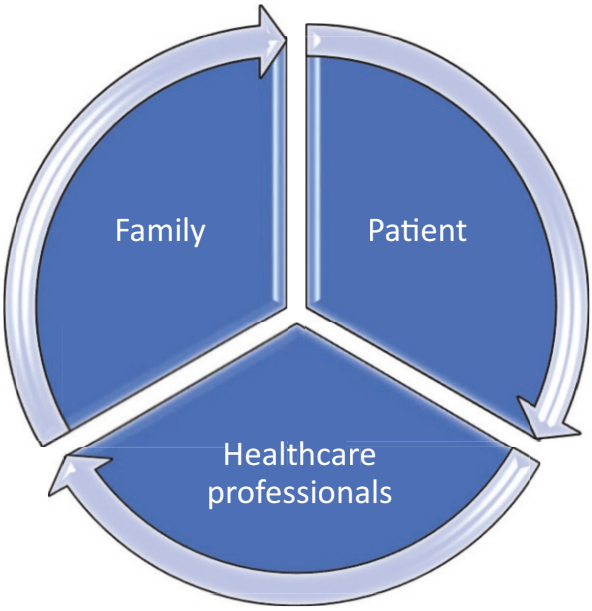

Fig. 27.1 The three groups involved in palliative decisions. Clear communication is essential to achieve results

Chronic Obstructive Pulmonary Disease

Due to increased ventilatory demand, static and dynamic hyperinflation and respiratory muscle weakness, several patients with COPD live with heavy symptom burden. The most frequent symptoms resulting in poor quality of life are breathlessness, fatigue, anxiety and depression [1, 6]. NPPV reduces mortality and the need for intubation in patients with ARF due to COPD exacerbation leading to acute or acute-on-chronic respiratory acidosis (pH $\leqslant$7.35) [7]. NPPV is used in almost one-third of COPD patients with poor life expectancy [8]. NPPV improves ventilation, oxygenation and the resistive load on the ventilatory muscle. All these facts reduce the work of breathing improving the breathlessness and quality of life [1]. There is a lack of systematic reviews comparing the use o NPPV in palliative care for COPD patients. Wilson et al. [9] performed a systemic review and meta-analysis about the use of NPPV in patients with ARF with do-not-intubate or comfort measures only orders. They found out that 56% of the patients with do-not-intubate orders survived to be discharged from hospital and 32% survived at 1 year. Also, in this review, the authors found that NPPV patients with comfort measures only were associated with slightly lower breathlessness scores and opioid requirements compared with standard oxygen treatments. Earlier studies indicate that NPPV may alleviate breathlessness and hypercapnia if combined with long-term oxygen treatment [1, 10].

Chest Wall and Neuromuscular Disorders

The mechanisms of dyspnea are complex in these disorders. Patients often describe their breathing as shallow or requiring undue effort, a consequence of increased neural drive despite normal respiratory system mechanics [6]. Hypoventilation during night is a major cause of sleep fragmentation and is very prevalent in chest wall and NMDs. Overnight oximetry is part of the guidelines' recommendations for the management of these patients.

Amyotrophic lateral sclerosis (ALS) is a degenerative motoneuron disease inducing rapidly progressive paralysis of the limbs, bulbar muscles and respiratory muscles. In ALS progressive degeneration of phrenic motoneurons results in diaphragmatic muscle impairment [11]. In 2020 Arnulf et al. published an important paper demonstrating a reduction of survival of ALS patients due to diaphragmatic involvement providing a major argument in favor of the use of NPPV in these patients [12]. Several studies have corroborated the use of NPPV in ALS showing an improvement in survival, quality of life and cognitive performance even in patients with bulbar involvement [11].

It is important to notice that although NPPV may improve survival, patients with chest wall disorders and especially NMDs have a reduced overall survival. Even

though NPPV may have a palliative role improving quality of life, sometimes these patients reach a point in their lives when they no longer wish to be supported by NPPV. As mentioned before in this chapter, the healthcare providers must communicate with the patient and his family to understand the reasons for the wish to stop NPPV and be sensitive enough to understand that NPPV may sometimes not promote comfort. Patient's autonomy to take this decision should be evaluated and dialog around this issue should start early in the disease course [6].

Advanced Cancer

Despite best possible medical management, many patients with solid tumors develop respiratory symptoms and dyspnea and are often breathless, especially in the later stage of the disease. The intensity of breathlessness in patients receiving palliative care often worsens the closer an individual comes to the end of their life, and it is an independent predictor of poor prognosis. Opioids may offer symptomatic improvement in earlier stages but in later stages, they may not be enough. Some studies have shown that NPPV might be an alternative option to relieve dyspnea in these patients [13, 14]. Most patients and relatives want to ensure comfort in the later stage of their life. NPPV would be an important tool in this context if healthcare achieves the goal to alleviate breathlessness and respiratory distress in the patients without provoking negative effects of the NPPV. Stefano Nava et al. published a study in 2013 suggesting that NPPV is more effective compared with oxygen in reducing dyspnea and decreasing the doses of morphine needed in patients with end-stage cancer and ARF. According to this study, the sensation of breathlessness might be related to other factors than low oxygen saturation. These factors include comorbid lung or heart disease, acute sepsis, cachexia, depression, anxiety and respiratory muscle weakness due to difficulty in breathing. The NPPV provides inspiratory and expiratory aid reducing the sense of breathlessness in these settings. Also, NPPV improves gaseous exchange more quickly than oxygen therapy, improving therefore central and peripheral perfusion, circulation and muscle metabolism [13].

There are some concerns about the risks and limitations of NPPV in patients with terminal cancer. As already discussed before in this chapter, NPPV's aim in palliative setting is to improve quality of life through symptom relief and not to prolong life, especially if the patient is suffering. Also, there are some complications that may occur with NPPV that undermine its initial purpose as a palliative measure [6] (Table 27.2). Healthcare professionals should be trained in NPPV in order to offer the best interface to deliver NPPV in each patient and minimize these complications. The use of a wrong interface is one of the most common reasons for NPPV intolerance.

Table 27.2 Main complications related to Noninvasive Positive Pressure Ventilation

Possible complications of noninvasive positive pressure ventilation
Facial skin breakdown (e.g.: nasal bridge ulcer)
Discomfort
Aspiration
Claustrophobia
Aerophagia
Dryness of mucous membranes
Persistent leak
Inability to talk or eat
Secretions clearness

Position of Learned Societies Regarding NPPV

In 2007, the Society of Critical Care Medicine charged a Task Force to provide guidance for the use of NPPV in palliative care settings [2]. This Task Force suggested an approach for deciding when to offer NPPV for patients for whom endotracheal ventilation is not an option for varied reasons. A daily evaluation of NPPV purpose is necessary with this approach, and patients are classified into three groups: Group 1, NPPV as life support for patients without treatment limitation decisions; Group 2, NPPV as life support for patients with do-not-intubate decisions, under the rationale that the adverse effects of NPPV are acceptable given the expected survival benefits; Group 3, NPPV as palliative measures in patients receiving comfort care only. Most of the group 3 patients, with the support of their families, are interested in ensuring comfort while dying but others may also be interested in prolonging their lives for a few hours preserving their cognition and ability to communicate. In this context, NPPV would be considered effective if it improves breathlessness and respiratory distress without causing other consequences such as discomfort or unduly prolonging life [3, 7]. Overall, studies support the use of NPPV for palliative purpose. Although ERS/ATS guidelines of noninvasive ventilation for ARF emphasize the need for appropriate patient selection and staff training, they suggest offering NPPV to dyspneic patients for palliation in the setting of terminal cancer or other terminal conditions (conditional recommendation, moderate certainty of evidence) [7].

Conclusion

Despite a vast number of diseases that can lead to respiratory failure NPPV has only been extensively studied in COPD, chest wall and NMDs and advanced cancer. Data are quite limited on the palliative role of NPPV in bronchiectasis and interstitial lung diseases.

Most of the investigation has been done in ICU focusing on survival as the main endpoint instead of the use of NPPV for palliative care. The few studies done so far support the use of NPPV for palliation in selected patients and learned societies recognize the use of palliative NPPV. However, there is still a lack of qualitative

studies. More investigations should be done to identify the actual benefits of palliative NPPV, within and outside the hospital, that are not related to survival. Also, they should examine the perspectives of patients, families and clinicians on issues such as symptoms, communication, satisfaction, harms and quality of end-of-life care.

Healthcare professionals should be aware of the goals of care when NPPV is used for patients that have decided to forego endotracheal intubation. Exploring patients' and families' fears and questions should be done at an early stage of illness.

Key Messages

- Communication between healthcare professionals and patients about the use of NPPV to palliate dyspnea should occur early in the course of progressive illnesses.
- Healthcare providers should explore patients' and families' fears and questions about palliative care and the decisions that were made may change over time.
- Learned societies such as ERS/ATS recognize the use of palliative NPPV for dyspneic patients for palliation in the setting of terminal cancer or other terminal conditions.
- More investigations should be done to identify the actual benefits of palliative NPPV that are not related to survival.

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Noninvasive Ventilation in the Respiratory Rehabilitation Unit

28

Rosana Mara da Silva and Thales Cantelle Baggio

Abstract

Noninvasive artificial ventilatory support for critically ill patients has evolved and numerous evidence have emerged, having an impact on improving survival and the quality of care offered in rehabilitation units, with the role of the physical therapist integrating the support team and directing the work together with the medical team. Noninvasive ventilation has been suggested as an additional therapy to improve the patient's functional capacity and life quality.

Keywords

Noninvasive ventilation · Rehabilitation unit · Pulmonary rehabilitation · Physical therapy · Respiratory pathologies

Introduction

Noninvasive ventilation (NIV) is currently employed for weaning from invasive mechanical ventilation (IMV) in the acute setting. The use of NIV in general wards, that is, in a rehabilitation unit (RU), may be an alternative for some patients, but it has rarely been described and is not used worldwide [1].

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In the RU, the use of NIV by the physical therapist in the cardiopulmonary rehabilitation process became evident during the Covid pandemic in 2020, due to the general situation triggered by this pathology and its repercussions in the post-Covid period. However, eligible patients in these intra-hospital units are all those who need cardiopulmonary, neurological, post-surgical and palliative care rehabilitation support. These are patients from the intensive care unit (ICU), post-cardiac surgery and general surgery patients, which do not meet the criteria for ICU but require intensive care from physiotherapy, due to the use of NIV.

The RU has a multidisciplinary team, which includes doctors, nurses, physiotherapists, speech therapists, psychologists and occupational therapists, each performing his/her role, with the physiotherapist being responsible for the care and administration of NIV, associating its use to the care protocol in the rehabilitation process. The indication is discussed and evaluated together with the doctor, analyzing its applicability in the patient's recovery process.

The physical therapist acts in the choice of parameters and interface, analyzing together with the doctor the need and its applicability. NIV is part of the rehabilitation process applied by the physical therapist in various conditions such as chronic respiratory failure (chronic obstructive pulmonary disease (COPD)), obstructive sleep apnea, acute respiratory failure (ARF), heart failure (HF) (NIV can improve the cardiac and respiratory performance of these patients), neuromuscular and restrictive respiratory diseases.

NIMV in Respiratory Rehabilitation Unit

Noninvasive mechanical ventilation should be the first line of treatment in ARF and the standard care in severe exacerbations of COPD, acute cardiogenic pulmonary edema and in immunosuppressed patients [2].

NIV is performed entirely spontaneously, through pressure support application (continuous or bi-level), an inspiratory pressure is used (IPAP and/or PSV) and a positive expiratory pressure to maintain the airway and open alveoli (EPAP and or PEEP), improving oxygenation. The CPAP is used through nasofacial interfaces [3, 4].

As a result, NIV decreases muscle work and improves gas exchange by recruiting hypo-ventilated alveoli. In addition, it maintains natural defense barriers, reduces the need for sedation, shortens the period of mechanical ventilation and can even avoid the process of orotracheal intubation and its complications, such as ventilation-associated pneumonia (VAP) [4, 5].

Respiratory rehabilitation is a comprehensive therapeutic approach focused on individualized assessment and treatment to improve or maintain the physical, social and mental health of people with lung disease. It includes physical training, education and lifestyle modification and aims to improve the overall health of patients with lung disease. Physiotherapy techniques are particularly relevant in the rehabilitation of patients with respiratory problems [6].

The use of NIV, as well as its various modalities, was disseminated in a complementary way to conventional techniques during respiratory physiotherapy, one of the specialties of physiotherapy used in the RU. NIV in respiratory therapy optimizes lung re-expansion, assists in the removal of secretions and decreases the respiratory work during respiratory muscle training, which aims to increase the patient's tolerance to the treatment, reducing the sensation of dyspnea [7].

NIV can significantly increase exercise tolerance in patients with acute exacerbations of chronic respiratory disease by reducing exercise desaturation. Exercise with NIV is practical, safe and well tolerated without significant adverse events [7].

The programs started at the RU are maintained with home exercise programs, presenting benefits in the prevention and improvement of muscle strength, activities of daily living, independence and functionality.

Model Applied in a Rehabilitation Unit

(Rehabilitation Unit of the Alcides Carneiro University Hospital of the Federal University of Campina Grande/PB)

In the RU, it is extremely important to define NIV indications and contraindications (Table 28.1).

NIV can be indicated by having as reference values:

- $PCO_2 > 45$ mmHg.
- $PaO_2/FIO_2 < 200$.
- $PaO_2 < 60$ mmHg in room air.
- FR > 30 irpm.
- $SPO_2 < 90\%$.

Table 28.1 Contraindications to NIV

Absolute
• Need for emergency intubation
• Cardiac or respiratory arrest
Relative
• Inability to cooperate, protect the airway, or copious secretions
• Lowered level of consciousness (except hypercapnic acidosis in COPD)
• Non-respiratory organ failure (encephalopathy, malignant arrhythmias, or severe gastrointestinal bleeding with hemodynamic instability)
• Facial or neurological surgery
• Facial trauma or deformity
• High risk of aspiration
• Upper airway obstruction
• Recent esophageal anastomosis (avoid pressurization above 20 cmH_2O)

Source: Barbas et al. (2014) [8]; Sarmento (2015) [9]

Models of Performance with NIV in the Rehabilitation Unit

Exacerbation of Chronic Obstructive Pulmonary Disease

In COPD exacerbation, NIV can be used in bilevel mode to avoid the need for orotracheal intubation (OTI) and improve prognosis [4, 9] (Table 28.2).

Cardiogenic Pulmonary Edema

The use of NIV reduces the need for orotracheal intubation (OTI) in patients with cardiogenic pulmonary edema, in association with standard drug therapy, except in patients with shock or acute coronary syndrome who need to be surgically treated urgently [4].

It has been shown that the effectiveness of NIV using bilevel mode is similar to CPAP mode on cardiac performance, referring to OTI rates, time and hospital mortality. However, the bilevel mode showed greater benefit in the respiratory condition, reducing the work of breathing and the sensation of dyspnea more quickly [4, 10].

The NIV (biphasic positive pressure ventilation [BIPAP], with positive expiratory pressure [PEP] of 5 to 10 and positive inspiratory pressure [PIP] up to 15 cmH_2O, and/or CPAP of 5 to 10 cmH_2O) should be used in patients with acute pulmonary edema of cardiogenic origin aiming to decrease the need for endotracheal intubation and reduce hospital mortality [9].

Asthmatic Exacerbation

NIV can be used together with conventional drug treatment for patients with exacerbation of the asthmatic process, aiming to improve respiratory flow limitation and reduce respiratory effort [4, 9]. Patients who received NIV were shown to have more rapid improvement in symptoms after NIV administration for 3 consecutive hours [4, 11].

Table 28.2 NIV indications and contraindications in COPD exacerbation

Indications	• Respiratory failure • Use of accessory muscles and paradoxical movement • Moderate to severe respiratory acidosis (pH < 7.35) • FR > 25 bpm
Contraindications	• Apnea, hypopnea and hemodynamic instability (hypotension and severe arrhythmias) • Inability to protect the airways: Vomiting, lowered level of consciousness, agitation • Excessive secretion with risk of aspiration

Source: Barbas et al. (2014) [8]

Patients who did not improve within the second hour of use or patients who experienced clinical worsening at any time (lowering of consciousness, worsening dyspnea and psychomotor agitation) should be recommended for orotracheal intubation [4, 9].

Immediate Postoperative

NIV can be used to treat hypoxemic respiratory failure in the immediate postoperative period of elective upper abdominal and thoracic surgery. The use of NIV in the postoperative period must be used with caution, respecting the limitations and contraindications for its use [4].

In the postoperative period of gastrectomy, if there is a careful evaluation of the patient, the CPAP can be used, being limited to 7.5 cmH_2O or even a PIP of 15 cmH_2O and a PEP of 5 cmH_2O [4, 9].

The use of NIV is still discussed in esophagectomies, and some studies have already shown that an anastomosis can tolerate pressures higher than those transmitted to the esophagus during NIV. Pressures must be maintained with a maximum PIP of 15 cmH_2O and a maximum PEP of 5 cmH_2O. Thus, the cost-effectiveness of NIV should be evaluated individually in each patient undergoing this type of surgical procedure [4, 9].

In esophageal surgeries, NIV can be used to avoid ARF, maintaining lower inspiratory pressures (PEP < 8 cmH_2O and PIP < 15 cmH_2O). The same suggestion is valid for thoracic surgery, abdominal surgery, cardiac surgery and bariatric surgery [9].

Acute Respiratory Distress Syndrome

NIV should be used in acute respiratory distress syndrome (ARDS), especially in cases of mild ARDS, with the care to observe the success goals of 0.5 to 2 h. In case of failure, avoid delaying intubation [9].

In severe ARDS, avoid using NIV, due to the high rate of respiratory failure and the need for OTI, especially in patients with PaO_2/FIO_2 < 140 and Simplified Acute Physiology Score (SAPS) II >35 [4, 8, 9].

Severe Community-Acquired Pneumonia

NIV can be used in severe community-acquired pneumonia (CAP) with hypoxemic respiratory failure, especially in patients with concomitant COPD, observing the success goals of 0.5 to 2 h. If unsuccessful, avoid delaying intubation [9].

Patients in Palliative Care

NIV can be used in terminal patients when the cause of the respiratory failure presented is potentially reversible, and not just the final evolution of pulmonary or extrapulmonary disease [4].

Post-Extubation

NIV should be used to shorten the duration of invasive ventilation (an action that facilitates the withdrawal of NIV), reduce mortality, decrease the rates of MV-VAP, generating fewer days of hospitalization in the ICU and hospital in the population of hypercapnic COPD patients [9].

NIV can be used preventively to avoid post-extubation ARF. Some factors can be considered risk factors in extubation, thus indicating the use of preventive NIV [4, 9]:

1. Patients over 65 years old.
2. More than one extubation failure.
3. Chronic HF.
4. Hypercapnia.
5. Ineffective cough.
6. Ventilation time over 72 h.
7. Patients with neuromuscular diseases.
8. Obese.

NIV should be assessed between 30 min and 2 h. In case of failure, the orotracheal intubation should be recommended [9].

NIV use should be monitored by a healthcare professional at the bedside for 30 min to 2 h. To be considered successful, the following items must be observed [4]:

1. Decreased respiratory rate (RR).
2. Increase in tidal volume (TV).
3. Improved level of consciousness.
4. Decrease or cessation in the use of accessory muscles.
5. Increase in PaO_2 and/or SpO_2.
6. Decreased $PaCO_2$ without significant abdominal distention.

When unsuccessful, immediate orotracheal intubation and invasive ventilation are recommended. Success is expected in the hypercapnic population with the use of NIV in 75% of cases, and in hypoxemic in about 50% [4, 8, 9].

Conclusion

NIV is a viable and beneficial tool in the RU based on pulmonary rehabilitation, being an important support in the hospital environment. Patients who need NIV benefit from a structured program of pulmonary rehabilitation, with improvement in functional capacity and health-related quality of life.

The use of NIV in a rehabilitation program has become widely publicized, serving a wide spectrum of pathologies, with the role of the physical therapist as fundamental in its applicability and follow-up. The turning point for the successful expansion of NIV is its ability to achieve the same physiological effects as IMV while avoiding the life-threatening risks correlated with the use of an artificial airway.

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Noninvasive Mechanical Ventilation During Intrahospital Transport

29

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Abstract

Intrahospital transport of critically ill patients from the emergency room to intensive care units or for diagnostic and treatment procedures that cannot be performed at the bedside in the intensive care and emergency room is frequently performed. In-hospital transfers are also common in patients with respiratory failure undergoing NIMV. Noninvasive ventilation (NIMV) is often performed in emergency rooms, pulmonology departments, and intensive care units in patients with respiratory failure. Physiological reserve may be deficient or decreased in these patients. In-hospital transfer risks are higher, and significant clinical complications may occur. Monitoring the patient by medical personnel during transfer and controlling the equipment reduces the risk. When transferring critically ill patients undergoing NIMV within the hospital, the risks and benefits of the transfer should be carefully reviewed.

Keywords

Respiratory failure · Noninvasive ventilation · Intra-hospital transport · Emergency department · Intensive care unit

Introduction

Transfer of critically ill patients for diagnostic studies, therapeutic or surgical procedures that cannot be performed at the bedside in the intensive care or emergency room is frequently required. Transfers may be to the radiology department,

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operating room, or other locations within the hospital to receive special diagnostic or therapeutic procedures.

Noninvasive ventilation (NIMV) is a respiratory support device proven to be effective in patients with acute respiratory failure of various etiologies. Its application in both prehospital and hospital settings reduces the need for invasive mechanical ventilation (IMV) and admission to the intensive care unit (ICU), especially in selected cases of acute cardiogenic pulmonary edema or exacerbation of chronic obstructive pulmonary disease [1, 2]. Transfers of this group of patients within the hospital are often required. With the wide variety of ventilator devices available today, patients can be transferred to different parts of the hospital without changing the modality and parameters of respiratory support.

In-hospital transport of critically ill patients has been associated with significant clinical complications. Even with the best planning, personnel, and equipment, there may be times during a transfer where monitoring can be difficult and the ability to manage emergencies may be limited. Mechanical ventilation may further increase the incidence of transfer-related adverse events [3, 4]. Even the shortest transfer can cause life-threatening complications [5]. In the studies conducted, adverse events were reported in 70% of in-hospital transfers, and these problems were categorized as patient related, equipment related, or environmental [6–9].

Monitoring of the patient by experienced staff during transfer also reduces the risk. Faster transport times and expert transfer teams are associated with better results. The architectural structure of the hospitals and the time to reach the target place significantly affect the exposure time to possible negative effects during treatment [3, 10, 11].

The development of adverse events can be prevented by checking equipment before patient transfer, monitoring the patient during patient transfer, finding appropriately qualified personnel, better planning, and communication.

Patient Selection to Be Transferred with NIMV

NIMV is the exact requirement for patients with respiratory failure who are conscious, hemodynamically stable, and able to maintain their airway [12].

Patients with inadequate response despite NIMV application, patients with dyspnea continuing despite ventilator application, patients with ventilator asynchrony, and patients who are agitated despite appropriate sedation application are risky patients in terms of transfer. After these patients are stabilized, their transfer should be considered. However, patient-related risk factors (such as high disease severity scores, ventilation with high positive end-expiratory pressure (PEEP), in-hospital sedation before transport, antihypertensive drugs, and body weight are factors that contribute to adverse events in intrahospital transfer [13–16].

Accompanying Personnel

Physician making the decision to transfer a critically ill patient within a facility should consider the risks and benefits of transfer. Unstable patients should be stabilized before transfer. It is essential that everyone involved in the care of critically ill patients has a basic understanding of the transport environment, personnel, equipment, and vehicles. The transfer of patients undergoing NIMV is performed by a doctor, nurse, and medical transplant officer. These personnel are well trained in airway management, advanced cardiac life support, critical care training, or equivalent. It is recommended to have clear instructions and a simple flowchart illustrating their role. These schematics should be easy to access.

The risks and benefits of transfer should be explained to the relatives of the patients. Informed consent should be obtained prior to pretransfer procedures or diagnostic tests. During the transfer of the patient, a patient transfer form should be prepared that will include the patient's medical history, vital signs, ventilator settings, treatment, and important events during the transfer. The team in the reception unit should have sufficient information about the patient and should be in direct communication with the transfer team. It should be reminded in advance that there are enough personnel in the reception unit. The admissions team should transfer the patient to bed and review ventilation parameters if necessary.

Equipment and Monitoring

It is important for the personnel involved in the transfer to familiarize themselves with the modalities, interfaces, accessories of NIMV, and solve any problems that may arise. A blood pressure monitor (or standard blood pressure cuff), cardiac monitor/defibrillator, pulse oximeter, capnography, airway equipment, and oxygen supply should be present during the transfer. Availability of a memory-capable monitor allows data to be reconsidered. Essential resuscitation medications are carried with each patient.

Equipment should be light and strong and easily transportable through corridors and elevators. Equipment placed on stands or attached directly to the bed can reduce transfer problems. There are several types of ventilators administered with NIMV. Portable mechanical ventilators are frequently used during transfer.

It is important to check the charging times of the devices and the condition of the oxygen cylinders before the transfer takes place.

There are different types of interfaces and ventilator modalities for NIMV. The modalities that the patient adapts to should be preferred and alarm settings should be adjusted. It is important that the ventilator interfaces comply with the characteristics of the ventilator system. Ventilator connections should be checked frequently, and airway pressures should be observed. Frequent displacements and air leaks can occur in the mask. The mask should be properly placed on the patient's face before the transfer and should be constantly checked during the transfer. Appropriate mask

and interface selection prevents unwanted air leaks and increases patient comfort [17].

Patients undergoing NIMV are monitored in terms of dyspnea and comfort in addition to basic physiological monitoring such as electrocardiographic monitoring, pulse oximetry, capnography, blood pressure monitoring, and respiratory rate monitoring during transfer.

Intrahospital Transfer Coordination

Communication and coordination are key to the success of a safe in-hospital transfer. Proper planning, training, suitably qualified personnel, and equipment can minimize risk. It ensures that there is no interruption in the monitoring or maintenance of the patient's vital functions during the transfer.

Hospital-wide guidelines for transferring patients within the hospital can greatly help ensure patient safety for transport. Thus, many transfer-related complications can be prevented, patient flow can be improved, and delays can be reduced. Before the transfer, providing detailed information about the patient to the receiving unit allows you to immediately review the diagnostic procedures, as well as eliminate the need for a second transfer. Hospital security and other allied health personnel should be informed about the patient and should secure the instruments related to patient transportation.

The team at the point of admission should review the patient's treatment plan through physician-physician and/or nurse-nurse communication, thus ensuring continuity of patient care.

Summary

Patients undergoing NIMV should be comprehensively evaluated for the risks and benefits associated with transfer and stabilized prior to transfer. The transfer team should consist of experienced people who have received adequate training in NIMV, airway management, and cardiopulmonary resuscitation. It is important to know the characteristics of the equipment to be used in the transfer well, and it should be checked frequently during the transfer. Patient transfer form records should be kept to cover important events during the transfer. Periodic training programs should be organized on the subject of NIMV.

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Models of Noninvasive Mechanical Ventilation in Pandemic Conditions

30

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Abstract

SARS-CoV-2 pneumonia can be associated with hypoxaemia, which can be very severe and lead to death. Treatment of hypoxaemia with oxygen therapy and respiratory support is therefore key to prevent mortality. In most cases, hypoxaemia can be adequately controlled with conventional oxygen therapy (COT) in a conventional hospitalisation area. However, in a minority of cases, hypoxaemia worsens and escalation to noninvasive respiratory support (NIRS) devices is necessary: high-flow nasal cannula (HFNC), continuous positive airway pressure (CPAP), bilevel positive airway pressure (BPAP); under close monitoring in an intermediate respiratory care unit (IRCU). Early initiation of NIRS is of vital importance in order to halt the progression of hypoxaemia and, consequently, to avoid escalation to orotracheal intubation-invasive mechanical ventilation (OTI-IMV), with the complications that this entails (bacterial pneumonia associated with IMV, nosocomial infections, polyneuromyopathy etc.). The main criteria to proceed with escalation from COT to NIRS is the need for an $FiO_2 \geq 0.40$ under COT to maintain an $SpO_2 \geq 94\%$; other criteria are a PaO_2/FiO_2 ratio ≤ 200, a tachypnoea >25 breaths/min and the use of accessory respiratory musculature. HFNC or CPAP can be used alone or in alternating combination, with the combination being preferred in more severe cases ($SpO_2 < 92\%$ despite HFNC, PaO_2/FiO_2 ratio < 100, tachypnoea > 25 breaths/min and/or use of accessory respiratory musculature despite HFNC) and in subjects with obesity (BMI > 30 kg/m^2) or with sleep apnoea. Prone decubitus sessions are recommended, especially under HFNC, to increase oxygenation and thus avoid OTI-IMV. The most impor-

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tant parameters that allow us to assess the patient's response to NIRS are the PaO_2/FiO_2 ratio (or, failing that, the SpO_2/FiO_2 ratio), the respiratory rate (RR), the use or non-use of accessory respiratory muscles, and the dyspnoea. Others are the alveoloarterial oxygen gradient, the HACOR index, the ROX index and the oesophageal pressure. It is reasonable to allow a window of opportunity of 48–72 h for NIRS from its initiation before considering escalation to OTI-IMV, without entailing to a significant delay in OTI-IMV leading to a significant impact on mortality in the case of NIRS failure; the benefit of avoiding OTI-IMV (which is avoided in 74.4% of cases) is considered much greater in the event of successful NIRS. After 48–72 h, if the patient remains the same or even worsens ($SpO_2 < 92\%$, PaO_2/FiO_2 ratio ≤ 100, decreasing curve in SpO_2 even though SpO_2 is $\geq 92\%$, tachypnoea >25 breaths/min, use of accessory respiratory muscles), despite optimised NIRS (with high FiO_2 and high flows or pressures), OTI-IMV will be performed, since after this time the probabilities of successful NIRS are low and, in contrast, the delay in OTI-IMV becomes significant and, consequently, will have a significant impact on mortality. Finally, in case of successful NIRS, de-escalation from NIRS to COT will generally be performed when NIRS can be lowered to an $FiO_2 \leq 0.40$ so that the patient maintains an $SpO_2 \geq 92\%$, a RR ≤ 25 breaths/min and no accessory respiratory muscle use for at least 30 min.

Keywords

COVID-19 · SARS-CoV-2 pneumonia · Conventional oxygen therapy · Acute respiratory distress syndrome · Noninvasive respiratory support · High-flow nasal cannula · CPAP · BPAP · Prone position · Orotracheal intubation · Invasive mechanical ventilation · Mortality

Abbreviations

ARDS	Acute respiratory distress syndrome
BMI	Body mass index
BPAP	Bilevel positive airway pressure
bpm	Breaths/minute
cmH_2O	Centimetres of water
COT	Conventional oxygen therapy
COVID-19	Coronavirus disease 2019
CPAP	Continuous positive airway pressure
EPAP	Expiratory positive airway pressure
FiO_2	Inspiratory oxygen fraction
H	Hour
HACOR index	Heart rate, acidosis, consciousness, oxygenation, respiratory rate
HFNC	High-flow nasal cannula
ICU	Intensive care unit

IMV	Invasive mechanical ventilation
IPAP	Inspiratory positive airway pressure
IRCU	Intermediate respiratory care unit
kg	Kilogram
L	Litre
lpm	Litres/minute
min	Minute
ml	Millilitre
mmHg	Millimetres of mercury
NIRS	Noninvasive respiratory support
NIV	Noninvasive ventilation
OTI	Orotracheal intubation
$PaCO_2$	Arterial partial pressure of carbon dioxide
PAFI	PaO_2/FiO_2 ratio
PaO_2	Arterial partial pressure of oxygen
PEEP	Positive end-expiratory pressure. PEEP = EPAP
Pplat	Plateau pressure
PS	Pressure support = IPAP – EPAP
P-SILI	Patient self-inflicted lung injury
ROX index	(SpO_2/FiO_2)/RR ratio
RR	Respiratory rate
SAFI	SpO_2/FiO_2 ratio
SARS-CoV-2	Severe acute respiratory syndrome coronavirus 2
SpO_2	Oxyhaemoglobin saturation
VT	Tidal volume

Organisational Scheme in the Care of Hospitalised Patients During the COVID-19 Pandemic. The Nurse Isabel Zendal Emergency Hospital in Madrid (Spain) as a Reference Model

Below we show a diagram that summarises very adequately the organisation of care for patients hospitalised by COVID-19 in pandemic conditions (Fig. 30.1). For this purpose, we have taken as a reference model the organisational scheme of the Nurse Isabel Zendal Emergency Hospital in Madrid (Spain), a COVID-19 monographic hospital built following the outbreak of the COVID-19 pandemic, which has provided care to COVID-19 patients from December 2020 to March 2022 and which has had the largest IRCU in Europe, where up to 96 patients have been admitted simultaneously and where more than 1800 patients have been admitted throughout this period [1].

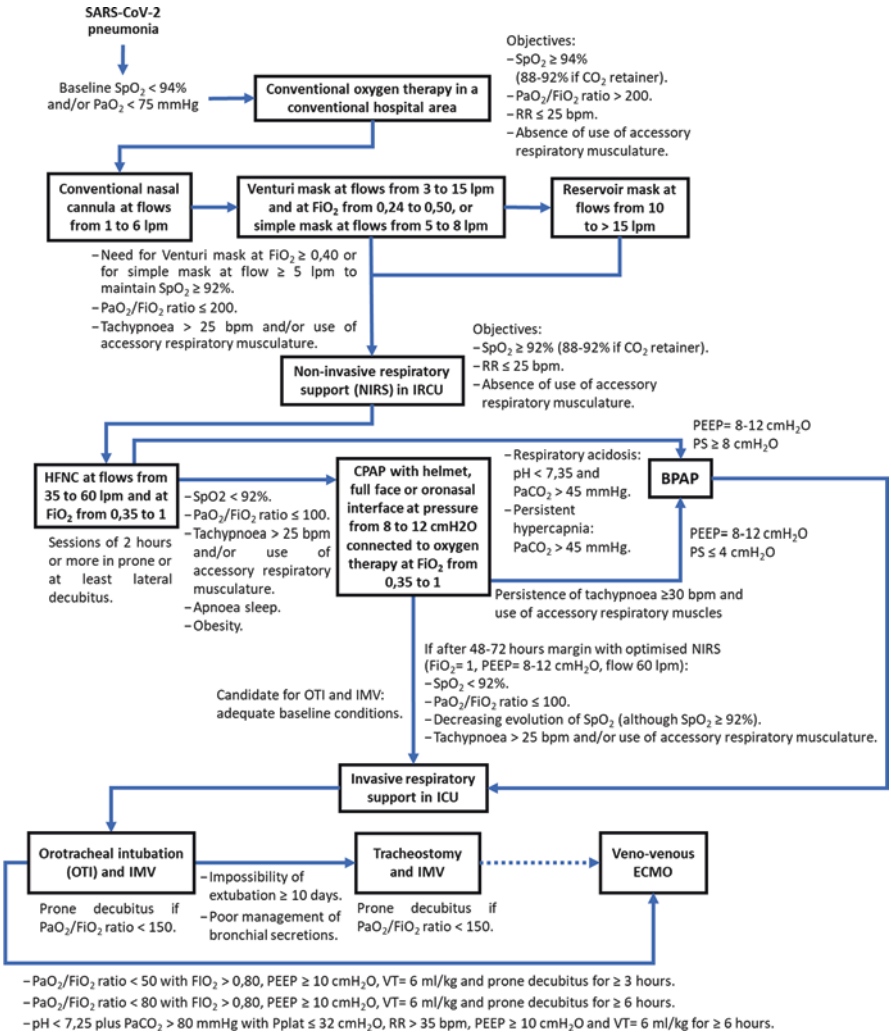

Fig. 30.1 Management algorithm of patients hospitalised for SARS-CoV-2 pneumonia with hypoxaemia: place of patient admission within the hospital and oxygen and respiratory support therapies employed

Noninvasive Respiratory Support in the COVID-19 Pandemic: A Paradigm Shift in the Treatment of Adult Acute Respiratory Distress Syndrome

Orotracheal intubation (OTI) followed by invasive mechanical ventilation (IMV) has always been the classic mainstay in the treatment of adult acute respiratory distress syndrome (ARDS) [2–4]. The use of noninvasive respiratory support (NIRS) devices (high-flow nasal cannula [HFNC], continuous positive airway

pressure [CPAP] and bilevel positive airway pressure [BPAP]) was considered to delay OTI-IMV (without being able to avoid it) and, as a consequence, to lead to increased mortality, so that the use of NIRS in the treatment of ARDS was not usually recommended, that is to say, direct escalation from COT to OTI-IMV was advised when hypoxaemia worsened and developed into ARDS, without first trying NIRS [3, 5]. Mosier et al. [5], in their retrospective observational study of 235 patients admitted to the ICU with ARDS or pneumonia, observed that those patients who received OTI-IMV after NIRS failure, compared to those patients who received OTI-IMV primarily, had significantly higher mortality.

However, it is worth mentioning that most of the existing studies discouraging the use of NIRS in ARDS had a scarce number of patients (high random error) and high heterogeneity (patients receiving NIRS tended to be older and have a higher frequency of comorbidities than patients escalating directly to OTI-IMV) (high selection bias), as reflected in the meta-analysis by Agarwal et al. [6], which consisted of three very different open-label randomised clinical trials and had a small total sample size of 111 patients, and in which they observed that the use of NIRS did not significantly reduce the likelihood of receiving OTI-IMV in patients with ARDS and had no significant effect on survival in ICU.

In the retrospective observational study by Meeder et al. [7], conducted in 173 critically ill patients admitted to the ICU with severe acute respiratory failure (due to ARDS, acute cardiogenic pulmonary oedema, exacerbation of COPD or pneumonia), of whom 133 received NIRS (in 92 the NIRS was successful and in 41 the NIRS failed and escalation to OTI-IMV was made) and 40 received primary OTI-IMV, they observed that patients in whom NIRS failed had worse outcomes (longer ICU stay and higher mortality) compared to those patients in whom NIRS was successful; however, the outcomes of patients in whom NIRS failed and who were then escalated to OTI-IMV were not worse (similar ICU stay and similar mortality) than those of those patients who received primary OTI-IMV. Patients in whom NIRS was successful had better outcomes (shorter ICU stay and lower mortality) not only compared to those patients in whom NIRS failed, but also compared to those patients who received OTI-IMV primarily [7]. In view of these results, it seems appropriate in patients with ARDS to first perform a proof with NIRS instead of considering primary escalation to OTI-IMV, and then, in case of failure of NIRS, to escalate to OTI-IMV [7].

In the wake of the COVID-19 pandemic from December 2019 onwards, the incidence of ARDS increased exponentially. Thus, there were periods in which the number of patients hospitalised for SARS-CoV-2 pneumonia who developed ARDS and therefore required OTI-IMV was enormous, which generated an unassumable pressure on care and occupancy in ICUs. At this time, IRCUs began to play a major role, admitting patients who developed ARDS by COVID-19 to keep them closely monitored and testing NIRS therapies (HFNC, CPAP, BPAP). As a consequence, the number of studies on management of ARDS with NIRS grew enormously [8–21], with a much larger number of patients (lower random error) and higher homogeneity (lower selection bias) in these studies, and even randomised clinical trials were designed [19–21].

As a result, it has been shown that the use of NIRS (HFNC, CPAP, BPAP) in patients with SARS-CoV-2 pneumonia who developed ARDS did not increase their mortality, regardless of whether (because NIRS had failed) or not they ultimately required OTI-IMV, provided that NIRS was initiated in an IRCU environment, and provided that the window of opportunity of 48–72 h from the initiation of NIRS was not exceeded to proceed to escalation to OTI-IMV in ICU in case the response to NIRS was not being adequate [8, 22–26]. Therefore, the initiation of NIRS therapies as a first line of treatment (before OTI-IMV) in ARDS secondary to COVID-19 should be considered. We should bear in mind that patients under OTI-IMV in an ICU have a much higher incidence of complications (pneumonia associated with IMV, urinary tract infection associated with bladder catheters, blood infection associated with vascular catheters, sepsis, other nosocomial infections, polyneuromyopathy, etc.), which can also lead to higher mortality, in addition to an increase in the average hospital stay and a considerable increase in costs [7, 26–29].

Taking into account that the leading cause of mortality in severe COVID-19 is underlying ARDS due to COVID-19, followed by IMV-associated pneumonia and sepsis of in-hospital origin, the management of the severe patient in IRCU under NIRS clearly presents an advantage over the management in ICU under OTI-IMV by avoiding the possibility of IMV-associated pneumonia and having lower incidence of sepsis [7, 26, 29], as well as by reducing the mean hospital stay [7, 26, 27] and even mortality [7, 26]. From a cost point of view, it has been estimated that the use of NIRS in IRCU for the management of severe acute respiratory failure, together with the use of OTI-IMV in ICU when NIRS fails, can save a tertiary hospital about 500,000 euros per year, without increasing mortality [28].

The aims of using NIRS in ARDS by COVID-19 are therefore to try to avoid escalation to OTI-IMV and, consequently, the multiple complications associated with a patient under OTI-IMV mentioned above [26, 29], as well as the associated mortality [7, 26, 29] and the related costs [28], and to reduce the average hospital stay [7, 26, 27].

To achieve these objectives, it is important to establish NIRS early, as soon as hypoxaemia progresses to ARDS, and not to delay it. As the most widely accepted criterion, we should escalate from COT to NIRS when an $FiO_2 \geq 0.40$ under COT is necessary to maintain an $SpO_2 \geq 92\%$ [8, 22], or, more strictly, an $SpO_2 \geq 94\%$ [8, 19, 23, 30].

All of these new findings have led to a paradigm shift in the management of ARDS from a previous model in which primary escalation to OTI-IMV from COT was made to a new model in which escalation from COT to NIRS is made first and, in case of failure of NIRS, escalation from NIRS to OTI-IMV is made afterwards.

In some observational studies conducted in patients hospitalised for SARS-CoV-2 pneumonia with severe hypoxaemia requiring NIRS, really high efficacies in terms of avoiding OTI-IMV with the use of NIRS have been described [9, 31]. Brusasco et al. [31] reported up to 83% avoidance of OTI-IMV under NIRS with CPAP ($n = 64$) (conversely, 17% of OTI-IMV); and Franco et al. [9] 73.4% avoidance of OTI-IMV under NIRS as a whole ($n = 670$) (conversely, 26.6% of OTI-IMV), 75.2% under CPAP ($n = 330$) (conversely, 24.8% of OTI-IMV), 72.3% under

BPAP (n = 177) (conversely, 27.7% of OTI-IMV) and 71.2% under HFNC (n = 163) (conversely, 28.8% of OTI-IMV). Three randomised clinical trials subsequently endorsed these results [19–21]: 66.6% avoidance of OTI-IMV under NIRS with CPAP (n = 380) (conversely, 33.4% of OTI-IMV) and 59.0% under NIRS with HFNC (n = 418) (conversely, 41.0% of OTI-IMV) in the RECOVERY-RS trial by Perkins et al. [19]; 65.7% avoidance of OTI-IMV under NIRS with HFNC (n = 99) (conversely, 34.3% of OTI-IMV) in the trial by Ospina-Tascón et al. [21]; and 70.0% avoidance of OTI-IMV under NIRS with BPAP (n = 54) (conversely, 30.0% of OTI-IMV) and 49.0% under NIRS with HFNC (n = 55) (conversely, 51.0% of OTI-IMV) in the HENIVOT trial by Grieco et al. [20]. Such favourable results in the avoidance of OTI-IMV really encourage the use of NIRS.

In contrast, other studies, all of them observational, found lower percentages of OTI-IMV avoidance with the use of NIRS [12, 13, 32, 33]: 38% under CPAP (n = 49) (conversely, 62% of OTI-IMV) according to Alviset et al. [32]; 40% under CPAP (n = 52) (conversely, 60% of OTI-IMV) according to Noeman-Ahmed et al. [33]; 44% under HFNC (n = 146) (conversely, 56% of OTI-IMV) according to Demoule et al. [12]; and 49% under HFNC (n = 76) (conversely, 51% of OTI-IMV) according to Bonnet et al. [13]. In any case, these percentages of OTI-IMV avoidance, although smaller, are by no means negligible and therefore continue to encourage the use of NIRS.

In a meta-analysis of 17 observational studies, 3 prospective and 14 retrospective (including several of the previously mentioned observational studies), conducted by the group of Cammarota et al. [34] from 21 February 2020 to 31 May 2020, in a total of 3377 patients hospitalised for severe SARS-CoV-2 pneumonia requiring NIRS, specifically CPAP or BPAP (HFNC was excluded), they found a frequency of receiving OTI-IMV of 25.6% (95%CI 21.4%–30.1%), with a high degree of heterogeneity between studies (I^2 = 86.2%; ranging from 10.9% [95%CI 4.5%–21.2%] to 40.4% [95%CI 27.0%–54.9%] of OTI-IMV), that is to say, 74.4% (95%CI 69.9%–78.6%) of escalations to OTI-IMV were avoided (ranging across studies from 59.6% [95% CI 45.1%–73.0%] to 89.1% [95% CI 78.8%–95.5%] of OTI-IMV avoidance) with the use of NIRS with CPAP or BPAP. The mean time of NIRS use in NIRS responder patients ranged from 2 to 12 days [8, 34]. These data clearly show, therefore, the therapeutic benefit of NIRS and thus strongly support the use of NIRS.

Regarding mortality among patients diagnosed with severe SARS-CoV-2 pneumonia receiving NIRS, specifically CPAP or BPAP, in this same meta-analysis by Cammarota et al. [34] (n = 3377), they observed a mortality throughout hospital admission of 35.7% (95%CI 30.1%–41.4%), with a high degree of heterogeneity between studies (I^2 = 90.4%; ranging from 18.9% [95%CI 11.4%–28.5%] to 74.4% [95%CI 63.2%–83.6%] of mortality). In the study by Franco et al. [9], 30-day mortality was 26.9% under NIRS as a whole (n = 670), 15.9% under HFNC (n = 163), 30.3% under CPAP (n = 330) and 30.5% under BPAP (n = 177). And if we look again at the three clinical trials mentioned above [19–21], in-hospital mortality was 19.8% under CPAP (n = 380) (16.7% at 30 days) and 21.2% under HFNC (n = 418) (18.8% at 30 days) in the RECOVERY-RS trial by Perkins et al. [19]; 28-day

mortality was 8.1% under NIRS with HFNC (n = 99) in the trial by Ospina-Tascón et al. [21]; and in-hospital mortality was 24.0% under NIRS with BPAP (n = 54) (15.0% at 28 days) and 25.0% under NIRS with HFNC (n = 55) (18.0% at 28 days) in the HENIVOT trial by Grieco et al. [20]. Note that the lowest mortality of all the studies mentioned above corresponded to the trial by Ospina-Tascón et al. [21], which was 8.1% at 28 days. In summary, the use of NIRS had demonstrated its efficacy not only in terms of avoiding OTI-IMV, but also in preventing deaths.

If we selected patients who were candidates for OTI-IMV, that is to say, with good baseline conditions (younger age, fully independent baseline life, lower frequency and severity of comorbidities), in-hospital mortality reported in the meta-analysis by Cammarota et al. [34] decreased to 19.0% (95%CI 14.5–23.9%), with a high degree of heterogeneity between studies (I^2 = 83.0%, ranging from 9.8% [95%CI 4.6%–17.8%] to 52.5% [95%CI 39.1%–65.7%] of mortality), with the use of NIRS (specifically CPAP or BPAP), regardless of whether or not these patients were subsequently escalated to OTI-IMV due to insufficiency or not of NIRS, respectively. These results further support, if possible, the recommendation for the use of NIRS in ARDS by COVID-19.

If we selected patients who required escalation to OTI-IMV for insufficiency of NIRS, the in-hospital mortality recorded in the meta-analysis by Cammarota et al. [34] was 44.5% (95%CI 35.6–53.6%), with a high degree of heterogeneity between studies (I^2 = 82.0%; ranging from 17.4% [95%CI 11.6%–25.2%] to 88.2% [95%CI 62.3%–97.9%] of mortality).

And if we selected patients who were not candidates for OTI-IMV, that is to say, with poor baseline conditions (advanced age, frail baseline life and major comorbidities), the in-hospital mortality reported in the meta-analysis by Cammarota et al. [34] was 71.7% (95%CI 65.1–77.9%), with a moderate degree of heterogeneity between studies (I^2 = 65.0%; ranging from 26.7% [95%CI 8.9%–55.2%] to 90.9% [95%CI 57.1%–99.5%] of mortality), with the use of NIRS (specifically CPAP or BPAP). In other words, 28.3% (95%CI 22.1–34.9%) of in-hospital deaths were avoided with the use of NIRS (specifically CPAP or BPAP), which also translates into a significant effectiveness of NIRS in avoiding deaths in those patients who are not candidates for OTI-IMV and thus encourages the use of NIRS in these patients and not to leave them helpless.

The Escalation from Conventional Oxygen Therapy to Noninvasive Respiratory Support

Treatment of hypoxaemia by oxygen therapy and respiratory support is the most important aspect in the management of SARS-CoV-2 pneumonia, since hypoxaemic hypoxia is the cause of mortality in practically all cases of SARS-CoV-2 pneumonia that reach severe stages [8, 22, 23, 35]. Thus, PaO_2, or SpO_2, or better still, the PaO_2/FiO_2 ratio (PAFI), or the SpO_2/FiO_2 ratio (SAFI), is the main prognostic marker in these patients [8, 22, 23]. In addition, hypoxaemia has also been shown to promote the pulmonary inflammatory response responsible for ARDS by causing

cell necrosis, as well as triggering the activation of hypoxia-inducible factor 1-alpha (HIF-1α) gene expression [36–38]. Both phenomena lead to the synthesis of pro-inflammatory cytokines, which also leads to a higher mortality [36–38]. On the other hand, the intense respiratory work (tachypnoea, use of accessory respiratory musculature), through an increase in transpulmonary pressure, causes lung damage to the patient, known as P-SILI (patient self-induced lung injury), which also leads to an aggravation of ARDS and thus to an increase in mortality [8]. From all this, we can see the transcendental importance of acting early in the establishment and optimisation of oxygen and respiratory support therapies in the face of hypoxaemia, in order to try to avoid death [8, 22, 23].

The indication for oxygen therapy in patients diagnosed with SARS-CoV-2 pneumonia is established in the presence of hypoxaemia with a baseline $SpO_2 < 94\%$ or a baseline $PaO_2 < 75$ mmHg [23, 30]. In that case, we will start COT in the conventional hospitalisation area, in the following order of escalation, the target being an $SpO_2 \geq 94\%$: (a) conventional nasal cannula (at flow rates from 1 to 6 L/min); (b) simple mask (at flow rates from 5 to 8 L/min) or Venturi mask (at flow rates from 3 to 15 L/min and FiO_2 from 0.24 to 0.50); (c) reservoir mask (at flow rates from 10 to >15 L/min) [22, 23, 30]. COT is usually sufficient in most cases of hypoxaemia due to SARS-CoV-2 pneumonia [8]. These cases are included in stage II (pneumonic phase) of COVID-19 (14% [39]), especially in sub-stage IIb, in which the phenomenon of inflammatory hyper-response rather than viral replication begins to predominate [35]. In most cases in subphase IIa, where viral replication predominates over inflammation, patients have SARS-CoV-2 pneumonia but are normoxaemic and therefore do not require oxygen therapy; a minority have mild hypoxaemia and require COT, in particular, conventional nasal cannula [35]. Patients in stage I of COVID-19 (early infection), who represent the vast majority (81%) [39], do not have pneumonia (only have upper airways infection) and therefore do not require hospital admission or oxygen therapy [35].

However, in a minority of cases (5%), hypoxaemia in SARS-CoV-2 pneumonia progresses and is not controllable with COT alone and escalation to NIRS is necessary [39]. This is the most advanced stage of COVID-19 (stage III), the adult acute respiratory distress syndrome (ARDS) phase, characterised by a systemic inflammatory hyper-response ("cytokine storm") [35]. There are three types of NIRS: HFNC, CPAP, BPAP [8, 22, 23].

The patient in need of NIRS will be transferred to an intermediate respiratory care unit (IRCU) for close noninvasive monitoring with electrocardiography and measurement of SpO_2, respiratory rate, heart rate, systemic arterial blood pressure and temperature [8, 22, 23, 27]. Patient monitors will be connected to the nursing control via telemetry in order to be able to detect any incidents instantly. The nurse/patient ratio will be from 1:2 to 1:4 [27]. And the physician/patient ratio will be from 1:2 to 1:6. The nursing and medical staff will be appropriately trained and skilled in the care of the semi-critical patient and the management of the NIRS [27]. The IRCU can be open or closed. If hospital resources permit, we prefer an open IRCU to a closed IRCU, since the proximity between patients, without separate rooms as such, allows us to have a quicker overview of all patients in the IRCU and therefore allows us to keep a better eye on them.

As previously mentioned, severe acute hypoxaemia is the cause of mortality in practically all cases of ARDS secondary to SARS-CoV-2 pneumonia [8, 22, 23], in addition to the fact that it promotes inflammatory hyperresponsiveness in ARDS through both cellular necrosis and activation of HIF-1α gene expression [36–38], which, in turn, leads to higher mortality. And, on the other hand, the intense respiratory work (tachypnoea, use of accessory respiratory muscles), through an increase in transpulmonary pressure, causes lung damage to the patient, called P-SILI (patient self-inflicted lung injury), which also leads to an aggravation of ARDS and, therefore, to an increase in mortality [8]. The establishment of NIRS is intended to mitigate the pathophysiological phenomena mentioned above and thus avoid the progression of ARDS to the stages of OTI-IMV and death. The three types of NIRS (HFNC, CPAP, BPAP), as opposed to COT, achieve better gas exchange (increased oxygenation and greater carbon dioxide washout), as well as providing a certain unloading in the use of the patients' inspiratory respiratory muscles (which alleviates their respiratory work, that is, the reduction of the respiratory frequency and the use of the accessory respiratory muscles) [8]. Thus, it is worth re-emphasising the transcendental importance of early initiation of NIRS, before hypoxaemia and P-SILI progress significantly and it is too late and the patient almost needs to be escalated directly from COT to OTI-IMV within an ICU because the window of opportunity for NIRS efficacy has been missed [8]. The aim of this early initiation of NIRS is to achieve a higher probability of success with NIRS and thus avoid escalation to OTI-IMV and, consequently, the multiple complications (IMV-associated pneumonia, nosocomial infections, polyneuromyopathy etc.) and longer hospital stay associated with a patient under OTI-IMV, while aiming for lower mortality [29].

The essential criterion, based on expert consensus, taken up by the Spanish [22] and European [23] societies of Pneumology, for escalation from COT to NIRS in acute hypoxaemic respiratory failure secondary to SARS-CoV-2 pneumonia is the need for the patient to use a COT device at $FiO_2 \geq 0.40$ (conventional nasal cannula at flows ≥5 L/min, simple mask at flows ≥5 L/min, Venturi mask at $FiO_2 \geq 0.40$ and flows ≥12 L/min, reservoir mask at flows from 10 to >15 L/min) in order to be able to maintain an $SpO_2 \geq 92\%$ [8, 22], or, more strictly, an $SpO_2 \geq 94\%$ [8, 23, 30]. In the case of a patient with carbon dioxide retention (chronic obstructive pulmonary disease, bronchiectasis, neuromuscular disease, rib cage deformity, sleep apnoea, hypoventilation-obesity syndrome, sedatives/hypnotics), the target SpO_2 to be achieved with COT will be between 88% and 92% [30]. Other criteria, under COT, for escalation from COT to NIRS, would be: (a) a PaO_2/FiO_2 ratio ≤ 200; (b) a tachypnoea ≥26 [8, 21] or ≥ 30 [8, 22] breaths/min; (c) use of accessory respiratory musculature (including paradoxical respiration) [8, 22]; (d) pronounced dyspnoea [22]; (e) and acute respiratory acidosis (pH < 7.35 plus $PaCO_2$ > 45 mmHg) [8, 22]. In the last case, that of respiratory acidosis, within the NIRS types, we would escalate directly from COT to BPAP (that is, we would choose BPAP as the type of NIRS) because the patient needs pressure support to be able to wash out excess carbon dioxide and thus solve respiratory acidosis [8, 22]. All these criteria predict a high probability of failure of COT, as well as reflecting the importance of early initiation of NIRS in order to try to achieve a higher probability of success with NIRS and thus avoid escalation to OTI-IMV and death [8, 22, 23].

Below, we will mention several key studies that compare the effectiveness in the avoidance of OTI-IMV and deaths between COT and NIRS in patients meeting these criteria. The RECOVERY-RS open-label randomised clinical trial is the study with the highest validity (lowest bias) and precision (lowest random error) to date examining this question.

In the RECOVERY-RS open-label clinical trial, within its methodology, Perkin et al. [19] selected 1273 patients with SARS-CoV-2 pneumonia with severe hypoxaemia who had an $SpO_2 \leq 94\%$ despite COT at $FiO_2 \geq 0.40$ and randomised them into three groups: COT ($n = 475$), HFNC ($n = 418$), CPAP ($n = 380$). They observed that the composite probability of receiving OTI-IMV or death at 30 days was significantly lower in the CPAP group than in the COT group (36.3% vs. 44.4%; OR 0.72; 95%CI 0.53–0.96; $p = 0.03$), that is, they demonstrated that CPAP was superior to COT in the avoidance of the composite endpoint OTI-IMV or death at 30 days [19]. However, no statistically significant difference in the frequency of this variable was observed between the HFNC group and the COT group (44.3% vs. 45.1%; OR 0.97; 95%CI 0.73–1.29; $p = 0.83$); neither when this composite variable was separated into its two independent components (41.0% vs. 41.6%; OR 0.98; 95%CI 0.73–1.30; $p = 0.86$; for probability of OTI-IMV at 30 days) (18.8% vs. 20.0%; OR 0.92; 95%CI 0.65–1.32; $p = 0.66$; for 30-day mortality) [19]. If they analysed separately the variables probability of receiving OTI-IMV at 30 days and mortality at 30 days between the CPAP group and the COT group, they observed that the first variable (probability of receiving OTI-IMV at 30 days) was significantly lower in the CPAP group than in the COT group (33.4% vs. 41.3%; OR 0.71; 95%CI 0.53–0.96; $p = 0.03$), while they did not detect any statistically significant differences between the CPAP group and the COT group in the latter variable (mortality at 30 days) (16.7% vs. 19.2%; OR 0.84; 95%CI 0.58–1.23; $p = 0.37$) [19]. In-hospital mortality also did not vary significantly between the CPAP group and the COT group (19.8% vs. 22.5%; OR 0.85; 95%CI 0.59–1.22; $p = 0.37$), nor between the HFNC group and the COT group (21.2% vs. 22.3%; OR 0.94; 95%CI 0.67–1.33; $p = 0.73$) [19]. Anyway, on the basis of this clinical trial [19] and in line with the European pneumological guidelines [23], it seems reasonable to adopt the criterion of needing COT at $FiO_2 \geq 0.40$ to maintain $SpO_2 \geq 94\%$ in order to proceed with escalation from COT to NIRS.

In another clinical trial, conducted by Ospina-Tascón et al. [21], HFNC was shown to significantly reduce the likelihood of receiving OTI-IMV within 28 days (34.3% vs. 51.0%; HR 0.62; 95%CI 0.39–0.96; $p = 0.03$), as well as the median [Q1-Q3] of time to clinical recovery within 28 days (11 [9–14] vs. 14 [11–19] days; HR 1.39; 95%CI 1.00–1.92; $p = 0.047$), compared to COT. However, they did not detect any statistically significant difference between the HFNC group and the COT group in terms of 28-day mortality (8.1% vs. 16.0%; HR 0.49; 95%CI 0.21–1.16; $p = 0.11$) [21]. In the methodology of this trial, Ospina-Tascón et al. [21] selected 220 patients with SARS-CoV-2 pneumonia with severe hypoxaemia, defined by a PaO_2/FiO_2 ratio ≤ 200, associated with pronounced work of breathing, defined by tachypnoea >25 breaths/min and use of accessory respiratory musculature, despite COT, and then randomised them into two groups: (a) COT ($n = 111$); (b) HFNC

(n = 109). Thus, based on this trial [21], other criteria to be taken into account to proceed with the escalation from COT to NIRS would be: a PaO_2/FiO_2 ratio ≤ 200 despite COT, a tachypnoea ≥26 breaths/min (or ≥ 30 breaths/min according to Spanish pneumological guidelines [22]) and the use of accessory respiratory muscles.

In the observational study conducted by Bradley et al. [16], of a retrospective and multicentre (seven hospitals in the United Kingdom) nature and with large sample size (N = 479), whose target sample consisted of patients hospitalised for SARS-CoV-2 pneumonia who had severe hypoxaemia defined by an SpO_2 ≤ 94% despite COT at FiO_2 ≥ 0, 40, and whose comparison groups were CPAP (n = 233) and COT (n = 246), no statistically significant difference was detected between the two groups (CPAP and COT) in 30-day mortality (77.7% vs. 75.6%; OR 0.84; 95%CI 0.57–1.23; p = 0.37).

After analysis of these two clinical trials [19, 21] and the retrospective observational study by Bradley et al. [16], the superiority of NIRS (HFNC, CPAP, BPAP), especially of CPAP (rather than of HFNC), over COT has been demonstrated, at least in the reduction of clinical failure (composition of receipt of OTI-IMV or death) and avoidance of receipt of OTI-IMV, although not in the avoidance of mortality (whose efficacy seems similar), in patients diagnosed with SARS-CoV-2 pneumonia with hypoxaemia whose respiratory status worsens, hence the recommendation to escalate from COT to NIRS versus maintaining COT in this type of patients [8, 22, 23]. Moreover, as explained above, the pathophysiology supports this recommendation, since NIRS (HFNC, CPAP, BPAP), compared to COT, achieves better gas exchange (greater oxygen supply and greater washout of carbon dioxide) and greater relief in the work of breathing (attenuation of the tachypnoea and the use of accessory respiratory muscles) of the patient hospitalised for severe SARS-CoV-2 pneumonia and, thus, achieves greater mitigation of severe hypoxaemia and self-induced lung injury (P-SILI), both phenomena that further aggravate ARDS and, consequently, can lead to a higher frequency of OTI-IMV and increased mortality [8].

Noninvasive Respiratory Support: Types, Definitions, Combinations, Indications, Tolerability and Outcomes

The NIRS used in the semi-critical patient admitted to the IRCU with ARDS due to severe SARS-CoV-2 pneumonia consists of three types of devices: HFNC, CPAP and BPAP; with HFNC and CPAP being the most commonly used.

The basic components of HFNC include a flow generator that provides air flow rates of up to 60 L per minute, an air-oxygen mixer that achieves an FiO_2 from 0.21 to 1 and a humidifier that heats the gas mixture at a temperature from 31 °C to 37 °C. The oxygen-enriched humidified air is delivered to the patient via two wide nasal cannulae. HFNC therapy has been shown to be useful for the following purposes: administration of oxygen up to a concentration of 100% (FiO_2 of 1), physiological clearance of residual gases (such as carbon dioxide) from the anatomical

dead space (thus preventing their re-inhalation), creation of an oxygen reservoir, increase of lung compliance, decrease in respiratory rate and use of accessory respiratory muscles (by exerting an unloading effect on the inspiratory muscles), increase in tidal volume, increase in end-expiratory volume, increase in alveolar recruitment (thereby increasing oxygenation) and improvement in mucociliary clearance [30, 40–43]. HFNC therapy, by delivering such high flows, provides positive end-expiratory pressures (PEEP effect), which promote alveolar recruitment (thereby increasing oxygenation) and decrease the work of breathing [30, 40–43]. At flow rates of 35 to 60 L/min with HFNC, average pharyngeal PEEP from 2 to 3 cmH_2O is achieved with the mouth open and from 5 to 7 cmH_2O with the mouth closed [43]. Thus, the average PEEP delivered to the patient over a day by the HFNC can be estimated to be about 4 cmH_2O.

CPAP therapy consists of the application of positive airway pressure at a single level (continuous), that is, a pressure that will be the same during inspiration and expiration. In other words, CPAP maintains a constant positive pressure level throughout the respiratory cycle. As a result, CPAP increases alveolar recruitment and thus increases oxygenation in acute hypoxaemic respiratory failure, as well as decreases the work of breathing [30, 44]. The pressures delivered by CPAP are higher than those achieved with HFNC, so greater alveolar recruitment, and thus greater oxygenation, is achieved with CPAP than with HFNC [10, 22, 30, 45]. The PEEP chosen in CPAP ranges from 6 to 15 cmH_2O, more frequently between 8 and 12 cmH_2O.

There are three schemes of use of NIRS depending on the types of NIRS chosen to treat ARDS by COVID-19: (a) simple NIRS with HFNC alone; (b) simple NIRS with CPAP (or BPAP) alone; (c) combined NIRS alternating between HFNC and CPAP (or BPAP) [8].

It is unknown whether one of these three schemes is superior in efficacy in the avoidance of OTI-IMV and death to the other two schemes. The scheme of simple NIRS with CPAP (or BPAP) alone, that is to say, use of CPAP (or BPAP) on a continuous-time basis, seems hardly tolerable for the patient, so that, *a priori*, it will be less eligible. The simple NIRS scheme with HFNC alone is much more tolerable and will therefore be much more eligible. In a number of circumstances (which will be mentioned below), the addition of CPAP (or BPAP) to HFNC, that is, a combined NIRS scheme of alternation between HFNC and CPAP, may be more beneficial in achieving greater efficacy in terms of avoiding OTI-IMV and death. Alternation between HFNC and CPAP will generally be performed according to the following regimen: use of CPAP for 2 h in the morning, 2 h in the afternoon and at least 8 h at night (to achieve a total of at least 12 h per day of CPAP use) alternating with HFNC use for the rest of the day [8].

As a strategy, we propose to initiate simple NIRS with HFNC alone in all patients admitted to the IRCU for ARDS by COVID-19 with a PaO_2/FiO_2 ratio > 100. In the event that the PaO_2/FiO_2 ratio $\leq$ 100 (severe ARDS), we will opt for combined NIRS between HFNC and CPAP in alternation, since CPAP, by delivering a higher PEEP, achieves greater alveolar recruitment and, therefore, provides greater oxygenation.

If the patient shows desaturation (SpO_2 < 92%) despite optimised therapy with HFNC alone (at a flow rate of 60 L/min and FiO_2 of 1.00), we will opt for the addition of CPAP, that is, for a combined NIRS of alternating HFNC and CPAP, or even a simple NIRS with CPAP alone used on a continuous-time basis if the patient does not tolerate breaks from CPAP to HFNC due to desaturation with SpO_2 below 92%.

The finding of poor respiratory mechanics (tachypnoea >25 breaths/min, use of accessory respiratory musculature) despite a flow rate of 60 L/min in the HFNC also constitutes another indication to use CPAP.

The existence of comorbidities such as sleep apnoea and obesity (BMI ≥ 30 kg/m^2) also benefits from the use of CPAP, in order to prevent nocturnal desaturation, as well as to counteract the ventilatory restriction sometimes present and responsible for hypoxaemia and hypoventilation-obesity syndrome, respectively.

The interface (mask) chosen for CPAP will cover both the nasal cavities and the oral cavity, this is, an oronasal mask, a full-face mask or a helmet interface, in order to avoid oral air leakage by the patient and, consequently, loss of efficacy of CPAP therapy. Let us take into account that the patient, since he/she is suffering from ARDS due to COVID-19, will probably have work of breathing and, consequently, mouth breathing, keeping the oral cavity open to be able to inspire more airflow and more oxygen.

Within the interfaces (masks) covering the nose and mouth, the interface (mask) used will often be of the helmet or full-face type, since the time of CPAP use by the patient is usually long and these interfaces have less support in facial regions that tend to ulcerate due to the mechanical pressure exerted by the interface; especially, these interfaces avoid contact with the nasal bridge, which is responsible for nasal ulcers that can become really deep [46].

When CPAP or BPAP is chosen in addition to or instead of HFNC, CPAP is preferred over BPAP. Both therapies, CPAP and BPAP, have the same efficacy, as they can be set to the same PEEP and therefore achieve similar alveolar recruitment and oxygenation. However, CPAP, since it does not deliver pressure support, is usually much better tolerated and avoids asynchronies compared to BPAP.

The use of CPAP devices in which positive pressures are generated by oxygen therapy flows increased by Venturi effect (for example, Pulmodyne® and Boussignac®) is generally discouraged unless classical CPAP devices, in which the positive pressures are generated mechanically by a turbine driven by electric current, are unavailable due to massive pressure assistance (pandemic conditions). This is because in the first CPAP devices the pressures achieved do not tend to remain as stable throughout the day (these drop below the set pressure at many moments of the day).

The use of BPAP is reserved for patients with hypercapnia ($PaCO_2$ > 45 mmHg) and respiratory acidosis (pH < 7.35 plus $PaCO_2$ > 45 mmHg), in whom the pressure support (≥ 8 cmH_2O) provided by BPAP is necessary to wash out excess carbon dioxide [22, 44]. Hypercapnia is uncommon in COVID-19; the pathophysiology of ARDS is characterised by purely hypoxaemic acute respiratory failure, attributable to shunt due to diffuse occupancy of the alveoli by inflammatory exudates [47, 48]. Patients with ARDS due to COVID-19 who develop hypercapnia and respiratory

acidosis are usually patients with previous pneumological pathologies that cause chronic retention of carbon dioxide (chronic obstructive pulmonary disease, bronchiectasis, hypoventilation-obesity syndrome associated or not with sleep apnoea, neuromuscular diseases [amyotrophic lateral sclerosis, muscular dystrophy of Becker, myotonic dystrophy of Steinert, myasthenia gravis, etc.], deformities of the thoracic cage [severe kyphoscoliosis, ankylosing spondylitis, etc], sedative/hypnotic agents), in whom SARS-CoV-2 pneumonia can decompensate these pathologies and thus lead to global acute respiratory failure (hypoxaemic and hypercapnic) and then to acute respiratory acidosis [8, 22, 44].

Another circumstance for which BPAP could be reserved would be for those patients with a very pronounced work of breathing in whom a slightly better control of respiratory mechanics is desired after having previously tried CPAP. In these cases, BPAP, by providing pressure support (IPAP - PEEP), could provide a small extra advantage over CPAP in controlling work of breathing. A low pressure support (PS), ≤ 4 cmH_2O, would be sufficient to try to control work of breathing (PS > 4 cmH_2O would not in principle offer any extra benefit); if this is not achieved, escalation to OTI-IMV should be considered.

When making the choice between HFNC and CPAP (or BPAP), we should consider the HENIVOT trial by Grieco et al. [20], which compares HFNC and BPAP (with helmet interface) therapies with each other in 110 patients admitted for SARS-CoV-2 pneumonia with hypoxemia defined by a PaO_2/FiO_2 ratio ≤ 200 despite COT. No statistically significant differences were detected in terms of the median of number of days free of respiratory support (IMV, BPAP, HFNC) between the BPAP with helmet group and the HFNC group (20 days vs. 18 days; $p = 0.26$). In contrast, they observed that the frequency of escalation to OTI-IMV from NIRS was significantly lower in the BPAP with helmet group than in the HFNC group (30% vs. 51%; OR 0.41; 95%CI 0.18–0.89; $p = 0.03$) [20]. And in patients who were escalated to OTI-IMV, they observed that those who had previously received BPAP with helmet had a significantly higher median of number of IMV-free days than those who had previously received HFNC (28 days vs. 25 days; $p = 0.04$) [20]. No statistically significant differences were observed in mortality during hospital admission between the BPAP with helmet group and the HFNC group (24% vs. 25%; OR 0.93; 95%CI 0.39–2.22; $p > 0.99$) [20].

In the retrospective observational study by Franco et al. [9], conducted in 670 patients with severe COVID-19 with $SpO_2 < 94\%$ and RR > 20 breaths/min despite a reservoir mask at 10–15 L/min flow with subsequent escalation to NIRS (HFNC, CPAP or BPAP), after adjustment for confounding variables (age, baseline PaO_2/FiO_2 ratio, number of comorbidities, use of systemic glucocorticotherapy), no statistically significant differences were detected in mortality or in the probability of receiving OTI-IMV between the HFNC, CPAP and BPAP groups.

We can therefore establish, on the basis of the HENIVOT trial by Grieco et al. [20], that the use of CPAP (at pressures of between 8 and 12 cmH_2O) in patients with low PaO_2/FiO_2 ratios (especially if PaO_2/FiO_2 ratio ≤ 100 [severe ARDS]) would be of choice over HFNC, as it avoids a higher percentage of escalations to OTI-IMV; although Franco et al. [9], in their the observational study, found no

significant difference in the likelihood of receiving OTI-IMV between the HFNC group and the CPAP group.

The presence of tachypnoea or poor adaptation to NIRS (especially CPAP or BPAP rather than HFNC), as well as the presence of psychomotor agitation, are relatively common in IRCUs, as we are dealing with semi-critical patients; but, unlike most ICU patients, who are sedated under OTI-IMV, IRCU patients are fully awake under NIRS. In our experience, the use of intravenous morphine perfusion for the control of tachypnoea and/or maladaptation to NIRS (especially CPAP or BPAP, rather than HFNC), as well as the use of intravenous dexmedetomidine perfusion for the control of psychomotor agitation, has a high efficacy and a good safety profile, as patients in IRCUs are under continuous monitoring and surveillance. Low level of consciousness should be monitored in the case of morphine, and arterial hypotension and bradycardia in the case of dexmedetomidine [49].

Prone Position

In the treatment of classical ARDS, together with respiratory support (noninvasive or invasive), prone postural therapy is found among the therapeutic options to improve the patient's oxygenation (it increases the PaO_2/FiO_2 ratio, the SpO_2/FiO_2 ratio and the ROX index and decreases the respiratory rate), based on the fact that the change to this position improves lung ventilation (prone decubitus produces a redistribution of ventilation to the dorsal areas of the lungs, which are mostly collapsed in supine decubitus in patients with ARDS) and, with it, the alveolar recruitment, hardly affecting the distribution of lung perfusion, which predominates in the dorsal areas of the lungs in both positions (supine and prone). Thus, in the prone decubitus, a better balance of ventilation/perfusion ratio (that would be closer to normality, that is, to one) in the lungs is established, with a reduction of shunt areas [2, 50–54].

Prone decubitus sessions in the patient under NIRS should have a minimum duration of 2 h to have a significant oxygenation-enhancing effect.

In a multicentre meta-analysis of six open-label randomised clinical trials involving a total of 1126 patients diagnosed with SARS-CoV-2 pneumonia with acute hypoxaemic respiratory failure (defined by an SpO_2/FiO_2 ratio ≤ 315 or a PaO_2/FiO_2 ratio ≤ 300) who used HFNC, a statistically significant reduction in the frequency of the composite endpoint clinical failure (OTI-IMV or death) within 28 days was observed in patients who were prescribed prone decubitus versus those who were not (40% vs. 46%; RR 0.86; 95%CI 0.75–0.98; $p = 0.02$) (HR 0.78; CI95% 0.65–0.93; $p = 0.0069$) [54]. Separately, the probability of receiving OTI-IMV at 28 days was significantly lower in the prone group (HR 0.75; 95%CI 0.62–0.91; $p = 0.0038$) [54]. In contrast, no statistically significant difference was observed between the two groups in terms of 28-day mortality (HR 0.87; 95%CI 0.68–1.11; $p = 0.27$) [54].

Based on the results of this meta-analysis, we can support a strong recommendation for the routine indication of prone decubitus in all patients with severe SARS-CoV-2 pneumonia with severe hypoxaemia requiring NIRS, especially HFNC.

In the case of intolerance to prone decubitus, which can occur in up to 60% of cases [8, 50–52], lateral decubitus can be recommended or, better still, the Rodin thinker's position, in which the patient is seated on a chair and leaned forward so that the thorax rests on a raised surface, that is, a semi-prone position [55].

Assessment of Response to Noninvasive Respiratory Support

Knowing how to assess the response to NIRS is essential in order to correctly decide whether to continue with the same type of NIRS, whether to change the type of NIRS or alternate various types of NIRS, or whether to proceed with the escalation to OTI-IMV.

The most important parameters that allow us to assess the response to NIRS are the following: (a) SpO_2/FiO_2 ratio, or better still, the PaO_2/FiO_2 ratio, and more so if it is accompanied by the alveoloarterial oxygen gradient; (b) respiratory rate; (c) use of accessory respiratory muscles (including whether or not it is associated with paradoxical breathing); (d) dyspnoea [8, 22, 23, 30].

An improvement in these parameters (increase in SpO_2/FiO_2 and PaO_2/FiO_2 ratios, decrease in the alveoloarterial oxygen gradient, decrease in respiratory rate, reduction in the use of accessory respiratory muscles and relief of dyspnoea) during the first 48–72 h from the start of NIRS constitutes a success of NIRS and will prevent escalation to OTI-IMV [8, 10, 45, 56]. In contrast, stagnation or worsening of these parameters during the first 48–72 h will indicate failure of NIRS and we should immediately consider escalating to OTI-IMV if the patient is a candidate for OTI-IMV.

If we observe that before the first 48–72 h the response to NIRS is stagnant or unfavourable, we will consider changing or alternating between various types of NIRS if we had started NIRS with only one type.

Thus, if we had started NIRS with HFNC alone and we observe in the first 12–24 h that the response to NIRS is inadequate (stagnant or unfavourable) by assessing the parameters described above (SpO_2/FiO_2 ratio or PaO_2/FiO_2 ratio, respiratory rate, use of accessory respiratory musculature, dyspnoea), that is, the development of an $SpO_2 < 92\%$, a PaO_2/FiO_2 ratio ≤ 100, a tachypnoea ≥ 26 breaths/min and/or use of accessory respiratory muscles despite HFNC (having raised their parameters to a flow of 60 L/min and an FiO_2 of 1.00), we will alternate HFNC with CPAP so that the patient uses CPAP for 2 h in the morning, 2 h in the afternoon and at least 8 h at night, and this uses HFNC for the rest of the day.

As discussed in the previous sections, if we see from the outset when escalating from COT to NIRS that the patient meets a series of criteria, our recommendation is to start with combined NIRS with alternation between HFNC and CPAP (CPAP for 2 h in the morning, 2 h in the afternoon and at least 8 h at night, and HFNC for the rest of the day) rather than starting with HFNC alone. These criteria are: (a) $SpO_2 < 92\%$ despite HFNC at flow rates of 60 L/min and FiO_2 of 1; (b) poor respiratory mechanics (tachypnoea >25 breaths/min, use of accessory respiratory musculature) despite 60 L/min flow at HFNC; (c) PaO_2/FiO_2 ratio ≤ 100; (d) concomitant

sleep apnoea (in order to avoid nocturnal desaturations); (e) obesity (BMI ≥30 kg/m^2) (in order to overcome ventilatory restriction) [46]. If none of these criteria are met, a simple NIRS is usually started with HFNC alone, given its much better tolerability compared to CPAP.

We should also take into account that if the patient does not tolerate CPAP therapy at all, it is preferable to maintain HFNC therapy. Poorly tolerated CPAP may even be counterproductive, as it can lead to multiple episodes of desaturation as well as increased work of breathing (which in turn is responsible for P-SILI).

CPAP provides higher PEEP than HFNC, thus promoting considerably higher alveolar recruitment, resulting in higher oxygenation than with HFNC [10, 22, 30, 45]. The PEEP chosen in CPAP ranges from 6 to 15 cmH_2O, most frequently between 8 and 12 cmH_2O. In contrast, using flow rates of 35 to 60 L/min at HFNC, average PEEP at the pharyngeal level of 2 to 3 cmH_2O is achieved with the mouth open and from 5 to 7 cmH_2O with the mouth closed [43]. Thus, the average PEEP delivered to the patient over a day by the HFNC can be estimated to be about 4 cmH_2O, that is, a lower PEEP than that achieved with CPAP. According to other sources [40], the positive airway pressure delivered by HFNC at a flow rate of 35 L/min is usually less than 3 cmH_2O with the mouth closed and equal to 1 cmH_2O with the mouth open, and increases by 0.7 cmH_2O for every 10 L/min increase in flow rate at HFNC. In addition, CPAP, since it delivers higher PEEP, often achieves greater control of a patient's work of breathing (both tachypnoea and the use of accessory respiratory musculature) than HFNC. However, CPAP is often worse tolerated by the patient than HFNC. Therefore, if the patient's SpO_2 and respiratory mechanics permit it, CPAP sessions should be alternated with HFNC sessions to provide periods of rest from CPAP [8]. The combined regimen of choice is usually to use CPAP for 2 h in the morning, 2 h in the afternoon and at least 8 h at night (reaching a total of at least 12 h per day of CPAP use) alternating with HFNC for the remaining hours of the day. The interface (mask) chosen for CPAP will cover both the nasal cavities and the oral cavity, that is, an oronasal mask, a full-face mask or a helmet interface, in order to avoid oral air leaks by the patient and, consequently, loss of efficacy of CPAP therapy. Let us take into account that the patient, since he/she is suffering from ARDS due to COVID-19, will probably have work of breathing and, consequently, mouth breathing, keeping the oral cavity open to be able to inspire more airflow and more oxygen.

When NIRS combined with HFNC plus CPAP or BPAP has been chosen, the use of CPAP is generally preferred over the use of BPAP, since CPAP is usually much better tolerated by the patient than BPAP and avoids asynchrony, and the efficacy of both therapies, CPAP and BPAP, in the treatment of ARDS by COVID-19, is the same. The reason for this same efficacy lies in the fact that ARDS secondary to SARS-CoV-2 pneumonia is purely hypoxaemic in the vast majority of cases, and here PEEP is the one that allows recruitment of alveoli and, consequently, the one that increases oxygenation in the organism, and both therapies, CPAP and BPAP, can provide equal PEEP [10, 22, 30, 45]. BPAP is usually reserved for patients with a very pronounced work of breathing in whom we wish to control respiratory mechanics a little better after having tried CPAP. In these cases, BPAP, by providing

pressure support (IPAP – PEEP), may provide a small extra advantage over CPAP in controlling work of breathing. A low pressure support, ≤ 4 cmH_2O, will be sufficient to try to control work of breathing (a pressure support >4 cmH_2O will not offer any extra benefit); if this is not achieved, escalation to OTI-IMV should be considered. In a minority of cases, acute respiratory failure can be hypercapnic ($PaCO_2$ > 45 mmHg), and can even be accompanied by acute respiratory acidosis (pH < 7.35 plus $PaCO_2$ > 45 mmHg); here BPAP will be of choice from the outset over CPAP, since we need the pressure support provided by BPAP to try to wash out excess carbon dioxide and thus overcome respiratory acidosis [8, 22, 44]. We will choose much higher pressure supports, ≥ 8 cmH_2O, for this purpose. These are generally patients with previous pneumological pathologies that cause chronic retention of carbon dioxide (chronic obstructive pulmonary disease, bronchiectasis, hypoventilation-obesity syndrome associated or not with sleep apnoea, neuromuscular diseases, rib cage deformities, consumption of sedative/hypnotic drugs), in whom SARS-CoV-2 pneumonia can decompensate these pathologies and thus lead to global acute respiratory failure (hypoxaemic and hypercapnic) and then to acute respiratory acidosis. In any case, the PEEP chosen in BPAP will be the same as the pressure chosen in CPAP, that is, between 8 and 12 cmH_2O.

The NIRS should therefore be set at FiO_2 and flows (if HFNC) or pressures (if CPAP or BPAP) with a view to aiming for an SpO_2 ≥ 92%, a respiratory rate ≤ 25 breaths/min and an absence of use of accessory respiratory musculature. The maximum FiO_2 provided by the three types of NIRS (HFNC, CPAP and BPAP) is 1. The maximum flows used in HFNC are 60 L/min; generally, flows between 35 and 60 L/min are used. And the maximum PEEP used in CPAP or BPAP is 15 cmH_2O, although PEEP greater than 12 cmH_2O is infrequently used for intolerance; PEEP between 8 and 12 cmH_2O is generally used.

In cases of respiratory acidosis, we will evaluate as respiratory parameters of response to BPAP, apart from those previously mentioned for hypoxaemia (SpO_2/FiO_2 ratio or PaO_2/FiO_2 ratio, respiratory rate, use of respiratory accessory musculature and dyspnoea), pH, $PaCO_2$, level of consciousness (assessed by Glasgow coma scale and by the Kelly-Matthay scale), state of consciousness (degree of confusion) and presence or absence of flapping. By stablishing BPAP, we will seek resolution of respiratory acidosis (target pH ≥ 7.35), decrease in hypercapnia, full recovery of level (Glasgow = 15 and Kelly-Matthay grade 1 or 2) and state (absence of confusion) of consciousness and elimination of flapping. The target SpO_2 should be between 88% and 92%, without exceeding an SpO_2 of 92%, in order to avoid further retention of carbon dioxide due to suppression of the neurological hypoxic stimulus. If there is a lack of response to BPAP within 1 h and, above all, 4 h after BPAP has been started (respiratory acidosis requires rapid correction to avoid associated death), escalation to OTI-IMV should be considered [57].

Other less commonly used parameters that could allow us to assess the response to NIRS include such parameters as oesophageal pressure [8, 56], transpulmonary pressure [8, 56], HACOR index [8, 58, 59], and ROX index [8, 60–62].

Continuous measurement of oesophageal pressure by means of a nasogastric tube allows us to know at all times the muscular strength of the diaphragm and,

therefore, the inspiratory muscular effort carried out by the patient. Thus, if when the patient is under COT we observe that the oesophageal pressure is high, this means that the patient is carrying out intense inspiratory muscle work and it will be time to consider escalating to NIRS to try to reduce this work, since, if such intense inspiratory muscle work is maintained, the diaphragm will eventually fatigue and the patient will begin to have severe hypoxaemia, in addition to which hypercapnia (due to hypoventilation) may be added. Moreover, the sustained intense respiratory work, as explained in the previous sections, leads to self-induced lung injury (P-SILI), which will be added to the ARDS caused by SARS-CoV-2 pneumonia, thus worsening the prognosis for life [8, 63, 64]. This P-SILI can manifest itself in various forms: alveolar and interstitial pulmonary oedema of an exudative (inflammatory) nature similar to ARDS, pulmonary atelectasis, peribronchial interstitial pulmonary emphysema, pneumomediastinum, subcutaneous emphysema, pneumothorax, pneumopericardium, pneumoperitoneum, pulmonary air cysts, air embolism.

If the patient is already under NIRS, sustained high oesophageal pressure (which translates into intense diaphragmatic muscle work) will indicate that we should switch to another type of NIRS, usually from HFNC to CPAP or BPAP, or from CPAP to BPAP, and, if the pressure remains high, consider escalation to OTI-IMV, especially if 48–72 h have passed since the NIRS was instituted.

However, it should be noted that oesophageal pressure measurement is not a standardised procedure as it is an invasive measurement and its use is usually reserved for research studies and, in the clinical setting, for selected severely ill patients under NIRS as a complement to help us assess NIRS failure and thus make the decision to escalate to OTI-IMV.

The HACOR index is composed of the following items: heart rate (beats/min), acidosis (pH), level of consciousness (Glasgow coma scale), oxygenation (PaO_2/FiO_2 ratio), respiratory rate (breaths/min) [58]. It has been used to assess therapeutic response in patients with acute hypoxaemic respiratory failure under CPAP or BPAP. Its score ranges from 0 to 25 points. The ideal cut-off point for the HACOR index has been set at 5, so that a value >5 ($\geq$ 6) within 1 h of initiating CPAP or BPAP predicts a very high risk of CPAP or BPAP failure and the need for escalation to OTI-IMV. The HACOR index has been shown to be very effective in predicting failure of NIRS, specifically CPAP (with an accuracy of 82.03%), in SARS-CoV-2 pneumonia, although its effectiveness is very similar to that demonstrated by the PaO_2/FiO_2 ratio (whose accuracy is 81.25%) [59].

The ROX index is defined as the SpO_2/FiO_2 ratio divided by the respiratory rate (RR), that is, $(SpO_2/FiO_2)/RR$. This is an index widely used in clinical practice to assess response to HFNC therapy. It has generally been measured at 0, 2, 6 and 12 h after initiation of HFNC therapy [8, 65]. An increase in the ROX index over the hours after initiation of HFNC therapy reflects an improvement in the patient's respiratory status and thus signifies success of HFNC therapy. We only have to deduce from the formula to realise that the increase in this index is beneficial, as it reflects that the patient needs a lower FiO_2 at HFNC to achieve higher SpO_2, as well as this has a lower respiratory rate (less work of breathing) due to the flow delivered by the HFNC. The generally accepted cut-off point of the ROX index in the

pre-COVID-19 era in patients with pneumonia and acute hypoxaemic respiratory failure was 4.88, so that values higher than 4.88 in the ROX index were associated with successful HFNC therapy [8, 65]. During the COVID-19 pandemic, several studies have been conducted to determine other cut-off points. Chandel et al. [60] demonstrated that a ROX index >3.0 at 2, 6 and 12 h after initiating HFNC therapy had a sensitivity of 85.3% for identifying that HFNC therapy was being successful. Zucman et al. [61] determined that the most sensitive cut-off point in the ROX index was 5.37 at 4 h after initiation of HFNC therapy, so that values below 5.37 in the ROX index at 4 h after initiation of HFNC predicted HFNC failure and thus a need for escalation to OTI-IMV. And Vega et al. [62] established a cut-off point of 5.99 in the ROX index as the most suitable (sensitivity = 62%; specificity = 96%; $p = 0.0008$) for assessing response to HFNC therapy at 12 h, whereas they considered that the classical cut-off point of 4.88 of Roca et al. [65] was not able to adequately discriminate between success and failure of HFNC ($p = 0.40$) in semi-critical patients with SARS-CoV-2 pneumonia. In any case, whatever the cut-off point adopted, we consider that the most important aspect, as mentioned above, is the measurement of the evolutionary curve in the ROX index over the first hours after initiation of HFNC therapy, so that if this curve is increasing, it means that HFNC therapy is being successful and the patient will very likely avoid escalation to OTI-IMV. And vice versa, a decreasing curve in the ROX index over the first few hours after starting HFNC will be predictive of a failure of HFNC therapy and, therefore, of a need for escalation to OTI-IMV, as demonstrated by Xia et al. [66] during the first 72 h.

Other authors advocate only the change in respiratory rate, rather than the ROX index, as a predictor of success or failure of HFNC therapy. Blez et al. [67] demonstrated that a respiratory rate ≥ 26 breaths/min at 30 min after initiation of HFNC therapy had a similar sensitivity (75% vs. 81%) to ROX index <4.88 at 30 min in predicting failure of HFNC therapy and subsequent escalation to OTI-IMV.

Failure of Noninvasive Respiratory Support

It is of paramount importance to know at what point NIRS is failing and OTI-IMV should be established. It is well known that a delay in OTI-IMV leads to increased mortality [3, 5].

On the other hand, in general, the experience acquired with the COVID-19 pandemic has taught us that we should not be extremely early in establishing OTI-IMV (not escalate directly from COT to OTI-IMV), but we should give a reasonable window of opportunity to NIRS [8], since, if it is effective, it will avoid OTI-IMV and, therefore, the increased complications that OTI-IMV entails (IMV-associated pneumonia, bladder catheter-associated urinary tract infection, vascular catheter-associated bloodstream infection, sepsis, other nosocomial infections, polyneuromyopathy, etc.), as well as increased costs [28]. In the meta-analysis by Cammarota et al. [34], as previously mentioned, an efficacy of NIRS, specifically of CPAP or BPAP, of 74.4% (95%CI 69.9%–78.6%) in the avoidance of OTI-IMV has been reported. The mean time of NIRS use in NIRS responders patients ranged from 2 to

12 days [8, 34]. In the event that NIRS fails and it has to be escalated to OTI-IMV, as long as we stay within a window of opportunity, this will not result in a significant delay in OTI-IMV and, therefore, it will not lead to an increase in mortality [7, 8]. Based on scientific evidence, this window of opportunity has been established as 48–72 h [8, 23–26]. This is the ideal waiting time to observe whether the patient is responding to NIRS without increasing the likelihood of death due to delayed OTI-IMV. Beyond 48–72 h, if the patient does not respond favourably to NIRS, without further delay, the patient should be transferred to the ICU for escalation to OTI-IMV. It should be remembered that every patient under NIRS should be closely monitored in an IRCU.

Thus, if a patient under optimised NIRS does not show any improvement in the clinical respiratory situation in the first 48–72 h after the initiation of NIRS, we will consider it a therapeutic failure of NIRS and the patient should be transferred to the ICU for the establishment of OTI-IMV. The absence of improvement in the clinical respiratory situation includes both those patients who remain in a stationary situation and those who suffer a progressive or abrupt worsening of this situation during the first 48–72 h after the initiation of NIRS. The clinical respiratory status of a patient is assessed by the following items: SpO_2 (SpO_2/FiO_2 ratio), or PaO_2 (PaO_2/FiO_2 ratio), respiratory rate, use of accessory respiratory muscles, dyspnoea. By optimised NIRS we mean maximised NIRS, that is, HFNC at flows of 60 L/min and FiO_2 of 1, or CPAP at pressure of 8–12 cmH_2O and FiO_2 of 1. In summary, if, despite an optimised NIRS (FiO_2 of 1, pressures of 8–12 cmH_2O, flows of 60 L/min), the patient presents a high oximetric compromise ($SpO_2 < 92\%$ or PaO_2/FiO_2 ratio ≤ 100), or a stationary or decreasing evolutionary curve in SpO_2 (although $SpO_2 \geq 92\%$ or PaO_2/FiO_2 ratio > 100), and/or poor respiratory mechanics (tachypnoea >25 breaths/min, use of accessory respiratory muscles) beyond 48–72 h after initiation of NIRS, we will consider it failure of NIRS and the patient will be transferred to ICU for establishment of OTI-IMV [8, 20].

Boscolo et al. [24] found a significant increase in mortality in non-responders patients under CPAP/BPAP beyond 48 h who then escalated to OTI-IMV (63% if CPAP/BPAP use >48 h vs. 41% if CPAP/BPAP use ≤48 h; $p < 0.01$). Similarly, Vaschetto et al. [25] determined that CPAP use time > 72 h was an independent predictor of mortality (HR 1.093; 95%CI 1.010–1.184) in those patients who did not respond to CPAP and were subsequently intubated.

Before considering NIRS failure, we should first rotate the type of NIRS, because it is possible that the patient can be refractory to one type of NIRS but not to another type of NIRS. In many cases, if HFNC therapy is not sufficient, CPAP therapy is alternated or even set to continuous time, which favours higher alveolar recruitment due to its higher PEEP, usually resulting in a higher SpO_2 [10, 30, 45]. It also favours a better control of respiratory mechanics if this is anomalous despite HFNC. However, if the patient does not tolerate CPAP therapy at all, it is preferable to maintain HFNC therapy. A poorly tolerated CPAP may even be counterproductive as it can cause multiple episodes of desaturation, as well as increased work of breathing (responsible, in turn, for P-SILI).

In addition, if the patient's respiratory status worsens abruptly, before considering failure of NIRS, we should rule out causes other than SARS-CoV-2 pneumonia itself, such as acute pulmonary thromboembolism and pneumothorax, both relatively frequent complications in patients with such severity of COVID-19 (stage III of inflammatory hyperresponsiveness and ARDS) that they already require NIRS [35, 68–70].

Two other indications for the establishment of OTI-IMV, apart from that indicated above with regard to the failure of NIRS, are: respiratory arrest; and severe alterations in the level of consciousness (coma: Glasgow ≤8) or in the state of consciousness (acute confusional syndromes uncontrollable with neuroleptic medication).

A final reason for admission to the ICU, although not necessarily for the establishment of OTI-IMV, would be haemodynamic instability (septic shock), since in this case the patient will require intensive intravenous fluid therapy and vasoactive pharmacotherapy (noradrenaline) via a central venous catheter.

In the case of patients who are not candidates for admission to the ICU for the establishment of OTI-IMV, due to advanced age, baseline-dependent life and important comorbidities, conditions under which the probability of failure of OTI-IMV is very high and subsequent extubation is practically impossible, NIRS will be established as the therapeutic ceiling and there will be no defined time limit for maintaining this NIRS. In the event that the patient who is not a candidate for OTI-IMV clearly worsens over the days despite NIRS, we will consider limitation of therapeutic effort (withdrawal of NIRS and de-escalation to COT) and establishment of palliative sedation in order to avoid therapeutic incarnation and patient suffering.

In order to identify patients at increased risk of NIRS failure (defined as the need for IMV or death within 28 days of the initiation of NIRS) at an early stage, and thus exercise closer monitoring and more intensive therapy on these patients (allowing an even earlier escalation to OTI-IMV, with the aim of avoiding a significant delay in OTI-IMV and thus reducing mortality), nomograms and calculators have been developed to estimate this risk [71]. Some variables that have shown predictive power in estimating the risk of NIRS failure are: age [71], number of comorbidities [71], Glasgow coma scale score [71], ROX index [71], lactate dehydrogenase blood levels [71], use of vasopressor drugs on the first day of NIRS use [71], SARS-CoV-2 vaccination status [73] and previous SARS-CoV-2 infections.

Success of Noninvasive Respiratory Support: De-Escalation from Noninvasive Respiratory Support to Conventional Oxygen Therapy

First, we will define the COT device to which we will de-scale. And secondly, we will specify the NIRS device from which we will de-escalate.

We will begin by explaining what maximum FiO_2 can be achieved by each of the COT devices. In order of lowest to highest FiO_2 emitted, we find the conventional

nasal cannula, followed by the simple mask or Venturi mask, and then followed by the reservoir mask.

Conventional nasal cannula, simple mask and reservoir mask are low-flow COT devices, that is to say, they deliver a flow whose FiO_2 can be roughly estimated but cannot be known exactly because it varies according to the patient's breathing pattern, that is to say, the FiO_2 delivered is not constant, but changing. This is because these devices provide flows ≤30 L/min, which are not able to fully satisfy the inspiratory flow demands of the patient, so the patient will have to inhale extra air coming from the environment in order to fully satisfy these inspiratory flow demands, so that the sum of flows coming from conventional nasal cannula (or simple mask or reservoir mask) and ambient air reaches >30 L/min. Thus, while the flow coming from conventional nasal cannula (or simple mask or reservoir mask) is static because we select it, the flow coming from ambient air depends on the patient's spontaneous breathing pattern (rate, amplitude and rhythm), which is variable [30, 74].

Conventional nasal cannula will be used at flow rates of 1, 2, 3, 4, 5 and 6 L/min, which are equivalent to estimated FiO_2 of 0.24, 0.28, 0.32, 0.36, 0.40 and 0.44, respectively. In other words, conventional nasal cannula can achieve a maximum FiO_2 of 0.44 at a flow rate of 6 L/min [30, 74, 75].

The simple mask is set at flows of 5–6, 6–7 and 7–8 L/min, which are equivalent to estimated FiO_2 of 0.40, 0.50 and 0.60, respectively [30, 74, 75].

And the reservoir mask is typically used at flows from 10 to >15 L/min to ensure that the bag remains inflated, which equates to an estimated FiO_2 of 0.90 to 1.00 [30, 74, 75].

On the other hand, we find the Venturi mask, which, unlike the COT devices mentioned above, is high-flow, that is to say, it delivers a fixed FiO_2 that we select and know, which remains constant throughout the patient's respiratory cycle without being modified by changes in the patient's spontaneous breathing pattern. This is because it delivers flows >30 L/min, which exceed the patient's inspiratory flow demands at all times, so that the patient does not have to inhale extra air coming from the environment to satisfy those demands. This is achieved by the Venturi effect, whereby the oxygen jet coming from the flowmeter (which can be set at a maximum flow rate of 15 L/min) passes through a narrow duct resulting in an increase in its velocity (flow rate) that exceeds 30 L/min. In general, the FiO_2 that can be selected in the Venturi mask are the following: 0.24; 0.26; 0.28; 0.31; 0.35; 0.40 and 0.50; for which we should select oxygen flows at the flowmeter of 3, 3, 6, 6, 9, 12 and 15 L/min, respectively, so that, once they pass through the narrow duct (Venturi effect), these flows exceed 30 L/min in order to ensure these FiO_2 [30, 74, 75].

Taking into account all these concepts in relation to COT, we can establish as a general rule that de-escalation from NIRS to COT is performed when NIRS can be lowered to an $FiO_2 \leq 0.40$ so that the patient maintains an $SpO_2 \geq 92\%$, a RR ≤ 25 breaths/min and absence of use of accessory respiratory muscle for at least 30 min [20].

Our recommendation is that, within the COT devices, de-escalation should be done directly to conventional nasal cannula, starting with a flow rate of 6 L/min and

then progressively decreasing according to the patient's SpO_2, aiming for a target $SpO_2 \geq 92\%$ at all times. As explained above, a flow rate of 6 L/min in conventional nasal cannula is equivalent to an approximate FiO_2 of 0.44. Therefore, if with NIRS we can lower the FiO_2 to 0.40 (to maintain an $SpO_2 \geq 92\%$, a RR $\leq$ 25 breaths/min and absence of use of accessory respiratory musculature for at least 30 min), we can then de-escalate to conventional nasal cannula at a flow of 6 L/min. In addition, we should bear in mind that, at equal FiO_2 in NIRS and COT, NIRS will generally achieve a slightly higher SpO_2, because, unlike COT, NIRS emits a PEEP that leads to alveolar recruitment and thus increases oxygenation [10, 22, 30, 40, 41, 43, 45]. For this reason, to increase the likelihood of successful de-escalation from NIRS to COT, we will ensure that the FiO_2 provided by COT is slightly higher than the FiO_2 provided by NIRS, as just explained in the case of de-escalation from NIRS with FiO_2 of 0.40 to conventional nasal cannula at a flow rate of 6 L/min (estimated FiO_2 of 0.44).

Another option, instead of de-escalating directly to conventional nasal cannula, is to de-escalate from NIRS first to a Venturi mask or simple mask and then to conventional nasal cannula. In this way, we aim for the de-escalation to COT to be at an FiO_2 initially higher than that achieved with conventional nasal cannula, which will be 0.50, and then progressively lowering it as SpO_2 allows. Thus, if with the NIRS we can lower the FiO_2 to 0.40 (to maintain an $SpO_2 \geq 92\%$, a RR $\leq$ 25 breaths/min and absence of accessory respiratory muscles for at least 30 min), we can then de-escalate to a Venturi mask at FiO_2 of 0.50 (and flow of 15 L/min) or to a simple mask at a flow of 6–7 L/min (which is equivalent to an FiO_2 of approximately 0.50; or even at 7–8 L/min flow if we wish to achieve an estimated FiO_2 of 0.60). We do not recommend de-escalation to a reservoir mask because it would not really be de-escalation, since its flows of 10–15 L/min are equivalent to an FiO_2 of 0.90 to 1.00, much higher than the FiO_2 of 0.40 required for de-escalation from the NIRS.

In terms of NIRS devices from which to de-escalate to COT, we can de-escalate from either HFNC or CPAP. However, we recommend that if the patient is under CPAP therapy, switch first to HFNC therapy and then de-escalate from HFNC to COT. The reason for this is that HFNC has a lower PEEP than CPAP [40, 43] and, to de-escalate to COT, it is desirable to lower the PEEP beforehand because COT has not PEEP effect.

To consider de-escalation from HFNC, the patient should first be able to tolerate oximetrically (maintain an $SpO_2 \geq 92\%$) a decrease in FiO_2 to $\leq$0.40. Secondly, we should be able to decrease the flow to $\leq$40 L/min and the patient should still maintain an $SpO_2 \geq 92\%$ and adequate respiratory mechanics (RR $\leq$ 25 breaths/min and absence of use of accessory respiratory muscles). By lowering the HFNC flow to $\leq$40 L/min, we are greatly diminishing the high-flow effect (we remember that a flow $\leq$30 L/min makes this therapy low-flow), which is responsible for an unloading effect on the use of the patient's respiratory muscles [8, 40, 41, 43], as well as an increase in SpO_2 due to its alveolar recruitment PEEP effect [8, 40, 41, 43]. In this way, we see if the patient is ready for a de-escalation to COT, since COT lacks these effects of respiratory muscle unloading and alveolar recruitment. This strategy of lowering flow and FiO_2 in HFNC prior to de-escalation to COT can be done in

three ways: lowering flow first and then FiO_2, lowering FiO_2 first and then flow, or lowering both parameters (flow and FiO_2) simultaneously; this is a question that is being studied in the SLOWH trial [76], which is evaluating the efficacy and safety of each of these three branches of parameter reduction in HFNC.

If we desire to de-escalate directly to COT from CPAP, without first switching to HFNC, we should be consider it when FiO_2 can be lowered to ≤0.40 and PEEP to ≤6 cmH_2O such that the patient maintains an $SpO_2 \geq 92\%$, a RR ≤ 25 breaths/min and absence of use of accessory respiratory muscle, according to the HENIVOT trial by Grieco et al. [20]. In the study by Aliberti et al. [10], they establish as criteria for de-escalation from CPAP to COT that the patient can maintain an $SpO_2 \geq 94\%$, a RR ≤ 25 breaths/min and absence of use of accessory respiratory muscle under an $FiO_2 \leq 0.50$ and a PEEP ≤5 cmH_2O. In this second model of de-escalation from CPAP to COT, more importance is given to lowering PEEP, in order to decrease alveolar recruitment (which increases SpO_2) prior to de-escalation to COT (which lacks this alveolar recruitment effect). However, we should remember that in any of the models of de-escalation to COT from CPAP, if we use a single circuit with passive leak in CPAP, we will never decrease PEEP to <4 cmH_2O, since we need a PEEP ≥4 cmH_2O so that the carbon dioxide exhaled by the patient can be expelled from the circuit through that passive leak, thus avoiding re-inhalation of carbon dioxide by the patient [57].

De-escalation from NIRS to COT will be considered successful if, under COT at $FiO_2 \leq 0.40$ (conventional nasal cannula at flow ≤5 L/min, Venturi mask at $FiO_2 \leq 0.40$ and flow ≤12 L/min or simple mask at flow of 5–6 L/min), the patient is able to maintain an $SpO_2 \geq 92\%$ (or PaO_2/FiO_2 ratio > 250), a RR ≤ 25 breaths/min and absence of use of accessory respiratory muscles for at least 24 h [8, 10].

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Models of Noninvasive Ventilation Organization in Bioterrorism and Other Catastrophic Conditions

31

Hilal Sipahioğlu

Abstract

There are different forms of terrorism in the world. However, bioterrorism has the potential to be more devastating than chemical and nuclear terror. The deliberate release of a biological agent into a civilian population, exposing hundreds and thousands of people to a severe pathogen, is called bioterrorism. Bioterrorism may be suspected when unusually high rates of a single disease are seen, or an unusual pathogen is isolated in the laboratory. Millions of people are affected by bioterrorism events and wars. Hospitals and health personnel need to be prepared to deal with thousands of critically ill patients in these cases. Positive pressure mechanical ventilation is required for patients who cannot achieve adequate oxygenation with only oxygen support and develop respiratory failure with high carbon dioxide levels and acidosis during serious epidemics and wars. Positive pressure ventilation is given to patients in two ways; invasive and noninvasive. Noninvasive mechanical ventilation (NIMV) can be preferred primarily in patients who are hemodynamically stable, conscious, and do not have upper airway obstruction with acute respiratory failure and for patients after extubation.

The purpose of NIMV is to reduce intubation rates and to accompany complications.

The risk of scattering microorganisms that cause droplet transmission is high due to positive airway pressure and leaks. These patients should be followed up in negative pressure rooms, and the health-care personnel must provide complete personal protection. Helmet NIMV seems to be more appropriate for these patients due to the leakage risk. In addition, transmission is less, and patients can tolerate it better.

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Keywords

Bioterrorism · Catastrophic conditions · Noninvasive mechanical ventilation · Mortality · Morbidity

Abbreviations

ARDS	Acute respiratory distress syndrome
CDC	Centers for Disease Control
CPAP	Continuous positive airway pressure
DIC	Disseminated intravascular coagulation
FDA	Food and Drug Administration
ICU	Intensive Care Unit
NIMV	Noninvasive Mechanical Ventilation
PEEP	Positive End-Expiratory Pressure

Models of NIMV in Bioterrorism

There are different forms of terrorism in the world. However, bioterrorism has the potential to be more devastating than chemical and nuclear terror [1]. Definition of bioterrorism is the deliberate release of a biological agent into a civilian population exposing hundreds or thousands of people to a serious pathogen [2]. Unlike most cases of mass injury, the release of bioweapons agents is covert, resulting in many patients in need of medical treatment. It is a public health problem, and the prevention of healthy individuals is vital.

Bioterrorism may be suspected when unusually high rates of a single disease are seen, or an unusual pathogen is isolated in the laboratory. Primary care providers, emergency room physicians, intensive care specialists, infection control practitioners, and infectious disease physicians are the first to recognize diseases caused by various biological agents, including rare pathogens. Clinicians should carefully assess the probability of bioterrorism, since an outbreak of disease may be due to deliberate exposure [3].

Positive pressure mechanical ventilation is required in patients who develop respiratory failure in severe epidemics, who cannot achieve adequate oxygenation with only oxygen support, and who have high carbon dioxide levels and acidosis. Patients survive despite severe respiratory failure with positive pressure mechanical ventilation in intensive care under special conditions. Positive pressure ventilation is given to patients in two ways: invasive and noninvasive. In mass incidents, when need exceeds capacity, a large number of health-care professionals specializing in noncritical care will need to be involved in patient care. Giving courses that provide basic critical care knowledge and skills to health personnel who are not specialized in intensive care will improve clinical outcomes. Hospitals need to be prepared to

deal with hundreds or thousands of critically ill patients in a certain city in the event of future bioterrorist attacks.

Appropriate Approaches to a Potential Bioterrorism Incident:

1. Early detection with real-time data from emergency rooms, laboratories, pharmacies, and even schools
2. Rapid case recognition
3. Postexposure prophylaxis
4. As needed, directed treatment for a probable or confirmed disease
5. Rapid isolation of victims
6. Increasing the capacity to provide medical care for the severe and critical patients

The Centers for Disease Control (CDC) has identified several pathogens that can be used in biological terrorism and categorized them according to their overall potential harm (Table 31.1) [4].

The United States Centers for Disease Control and Prevention has ranked various pathogens into these categories based on their potential harm.

- **Category A** agents are the highest priority. They can cause high mortality, can be grown easily in massive quantities, and are resistant to destruction. They are also well suited to airborne dissemination and can thus infect a large number of people.
- **Category B** agents are the second highest priority. They are moderately easy to spread but cause less morbidity and mortality than Category A agents.
- **Category C** agents include pathogens that could be engineered for mass dissemination and have significant potential morbidity and/or mortality [4, 5].

Table 31.1 Potential bioterrorism agents by category

Category A agents	Category B agents	Category C agents
Variola major (smallpox)	*Coxiella burnetii* (Q fever)	Nipah virüs
Bacillus anthracis (anthrax)	*Brucella spp.* (brucellosis)	Hantaviruses
Yersinia pestis (plague)	*Burkholderia mallei* (glanders)	Tickborne hemorrhagic fever viruses
Clostridium botulinum toxin (botulism)	*B. pseudomallei* (melioidosis)	Tickborne encephalitis viruses
Francisella tularensis (tularemia)	*Chlamydia psittaci* (psittacosis)	Yellow fever
Filoviruses (Ebola, Marburg)	*Rickettsia prowazekii* (typhus fever)	Multidrug-resistant tuberculosis
Arenaviruses (Lassa, Junin, and related viruses)	Alphaviruses (eastern equine encephalitis, western equine encephalitis, Venezuelan equine encephalitis)	
	Ricin toxin	
	Epsilon toxin of *Clostridium perfringens*	
	Staphylococcus enterotoxin B	
	Salmonella spp.	
	Shigella dysenteriae	
	Escherichia coli O157:H7	
	Vibrio cholerae	
	Cryptosporidium parvum	

Recognition of the bioterrorism agent is difficult at first, since the early prodromal phase of most agents is similar. Respiratory diseases with fever and respiratory failure may indicate a natural epidemic (e.g., severe acute respiratory syndrome, plague, tularemia, or a new strain of influenza) or a bioterrorism event [6].

Most febrile respiratory diseases admitted to intensive care units (ICUs) cause community-acquired pneumonia, and then respiratory failure and acute respiratory distress syndrome (ARDS) develop in 11% of these community-acquired pneumonia cases [7]. NIMV can be used as a bridge treatment in patients who develop ARDS and acute respiratory failure. Early recognition is needed to prevent the public spread of the disease at its most contagious early stage. Droplets can spread some viral infections during respiratory support. NIV can distribute potentially infected aerosols, particularly when patients cough and sneeze frequently, contributing to the hospital-acquired transmission of influenza. In patients undergoing NIMV, mask leakage at a distance of 1 m and spread of droplets with high inspiratory pressure are high [8].

In cases where treatments that cause droplet spread, such as NIMV, are performed, health-care personnel should take full protection measures with an FFP3 mask (N95 masks are the second choice), eye protection, apron, and gloves. Adequate oxygenation should be provided at the lowest possible pressures. It is better to prefer full face masks to nasal masks when applying NIMV to minimize the spread of infected particles through the mouth. Helmet masks cover the patients' heads and necks while applying NIMV. In this way, patients using Helmet masks have less air leakage than those using face masks. Helmet mask use is more effective in ARDS patients who require high positive end-expiratory pressure (PEEP) and have high peak pressure. The use of face masks at high pressures can cause wounds on the patient's face. In these patients, the use of Helmet masks can be tolerated longer than the use of face masks.

Early detection of a bioterrorism or epidemic event with early preventive measures and public health contact will reduce its spread to health-care workers, visitors, patients, and the community.

Bioterrorism-causing agents initially present with a nonspecific prodromal phase, but they have epidemiological clues distinguishing them from other febrile respiratory disease causes. First of all, the properties of these agents will be mentioned to better recognize the agents in the CDC A category.

Smallpox

The smallpox vaccine was discontinued in 1980 after the World Health Organization declared the disease to be eradicated [9].

In conclusion, the civilian population under the age of forty is completely susceptible as it is unvaccinated. The rate of person-to-person transmission of smallpox is extremely high, and because it can live outside the host, it can cause great harm if deliberately released. Patients' lesions first appear in their mouth and throat, and their transmission begins with these lesions. Infectiousness continues until the rash

ends in the body. Infection can also occur through the fluids of the lesions in the body.

Smallpox is divided into five categories according to its clinical features: Ordinary type, Modified type, Flat type, Hemorrhagic type, and Variola sine eruption. All these forms have characteristic rashes, except for Variola sine eruption. The incubation period is between 12–14 days. One to four days before the rash, fever symptoms are accompanied by fatigue, headache, backache, chills, vomiting, or severe abdominal pain. The features of the rash are that they are deep, round, hard and well-circumscribed, vesicular, and pustular. All lesions show the same developmental stage; all are either vesicular or pustular. The definitive diagnosis of smallpox is typically made by molecular testing. The primary treatment for smallpox is supportive care, which includes maintaining fluid and electrolyte balance, skincare, and treatment of infectious complications. Antiviral treatments (Tecovirimat, Brincidofovir) are approved by the Food and drug administration (FDA) for smallpox.

The mortality is related to the degree of confluence among the lesions. Death usually occurs on the eighth and tenth days. While negative pressure rooms are sufficient to reduce transmission in small outbreaks, it is necessary to separate hospitals and quarantine practices in large outbreaks. Patients are at elevated risk of pulmonary edema and may require mechanical ventilation. These patients may benefit from higher PEEP. Patients can benefit from continuous positive airway pressure (CPAP) with a Helmet mask in the initial period to minimize transmission.

Anthrax

Bacillus anthracis is an encapsulated, Gram-positive, spore-forming bacillus, transmitted by contact with infected animals or animal products and causes three types of disease: cutaneous, inhalation, and gastrointestinal. Inhalation anthrax has not occurred naturally in the United States since 1976; any case is therefore considered a possible sentinel case of a bioterrorist event [2].

After the *inhalation of anthrax*, spores that reach the distal airways are transported to the mediastinal lymph nodes by inflammatory monocytes or dendritic cells, replication starts, and then disease begins [10]. The average incubation period is 1 to 7 days, followed by clinical symptoms of a nonspecific febrile illness that often mimics influenza. Typical bronchopneumonia is not seen in patients, and it is difficult to suspect inhalation of anthrax in the initial period. The mediastinum enlarges due to massive lymphadenopathies developing in the mediastinum on the chest X-ray [11]. The disease progresses rapidly, with respiratory failure, hemorrhagic mediastinitis, necrotizing pneumonia, shock, multi-organ failure, and death within 24 h [12]. Many antibiotics are effective; however, resistance to third-generation cephalosporins has been noted. Combination therapy with one or two antimicrobial agents is given together with intravenous ciprofloxacin. High-dose penicillin and steroid therapy are recommended in cases of anthrax meningitis. Also, steroid treatment is recommended in intrathoracic and extrathoracic

mediastinal lymphedema cases. In massive pleural effusions, chest tube thoracostomy may be necessary to allow adequate ventilation and to evacuate infected material. Since these patients progress with severe hemodynamic impairment and hemorrhagic tracheobronchitis, they require close follow-up in the intensive care unit [13].

Since respiratory failure progressed rapidly in the case series, the patients were intubated without delay, and invasive mechanical ventilation (IMV) support was provided [14].

In these cases, with dyspnea, hypotension, and hemorrhage, it may be more appropriate to prefer primarily invasive mechanical ventilation. However, if the number of cases is too high and there is not enough invasive mechanical ventilation device according to the conditions of the hospital, noninvasive mechanical ventilation can be planned for suitable patients; using a Helmet mask seems like a more accurate approach due to hemorrhage.

Patients' oxygenations can be improved, and tamponade can be provided on the bleeding site by giving PEEP to these patients [15]. It has been emphasized that NIMV is not appropriate, since inhalation anthrax progresses to septic shock rapidly [8]. NIMV seems to have a higher priority in acute respiratory failure that develops in epidemics, because it does not require sedation and is more advantageous than *IMV* since it is cheaper. However, patients with anthrax inhalation should have more frequent vital and physical examinations as their clinics deteriorate rapidly. Patients diagnosed with inhalation anthrax may need aggressive pleural fluid drainage. Meanwhile, the NIMV can function as a bridge.

Plague

Yersinia pestis is a nonmotile, Gram-negative coccobacillus that causes plague. It has historically killed millions of people. Aerosol dispersal would be the most likely route of dispersal during an attack. Human plague occurs worldwide and is native to the southwestern United States, where an average of 10 cases is reported each year [16].

It is transmitted to humans through the bite of an infected flea, the inhalation of respiratory secretions of animals or humans with pneumonic forms of the plague, or the direct use of infected animal tissues. The most common clinical manifestation is acute febrile lymphadenitis, called bubonic plague.

Bubonic Plague

It is clinically characterized by sudden fever, chills, malaise, and headache, followed by intense pain, and swelling in an area of lymph node (bubo) with preceded lymphadenopathy. Acute bubo is painful but lacks ripple. It is usually associated with erythema and edema of the overlying skin. The groin is the most frequently involved area. In the absence of treatment, the initial bubonic stage can be followed by disseminated infection (sepsis) in about 50% of untreated cases, which can lead

to complications such as pneumonia (secondary pneumonic plague) and meningitis [17]. Septic shock symptoms may develop in bacteremia patients [18].

Septicemic Plague

It can be particularly difficult to diagnose the septicemic form of plague on time if characteristic clinical clues such as a bubo are not present. In septicemic plague, fever is high, and localized signs or symptoms may not always be present. Gastrointestinal symptoms such as nausea, vomiting, diarrhea, and abdominal pain may occur. In the later stages of the disease, hypotension, disseminated intravascular coagulation, and multiorgan failure develop [18].

Pneumonic Plague

Pneumonic plague can be primary or secondary. Primary pneumonic plague can be transmitted by inhaling respiratory secretions or aerosolized droplets from infected animals or humans or by laboratory exposure [19, 20]. Secondary pneumonic plague is more common and is caused by the hematogenous spread of bacteria from a bubo or other source. Primary pneumonic plague has a short incubation period ranging from a few hours to a few days. Affected patients typically present with sudden onset of shortness of breath, high fever, pleuritic chest pain, and cough that may be accompanied by characteristic bloody sputum. Pneumonic plague is rapidly fatal unless an appropriate antimicrobial agent is started on the first day of illness [21]. Patients with fever and painful lymphadenopathy should be questioned about travel to endemic disease areas and animal or rodent vector contact in the last 10 days. The presence of pneumonia, in addition to hemoptysis with sputum containing Gram-negative bacilli in Gram staining, establishes the diagnosis (Fig. 31.1).

Disseminated intravascular coagulation (DIC), septic shock, ARDS, and rapid progression to multiorgan failure due to endotoxemia should be carefully monitored in patients. Patients require aggressive fluid resuscitation, vasopressors, and mechanical ventilation. The CDC recommends treating with an aminoglycoside

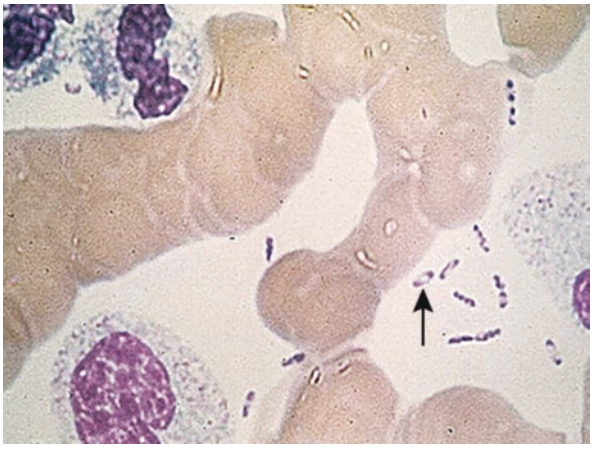

Fig. 31.1 Wayson stain of *Yersinia pestis* (http://www.cdc.gov/ncidod/dvbid/plague/wayson.htm)

(*streptomycin* or *gentamicin*) or a fluoroquinolone (*levofloxacin*, *ciprofloxacin*, or *moxifloxacin*).

It is recommended that people in contact wear N95 masks and the patient stays in a negative pressure room to prevent airborne transmission. The application of NIMV seems to be inconvenient due to the high infectiousness of the particles in patients. However, there is no clear information or recommendation.

NIMV Models in Catastrophic Situations

Major disasters caused by industrial accidents, natural events, terrorist attacks, or wars cause death and disability. The world is recently witnessing the third month of the Russian-Ukrainian war; thousands of people have been killed, including adults, children, the elderly, and the sick. They used banned rockets and bombs in warfare, such as thermobaric explosions, cluster bombs, and white phosphorus [22].

Specialists and hospitals not specialized in trauma and war medicine found themselves at the forefront. Triage is provided in the scenery with intense cases, and patients are referred to the surrounding hospitals according to their clinical condition. Hospitals that can perform all kinds of operations during normal times have the most experienced personnel in the treatment of multiple trauma and acute bleeding. These hospitals are usually designated as primary care hospitals. Patients are first referred to these hospitals according to their clinic. Afterward, patients who do not need emergency surgery and postoperative intensive care are referred to other hospitals.

Fluid replacement therapy, infection control, dressings, surgery, antimicrobial therapy, intensive care, and nutrition planning are particularly important in burn patients. When appropriate treatments are not given, mortality and morbidity are extremely high. Infection is the most important cause of mortality in major burns. The risk of sepsis and pneumonia in patients is very high. In burn and trauma patients, atelectasis due to pain and hypoventilation due to burns in the chest and abdomen develop [23, 24].

Another cause of respiratory failure in burn patients is protein denaturation due to burning in the oropharynx and edema formation in the tissue due to extravasation.

The mainstay of treatment for respiratory failure in patients with major burns has been invasive-noninvasive mechanical ventilation. NIV is less preferred in burn patients. The benefits of NIV are to reduce intubation and its accompanying complications.

Patients receiving NIMV have better oral hygiene, less sedation, avoidance of barotrauma, and less ventilator-associated pneumonia [25]. The hemodynamic status of patients who will undergo NIMV should be stable, and there should be no upper airway obstruction. Patients who are predicted to develop airway edema within hours should be intubated quickly. Since the risk of hemodynamic instability and edema is high in burn patients, the use of NIMV seems to be limited. Studies have shown that the use of NIMV in post-extubation respiratory failure in burn patients reduces reintubation [26, 27].

Helmet masks have been developed to prevent facial compression in patients undergoing NIMV. A Helmet mask may be the right choice for patients with facial wounds and burns. NIV with a Helmet mask has been shown to be as effective as a traditional face mask in reducing hospital stays, mortality, pneumonia, and the need for invasive ventilation. However, rebreathing of CO_2 seems to be the only handicap of the Helmet mask.

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Part V

Respiratory Care, Education, Ethics and Cost of Noninvasive Ventilation Outside Intensive Care Unit

Airway Clearance Techniques and Devices: Implications in Noninvasive Ventilation

32

Paolo Buonpensiero

Abstract

Mucus problems in ventilated or nonventilated people potentially are causative of disease progression. Efficient management of bronchial secretions is of uppermost importance in a wide spectrum of diseases and conditions. Airway clearance techniques can be considered a complex therapeutic approach composed of careful evaluation of the patient needs, clinical condition, care setting, integrated with the best evidence. Every technique should be tailored, personalized, and proposed to the patient considering indication possible adverse effects and absolute contraindications.

Keywords

Airway clearance techniques · Devices · Postural drainage · Active cycle of breathing techniques · Positive expiratory pressure · Positive oscillatory expiratory pressures · Flutter and acapella · Extrathoracic assisted oscillations · High-frequency chest wall oscillations · HFCWO · Intrapulmonary percussive ventilation · Lung volume recruitment · Mechanical insufflation-exsufflation

Introduction

In the last decade, the use of noninvasive mechanical ventilation in both acute and chronic patients with respiratory conditions and decompensated respiratory failure has shown in current clinical practice to be a useful care approach. Evidence data

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also regarding the use of NIV for COPD patients after AE in a home setting are now more robust although data on mortality rate of these patients are still equivocal [1].

As carriers of chronic respiratory disease, these patients may show disorders of the normal mucociliary clearance mechanisms and the further need to add noninvasive ventilotherapy to the treatment plan cannot ignore the possible interactions between the machine and the patient in terms of mucociliary clearance. In the same way when adding noninvasive ventilation (NIV) to a patient it is not possible not to consider the pre-existence of airway clearance techniques (ACTs) programs in patients who start a program of noninvasive mechanical ventilation at home. Default in Mucociliary Clearance (MCC) can occur in many diseases with different causes and in different ages of the life. Increased mucus production, impaired mucociliary transport, and respiratory muscle weakness with inefficient cough are the main causative elements for mucus retention.

Retained secretions cause obstruction of the airways increased resistance, ventilatory inhomogeneity impaired ventilation perfusion ratios up to respiratory failure or can be a precipitating factor to decompensation on pre-existing diseases. Mucus retention is also responsible of others pathophysiological elements that manifest themselves with oxidative imbalances, respiratory infections with rheological changes of the mucus. Cellular and molecular mechanisms can induce mucus hypersecretion with different physiopathological basis as we can find in cystic fibrosis and chronic obstructive pulmonary diseases (COPD) [2]. Common features of chronic respiratory conditions with mucus obstruction are dyspnea, reduced exercise tolerance, acute exacerbations, progressive lung damage, hemoptysis, sleep disorders, and poor quality of life. Kyphoscoliosis, gastroesophageal reflux, weak cough, and respiratory infections predispose patients with neuromuscular disorders (NMD), cerebral palsy, to severe mucus obstruction recurrent aspiration, recurrent pneumonia with respiratory morbidity [3–5].

Other concomitant pathological events should consider such as malnutrition, constipation, and muscle wasting.

Airway Clearance Techniques [ACTs]

The term ACT refers not only to a series of techniques aimed at the removal of bronchial secretions with related or expected positive effects, but also to a methodological system based on the understanding of the underlying disease, of the physiopathological mechanisms responsible for bronchial obstruction, and of the best possible application of the techniques. It is an evaluation process relevant for a correct application of the techniques. In few words not only techniques and devices. In the course of the last over the last 40 years we have witnessed a radical change in the meaning of this complex of this care process that is considered a corner stone in the prevention and treatment of many chronic and acute respiratory conditions. From a very limited concept of effectiveness restricted to a “cleaning effect” of what we have called in the past “Chest Physiotherapy” (historically referred to postural drainage and percussions) after about 20 years of clinical trials, we can assume that

ACTs if integrated in a modern concept of the patient care are able to reduce morbility and morbidity in chronic respiratory conditions with mucociliary dysfunction [6] and in complex neurodisabilities positively interfering in many absolutely not negligible assistance elements such as costs of care number of respiratory exacerbations quality of life of patients.

This methodological system cannot fail to consider factors inherent to the specific evidence of the single technique or of the single device and to the patient's preferences often determining adherence to the proposed treatment.

A preliminary fundamental consideration must be done in order to explain the specificity of regional action of the ACTs. Actually, we can explain the regional specific (proximal and peripheral) action of ACTs applying a single compartment equation of motion.

The equation: Ppl = ExVa + RxV1bR + IxV2 is referred to a single compartment model described from Roher in the 1915 [7] and Otis in the 1956 [8].

This model was taken as a theoretical reference model for ACTs in 2009 at the European congress of the European Respiratory Society. The explanation of the model and its practical applications, conducted by the French group of Guy Postieaux, allows us to draw some general principles that relate the distal zones (right side of the equation) to be treated with constituent elements of many ACTS such as depth of breath, long inspiratory times, use of the inspiratory tele apneas, and lateral decubitus.

In the same way, the right side of the equation leads us to consider the use of maneuvers that induce greater gas-liquid interactions and therefore related to rapid exhalation.

Currently, independently of the ACT chosen, the intervention strategy includes four cyclical steps that can be summarized as follows:(1) open up and get air behind secretions, (2) mobilize and collect secretions from the peripheral airways, (3) transport secretions toward the central airways, and (4) evacuate secretions [9]. The model mentioned is however supported by precise (E.P.P) and well-known physiological mechanisms such as alveolar interdependence, collateral ventilation, gravity, supporting inspiratory depending on factors and two gas flow liquid interactions and equal pressure point obtained also with forced expiratory maneuvers cough for expiratory dependent part of the model related to proximal airways.

The application of two different mechanical perturbation on the respiratory system, oscillations and vibration, can produce improvement in MCC.

Oscillations at specific frequencies (11–15 Hz) improve mucus clearance, rheological characteristic, and spinnability. Vibrations intended as the application of fine manual oscillatory movements on the chest (during expiration) and studies in healthy subjects showed improvement in peak expiratory flow rates over 50% [10].

Clinical studies also provided informations about frequency of vibrations and their effects on expiratory airflow in comparison with other ACTs percussion, positive expiratory pressure mask (PEP.) oscillatory PEP with Flutter, and oscillatory PEP with Acapella always in cystic fibrosis patients.

The values of PEFR. (94.8 L·min 1) and PEFR/PIFR ratio (1.51) are sufficient to assist in mucus clearance and were greater than the other interventions, but lower than a cough or huff maneuver.

The peak expiratory flow/peak inspiratory flow ratio [PEF/PIF] needs to be 1.1 to achieve this and the frequency of oscillation needs to be 3–17 Hz [11, 12].

Airway Clearance Techniques and Devices

Beyond scientific evidence and physiological rationale, they must be integrated in daily practice into a more complete vision of the needs of patients, especially pediatric ones.

In this regard, ACTs should be integrated with other interventions such as physical exercise, inhalation therapy and not least all the possible interventions aimed at a correct education of the patient and caregivers not only on the specific aspects inherent to the techniques but also and on the real motivations of the proposed treatments. These basic care elements are well represented in the modern definition of pulmonary rehabilitation programs [13].

Respiratory therapists play an extremely significant role also in setting up an overall feasible treatment program that is effective and shared with the patient in relation to specific needs as well as preferences.

Never forget that ACTs can play a preventative role in many chronic respiratory diseases and considering this point, ACTs should be implemented in the most effective way.

Postural Drainage [PD]

Postural Drainage is the first technique used in CF and BCT patients. Used with the addition of manual techniques and breathing modifications. Until now some patients use PD in combination with other ACTs.

In PD, an individual is placed in various positions allowing gravity to facilitate mucus drainage in specific lung areas [14].

The positions via a gravity-dependent effect should facilitate mucus dislocation from peripheral to central airways, thus helping mucus expectoration [15].

Usually, 12 positions can be considered, and the choice is anatomical dependent. PD has effects also on regional ventilation and could be utilized in localized lung pathology situations such as lung abscess, in absence of other ACTs or in presence of evident not applicability of the last ones.

Traditionally, PD manual techniques such as chest percussions and vibrations, breathing pattern modifications such as BC and TEE and FET are considered in PD. All the elements should contribute to a mucus-clearing strategy.

PD has been considered a pillar and a standard of treatment for CF patients until new techniques with an optimum physiological proof of concept, and absolutely

better acceptable from patients and parents have been introduced with good clinical trials.

Head-down position traditionally used in PD has been shown to be correlated to gastroesophageal reflux and aspiration, and it is possible to conduct PD without using head-down position [16], while percussions could lead to bronchospasm (also from GE-reflux) and hypoxia [17].

PD is not indicated in very preterm babies, individual with cardiac rhythm changes cardiac rhythm changes, newborns, and immature infants [18].

Active Cycle of Breathing Techniques [ACBTs]

This uses breathing control (BC) thoracic expansion exercises (TEE) forced expiration technique (FET) and cough [19].

In the BC, the person breathes near his tidal volume [TV] at his rate and in the most comfortable way. BC phase helps to prevent irritation bronchoconstriction and is useful after active phases of FET and cough.

The more the patient shows fatigue ineffective cough the more BC components will be present in the whole cycle.

With TEE the intention is for peripheral airway and if possible, a 3 s of end inspiratory hold can be asked to the patient and incorporated in the treatment cycle. No effort is required during expiration (and teach the patient to always do a relaxed expiration) [20].

A sufficient increase in lung volume activates collateral channel with less airway resistances and air will be facilitated to pass behind the secretion (volume related building up). The end-inspiratory (3 s) holding will result in a more evenly ventilation [21].

ACBT can be combined with mechanical maneuvers such as percussions and during expiratory phase vibrations.

Fast expirations at open glottis [huff] at low lung volumes should assist in loosening and mobilizing excess bronchial secretions from smaller peripheral airways to larger central airways. FET is the combination of one of two huffing with BC. When secretions reach the larger airway can be cleared with cough or with a high volume huffing. Effective huffing maximize airflow, an effective huffing should take in consideration force muscle contraction that should be optimized (not too strong not too weak).

During a huff maneuver, the generation of a compression of the airway downstream toward the mouth of the equal pressure point acts with a squeezing action, which moves peripherally with decreasing lung volume, together with the increase in air speed, as air flows through the narrowed segment, facilitating the movement of secretions along the airway.

ACBT can be used in various positions if required after clinical evaluation, but sitting position is often preferred by patients.

ACBT can be used in adjunct with NIV if required, and usually settings are those allowing to the patient to increase thoracic expansion during [TEE]. Usual settings for BC maneuver.

Length of each session and quality of the cycle [ratio between number of BC-TEE-FET-COUGH] are factors strictly depending on severity of mucus obstruction, patient status, and therapist evaluation.

ACBT has been shown to an effective treatment in CF population, non-CF bronchiectasis, and COPD for sputum expectoration, dyspnea, and patient preference [22, 23].

Autogenic Drainage [AD]

AD is based on adjusting the level of breathing and rate. Basically, during AD, the attempt is to maximize the "erosive effect" airflow shearing forces on the mucus.

Performing AD patients adjust his breathing pattern in depth, rate, and localization [24].

To generate the best shearing forces [expiratory] its mandatory a fine equilibration between inspiration and expiration that means inspiratory airflow and expiratory airflow.

Too high inspiratory airflows (rapid inspirations) cannot inhibit inhomogeneous airway filling and back flow of secretions.

During exhalation, the best shearing forces induced by the higher expiratory linear airflow velocity can be localized to where secretions are. The continue modulation of the "breathing level" inside the vital capacity and the expiratory muscle activity determining the intrathoracic pressure can produce the optimal airflow at the level of the bronchial funnel.

The stability of the airways must be preserved, and the intrathoracic pressures must not exceed bronchial stability and must not produce dynamic compression (no EPP) airflow drop inhomogeneous emptying and increase of trapped gas.

Adjusting the depth of inspiration from low to medium to high lung volume followed by exhalation to the expiratory reserve volume can generate the process described above of detachment—collection and expectoration of secretions.

The process is considered as a sequence resumes when the subject expects or eliminates his secretions even without coughing.

As expected, the technique requires both the physiotherapist and the patient to have a great ability to concentrate.

Normally the DA is performed in a sitting position, but it is possible to use alternative/complementary postures in order to improve ventilation in specific lung regions.

Feedback leads the way and is an essential component.

Basically, no element of superiority, comparing the clinical efficacy of AD with other techniques used, has currently been demonstrated in CF.

However, there is a tendency to recommend the method in the collaborating patient with bronchial hyperreactivity.

In the uncooperative child it is possible to apply the same guiding principles of the technique through the modified DA.

Positive Expiratory Pressure [P.E.P]

The use of a resistance in the expiratory phase creates a positive pressure inside the bronchial tree [PEP].

This [temporary] pressure can be used to improve the MCC and ventilation of obstructed area of the lung of the patient with obstruction and stagnation as in the patient with Cystic Fibrosis [25].

The increase in endobronchial pressure induces a temporary increase in functional residual capacity [FRC] with an increase in alveolar interdependence, and subsequent increase in collateral ventilation via a decrease of collateral resistance, thus recruiting previously obstructed lung, furthermore has been proven effects in improvement of gas mixing at different level of pressures, and significative reduction in residual volume (Cystic Fibrosis patients from moderate to severe impairment) [26].

PEP

The application in clinical practice of ACTs in CF usually foresees variable cycles or periods of breathing [a little deeper than normal] normally obtaining an expiratory pressure [Sustained Expiratory Pressure] of about 15–20 cm H_2O and with an expiratory time ranging from 4 to 6s [phase of increase in FRC, alveolar recruitment with increase in back pressure].

Then follow maneuvers [such as huffing or accelerated and modulated expirations towards the VRE] aimed at moving and expectorating the secretions taking in account that PEF/PIF ratio obtained with this device is 0.47 [27].

The use of PEP in young children FC [Baby PEP] produces comparable results in terms of clinical effectiveness when compared to other ACT methods often associated with games that implement accelerations in the expiratory phase or oscillations on gym balls [28].

Due to their physiological characteristics, these maneuvers will tend to bring the FRC gain obtained with breathing against resistance back to lower levels again.

The effectiveness of low PEP in CF has been demonstrated in many clinical trials with an investigation period of even more than 1 year.

A systematic review comparing the efficacy of PEP and other ACTs methods in cystic fibrosis does not report significant differences in terms of lung function gain.

However, an increase in respiratory exacerbations in CF was documented in a 1-year study following the replacement of the PEP mask with High-Frequency Chest Wall Oscillations [HFCWO] [29, 30].

High-Pressure PEP

It is conducted by producing forced expiration maneuvers against a resistance and producing a variable expiratory pressure [S.E.P.] of not less than 40 cmH_2O and not more than 100 cmH_2O. The session is normally composed of a series of breaths [6–8] against resistance producing an SEP of 10–20 cmH_2O, the last two are either forced expiration maneuvers [with an SEP variable between 40 and 100 cmH_2O] against resistance up to the VRE [31].

The first part would obtain effects similar to PEP at low pressure, the second using adaptive extracorporeal flows would be able to homogenize the emptying of lung regions whose ventilation would be particularly inhomogeneous due to obstructive and stagnation processes [32].

In this method, the resistance to be used is chosen by measuring the forced maneuver in PEP by interfacing the system with a pneumotachometer [32].

The resistance choice parameter turns out to be the best FVC obtained from the maneuver and with the resistance in question, but a careful evaluation and interpretation of the obtained curve is advisable [32].

The number of cycles and the frequency of treatment as for the other ACTs in cystic fibrosis and other chronic respiratory conditions requiring ACT is individualized in relation to the needs and characteristics of the patient.

A short term study demonstrated superiority in terms of secretion production of HI PEP over AD [33].

A long-term study comparing HI PEP and conventional DP [Postural Drainage] has shown a significant increase in the parameters of pulmonary function, secretions produced and hyper-inflation in CF [34].

Contraindications and complications of applying high pressures are to be considered in patients with extreme bronchial lability, particularly fatiguing, with a previous history of pneumothorax, recent hemoptysis, hemodynamic instability, and cardiac pathology.

Low-Pressure PEP

Aims of PEP breathing are to improve gas exchange and reduce work of breathing. Expiring against a light resistance is what we normally see in COPD patients when doing spontaneously pursed lips breathing to reduce dyspnea secondary to hyperinflation [35].

PEP can reduce hyperinflation and related dyspnea improving in secondary instance the ability of the patients also to clear his secretions more easily.

Patients learn to get a time related expiratory target previously breathing in slowly to decrease slowly FRC to normal values, with a pressure range of 5 up 10 cmH_20 [20].

Two physiological proofs of concept can be advocated:

1. Reducing expiratory time during PEP decreases pressure drop along airway wall, thus reducing airway collapse [25].
2. Increased airway pressure during PEP breathing decreases the risk of airway closure [36].

Some studies demonstrate efficacy of PEP mask for in COPD patients in positively interfere with relevant outcomes but relevant review still suggest the need of better conducted clinical trials although real life data are encouraging [37].

Positive Oscillatory Expiratory Pressures [OPEP]—Flutter and Acapella

Flutter and Acapella are devices used in CF and other chronic suppurative lung diseases such as non-CF bronchiectasis [Non CF Bronchiectasis] and in patients with Primary Ciliary Dyskinesia (P.C.D) [38].

Flutter and Acapella generate oscillating positive expiratory pressures and alterations of the expiratory airflow with improvement of the viscoelastic properties of bronchial secretions and therefore more movable [39].

The Flutter oscillates at frequencies ranging from 15 to 29 Hz with PEP generated ranging from 5 to 19 cm H_2O.Acapella, on the other hand, generates intrabronchial oscillations ranging from 13 to 30 Hz and PEP ranging from 6 cmH_2O to 21 cm H_2O [39]. Two essential variables oscillation frequency and amplitude are strictly related with the force of the expiration [40].

Oscillations has been proven to be effective [from in vitro studies] on the increase in thickness of the Airway Surface Liquid [ASL] and the effects of these frequencies have not yet been investigated.

However, it has been shown that the oscillations produced if they reach the resonant frequency of the lung produce vibrations of the endobronchial structures [41].

The Flutter, while satisfying the [physiological] criteria useful for the detachment and mobilization of secretions, may have no effect on the increase in FRC that is normally observed with PEP and the exhalation towards ERV required in the procedure can create phenomena of early closure of the airways.

In the procedures described for both techniques, the addition of 3 s breath hold is useful in improving alveolar gas mixing.

The minor complication described can be avoided by using Acapella which allows an increase in FRC similar to the PEP mask [thus recalling the physiologies of collateral ventilation and alveolar interdependence] but at the expense of an optimal ratio of flow peaks [PEF/PIF] which as in the PEP are approximately 0.64 therefore insufficient, since their effective threshold value is greater than or equal to 1.1.

Hence the need, in the choice of the two aids, for a rigorous assessment of the patient's characteristics in relation to the greater or lesser presence of bronchial instability as well as the relationship to the severity of the patient's pulmonary status.

As with the PEP mask with both devices, the patient undergoes breathing cycles during which it is possible to obtain the physiological effects characteristic of the two aids.

Patients inhale a little above the tidal volume hold the breath for 3 s and then exhale with the help of abdominal muscles through the device towards a lowered FRC level but not all the way.

A reinforcement of resonance of lower chest and upper abdomen will indicate an optimal flow amplitude and oscillations frequency [42].

With the Flutter the inclination of the device will produce different frequencies [in relation to the flow produced], the best resonance frequency [43].

Frequency and number of treatments will be tailored accordingly with the specific needs of the patient play an import role to teach and try together with the patients.

Oscillatory PEP has been proven to be effective not only in CF patients but also in other Chronic Respiratory Conditions such as Bronchiectasis and COPD and equally effective of ACBT [44].

The specifications made so far in relation to the PEP and o-pep should have served to make it clear that it is not just a matter of pressure. The clinical effects to be obtained in relation to the clinical needs of each patient must consider not only elements such as pressures and duration of treatment but also and above all the modulation of both the inspiratory and expiratory modalities, i.e., duration of expiration and greater or lesser effort of the expiratory muscles.

ACTs cannot be standardized and PEP and OPEP cannot be standardized. Carefully read performance characteristics of the devices especially oscillation index.

Extrathoracic Assisted Oscillations [High-Frequency Chest Wall Oscillations] HFCWO

HFCWO are devices composed by an air pulse generator connected to an inflatable jacket worn on the chest.

HFCWO compresses the chest wall externally generating short rapid expiratory flows pulses and relies on chest wall elastic recoil to return the lungs to functional residual capacity [45].

The vest inflation results in a short expiratory flow burst, and the deflation results in a chest wall recoil to the resting position.

The system operates superimposing on a baseline pressure of about 12 cmH_2O.

The deflation of the vest will result in a chest wall recoil the rest position creating flow in inspiratory direction.

These systems usually operate at 2–25 Hz generating esophageal pressures and airflow oscillations and are declared air volumes changes from 17 to 57 mL and flows up to 1.6 L.

These systems work as minicough generators generating expiratory flow bias at variable frequency.

The physiologic effects expected and also supported from several clinical and physiology evidence studies are related to the effects of shear forces [inspiratory expiratory bias dependent], and to the effects of the vibration's compressions on mucus rheological properties and not secondarily on peripheral clearance [45, 46].

The airflow spikes produce a sweeping effect on the secretions, the high-frequency oscillations transmitted to the airwall break up DNA and mucus, and the oscillations of the airways dislodge the mucus from the bronchial wall. The effects of different waveforms [specific for different device on the market] have been studied in several studies and clinical trials in CF patients and now triangle waveform seems to be more effective to act simultaneously on volumes and flow and more comfortable for the patient that refer less squeezing effect on chest wall.

While working with triangular waveforms, different frequencies must be utilized in the same treatment session to achieve better results in terms of sputum expectoration airway stability preservation and pulmonary function [47].

Until now we have explained the proof of concept regarding mucus-clearing properties of HFCC, but not how these minicough train acts on breathing dynamic.

From clinical trials and physiology study, HFCC improves gas mixing, ventilation distribution, and pulmonary function although CF patient under pulmonary exacerbation HFCC can induce temporary oxygen desaturation.

Gas mixing improvement during HFCC advocates until now several speculative theories.

Among them the mostly convincing explanation is the Pendelluft [48].

In mild and moderate CF patients and during AE, decreased values of transcutaneous saturation can be observed during the treatment and at high-frequency values, due to the squeezing effects of chest compression.

In the current clinical practice, an expert RT can obviate at that complication adding temporarily a physiological splint that we now can recognize or in the PLB or application of a PEP system or adding a NIV for most weak patients decision that must be taken together the patient, family and not least our reference medical specialist [49].

During a typical ACT session, the device can be set in auto mode with pressures and frequencies from 8 to 20 and pressures from 6 to 10 taking in account that at higher frequencies patients could not to tolerate higher pressures.

Until now typical settings were related to a protocol developed by prof Warwick that should change when using different waveform.

Every ACT performed with HFCC and for every frequency [3–5 min] patient follows TV breathing with PLB or nose expiration followed [at stopped machine] from huffing and BC. It is possible to make inhalation therapy and adjunct, if necessary, PEP breathing or CPAP [50].

HFCC is currently being utilized in many acute and chronic respiratory conditions. In USA is widely prescribed and utilized in conditions such as Cystic Fibrosis PCD Bronchiectasis COPD and also in neuromuscular diseases less more utilized in European regions [51].

Clinical trials showed same effectiveness of other ACTs in weaning process of intubated patients without any compliant about safety and reported better comfort [vs. conventional PT] in intubated adult patients [52].

HFCC has been also studied about possible hemodynamic detrimental effects in 25 patients cohort study immediately after thoracic surgery patient population that may be predisposed to hemodynamic compromise.

The authors evaluated and reported the hemodynamic safety of HFCC despite a decade of information's related to the incompatibility of HFCC and cardiothoracic patient [53]. However, the chapter is still ongoing to demonstrate the effectiveness of the method in this type of patient as a standard of treatment.

Intrapulmonary Percussive Ventilation [I.P.V]

It is a pressure-limited, time-cycled, high-frequency mode of ventilation that delivers subphysiologic tidal volumes.

This device induces intrathoracic percussions and inspiratory pressures through rapid minibursts superimposed on the spontaneous breath of the patient so positive pressures are generated. The mechanism of action results in increasing the expiratory flows, maintenance of small airway patency.

The device generates short, rapid pulses high frequency gas inspirators (100–500 cycles/min) in the airways, superimposed on the patient's breathing at pressures of 5–35 cmH20 (percussion); expiration is produced by normal elastic recoil.

Adjusting parameters as amplitude of oscillations, I/E ratio, pressures, accordingly with patient needs and settings is crucial. All the systems can provide complementary adjunctive action in patient on mechanical ventilation with special consideration about mode of ventilation and patient characteristic. The device can be used applied to the patient's spontaneous breathing or in line with the ventilation circuit; it is associated with aerosol therapy for the purpose of humidifying the airways.

Special consideration must be taken in account for NMD patient.

Proximal ACTs Strategies: Related Devices

Accordingly with the previous definition of ACTs and the related physiological principles explaining their local actions, some ACTs perform their action specifically at the level of the proximal airways.

Implementing cough efficacy, or huffing, or implementing huffing with the tidal volume breathing [FET] usually represent the last part of a good ACT in people without any kind of impairment [qualitative or quantitative] of the respiratory pump.

Weak or noncoordinated physiology will be implemented or totally assisted one.

In NMD a weak cough can be the cause of decompensation especially in the presence of an AE [54].

The natural history of neuromuscular diseases and the related epidemiological data concerning the relationship between pump weakness, respiratory infections, pneumonia atelectasis and decompensation clearly show that these patients can require and benefit from a dedicated path towards noninvasive ventilation. Proximal ACTs therefore become even more an element of strong coexistence in the therapeutic assets of these peoples. The impact of strategies such as LVR on FVC lowering and cough efficacy has been well documented in neuromuscular diseases.

Lung Volume Recruitment

Usually consist in deep lung insufflations utilizing a ventilator or a resuscitator bag (with a one way valve to avoid non voluntary expirations). Stacking the breath maneuvers are utilized to achieve in the LVR technique the maximal lung capacity of the patient [55].

The inflation of the lung is usually followed by a forced expiration or manual assisted cough [M.A.C.] based on patient's characteristic or clinical conditions. The clinical efficacy of combining the two techniques has been shown in NMD patients [56].

LVR procedures in the care plan of DMD patients reduce disease progression.

The necessary gain in terms of IC is difficult to achieve (with this maneuver) in patients with moderate or mild glottis dysfunction and with a complete glottis dysfunction the technique become ineffective.

A single "assisted deep breath" to lung insufflation capacity may be utilized [57].

The cough peak measured [PCF] at the mouth represent up to now a simple, effective low cost measure capable of providing fundamental indicators of efficacy of these techniques.

Patients undergoing NIV or in NIV can apply LVR with MAC to increase lung volume and manipulate in an efficient way expiratory flow a as integral part of their care plane. Albeit with a retrospective study Tzeng demonstrate the preventive role of a home care protocol, by the use of noninvasive intermittent positive-pressure ventilation and manually and mechanically assisted coughing as needed, on hospital admissions for an AE [58].

Using intermittent positive pressure breathing devices can produce similar effects on lung recruitment and cough efficacy in neuromuscular diseases, especially in children. [IPPB] [59].

LVR represent furthermore a usual way of deep breathing [with all the positive effects related to a deep breathing] as a usual procedure also not related to ACT.

Implementing these strategies in home care settings require knowledge and skills perfectly translated and to the patient's family and caregivers: RT should have specific educational competencies to explain reasons [utility] technical aspects and possible complications. Modifications of specific areas of the techniques concerning patients preferences and personal attitudes should be seriously taken in account to avoid adherence issues.

Mechanical Insufflation-Exsufflation [MI-E]

These techniques utilize specific devices able to produce an insufflation to a set pressure and a rapid switch to a negative pressure.

MI-E can be utilized in home settings and in hospital with critical ill patients [60].

The physiological proof of concept is related to the direct effect of MI-E on the expiratory flows augmentation and therefore on the cough efficacy.

The clinical rationale has been widely described in acute and long term care of NMD patients.

Fine tuning of the devices accordingly to patients characteristics, accurate observation of the patients response in terms of positive modifications of measured PCF seems to be today a key to a safe, rationale, and efficient way to use and integrate them in the care asset of our patients.

Recurrent lower respiratory infections [i.e., >3 in 12 months] and the inability to improve PCF to 160 L/min with other techniques or strategies can be considered to MI−/E.

In children younger than 12 years, as stated in the British Society Guidelines, recurrent lower respiratory infection, and PCF less than 50%of the predicted value MI-E can [should] be considered in the care plan [61, 62].

Integrating these devices in the care plan requires careful ex ante evaluation of the settings that will be applied.

Integral part of the procedure is the titulolation of the device in order to choose the "best" pressures, inspiratory times, expiratory times, mode (manual, automatic, auto triggered, with or without oscillations, frequency and amplitude of the oscillations [63]).

Contraindications are undrained pneumothorax present prior to initiation, pneumomediastinum, tracheoesophageal fistula, severe facial deformity, unstable upper airway, epistaxis, severe gastroesophageal reflux with risk of aspiration, severe esophageal and gastric varices, and inability to use a full facemask.

Possible adverse events are pneumothorax [64], nausea, bradycardia, tachycardia, and abdominal distention [6]. In children, thoracic wall discomfort, crying, and agitation in response to treatment with MI-E have been reported.

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Nutrition Support in Noninvasive Mechanical Ventilation

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Abstract

Noninvasive mechanical ventilation (NIMV) is getting increasingly popular. Malnutrition has been known as a cause or consequence resulting from acute or chronic disease. Any of the conventional indications for NIMV could be potentially associated with a state of baseline malnutrition. In addition, NIMV itself causes malnutrition. NIMV impairs oral and enteral nutrition. When patients are given the option to eating an oral meal, their respiratory function may decline as a result of removing the NIMV to eat. In patients treated simultaneously with enteral nutrition, airway problems may occur with longer median NIMV time. Placing a nasal gastric tube for nutrition may result in air leakage, which may compromise the effectiveness of NIMV, and stomach dilation, which may affect diaphragmatic activity and affect NIMV outcome. New alternative mask and techniques may be decreased for nutrition support of NIMV patients. It is important to adopt a multidisciplinary and protocolized approach for nutrition management of NIMV patients. In this chapter, it was given the important detail for NIMV and nutrition outside of the intensive care unit.

Keywords

Noninvasive mechanical ventilation · Nutrition support · Snorkeling mask enteral nutrition · Parenteral nutrition

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Introduction

Noninvasive mechanical ventilation (NIMV) in terms of assisted mechanical ventilation is getting increasingly popular. The first paper on NIMV in patients with acute respiratory failure was published in 1989 by Meduri et al. [1]. In this paper, NIMV was used for four patients with hypoxemic acute respiratory failure (two of them cardiac and others acute respiratory distress syndrome) and six patients with hypercapnic acute respiratory failure. A clear anesthetic face mask was used for an interface between the patient and the ventilatory machine. Noninvasive ventilation does not require an invasive airway between the patient and the ventilatory device; therefore, NIMV is preferred, because it avoids endotracheal intubation and its associated complications. NIMV is indicated for patients with acute or chronic respiratory failure as a ventilatory support. Due to the limited opportunities in mechanical ventilation during the pandemic, the use of NIMV has increased even more for delivering oxygen to hypoxemic patients with Coronavirus disease-19 [2]. The range of indications may expand more in the coming years.

NIMV patients could need care from a team composed of multiprofessionals: doctors (neurolog, and pneumolog, ear, nose and throat specialists), skilled practice nurses, respiratory therapist, nutritionist, and others. Here in this chapter, it was given some detail about NIMV and nutritional aspects.

Noninvasive Mechanical Ventilation Outside ICU

Patients who need NIMV are generally those with chronic obstructive pulmonary disease (COPD). In addition, patients with neuromuscular diseases, preserved swallowing reflexes, and conscious patients may also be candidates for NIMV. Noninvasive ventilation has been used in patients with following diagnoses:

1. Chronic obstructive pulmonary disease (stable or acute exacerbations)
2. Asthma
3. Do-not-intubate patients (advanced disease or terminal malignancy)
4. Traumatic chest injuries
5. Immunocompromised patients and hypoxemic respiratory failure, solid organ transplantation, febrile neutropenic patients
6. Postoperative patients
7. Cystic fibrosis
8. Neuromuscular disease; nocturnal use would be effective for daytime hypercapnia; effective in patients with muscular dystrophy, postpolio syndrome and kyphoscoliosis
9. Obesity and/or hypoventilation (obstructive sleep apnea)
10. Upper airway obstruction
11. Mild *Pneumocystis carinii* pneumonia; avoid intubation in some patients
12. Support during invasive procedures; bronchoscopy, percutaneous gastrostomy
13. Idiopathic pulmonary fibrosis [3–6]

Noninvasive Mechanical Ventilation and Malnutrition

Malnutrition can be termed as "a state resulting from lack of intake or uptake of nutrition that causes to decreased fat free mass and body cell mass leading to diminished mental and physical function and compromised clinical outcome from disease" [7]. Malnutrition has been known as a cause or consequence resulting from acute or chronic disease. Any of the conventional indications for NIMV could be potentially associated with a state of baseline malnutrition. Besides the underlying disease, the use of NIMV itself further impairs the degree of malnutrition [8, 9]. There are not so many studies about NIMV and malnutrition. There are no guidelines or recommendations for nutritional support for patients undergoing NIMV. Therefore, the exact assessment of malnutrition and nutritional support is still a challenge for patients undergoing NIMV.

Nutritional studies in hospitals indicate that 40–50% of patients in hospitals are moderately malnourished [10]. All sequential adult patients who were undergone on NIMV within first 24 h in intensive care and required NIMV for 3 or more days were enrolled in the prospective, observational study. Patients are fed orally or nasogastric feeding. They reported that a very high prevalence of mild/moderate malnutrition (76%) in this patient population. This is due to the fact that patients had a chronic disease and/or immunocompromised state [11].

Patients who need NIMV are generally those with COPD. In addition, patients with neuromuscular diseases retained swallowing reflexes and conscious patients may also be candidates for NIMV. When we look at the patients who are suitable for NIMV, they present a patient profile that shows hypoxic, hypercapnic, or mixed-type respiratory failure due to dyspnea, physical symptoms of respiratory muscle weakness, is tachypneic, hemodynamically stable, has no secretion problems, and accepts the use of NIMV. Of course, the degree of COPD and the nutritional status of the patient before the acute attack will also be one of the most important factors that show how severe the event will be. The etiology of nutritional deficiency is multifactorial. These include increased systemic inflammation, impaired functional capacity, and inability to meet changing nutritional needs due to drug side effects [12]. Malnourished COPD patients have more gas trapping, less diffusion capacity, and less exercise capacity than patients with the same disease, who are not overweight or malnourished [13]. Therefore, nutritional support is aimed not only at providing nutritional status and nutrient intake, but also improving impaired functional capacity, muscle strength, and quality of life. Meta-analyses have shown that nutritional support provides an increase in food intake, body weight, muscle mass, fat mass, and peripheral muscle strength in COPD patients [14].

Nutritional screening and assessment of nutritional status is very vital in hospitalized patients. Patients' history, anthropometric measurements (body weight, height, subcutaneous fat tissue measurement, etc.), subjective global assessment (SGA), NRS (Nutritional risk screening) 2002 scoring, and laboratory parameters may be used for this purpose. SGA is a simple bedside method used to diagnose malnutrition. It allows us to evaluate whether the patient's disease state affects nutritional needs and the effect of malnutrition on organ function and body composition.

SGA includes a history of recent intake, gastrointestinal symptoms, weight change, and a clinical evaluation. SGA has been confirmed in a variety of patient populations [10]. Nutritional risk index (NRI) and SGA were compared in terms of nutritional assessment: it was concluded that both tests correlated with each other and could be used in the evaluation of nutritional status in hospitalized patients [10]. The NRS 2002 scoring is a nutritional risk-monitoring tool and has been recommended by ESPEN for use in hospitalized patients [15]. There are also studies investigating the effectiveness of NRS 2002 scoring in patients receiving NIMV. Cui et al. [16] stated in their study that the initial NRS 2002 score ≥ 3 and $PaCO_2$ values could predict unsuccessful NIMV treatment in patients with type 2 respiratory failure. It has been stated that NRS 2002 as a noninvasive and simple method that makes it possible to switch to extended treatment methods as quickly as possible in high-risk patients [16].

The most reliable method for assessment of energy requirement is indirect calorimetry in ICU patients. Siirala et al. [17] used a NIMV and the metabolic monitor (Deltatrac II, Datex) to exhibit the technical feasibility of gas exchange measurements during NIMV. They found that resting energy expenditure can be accurately measured with an indirect calorimeter on NIMV. It was suggested a higher sampling air flow in indirect calorimetry increases the reliability of energy expenditure measurement and decreases the risk for air leak in the system. If indirect calorimetry is not available, energy expenditure calculated according to the predictive equations. Simple weight based equations are used also for calculation of energy requirement (such as 20–25 kcal/kg/day) [18].

Noninvasive Mechanical Ventilation and Nutrition

The nutritional risk of a nonintubated patient with acute respiratory failure, the severity of the acute respiratory failure, the patient's mental level, and the chosen route of oxygen supply should all be considered when deciding whether or not to start nutrition on NIMV patients. The severity of respiratory failure and the potential necessity for endotracheal intubation are the most pressing worries. For example, if endotracheal intubation is highly possibly required, the patient should be kept nil per os. If the patient has clear contraindications to oral or enteral feeding, keep the patient nill per os. It was recommended a protocolized and multidisciplinary approach to the initial nutrition management for these patients [19]. Bedside multidisciplinary evaluation should be done regularly: swallowing screening, mental status assessment, and severity of illness.

Patients on NIMV are not allowed to eat during the ventilation interval, according to standard practice. However, in uncommon cases, a few patients may be permitted to eat little meals during their "off" period, particularly in the event that parenteral nourishing isn't wanted. One or two hours after starting NIMV, patients are routinely evaluated clinically and with blood gas. Following 4 h of NIMV, a clinical reassessment is usually undertaken. If the patient is feeling better at that moment, a small break from NIMV might be taken and oral swallowing tested at the

bedside. If the patient's respiratory failure improves, the patient can be given oral nutrition on a regular basis with regular clinical assessment [19]. Patients may be unable to remain off NIMV for a adequate time to take adequate food or may feel too short of breath to eat. Oral intake during NIMV therapy, on the other hand, may be challenging. Patients receiving NIPPV therapy who were given oral nutrition had lower nutrient intake than patients who were given nutrition via enteral or parenteral routes, according to Reeves et al. [20]. Inadequate oral intake was caused by patients' lack of energy for chewing and insufficient time for eating due to respiratory distress.

NIMV patients should be assessed for swallow screening. The Yale swallow screening protocol is an effective tool for determining the probability of presence of dysphagia and to find out when it is safe to start an oral diet [21]. Swallowing function may worsen during an acute exacerbation of diseases. Terzi et al. [22] studied the relations between nasal NIMV and the breathing-swallowing mechanism in fifteen patients with COPD exacerbation. They studied that patients were able to breathe without NIMV for at least two hours. The investigators evaluated breathing-swallowing interactions with water boluses of 5 and 10 ml. Water boluses were given during unassisted respiration and when on NIMV. It was shown improved swallowing efficiency on NIMV when compared with unassisted respiration. Patients have fewer swallows needed with the fluid bolus, fewer breaths taken during the per swallowing and shorter swallowing time with each bolus. This is a small challenging study.

The patient may not be able to start oral nutrition for 48 h due to reasons such as increased respiratory distress, deterioration in mental status and impaired swallowing. In that cases, consider enteral nutrition via feeding tube. Enteral nutrition can be used via nasogastric tube is usually meaning up to six weeks. When percutaneous endoscopic gastrostomy (PEG) or gastrostomy are not possible for patients, fine-bore nasogastric tubes are possible even longer periods. PEG or gastrostomy is indicated that patients need enteral nutrition more than 6 weeks. The ideal access method is a PEG or, a percutaneous endoscopic jejunostomy (PEJ) for long time nutrition [22]. The PEG group had fewer treatment failures (e.g., better tolerance to treatment, feeding cessation, blocking or leakage of the tube) and improved nutritional status (e.g., mid-arm circumference, weight loss from baseline,) than the nasogastric tube group, according to a systematic review [23]. In addition, PEG had a better quality of life (e.g., inconvenience, altered body image, discomfort, and social activities). In terms of mortality and aspiration pneumonia, there was no significant difference between the two groups. For long-term HEN, a PEG should be preferred to a surgical gastrostomy, owing to decreased complication rates, operating time, and cost-effectiveness. If there is a contraindication to oral or enteral feeding, consider parenteral nutrition [19].

Adult patients who were undergone on NIMV were followed up for nutritional complication and mask leakage. Three patients had intolerance to nutrition: one had high gastric residual volume and two were suffering from diarrhea. None of them developed clinically relevant aspiration. Leaks due to the presence of nasogastric did not result in a clinically significant lack of NIMV efficiency. They concluded

that this study shows high prevalence of malnutrition and found the practicability and acceptance of nutrition therapy in NIMV patients [11]. The large French observational retrospective multicentric cohort study reported that 60% of patients were starved during the first 2 days of treatment and only 2.6% received enteral nutrition. In addition, enteral nutrition is associated with increased invasive ventilation support, longer ventilation days, and increased 28-day mortality compared to no nutrition [24]. The Nutrition Day review of 10,000 patients, including 6.2% with NIMV, found that 40% of the patients were hungry during the first day of ventilation and 20% on the second day [25]. Kogo et al. [26] studied a trial of more than one hundred patients who had been on NIMV for more than 48 h, 60 (56%) were given enteral nutrition. When compared to patients who were not on enteral nutrition, patients on enteral nutrition experienced significantly greater airway difficulties (53% vs. 32%, $P = 0.03$), which were characterized as episodes of vomiting leading to desaturation, mucus plug, and aspiration pneumonia. Enteral feeding remained a significant risk factor for airway problems after multivariate adjustment (odds ratio 2.46, 95% confidence interval 1.03–6.13). Patients on enteral nutrition had a greater in-hospital mortality, although there was no statistically significant difference [26]. However, in this study, sample size was small, and was unlikely to be powered for that outcome. No adjustment for disease severity was made in the multivariate analysis.

The nasogastric tube might produce an air leak by disrupting the patient-mask interface [27]. The fear of an air leak may cause one to use a small diameter nasogastric tube. Nasogastric tube feeding also could be associated with complications such as nosocomial sinusitis, tracheobronchial aspiration of gastric contents, and gastric inflation [28]. In addition, the risk of gastric inflation with NIMV and aspiration of nutrients discourages clinicians from early initiation of enteral nutrition.

The presence of a nasogastric tube can cause air leakage, reducing NIMV's efficiency. The stomach is also distended with air when positive pressure ventilation is used using a face mask. Silicone dressings may be used to reduce the risk of pressure damage to the skin and air leakage. While customized NIMV masks with a port for nasogastric tube can solve leakage problem, they are not always expensive and are available. Quintero et al. [29] created a tube adapter for NIMV in response to the necessity for a device that allowed for both NIMV and enteral nutrition without compromising the mask's typical form. This device permits up to two tubes to be used at the same time, one for nutrition and the other for gastric decompression, avoiding gastric insufflation and managing residual stomach volume. This device provides for adequate ventilation with enteral nutrition support, while reducing air leakage through the mask and gastric distension. Another solution for enteral nutrition complication, helmet mask, could be related with less gastric distention and fewer vomit events if compared with the normal nasal or face mask during pressure support ventilation. It was modified a new snorkeling mask specially-fit to provide NIMV and continuous enteral feeding at the same time [30].

Enteral nutrition should be given with pump continuously to reduce gastric distension. Patients should be in an upright position at an angle 40–45° during feeding. If the attempt fails, the inspiratory pressure may be reduced and the backup rate

increased to compensate. Procinetics can be used for carrying out gastric emptying. Patients with prolonged stomach distention may benefit from decompression devices.

In amyotrophic lateral sclerosis, weight loss and malnutrition are independent poor prognostic indicators for survival. To maintain appropriate food intake in individuals with severe dysphagia and/or malnutrition, gastrostomy is usually recommended. Current guidelines suggested taking into account the severity of malnutrition, dysphagia, respiratory function (vital capacity>50%), and the patient's general health when determining the best time for gastrostomy. The placement of a feeding tube as soon as possible is recommended, although this is sometimes delayed due to the patient's conditions regarding enteral nourishment [31]. Two key predictive markers after gastrostomy were identified in a recent large prospective study: age at onset of ALS and nutritional status [32]. In this study, 25% of the patients were undergoing NIMV. Specific predictive factor was not studied in this NIMV subpopulation. Hesters et al. [33], studied the survival after gastrostomy in NIMV patients. Ninety two NIMV patients were included in that study. Three factors were found to have a significant impact on the risk of death following gastrostomy placement: BMI 20 kg/m^2 at the time of gastrostomy insertion, age at onset, and repeated accumulation of airway secretions. The dependent NIMV group had a significantly shorter time from gastrostomy to death (133 vs. 250 days, $p = 0.04$) than the nondependent NIMV group. Dependent NIMV patients had a significantly higher 30-day mortality rate. When considering gastrostomy tube installation in NIMV users with amyotrophic lateral sclerosis, preoperative ventilator dependency and airway secretion cumulations are related with a worse outcome. It was evaluated amyotrophic lateral sclerosis survive after NIMV, IV, and enteral nutrition in a population study in Italy. Total 193 patients included, whereas 66 patients had NIMV plus enteral nutrition. Enteral nutrition was given via PEG. Patients lived after enteral nutrition, IV, and NIMV for about 9, 19, and 15 months, respectively. No detail on nutrition and NIMV were given in their study. They concluded that service organizations may influence postprocedure survival by promoting IV, NIMV, and EN adherence [34].

In conclusion, nutrition should not be thought of as an adjunctive or supportive treatment when caring for NIMV patients, but rather as a fundamental and regular aspect of care. It is critical to develop nutritional care guidelines based on evidence-based practice and to apply nutritional care procedures for NIMV patients. We suggest doing a large prospective observational study or conducting a comprehensive data reference analysis for this population.

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Respiratory Care, Education, Ethics and Cost of NIMV Outside Intensive Care Unit: Psychological Support

34

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Abstract

Psychological consequences of respiratory diseases, such as anxiety, depression, and cognitive dysfunctions, impact on patient's quality of life and hinder the adherence to treatments. Quoting Everett Koop "Drugs don't work in patients who don't take them" and it is a duty of the health-care system to try to optimize adherence in order to improve global wellness, besides a specific improvement in medical treatments. Psychological support maximizes patient engagement and guides patients toward managing the psychological challenges of their condition. The costs of including psychological services in respiratory facilities are compensated by the savings originating from reduced need for health-care services and from a global improved physical health.

Keywords

Respiratory failure · Adherence · Psychological symptoms · Anxiety · Depression Cognitive impairment · Memory · Attention · Quality of life

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Beyond the Physical Impact: Mental Health Consequences of Respiratory Failure

According to the biopsychosocial model, body's diseases are intrinsically linked to mental disorders. So, it is not surprising that chronic respiratory pathologies involve an assorted constellation of neurocognitive and psychological symptoms, often overlooked, that impact on patient's quality of life.

Many people who live with respiratory conditions, such as COPD or severe asthma, face psychological dysfunctions, for example, anxiety and depression [1]. The relationship between chronic respiratory diseases and psychological symptoms is complex, not unilateral, and not yet fully understood [2]. Anxiety and depression, on the one hand, and chronic respiratory diseases, on the other hand, have overlapping somatic symptoms: anxiety is related to respiratory abnormality [3] and common symptoms of both anxiety and depression are problematic sleeping, weakness, and tiresomeness [4]. Experiencing these conditions continuously may increase the daily levels of anxiety and/or depression, which may facilitate the development of psychological disorders, which in turn may exacerbate chronic illness symptomatology as they may cause chronic inflammatory changes [5, 6].

Moreover, people with respiratory conditions display moderately severe impairments in attention, memory, and executive function. Hypoxia and fragmentation sleeping are the mechanisms that are responsible for the cognitive impairment common to all these diseases [7, 8]: chronic intermittent hypoxia can induce neurodegenerative changes in parietal, frontal, and temporal lobes, which are the brain regions involved in memory, attention, and executive functions [7].

Finally, patients with chronic diseases have to adapt to the challenges given by their own medical condition, which may decrease self-esteem and faith in being able to solve the challenges that the disease may pose to them, as well as increase the feeling of uncertainty about the future and psychological symptoms [5]. Moreover, mental health difficulties are more likely to expose them to a higher risk of developing different unhealthy behaviors, such as smoking and alcohol consumption [9]. Patients with mental health difficulties are less likely to adhere to treatment recommendations and have less motivation for self-management [10].

Adherence to Treatment Plans

NIV methodology is broadly used to assist respiratory efforts [11]. It increases life span and improve patients' quality of life [2]. Despite its efficacy, adherence to the treatment is not optimal [12].

The adhrence to long-term therapy has important consequences for morbidity, mortality and health costs. Despite their frequent use, the terms "adherence" and "compliance" are not equivalent. "Adherence" entails that patient's agreement with the recommendations, whereas "compliance" presumes that the patient passively accepted it [13]. For best results, it is necessary for the patient to adhere to the doctor's advice [14]. The adherence response is the result of the interaction of

multifactorial aspects [14, 15]: (a) *patient-related factors*, which include self-efficacy, cognitive abilities, psychological comorbidity, heath belief, understanding degree of own pathology, and involvement degree in the treatment decision-making process; (b) *physician-related factors*, which include effective level of communication, dosing regime, method of administration, polypharmacy, and integration level of health-care system, (c) *society-related factors,* which include social support, access to medication, and patient-prescriber relationship. Thus, it is necessary to overturn the belief that poor adherence is a patient's liability and opt for a multifactorial view of adherence that entails a sustained and coordinated effort to obtain full benefits from the actual medical therapy [14].

Patient-Related Factors

Psychological consequences of respiratory diseases, such as anxiety, depression, and cognitive dysfunctions, hinder the adherence to treatment. Patients with cognitive dysfunction may show reduced ability in weighing up information, leading to a more material interpretation of the intervention [16]. Moreover, cognitive dysfunctions often imply impaired intended behavior, such as reduced motivation, poor mental elasticity, and organization, that, in addition to linguistic deficiencies, such as scarcities in oral communication and comprehension, may cause problems in the process of NIV adaptation [17].

Moreover, some patients reported negative experiences using NIV methodology. The most common are (a) difficulties in following their own breath rhythm and being forced to follow the machine's pattern; (b) feeling of being powerless and vulnerable, since they feel trapped in a vacuum cleaner bag [18]. This sensation may intensify anxiety and impact adversely on breathing, which in turn may cause a sense of loss of control, irrational behavior, and panic [5, 18]. Moreover, major psychological disturbance is produced by the patient perceiving limited independence [18, 19], given by the actual need of a support device to breath [18]. The patients experience various levels of conflict between dependence and autonomy. Anxiety, panic, and loss of control are strong emotions that need a feedback counteraction to re-balance dependence and autonomy. Receiving the mask supplying life-saving oxygen is a major relief but coping with the mask itself may be problematic [19].

Psychological Intervention

NIV is a multifaceted intervention, the efficacy of which depends on the interaction of multiple equipment, service, and patient- and career-related variables [19]. Psychological and neuropsychological changes may be consequences of respiratory failure, and they also impact both the course of the disease [20] and the adherence to recommendation [21]. Thus, taking care of psychological and neuropsychological needs is an essential part of the intervention, and it turns out to be a system

value, not merely an individual one [22, 23]. The availability of psychological treatments within a respiratory health-care service is associated with a lower bed day-use and a lower hospital admission rate. Thus, the costs of psychological therapies are more than compensated by the savings originating from reduced need for health-care services and from a global improved physical health [24]. In this framework, the psychological intervention macro-goals are to support the reduction of emotional distress and to promote a better adherence to the treatment. Despite psychological therapy is tailored to the needs of each individual patient, some themes are in common in a respiratory health context [22]. The bio-psycho-social model helps in promoting a better understanding of the nature and of the implications of patients' pathology [25], which in turns helps in eliciting a discussion focused on the patients' hopes related to the therapy to address unrealistic expectations. It is essential to explore how each individual faces both his medical condition and the suggested treatment to support the adaptation to their respiratory illness [26]. To reduce emotional distress, it can be useful to adopt a mindfulness-based approach [27] that encourages the adoption of a nonjudgmental state of mind allowing to live the present moment as it is, without any will change it. This is a powerful attitude that allows expanding their own tolerance window over the triggers of the emotional distress. Using a mindfulness-based approach in patients with moderate-to-severe asthma produced significant improvements in quality of life and stress at 1-year follow-up [28]. Valorizing of existing coping resources [29] and learning new strategies [30] to face illness challenges are key points to build self-efficacy and coping skills necessary to gather information, communicate effectively, self-manage medications, symptoms, psychological and social consequences, use social support, and adjust their own lifestyle [31].

Thus, psychological support promotes the process of cocreating targets with patients and maximizes their engagement in the health-care path. In this way, patients are encouraged to look at the therapeutic targets, at the strategies to achieve them, and at their success as own.

Conclusion

Chronic respiratory pathologies involve an assorted constellation of neurocognitive and psychological symptoms that impact on patient's quality of life and hinder the adherence to medical recommendations. Recently, the interpretation of the concept of adherence to treatment is evolving to include the acceptance of the responsibility of the health-care system for the success or failure of the patient's therapeutic path. After all, as Everett Koop said, "Drugs don't work in patients who don't take them" and it is a duty of the health-care system to try to optimize adherence to improve global wellness, besides a specific improvement in medical treatments [13]. Including a psychological service in a respiratory health-care system is consistent with this new view: the psychological support maximizes patients' engagement and guides patients toward managing the challenges of their condition. The psychologist must work explicitly to facilitate goal setting, estimate the impact of breathing

difficulty, improve coping (i.e., with distress due to shallow breathing and anxiety), and maximize the upkeep of the advances. The psychologist also meets group members separately to maximize the benefit resulting from the treatment and to address possible blocks to progress [22]. In conclusion, the effects of psychological support are various and related to each other: reduction of emotional distress triggered by breathlessness and/or treatment; improvement of the adherence to treatment and to lifestyle recommendations; health-care system saving.

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Nurse Planning and Family and Caregivers Support in Noninvasive Mechanical Ventilation

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Abstract

Nursing care in the treatment of patients with NIV and HFT is key to the success of therapy. The evidence recommends that monitoring during the first hours of these patients should be carried out by nurses adequately trained to recognise complications early. This chapter will address minimum recommendations that can serve as a basis for standardised, evidence-based nursing care in both acute and chronic respiratory failure treatment with NIV and HFT and also serve as a basis for their caregivers at home.

Keywords

Nursing care · Noninvasive ventilation · High-flow therapy · Paediatric nursing care · Skin care · Pressure ulcers · Interface

Introduction

NIV has been a known therapy since the 1920s, but it was not until the 1960s that the field was further developed, and its use became widespread. Since then, its application has been relegated to intensive care areas. During the last decades, the use of noninvasive mechanical ventilation has spread outside intensive care units, becoming the Gold Standard in the treatment of respiratory acidosis in COPD patients also in emergency units in and out of hospital, as well as in hospital wards and even at home in chronic patients. To ensure the success of the therapy, it is crucial, on the one hand, to get the patient's cooperation and, on the other hand, the

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meticulous dedication and adequate training of the nursing staff involved in the care of the patient. This will allow early recognition of complications and improved tolerance to treatment [1, 2]. Nursing interventions in these patients are numerous. The following are some minimum actions that can serve as a basis for standardised nursing care based on scientific evidence for the care of this type of patient.

Nursing Care of Adult Patients Undergoing Noninvasive Mechanical Ventilation and High-Flow Therapy in Acute Respiratory Failure

Throughout the chapter, reference will be made to the care to be taken prior to the start of treatment and during the various therapies.

Preconnection Care

- The first action to be taken is to inform the patient and those accompanying the patient of the technique to be performed.
- In 2016, at the XXXVII National Congress of the Spanish Association of Cardiology Nurses held in Valencia, a paper entitled "Non-invasive mechanical ventilation: patient perceptions" won second prize. It referred to a study conducted by the authors in which a sample of patients were asked about the information received about the technique, their impressions about the safety related to NIV and about the complications that most bothered them. The study concluded that training nurses in NIV was useful not only to prevent complications, but also to provide adequate and accurate information to the patient, thus improving patient participation, which is crucial for the success of the therapy [3].
- Simultaneously with or immediately after the above, it is essential to prepare the necessary equipment, checking and verifying that it is functioning optimally. This includes choosing the interface and its size, checking the battery level, checking the availability of a working oxygen supply and the water level of the humidifier.
- What size of interface is the most suitable? It is recommended to make use of the gauges provided by the manufacturers, in the case of nasal interfaces measuring from the junction of the cartilage with the nasal bone at the top and at the bottom above the upper lip and in the case of oronasal masks from the junction of the cartilage with the nasal bone, occupying the nasolabial fold to the bottom of the lower lip. Whenever possible, use the smallest size.
- An essential element of safety is antimicrobial filters. Prior to the COVID 19 pandemic, only one filter was required at the connection between the ventilator and the tubing to prevent contamination of the machine by microorganisms, Since March 2020, it is recommended to place a second antimicrobial filter between the interface and the tubing, limiting the dispersion of particles and

protecting healthcare professionals and other patients in close proximity to the patient, which becomes even more important in case of infection by COVID 19 or any other type of infectious disease via the respiratory tract.

- At this point it would be advisable to check the availability and correct functioning of the expiratory valve to be fitted (Plateau®, Whisper®) or disposable exhalation port as well as the chosen elbow.
- Before connecting the patient to the ventilator, we must check the alarms programmed by default and that the programmed parameters are those prescribed by the physician.
- There is disagreement in the literature on whether to remove dentures, due to the increased resistance in the upper airway if they are not removed and the risk of aspiration in patients with a low level of consciousness, although evidence-based practice shows that the adjustment of the interfaces is better, minimising leaks and associated complications. Bearing in mind that these patients should be cared for in highly complex boxes with close monitoring by nursing teams trained in the technique, the authors recommend not to remove them [4].
- The most suitable positions for these patients are Fowler and Semifowler, always considering and seeking the patient's comfort.
- All interfaces should be placed between two people in an attempt to achieve symmetry of fit and avoid or reduce pressure-related complications. It is advisable to teach patients who are conscious and cooperative to remove the device in case of an emergency such as nausea or vomiting.
- Another recommended aspect is the initial adjustment of the fixed clips, if the mask has them, and subsequently adjusting the straps, helping in the case of rapid removal of the device due to breaks or any other aspect (nausea, vomiting) to maintain the position of the interface once the break is over. Although in some cases, such as when fitting the Boussignac® Cpap, it is recommended to adjust the straps in an X-shape, the most widespread way of fitting the straps is from top to bottom and always by two people, thus minimising ocular leakage.
- Depending on the manufacturer, brand and geographical origin of the interfaces, we can find that they may or may not have a built-in anti-suffocation valve, a safety device that allows the entry of outside air in the event of failure, obstruction or depressurisation of the system. If they are fitted, it is essential to check that they are detached and allow air to enter correctly before fitting them.
- An especially important aspect of the care of patients undergoing noninvasive mechanical ventilation and high-flow therapy that is the sole and exclusive competence of nursing is skin and mucosal care. Therefore, because nurses have been excluded from research in their daily practice for decades, there is little literature relegating this aspect to the evidence-based practice of these professionals but without normalisation or standardisation in this care.
- In the prevention of mucosal lesions, the recommendation is to use water-soluble ointments on the nose and lips, excluding the use of vaseline and any other flammable products.

Skin Care in NIV and HFT Patients

One of the most frequent complications in this type of patient is facial pressure ulcers in relation to the tisular hypoxia produced by the pressure maintained over time by the interfaces on the skin, which is necessary for an adequate sealing of the system that leads to the achievement of the pressure and volume objectives.

According to Iglesias [5], the injuries associated with clinical devices are problems with a high prevalence that not only deteriorate the health of patients, but also prolong hospital stay. The incidence of pressure ulcers on the nasal bridge caused by interfaces for NIV administration is estimated to be over 17% [6].

In 2002, a prospective observational study was carried out at the Hospital General Universitario Morales Meseguer in Murcia with the aim of analysing the complications derived from noninvasive mechanical ventilation. The sample consisted of 45 patients who underwent noninvasive mechanical ventilation, 31.8% of whom developed pressure ulcers despite having taken preventive measures such as placing hydrocolloid dressings in 78.6% of cases: 58% of the ulcers were grade I, 21% grade II and 21% grade III.

The location of facial pressure ulcers is directly related to the type of interface used. The most frequent locations are the forehead, nose, cheekbones, nostrils and nasal septum. The area most susceptible to injury is the bridge of the nose due to the small amount of subcutaneous cellular adipose tissue it has adipose tissue. This, together with the fact that the most frequently used interface is the nasobuccal interface, with direct support in this area, means that it is the area where the most pressure ulcers related to noninvasive mechanical ventilation are most prevalent. On the other hand, the interfaces with less support in the nasal area and which therefore produce fewer lesions are the full facial and the helmet-scaffold or helmett®.

Inadequate choice of interphase type or size, excessively tight fastening, tubuludura tractions that are transmitted to the interphase and inadequate protection of pressure points together with poor skin hygiene and hydration are often the causes of such injuries [7].

The negative impact not only affects the health of patients but also the economy of the health system related to a large administration of pharmaceuticals. According to the literature, spending on medical devices related to pressure ulcers accounts for 5% of total health care spending in Spain [8].

Efficient nursing actions regarding pressure ulcer prevention reduce the incidence and recurrence of pressure ulcers.

The available evidence is scarce, outdated and of inferior quality, leading to a false consensus.

A review of the literature (eight studies less than 10 years old) reveals three main lines of research.

Of the eight studies reviewed, all but one of them recommended some form of pre-preparation preparation before applying the mask to the patient's face. Six of them proposed some form of wet dressing and only one of them proposed the application of hyperoxygenated fatty acids to the facial skin.

Regarding dressing recommendations, two of them do not recommend any specific dressing, two recommend the use of polyurethane foams and two recommend the use of hydrocolloid dressings.

One of the studies advised against the use of dressings to prevent pressure ulcers in patients undergoing NIV, since according to the authors, they may increase the pressure exerted by the interface on the pressure ulcers in patients undergoing NIV, because, according to the authors, they may increase the pressure exerted by the interface on the face and cause leakage, making it difficult to achieve pressure or volume targets.

It is therefore clear that there is a need to apply preventive measure on the skin of these patients to prevent pressure ulcers.

Regarding which of these preventive measures should be applied, there is variability in recommendations. Most authors indicate that some form of wet dressing is necessary, but there does not seem to be much evidence on the superiority of one over the other.

Only one of the studies introduced the possibility of using hyperoxygenated fatty acids for pressure ulcer prevention compared to direct application of the mask on the skin, hydrocolloid dressings and polyurethane foams. Surprising results were obtained, where hyperoxygenated fatty acids were shown to be clearly superior to dressings with respect to injury prevention.

Care During Treatment

- The water level in the humidifier as well as the correct functioning and set parameters of the fan must be checked continuously.
- To avoid increased airway resistance, it is essential to maintain correct alignment of the neck, which may be aided by the use of a soft collar.
- There are many aspects that nurses must review when caring for patients undergoing noninvasive mechanical ventilation, one of them being the level of interface leakage. Considering that the latest generation ventilators compensate for elevated levels of leakage, we can tolerate leaks of 15–25 bpm or up to twice the minute volume, always with the aim of achieving optimal pressure, volume and flow patterns beneficial to the patient and preventing complications associated with leaks such as eye damage. It is for this reason that all nurses must know how to place the diverse types of interfaces and the most appropriate way to do so, to avoid ocular leaks and to apply care in a systematic way to prevent such injuries and treat them if they occur.
- As mentioned in the previous section, the main focus of nursing care should be on skin and mucosal care, reapplying and checking the chosen products or dressings in each of the breaks every four hours and whenever necessary.
- Another important aspect is the monitoring of the occurrence of abdominal distension in relation to the high pressure parameters prescribed (with IPAP above 20 cmH_2O, the resistance of the upper oesophageal sphincter is overcome, resulting in abdominal distension with a risk of nausea and vomiting). If this occurs, a

nasogastric tube can be placed to reduce the risk of aspiration, but it will not be systematically placed in all patients.

- In the SEPAR (Spanish Society of Pneumology and Thoracic Surgery) manual on NIV [9], in the chapter entitled "Procedures in NIV of acute or chronic patients with acute illness," the importance of monitoring during NIV is discussed in order to provide control and surveillance of the clinical situation, providing safety and serving as a guide to adjust or correct, depending on the data obtained, the ventilation parameters and the rest of the treatment, thus achieving better results. Remember that no technology can replace good clinical observation, and that this can only be done if the nursing staff knows the technique and acts with dedication and speed in the correction and prevention of side effects.

That Being Said, What Parameters Should Be Monitored? [10]

1. All critical or semi-critical patients should undergo electrocardiographic monitoring, including all vital signs. Blood pressure is even more important because of the possibility of hypotension due to increased intrathoracic pressure, especially in cases of extremely high IPAP.
2. If available, transcutaneous capnography is an excellent method of determining PCO_2 without the need for invasive procedures and minimising patient venipunctures, thus increasing patient comfort and reducing infectious and thrombotic complications of the technique. An initial arterial blood gas measurement prior to treatment is necessary to determine the baseline situation and to base the choice of treatment and the parameters to be established on it. Since the variation of PCO_2 in venous and arterial blood is very small, the following blood gases once the pH has been corrected could be venous (at one hour, at four to six hours and prior to withdrawal of treatment). Whenever the patient's clinical situation changes, there is a worsening or a change of mode or of the prescribed parameters, it will be necessary to take a new sample every thirty minutes to one hour until stabilisation. This should always be assessed on a case-by-case basis. It is important to emphasise that there may be clinical improvement although not gasometric improvement, which is why it is more important in the first hour to reduce the respiratory rate than to improve PCO_2.
3. It is also important to assess and observe the oral tolerance of these patients, noting the presence of nausea and vomiting in relation to the gastric distension resulting from the treatment.
4. Either because of hypercapnic or hypoxaemic patients, we may find variations in the level of consciousness; therefore, it is recommended to pass the Glasgow Coma Scale at least three times a day and to check for variations.
5. As a result of treatment, interface, positioning, posture and many other factors, this type of patient can frequently develop pain, either chronic or acute, and the Visual Analogue Scale is a simple method to assess it, and any other method with which the nurse is familiar can be used.

6. We must not forget that these are respiratory patients, which is why respiratory monitoring must be closer. In this aspect, it is essential to assess the respiratory pattern, the presence of cyanosis, and dyspnoea scales such as the modified Borg Dyspnoea Scale can be used as a support. Despite its subjectivity, it is easily reproducible and accessible [11].
7. Just as important as observing the patient is observing the ventilator, as it provides us with up-to-date information on the patient's clinical situation, helping us therapeutically and prognostically and in many cases in anticipation of the blood gas assessment. It is vital that the machine and the patient work synchronously, not only for the ventilatory benefit but also for the greater patient comfort related to a higher probability of successful therapy. This level of adaptation between ventilator and patient can be observed not only by physical examination of the patient but also by assessing asynchronies in the pressure, volume and flow graphs. It is important to note that a very high percentage of these asynchronies are due to leaks, a factor in which nursing is of particular importance.
8. As mentioned in previous sections, the focus of nursing care in patients treated with noninvasive mechanical ventilation should be skin and mucosal care. It is essential to take scheduled breaks of five to fifteen minutes every four hours, taking the opportunity to remove the interface and reapply or change the products chosen to protect the skin (dressings or hyperoxygenated fatty acids). If drinking is not contraindicated, water should be given to patients during these breaks to reduce xerostomia due to the pressure that occurs in this type of treatment. In relation to pressure and leakage, and as mentioned above, dry eyes and even corneal ulcers are common, and to prevent these, artificial tears or epithelial ointments should be applied. A strategy to take into account in order to rotate the pressure points and reduce the complications associated with pressure is the rotation of interfaces according to the clinical condition of the patient. Whenever pressure lesions appear, they should be treated like any other lesion of this type, in which case the use of hyperoxygenated fatty acids should be discouraged.
9. Another complication of the pressure is otitis, which can be prevented by regular nasal lavage with isotonic saline.
10. To assess the cleanliness of the oral cavity, the Walt Scale can be useful, passing it at least five times a day, providing information not only on the hygiene of the mouth but also on the level of xerostomia mentioned above. Oral hygiene should be carried out every 6–8 h with a 0.12–0.2% chlorhexidine rinse and always with the head of the mouth elevated.
11. There are complications related solely and exclusively to certain interfaces that nurses should be aware of. This is the case of the risk of thrombosis of the axillary veins in relation to the use of the Helmett®, and the nursing staff must check the placement, position and adjustment of the interface fixation harnesses in a systematic way.

A 2016 study in patients with acute respiratory failure concluded a reduction in mortality, shorter ICU stay and reduced intubation rate when comparing the use of Helmett® with orofacial interfaces [12]. Despite this, its use is not widespread in Spain, partly due to the lack of training of nursing staff with this type of interface.

1. Checking the condition and correct functioning of the ventilators is also the responsibility of the nursing staff, which is why the circuits should be changed every seven days unless there are biological remains or malfunctions, and the filters every 24 h or after the administration of nebulised medication (in this aspect, vibrating mesh devices are recommended due to the greater bioavailability of the drug). The most appropriate way to clean the interfaces is with water and detergent, avoiding the use of bleach and other more aggressive products that can damage the silicone of the interfaces.
2. To avoid condensation in the tubing, the tubing should be positioned to prevent backflow to the patient, and the humidifier settings may be changed if condensation is very present.
3. The important role of patient comfort in the success of therapy has already been mentioned several times in this chapter, and it is essential that the patient is kept informed at all times of the process, integrating him/her in his/her care. To this end, it is recommended that alternative communication methods such as providing paper and pen, using pictograms are provided. In addition, relaxation techniques can be taught and conducted, always providing emotional support, and encouraging a good night's rest.
4. Finally, in this section, we should mention the possibility of aspirating secretions if necessary and collaborating in a multidisciplinary way in respiratory physiotherapy.

Specific Care in High-Flow Therapy

All the above-mentioned precautions are also applicable to patients undergoing treatment with high-flow therapy. Specifically, once the equipment has been checked and prepared, with special emphasis on the availability of an electrical outlet as some of the HFT devices do not have a battery, the interface should be chosen to occlude at least fifty percent of the diameter of the nares.

The care of these patients should focus on reducing and early detection of complications. It is important to take into account the main complaints of patients undergoing this treatment.

1. Discomfort in the nose
2. Discomfort from the cannulae
3. Paradoxical dyspnoea
4. Sensation of chest pressure
5. Lack of knowledge of therapy

6. Mobility problems
7. Claustrophobia
8. Intolerance

One of the potential complications of high-flow therapy as well as noninvasive mechanical ventilation is pneumonias. It is the responsibility of the nursing staff to clean the equipment to reduce the risk of transmission of microorganisms. Some specific high-flow devices such as the Airvo or Airvo2 require not only external cleaning but also high-level disinfection, and it is the nurses' responsibility to carry out such disinfection and to check that they are in good condition before connecting patients.

Specific Care of the Paediatric Patient on Noninvasive Mechanical Ventilation and High-Flow Therapy in Acute Respiratory Failure Situations

Introduction

The use of noninvasive mechanical ventilation in paediatrics has increased in recent years due not only to its proven efficacy in the treatment of both acute and chronic episodes of respiratory failure, but also because of its ease of use, its rapid implementation, its greater ability to provide patient comfort and the possibility of continuing treatment at home [13].

The efficacy of this mechanical ventilation system means that this option is becoming increasingly common in paediatric intensive care units, so that nursing staff require expert and specialised knowledge in the handling of the technique and the care necessary for its proper functioning, to resolve or reduce the complications derived from its management [14].

Over the last 15 years, the use of NIV has reduced the number of intubations and complications associated with invasive mechanical ventilation, but above all, it has reduced the length of stay in paediatric intensive care units.

The participation of nursing professionals in the management of patients undergoing NIV is of vital importance, as they are the ones who will be at the bedside during the entire process, observing any anomaly in the patient's condition during treatment, ensuring the proper functioning of the mechanical ventilator, preventing the appearance of pressure ulcers due to the use of the different interfaces and are responsible for providing comfort measures to the patient at all times.

The training of nurses in the application of NIV treatment will ensure the success of the technique. This training is necessary to be able to apply quality nursing care. It will be the Paediatric Emergency/Paediatric Intensive Care units together with the related Scientific Societies who will guarantee the adequate training of these professionals [15].

NIV in Paediatrics

Respiratory emergencies in the paediatric age group are one of the most frequent reasons for hospital admission, so early detection of situations of acute respiratory failure avoids preventable risks and even death. Early recognition, support and appropriate treatment can prevent them [15]. For this reason, it is vitally important that nursing professionals working in units where NIV is administered know the indications and contraindications of this ventilation system, the most up-to-date recommendations in related nursing care and are able to identify the needs and patterns that may be altered in order to be able to act on them and provide the paediatric patient with comprehensive quality care that guarantees their well-being.

At present, very few paediatric emergency departments have the appropriate conditions for initiating treatment with NIV in paediatric patients with acute respiratory failure, so it is used in these departments as a tool to stabilise the patient until subsequent transfer to the paediatric intensive care unit (PICU) or hospital ward, where the appropriate conditions are met for the safe management and subsequent follow-up of this type of patient. In the not too distant future, given the boom in the management of the technique, NIV could be used in paediatric emergency departments for the treatment of asthmatic patients of moderate severity [16].

The initiation of NIV in the acute paediatric patient can rarely be performed on the hospital ward except in specific cases due to overloading of the PICU due to seasonal endemic periods (bronchiolitis) or oncological or neuromuscular patients with acute or chronic respiratory failure that becomes acute during admission, as it is necessary to have properly trained staff capable of dealing with any problems that may arise. Ideally, intermediate care units should be available to ensure adequate treatment of such patients who require admission but do not meet the criteria for admission to the PICU [16].

The NIV in Acute Respiratory Failure (ARF)

NIV is a respiratory support modality that allows increased alveolar ventilation without the need for artificial access to the patient's airway, and therefore does not require an endotracheal tube. It is performed by means of positive pressure through distinct types of interfaces (devices that connect the patient to the ventilator) [15, 16].

NIV is used in the treatment of both acute and chronic respiratory failures.

Acute respiratory failure occurs when the lungs are unable to perform the gas exchange (oxygen/carbon dioxide) necessary to meet metabolic needs. Acute failure may occur in one or more phases of respiration (in the transport of oxygen to the alveolus, in the diffusion of oxygen across the alveolar-capillary membrane, during the transfer of oxygen from the lungs to the tissues or in the removal of carbon dioxide from the bloodstream to the alveolus for exhalation).

Acute respiratory failure can also be defined as the alteration of blood gas parameters measured in arterial blood, but these will not be determinant for the

establishment of an early and adequate treatment, which will depend more on the underlying cause and the clinical evolution of the child than on the blood gas values [15, 16].

ARF is more common in children than in adults because of their different physiology [15]:

1. They have a higher basal metabolic rate, which implies a lower metabolic reserve.
2. Neonatal breathing is irregular, so there is less response to hypoxaemia and hypercapnia. Their airways are smaller in diameter, so airflow resistance is greater.
3. The infant's thorax is more elastic and deformable, its respiratory muscles are underdeveloped and its ribs are horizontalised.
4. The diaphragm is shorter, and its type I muscle fibres are smaller, making them more prone to fatigue.
5. Alveolar septa exert traction on the airway and help to keep it open. In addition, the smaller number of alveoli per body surface area facilitates collapse, which, together with reduced collateral ventilation, predisposes them to atelectasis.

Clinical management should be based on two pillars: the treatment of the underlying disease and the administration of supportive measures for acute respiratory failure aimed at achieving acceptable arterial oxygen levels and pulmonary ventilation.

The benefits of noninvasive mechanical ventilation (NIV) in the child with ARF are increasingly recognised, although the evidence is still limited. It has been shown to improve the patient's symptoms [15, 16]:

1. It reduces the load on the respiratory muscles, stabilises the chest wall and improves minute ventilation.
2. Produces recruitment of collapsed alveolar units and increases end-expiratory lung volume.
3. Improves functional residual capacity and decreases the alveolar-arterial oxygen gradient.
4. Prevents (but does not replace) endotracheal intubation.
5. Improves gas exchange while the process that led the child to the ARF is resolved. Child to the ARF.

There are also a number of drawbacks or complications that will limit its use, generally all of them mild, related to the interface: the appearance of irritative conjunctivitis secondary to leaks, skin ulcers due to support and facial deformities; related to humidification of the system: nasal and pharyngeal dryness, mouth breathing and related to ventilation: high pressure, gastric distension (which can favour vomiting and aspiration), hypercapnia and rarely, pneumothorax [15, 16]. Some children are anxious about mask placement, which may hinder correct positioning and subsequent efficacy. The efficacy of NIV should be assessed according to the

appearance of agitation, worsening respiratory distress or gas exchange, all of which are signs of failure of the technique. If, on the other hand, there is a decrease in respiratory rate, this is an early sign of success [15]. Determining whether NIV will fail is difficult but particularly important. The best predictor of failure is high oxygen requirements on admission ($FiO_2 > 0.6$) and initial PCO_2 and within hours of initiation of ventilation. The pathology with the highest failure rate is acute respiratory distress syndrome [15]. On the other hand, high-flow oxygen therapy systems have recently been introduced in paediatric units. They are a simple technique and evidence of their efficacy in neonatal and paediatric practice is beginning to emerge [15].

Indications and Contraindications for NIV in Paediatrics

Indications for NIV [16–18]

1. Decompensated obstructive pulmonary diseases: asthma, cystic fibrosis, bronchiolitis, upper airway obstruction.
2. Decompensated restrictive diseases: chest wall and spinal deformity (congenital, achondroplasia, kyphoscoliosis), neuromuscular diseases (infantile spinal atrophy, Guillain-Barré) and obesity-hypoventilation syndrome.
3. Parenchymal diseases: acute respiratory distress syndrome (ARDS) of the newborn, pneumonia, tracheomalacia, pulmonary fibrosing diseases.
4. Cardiogenic alterations: heart failure, acute oedema of the lungs.
5. Other causes: pulmonary complications of sickle cell anaemia, apnoea after adeno-tonsillectomy, postoperative scoliosis surgery, ventilator weaning, situations requiring high oxygen intake (sepsis, shock, anaphylaxis) and severe respiratory failure in terminal illness (palliative).

In paediatric patients with asthma, the administration of NIV acts as a bridge between the effect of pharmacological treatment and the use of invasive mechanical ventilation. It reduces bronchospasm, acute lung damage, barotrauma, pneumonia and cardiovascular instability that can result from invasive ventilation.

Patients with neuromuscular disorders (spinal muscle atrophies, myasthenia gravis, congenital myopathies and muscular dystrophies) do well undergoing NIV by decreasing the work of the respiratory muscles, increasing carbon dioxide sensitivity and decreasing sleep disturbances. Obstructive sleep apnoea is one of the main indications for NIV when tonsillectomy does not achieve the expected results. ARDS is one of the most frequent problems that occur in the neonate due to lack of lung maturation, with the incidence increasing the younger the gestational age. Thanks to the use of ventilatory support, it is possible to treat and increase the survival of neonates suffering from this pathology.

Contraindications to NIV [16, 17]

When considering treatment with noninvasive ventilation in paediatric patients, different parameters that may contraindicate it must be assessed, such as: age, the type

of respiratory system dysfunction, the presence of cardiorespiratory instability or the clinical condition of the child.

It is contraindicated in patients with established haemodynamic instability and the child must be stabilised first, which may result in sedation and intubation of the patient for better haemodynamic control. Other fundamental contraindications for the use of NIV are related to the inability to adequately protect the patient's airway, as in the case of patients with neurological disorders, incoercible vomiting, severe swallowing disorders or the inability to mobilise secretions.

It is also contraindicated when there is physical limitation for interface placement (due to facial deformity or trauma), if there is severe fixed airway obstruction, if the need for ventilation exceeds 16 h/day, in cases of previous pneumothorax, or when IV offers increased patient survival.

Extreme anxiety or lack of cooperation from the patient during treatment as well as lack of family support are reasons to contraindicate the technique.

The lack of education and training of the personnel who manage NIV in paediatric patients is an absolute contraindication for this type of treatment, as its success cannot be guaranteed if they do not know how to administer the quality and highly specific care that it requires.

Treatment with a High Level of Safety and Efficacy

The first thing to assess in a child with signs and symptoms of ARF is the urgency of taking measures such as the need for intubation or noninvasive respiratory support [15]. This decision should be made by the responsible physicians within the first few minutes after close monitoring of the child, assessing whether spontaneous breathing is present and whether the airway is patent.

Once the decision has been taken to treat the patient with NIV, the environment will be adapted and the different actions necessary to receive and treat the patient will be coordinated.

The patient (if the patient's age permits) and family will be informed about the technique to be performed, providing the calmest possible environment, providing confidence and security in order to obtain a constant assessment of tolerance and response to ventilatory therapy. Patient tolerance will be directly related to good patient participation, so it will be essential to provide clear and understandable explanations for each age range, supported, if necessary, by drawings or other multimedia formats that allow the paediatric patient to understand the treatment to be applied [13].

Pre-nursing Care Prior to the Start of the First Year of Life

An assessment of the patient's condition prior to the introduction of NIV shall be performed in order to be able to evaluate the impact of this ventilation modality on the patient. It shall consist of:

1. Monitoring and recording of vital signs: blood pressure, heart rate, respiratory rate, oxygen saturation.
2. Venous or arterial blood gas sampling in order to subsequently assess the effectiveness of ventilation.
3. Record the presence or absence of pain, the general condition of the child, the abdominal diameter; if there is a cough and its effectiveness; if there are skin lesions, with emphasis on those on the face and, if present, assess the degree to which they are present; assessment of the patient's state of hydration, both systemic and tissue; recording whether there are signs of conjunctivitis, muscular fatigue (such as tachycardia, tachypnoea, sweating, dyspnoea, cyanosis or the use of accessory muscles).
4. The patient will be placed in their bed or cot, the need for restraint and safety measures (bed or cot bars) will be assessed and the patient will be placed in the position that optimises their respiratory effort and provides the best degree of comfort and safety. This position is the semi-sitting or semi-Fowler position with the neck in a neutral position, the trachea aligned with the trunk, the legs semi-flexed and the feet at 90° on a plane. The upper limbs should be in a neutral position, slightly separated from the body. This posture facilitates relaxation of the abdominal muscles and allows wider diaphragmatic movements with less effort [19, 20].
5. Depending on the age of the patient, different supports or cushions can be used to maintain the most appropriate posture to provide the best comfort for the child while providing effective ventilatory therapy. In infants, bracing can be used on both sides of the face to centre the head in a neutral position, a cervical support will prevent flexion of the neck over the thorax, but it must be taken into account, especially in young children, that excessive cervical extension may compromise the opening and therefore the patency of the airway [18].
6. Check that the treatment orders correspond to the patient who has to undergo NIV and that there are no contraindications to undergo NIV.
7. Maintain the patient on the previous oxygen therapy for the duration of the preparation of the device.
8. Ensure the presence of patent vascular access for sampling or drug administration as prescribed.
9. Check the patency of the airway, aspirating secretions if required.
10. The skin of the areas that will be in contact with the interfaces and the harness shall be prepared. These areas shall be subjected not only to pressure and friction, but also to the action of moisture and heat.
11. Adequate hygiene of the mouth, nostrils and eyes shall be carried out prior to the start of treatment and routinely thereafter. The areas under pressure should be hydrated with hyperoxygenated fatty acids. It is advisable to apply hydrocolloid dressings in these areas to prevent pressure ulcers if necessary.
12. The need for a nasogastric tube should be assessed to allow gastric emptying on an ad hoc basis or, if it is decided to leave a permanent tube in place, to fix it appropriately.
13. The assembly and operation of the ventilator shall be checked. Where available, a dedicated ventilator is the ventilator of choice, which will give better results

due to its higher trigger sensitivity and leak compensation [16], although conventional ventilators with NIV mode can also be used.

14. The ideal interface is one that is comfortable, light, transparent, adaptable to the facial morphology of each patient, easy to fit and remove, with reduced dead space, which is easy to secure and allows an adequate seal without exerting excessive pressure. It is recommended that it be fitted with an anti-asphyxia valve and prevent rebreathing or re-inhalation of carbon dioxide. It should be hypoallergenic, inexpensive, disposable or easy to clean [14, 17, 20].

An excellent choice of interface is directly related to the success of NIV as it promotes patient comfort and tolerance. There are several types, so it will have to be individualised in each case, considering the resources available and the types of ventilators. In addition, the characteristics of the patient (age, facial anatomy), as well as their condition (if they are conscious, cooperative), or if it is an acute or chronic process, will also be taken into account.

The available interfaces are nasal (covering the nose), nasobuccal (covering the mouth and nose), facial, full facial (covering the whole face) and *helmet* type (covering the whole head). In the case of neonates or infants under 5 kg, nasal pillows, or pillows (incomplete nasal) are used [21].

In paediatrics, the bucconasal interface is the interface of choice in the acute phase or when NIV treatment is first initiated [16]. although full nasal prongs are extremely popular because they are easy to fit, are well tolerated and, unlike in adults, can be used in situations of acute respiratory failure with optimal results [21]. There are varied sizes and varied materials (silicone, gel, rubber). Most of the existing ones are made of silicone, but the gel ones, being modellable, allow a better coupling. Incomplete nasal pillows or nasal pillows are especially useful in patients who have not tolerated oronasal pillows or complete facial pillows, in patients with skin lesions around the nose and, as already mentioned, in neonates.

The Helmet system is rarely used in paediatric patients, because although it requires less cooperation from the patient and is more comfortable for them, it has more dead space and generates greater claustrophobia.

It is important to choose a cap size that is the correct size for the patient's head to avoid injury. In the case of neonates and smaller patients, this should be based on weight, length and head circumference [18].

Nursing Care During NIV Therapy

Once the patient is prepared, the selected interface is fitted. This process is preferably conducted by two people (whenever possible). The ventilator will be switched on and already programmed by the physician. First, the headgear is placed in the correct position starting at the back of the head and bringing the interface over the patient's face. A first hold is made with the practitioner's hands, giving the patient room to adjust. In a second phase, the straps of the headgear or cap should be adjusted to allow the interface to fit properly. The pressure of the headgear on the

mask should be evenly distributed, so it is advisable to tighten the headgear straps crosswise rather than on one side of the face. Lateral displacements of the interface should also be monitored to avoid, as far as possible, an increase in pressure at any point between the anchorages and the support areas of the interface.

- The patient's adaptation shall be checked to ensure that he/she is comfortable, and any leaks shall be checked. An initial monitoring of the patient's vital signs shall be performed after the start of the procedure [20].
- Once NIV therapy has been instituted, close monitoring of the patient should be maintained; records should be made of time of initiation, duration of treatment (if previously established) and the care that has been provided throughout the process.
- The monitoring of vital signs will be continuous, being of vital importance during the course of the first hours in which it will be possible to assess how the patient is adapting to the therapy and how it is achieving its objectives. In this way, the ventilator parameters can be readjusted, correcting the positioning of the interface and harness, if necessary, in order to avoid possible leaks or modifying the patient's posture according to its efficacy and degree of comfort. Reduction in respiratory rate and improvement in pH as well as PaO_2/FiO_2 ratio 2 h after treatment are key markers of response to the technique [16].
- The correct functioning of the ventilator shall be monitored, and the tubing, connections, humidifier, interface and harness shall be properly maintained by periodic cleaning with sterile water; the anti-suffocation valve shall be checked, and the filters shall be replaced at least once per shift.
- The interphase should be changed every 4–6 h and, according to some recommendations, the type of interphase should be rotated at least twice a day, in order to exchange areas of support and therefore also of pressure, minimising the appearance of lesions, which are more frequent in exceptionally low birth weight newborns. The interphase should be changed by cleaning the support area and placing the new one in the same position to avoid pressure points in other areas that could cause damage. Even if the interface is not changed so frequently, it is advisable to moisturise the area by administering creams and hyperoxygenated fatty acids at each constant monitoring or the necessary intervention on the patient in order to maintain a close monitoring of the skin. This is especially important in neonates to avoid deformities and lesions.

Dressings can also cause damage to the skin of patients, especially neonates, which is even more delicate. Dressings should be changed every 12 h.

- Abdominal distension is also a parameter to watch for during the monitoring of the patient undergoing NIV, because the accumulated air at the digestive level causes discomfort and discomfort due to the elevation of the diaphragm, which hinders breathing and thus the goal of positive pressure ventilation therapy. It can also cause nausea and vomiting for which it is sometimes necessary to place a

nasogastric tube to relieve abdominal distension. The patency of this tube should be checked periodically.

- If not contraindicated, patients on NIV therapy can maintain adequate enteral feeding. The most appropriate nutrition should be chosen in each case if the patient is a neonate (tube, bottle or breastfeeding). It is preferable to disconnect the NIV at the time of feeding. If the patient's situation does not allow disconnection, placement of a nasogastric tube for enteral nutrition would be indicated.
- Routine monitoring of airway patency is recommended for effective ventilation. In the case of the smallest patients, it is recommended that checks be made every 3h, trying to coincide with feedings to avoid excessive manipulation of the neonate [18]. In many cases, the loss of patency is due to the accumulation of secretions in the upper airways, for which the introduction of a probe connected to a vacuum system is recommended, which, introduced through the nose or mouth, aspirates the contents that are obstructing the airway. It is advisable to moisten the nostrils beforehand with physiological saline solution in order to fluidify the secretions and make them easier to remove. This technique is an invasive process that is uncomfortable for the patient, entails a risk of bronchoaspiration, mucosal lesions, episodes of desaturation, etc., and should therefore be performed only when strictly necessary.
  - One way to minimise airway obstruction by secretions and to keep the patient's mucosa hydrated in order to avoid injury is to maintain the ventilation system at a good humidification and temperature (around 37 °C). The presence of water in the tubes or any other obstruction in the system may be due to over-humidification, which can cause difficulty in airflow and increased resistance. Conversely, a lack of humidity will dry out the patient's mucosa, facilitating the formation and accumulation of secretions that will become increasingly dense, becoming more difficult to eliminate and increasing the risk of infection, making the objective of the therapy more difficult.
  - Maintain proper ocular hygiene and hydration, especially in patients wearing a full face mask. Physiological saline solution should be used for routine cleaning, and artificial tears should be administered to maintain hydration. It is important to check that the interface is properly secured, as air leakage over the conjunctiva can lead to irritative conjunctivitis [20].
  - The use of a dummy should be avoided during the application of NIV with a face mask, as in the event of vomiting, this would be an obstacle that would add to the difficulty of eliminating the contents that accumulate in the mask. On the other hand, in acute respiratory failure, breathing is mainly mouth breathing (gasping) and therefore, the use of a dummy will significantly limit the child's ventilatory capacity. However, this device can be especially useful when nasal interfaces are used, as it contributes to improve pressure control by reducing air leakage through the neonate's mouth. On the other hand, it is a great analgesic measure as an alternative to breastfeeding and kangaroo care when the mother is not at the patient's bedside and is a crucial factor in reducing the risk of sudden infant death [21].

- Postural changes should be made periodically, as a recommendation every 3–6 h to avoid the appearance of pressure ulcers, which would generate an extra complication to the patient's original process and could cause an accessory infection pathway [18].
- Situations that may cause stress in paediatric patients should be reduced as far as possible by providing them with a calm and comfortable environment, avoiding noise, alarms, lights, the tone of conversations, etc., and paying attention to any postural or thermal discomfort, etc., resorting, if necessary, to the administration of analgesia and/or sedation [18, 19].

It is important to provide paediatric patients with elements or situations that make them feel protected (their favourite doll, their sleeping blanket) and keep them distracted (talking about their favourite football team, their favourite children's series). During therapy, the effect of the permanent or occasional presence of the family will be assessed, depending on their degree of anxiety and collaboration and the impact it has on the patient's condition [18].

It is also interesting, depending on availability, to have at their disposal entertainment media appropriate to the age and situation of each child, such as TV, films, games, reading... and when available, to request the presence of specific personnel such as teachers, members of children's associations that collaborate with paediatric hospitals.

Noninvasive Home Mechanical Ventilation for Patients with Chronic Respiratory Failure

Over the last 15 years or so, the use of noninvasive home mechanical ventilation has become widespread, largely due to medical and technological advances that have contributed to increased survival of critically ill patients, better diagnosis and knowledge of diseases with increased upper airway resistance or central and/or peripheral hypoventilation, the new development of easy-to-use devices adapted to home treatment, the ageing population and the increased incidence of chronic diseases such as COPD and obesity [22, 23].

The increase in NIV prescribing may also be since medicine is increasingly considering aspects other than patient survival, such as quality of life [24]. The term "health-related quality of life" (HRQoL) is an individual's multidimensional assessment of the impact of illness on his or her own life. It includes personal aspects such as health status, autonomy, independence, life satisfaction or beliefs, and environmental aspects such as support networks or social services. The assessment of HRQOL is important because it allows us to know and treat our patients better. There is sufficient evidence in the literature linking home NIV with an increase in HRQOL.

Another interesting aspect of home NIV is the economic aspect. Although it is difficult to establish its exact cost due to the variability of the causative pathologies that make different resources necessary for each patient and the various sources of funding, it is generally accepted that the implementation of home NIV saves costs for

administrations. Home ventilation can be performed with positive pressure either invasively through a tracheostomy or noninvasively. It can also be performed with negative pressure thanks to the implantation of a diaphragmatic pacemaker in patients with hypoventilation of central origin, usually caused by spinal cord injury. Ventilation through tracheostomy has advantages such as reducing dead space and airway resistance, facilitating drainage of secretions, and allowing long-term ventilation. But it also has associated complications such as increased patient complexity, risk of potentially serious complications, reduced quality of life or impaired phonation. This, together with the development of new systems, has led to a growing preference for NIV.

The objectives of home-based NIV are [22, 24]:

1. Improve gas exchange by correcting alveolar hypoventilation, decreasing work of breathing and improving respiratory muscle function.
2. Prolonging survival.
3. Improve the quality and duration of sleep.
4. Improve quality of life and functional status.

Indications

Consensus criteria for the indication of home NIV were established in 1999 [22, 23, 25]. These are:

- In neuromuscular diseases, presence of clinical symptoms such as dyspnoea, morning headache or daytime hypersomnia associated with the presence of physiological criteria such as hypercapnia in baseline arterial blood gases, nocturnal desaturations with SpO_2 below 88% for 5 or more consecutive minutes, peak inspiratory pressure below 60 cmH_2 or forced residual capacity below 50% of baseline.
- In patients with COPD, hypercapnia above 55 mmHg or in the range 50–54 mmHg with nocturnal desaturations below 88% for at least 5 min and frequent exacerbations with respiratory acidosis (more than two in the last year). The pathologies for which home NIV is most frequently prescribed are: neuromuscular diseases such as ALS, Duchenne disease or myotonic dystrophy.
- Diseases of the rib cage such as kyphoscoliosis.
- Hypoventilation syndromes such as hypoventilation-obesity syndrome or congenital central alveolar hypoventilation.
- COPD in the stable phase (controversial use and only in selected cases). In any case, the decision whether or not to indicate NIV should not be based solely on clinical criteria but should also consider the patient's environment and willingness or, if necessary, also that of the caregivers. So much so that lack of motivation and lack of social and family support are considered relative contraindications for home NIV.

Another factor to take into account is age. Some authors consider that its indication beyond 75 years of age is not appropriate, but there are many studies that show that

in these patients, it produces a gasometric improvement, reduces nocturnal desaturations, the number of hospital admissions and their duration and therefore improves quality of life [22]. For its indication in palliative care, the wishes of the patient and family must be taken into account, ensuring that they have received all the information necessary to make the decision.

Contraindications to Home NIV

- Absolute: complete airway obstruction, very abundant secretions that cannot be cleared, lack of patient cooperation or inability to maintain interface.
- Relative: significant impairment of swallowing, lack of cooperation from family or caregiver or need for continuous ventilatory support.

Complications of Home Nursing

They are the same as those for noninvasive mechanical ventilation in acutely ill patients.

1. Irritant dermatitis secondary to pressure of the interface on the support points. This can progress to pressure ulceration. A strategy of interface rotation combined with the use of hyper-oxygenated fatty acids or moist wound dressings is useful to prevent pressure ulceration.
2. Irritative conjunctivitis related to air leakage into the eye. Leakage at this level should be prevented as far as possible by correct adjustment of the interface and hygiene and hydration of the eye, if necessary, with artificial tears. Patients with poor ocular occlusion are especially at risk and may require eye shields to allow vision.
3. Gastric distension due to opening of the upper oesophageal sphincter at pressures greater than 25 cm H_2O or 20 cm H_2O in neuromuscular patients. Nasogastric tube placement may be necessary.
4. Food aspiration, especially in patients with dysphagia and in nasogastric tube carriers. It is advisable to allow a period after ingestion or intake of enteral nutrition before restarting ventilation.
5. Related to humidification, nasal mucosal alteration and mucus plug formation may occur, which can lead to airway obstruction [26].

Necessary Equipment

The equipment that patients should have at home will be [22–24]:

- Respirator. Ideally, it should be simple, quiet, lightweight and have alarms. In patients who require therapy for more than twelve hours a day, they should also

have a spare. It should have at least anti-bacterial, pollen and dust filters to ensure the quality of the air supplied to the patient. The tubing should be anti-collapsible, of low distensibility and of a standard length of two metres and a diameter of 15–22 mm. It is also recommended that they be equipped with downloadable software systems to facilitate therapy monitoring.
- Interfaces and restraint systems, plus a submental band if required.
- Pulse oximeter. It should be simple, reliable, easily transportable and with acoustic alarms.
- Secretion aspirator with adjustable suction pressure.
- Assisted cough devices. They favour the expulsion of secretions and are especially useful in cases of neuromuscular pathologies.
- Humidification. The need for this will be assessed on a case-by-case basis.
- Oxygen therapy devices if required by the patient.

Interface

The ideal interface should be easy to put on and take off, light, soft, made of breathable, transparent, washable material and available in several sizes. To increase patient safety, it is recommended that all of them are fitted with an anti-suffocation valve.

In addition to the choice of the interface, it is equally important to choose a suitable anchorage system. It should be stable, easy to put on and take off, non-traumatic, light, soft, washable, breathable, and available in several sizes. To fix it with adequate but not excessive tension, it should be possible to pass two fingers between the sling and the skin [23, 26, 27].

Team Responsible for Assistance

The control and follow-up of these patients is complex, requiring multidisciplinary management by specialised units that can provide their services if necessary, moving to the patient's home. This will have a positive psychosocial impact on the patient and family and a positive economic impact on the health care system. For home NIV to be carried out successfully, it is not only necessary to have the technical means. It is crucial to train and educate the patient, family and caregivers about the pathology, management, and control of NIV equipment and associated techniques, possible complications, recognition of worsening of the underlying pathology and emergency situations. In addition to all this, there must be an adequate psychosocial assessment and support, assessing the family environment, home, economic needs (financing and aid) and social support. Ideally, the patient and family should be cared for by a multidisciplinary team consisting of at least a pulmonologist, an intensivist, a nurse, and a physiotherapist specially trained in noninvasive ventilatory therapies. This team should be properly coordinated with the primary care team responsible for the patient [23].

Start of Treatment

Therapy can be administered in hospital or in the patient's own home. Some authors argue that home-based therapy has some advantages, such as being cheaper and having shorter waiting lists than hospital-based therapy and has not been shown to result in poorer compliance with the prescription. On the other hand, hospital-based treatment allows for better observation and monitoring of the patient. It is also more practical, because its prescription is usually decided after the resolution of an acute process that has required hospitalisation, which means that the patient is already admitted to hospital.

Ideally, treatment should begin in a service with the appropriate material, personal and technical resources. A 3–5 days admission is usually required, during which the necessary parameters will be optimised and during which the family and the patient will have the opportunity to familiarise themselves with the therapy, the interfaces and their management, the most common problems or side effects and to learn how to solve them. The first step is to choose a suitable ventilator, tubing and interface for the patient, taking into account the patient's physiognomy, degree of mobility and available equipment. Initially, if the patient's condition permits, therapy should be started for short periods of time and at low pressures, even if these are lower than those required by the patient. This, although it may produce ventilation that is not entirely effective, makes it more comfortable at the start and avoids subsequent rejection of the technique. Sometimes it will be necessary to start with a CPAP mode and when the patient becomes accustomed to the continuous airflow, progress to BiPAP mode. The ramp should also always be used during adaptation. Subsequently, its use or non-use will be maintained on an individual basis. When the appropiate settings have been reached, the patient is comfortable and the SpO_2 relative to baseline (with or without supplemental oxygen) is maintained above 94% for at least 30 minutes, an efficacy arterial blood gas measurement should be taken. It is recommended that therapy is started with the same equipment that the patient will later take home [22–24, 27].

Other Aspects to Assess Before Discharge Home

To ensure continuity of care and patient follow-up, coordination of the hospital noninvasive mechanical ventilation team with the primary care team responsible for the patient is necessary. The primary care physician responsible for the patient should be informed of the patient's situation and agree with the primary care physician how the patient will be monitored and the responsibilities of each physician. The nurse in charge should also be contacted, informed of the nursing care required and provided with a list of the equipment and drugs that the patient will need.

Depending on the autonomous community, the responsibility for providing consumables for home NIV will fall on the primary care centre, on the hospital ventilation unit or on the company supplying the equipment. Most commonly, it is the

responsibility of the supplying company, which will also carry out maintenance of the equipment and training of patients and caregivers.

Patients should contact the electrical companies to inform them of the need for the use of respiratory support equipment dependent on electrical power. The patient should have a list of emergency telephone numbers at home to resolve any problems that may arise and a complete and always up-to-date report of the type of ventilator, the prescribed parameters, the name and telephone number of the company supplying the equipment and the telephone number of the monitoring team at the hospital.

Before discharge, we must have ensured that

1. The patient is completely stable.
2. Both patient and caregivers are motivated and adequately trained and prepared.
3. The necessary means and equipment are available at home.
4. Appropriate medical follow-up and 24-h technical assistance are assured.
5. Psychological support for patients, relatives and carers [22, 23].

Effectiveness and Compliance Monitoring

To monitor efficacy, we must assess the patient's symptoms, blood gas status and nocturnal pulse oximetry. If there is intolerance, we should inquire about its causes in order to try to solve them. For clinical monitoring, we should ask the patient about the improvement or not of the symptoms he/she presented prior to the introduction of home NIV (morning headache, daytime sleepiness, fatigue, dyspnoea, etc.), satisfaction with the therapy, quality of sleep and comfort of the interface and support harnesses.

Measurement of arterial blood gases is considered the Gold Standard for assessing the efficacy of NIV. It should be performed whenever there is a deterioration in the patient's condition or when changes in ventilator parameters are made. Its purpose is to determine changes in $PaCO_2$. Despite this, nocturnal transcutaneous $PaCO_2$ measurement is increasingly being introduced as it is more comfortable for the patient and better reflects the situation during sleep.

Pulse oximetry will also be useful to assess SpO_2 during sleep, with the limitation of its low specificity, which means that it does not differentiate the cause of the same. Other tools that can be used to monitor efficacy are nocturnal capnography or polysomnography.

Compliance monitoring will be done by analysing the information provided by the ventilator software [22, 23, 27, 28].

Follow-Up of Patients

The first follow-up consultation will take place in the home NIV monographic consultation. It will assess the symptoms of alveolar hypoventilation, any technique-related problems the patient may have encountered, review compliance and treat

any complications (interface-related discomfort, pressure ulcers, leaks, dry mucous membranes, eye discomfort).

In the case of patients with neuromuscular diseases, aspects such as the degree of nutrition, functional deterioration, secretion management (it may be necessary to introduce the use of mechanical cough aids, humidifiers if not already in use, or to reinforce the technique of secretion aspiration) and to assess the need to switch to invasive ventilation through tracheostomy when the time comes. In these patients, it is also necessary to take care of the caregiver and establish therapeutic limits with them through successive visits.

The second consultation will take place three months after the first and subsequent consultations will be carried out according to the needs and characteristics of the patient and the pathology, but usually every 6 months. Consultations should also be performed whenever ventilator parameters are modified [22–24, 27].

According to the SEPAR manual on noninvasive mechanical ventilation, the role of nursing in the follow-up of patients undergoing home NIV is aimed at [27]:

- Check that everything is in accordance with the discharge report or later.
- Increase compliance.
- Detect all those problems or doubts that have arisen in the home. Prevent and assess the possible existence of undesirable effects.
- Check respirator compliance and ventilation efficiency.
- Family and carer support.
- Assessment of the caregiver and the social environment.

Complementary Techniques

Management of Secretions

This will be done by manual or instrumental management techniques and secretion suctioning. Manual techniques aim to generate flows at different lung volumes to bring secretions closer to the upper airways so that the patient can cough them out. Before discharge from hospital, a physiotherapist should assess the patient and instruct the patient or caregivers in these techniques. Instrumental techniques will require oscillating and non-oscillating positive expiratory pressure devices, intrapulmonary percussive ventilation or external high-frequency chest wall oscillation-compression devices, depending on the pathology and characteristics of each individual, as some of them require the patient's cooperation and a minimum degree of muscular strength.

Manual Assisted Cough Techniques

Indicated to improve coughing efficiency in patients with neuromuscular diseases in whom the peak flow of spontaneous coughing is diminished. Requires patient cooperation. It requires a mechanical device applied to the patient via an oronasal interface that generates a positive pressure followed by a negative pressure alternately, causing secretions to move from distal to proximal airways. The programming of the equipment should be done on an individual basis by the physiotherapist responsible for the

child's care, who in turn will be responsible for instructing the family and caregivers in its management. Mechanical cough support will be provided three times a day and whenever there is an increase in secretions or desaturation due to secretions.

Caregivers should be carefully instructed in the technique. Negative pressures of 120–150 mmHg in adults, 80–120 mmHg in adolescents, 80–100 mmHg in children and 60–80 in neonates are recommended. Insertion of the tube should be shallow, and each aspiration should not exceed 15 s to avoid injury from vigorous aspiration.

The technique should be applied as aseptically as possible, and it is recommended that the probe be discarded after each use or at least cleaned internally by aspirating double-distilled water and externally with alcohol and discarded after 24 h of use.

Inhaled Medication Delivery

Drugs can be administered by pressurised cartridge inhalation devices known as pressured metered dose inhaler (MDI) or by nebulisation using different methods. All of them require an adapter to be placed on the tubing (on the inspiratory branch in the case of a dual-branch ventilator), which should always be placed as close as possible to the interface to prevent drug leakage. For the administration of nebulised medication, there are several systems available on the market:

- Jet type: Requires an oxygen source capable of delivering high oxygen flows (6–10 L/min).
- Ultrasonic: These work by generating sound waves that vibrate a piezoelectric crystal at a high frequency. This converts the liquid into a cloud of micro-droplets that is pushed into the patient's airway by the flow generated by the ventilator. They are used for the administration of saline or bronchodilators. Suspensions and antibiotics should not be administered by this system, as it generates heat, and the drugs can be denatured.
- Vibrating mesh: These consist of a membrane with microscopic holes and a vibrating element that pushes the medication through the holes, generating an aerosol. They are smaller, less noisy and less heavy than all the above. They achieve greater drug deposition and better adherence to treatment, as they take less time to nebulise. Whenever aerosols are administered, there is always a risk of bacterial contamination due to poor cleaning, which increases the risk of respiratory infection. Therefore, it is necessary to insist on proper cleaning of the equipment after each use according to the manufacturer's instructions. The choice of one medication delivery system or the other will depend on the patient and the drug, as not all are available in both presentations.

Oxygen Therapy

In some pathologies, in addition to NIV, oxygen supplementation via tubing or ventilator connections is necessary. There are several sources of oxygen suitable for home use:

- Static concentrator: Concentrates oxygen from ambient air. They need to be permanently connected to the mains. The normal ones achieve flows of up to 5 L/min, but there are high-flow concentrators on the market that can reach 10 L/min.

- Oxygen in cylinders or bullets.
- Liquid oxygen stored in a container called a dewar.
- Portable concentrator: Unlike the static concentrator, it has a battery, which allows the patient to leave home. But it only reaches flow rates of 2–3 L/min.

Noninvasive Home Mechanical Ventilation for Paediatric Patients with Chronic Respiratory Failure

Situation of Home Care in Paediatric Patients

In 2012, a multicentre study was conducted in Spain [28] that analysed the characteristics of children requiring home ventilatory support (both invasive and noninvasive) and their social supports and resources. According to this study, the mean age of initiation of home NIV is 5.9 ± 4.5 years. Regarding the daily time of NIV, the mean was 9 ± 2.8 h distributed at night and allowing the child to do without it during the waking period. This is because up to a quarter of paediatric patients requiring home NIV do so for OSAHS.

Home NIV has a major impact on the functioning of the family unit, since in 98% of cases, home care is entirely the responsibility of the family. Only 3.4% of families have health personnel at home to provide this care.

In 2012, 72.1% of children with home invasive mechanical ventilation in Spain were in school, 93.9% in adapted schools and 6.7% at home. The remaining 26.9% were unable to attend school due to their pathologies. In our environment, the figure of the school nurse is becoming increasingly common in schools, but the presence of health personnel who collaborate with educators to enable the schooling of patients with special needs is still insufficient. The presence of school nurses in schools is beneficial both for children with chronic illnesses and for parents and teachers. For parents, they provide reassurance and security and for teachers, they are a great support, especially in emergency situations.

Objectives of Home-Based Care

In addition to the objectives mentioned above in the chronically ill adult patient, NIV in the paediatric patient aims to enable the child's schooling [29].

Indication of Home NIV

Five factors must be considered for the indication of home NIV [23, 30]:

- Pathology causing chronic respiratory failure (neuromuscular diseases, metabolic diseases, anomalies of the airways, rib cage or lungs, ventilation control disorders).

- Patient and family motivation. It is necessary that the patient and their caregivers are aware of the disease, prognosis, therapeutic possibilities and risks and complications of NIV. They must also have the minimum intellectual capacities necessary to learn how to use the equipment. A high degree of involvement of the team is also important, which will transmit security and confidence to the family.
- Assessment of the family's economic and social resources and housing conditions.
- Clinical situation of the patient. Unlike in adults, in children, there are no validated criteria on when to indicate home NIV. It will be indicated if there are symptoms of hypoventilation or sleep disturbances (morning headaches, daytime hypersomnolence, enuresis, nightmares, etc.), gasometric alterations (pCO_2 greater than 45 mmHg in wakefulness or SpO_2 less than 88% for more than 5 min at night), severe alteration of pulmonary function, frequent hospitalisations due to respiratory causes, if hypoxia and hypercapnia are refractory to other treatments such as physiotherapy or bronchodilators and if there are no contraindications for NIV.
- Clinical stability. It will be necessary that continuous monitoring is not required, an stable airway, the absence of severe dyspnoea, and yhe stability of the other organs. The contraindications for therapy are the same as those for adult patients.

Complications

In addition to the complications found in adults, we must pay special attention to the possible appearance of malar hypoplasia due to the pressure of the interfaces on the developing cartilaginous mass in children under 8 years of age. To avoid this, it is useful to rotate the interfaces, including the use of the total face [30].

Interface

There are important limitations on the choice of interface in children, especially in the youngest, but the industry is constantly developing new tools. Therefore, professionals must be in contact with the companies in the sector, in order to be aware of the possibilities available on the market that can best suit our patients. The most commonly used interfaces in home NIV in paediatric patients are the nasal interfaces, because they are relatively more comfortable, have less dead space and are safer than oters. The main drawbacks of this type of interface are pressure ulcers and mouth leaks. To minimise the latter, the use of dummies or chinstraps may be helpful. If leakage is still excessive, the interface should be replaced by an oronasal interface. In addition to being less comfortable, the latter is less safe because of the increased risk of aerophagia and aspiration. In older children and adolescents, Adams-type interfaces and nasal prongs may be useful, as they have less risk of pressure ulcers than other interfaces and produce less claustrophobic sensations. Total-face interfaces are rarely used, but may be considered especially in patients

who have developed pressure ulcers or malar hypoplasia. The use of helmet-type interface in paediatric home NIV is anecdotal [23, 25, 30].

Start of Treatment

As in the case of adult patients, the ideal is to start therapy in hospital, in a department with the appropriate material, personal and technical resources, with an admission of 3–5 days. There, the necessary parameters will be optimised and the family and the child will have the opportunity to become familiar with the therapy, the interfaces and their management, the most common problems or side effects and to learn how to solve them. In infants, it can be useful to take advantage of moments when they are asleep or in their parents' arms to place the interface and begin the technique. In school-age children, it can help to present it as a game. In adolescents, it is usually easier to adapt, as they are able to understand their pathology and the need for ventilation [23, 30].

Parent and Caregiver Training

Initially, during admission, basic knowledge, use and maintenance of the different devices and the foreseeable problems that may arise will be explained to the parents or carers. It is important not to saturate them with information, to check that they have understood it and to provide them with the information in writing. It may also be useful for them to take their own notes, adapted to the child's situation. They will first observe how the health staff performs the tasks, then they will do them themselves under supervision and finally, they will do them independently. Before discharge, they should have learned:

- Placement of the interfaz
- Leakage monitoring
- Skin and mucous membrane care
- Operation and cleaning of equipment
- Interpretation and setting of alarms
- Adjustment of some parameters if deemed appropriate by the physician—assessment of signs and symptoms of respiratory worsening
- Recognising urgent situations and how to act
- Special feeding techniques if required by the child
- Care for activities of daily living, including play
- Physical and respiratory rehabilitation techniques, speech therapy and occupational therapy if the child needs them [23, 30].

What to Assess in the Follow-Up of the Paediatric Home Care Patient

Symptoms of hypoventilation should be assessed and will vary according to the age of the child. Younger children show irritability, psychomotor retardation, poor school performance, drowsiness, intense night sweats, enuresis, malnutrition and restless sleep with frequent awakenings and nightmares. In adolescents, morning headache, drowsiness, tiredness, difficulty concentrating and sometimes dyspnoea appear. In the physical examination, HF, BF, temperature and SpO_2 should be measured. Ponto-statural development, signs of pulmonary hypertension, neurological assessment, psychomotor development and nutritional assessment will be assessed. SpO_2 during the day and during sleep should be assessed for desaturation. If present, this may be due to persistent hypoventilation, intermittent airway obstruction, excessive leakage or asynchrony. This will help in deciding whether to change parameters, add oxygen therapy, whether humidification or nutritional support is needed. At all times we must be alert to detect complications and adverse effects, swallowing problems, respiratory infections and facial or facial bone deformities derived from the interfaces. Specific questionnaires will help us to assess the psychosocial and quality of life of the child and the family [23, 30].

Process of Nursing Care for Patients Undergoing Treatment with NIV

For the first step of the nursing care process, Marjory Gordon's assessment according to functional patterns has been chosen. This consists of an artificial division of human functioning into 11 patterns that facilitate the systematised collection of data during the anamnesis for subsequent assessment, the formulation of diagnoses, the establishment of objectives and the choice of the relevant interventions to achieve them.

Pattern 1: Perception—Health Management

This pattern assesses how the individual perceives their health and well-being, how they manage everything related to their health, adherence to prescribed treatment and whether they carry out preventive practices (vaccinations, and dietary habits).

To do so, we will assess their hygiene habits, vaccinations, the presence or absence of pathological antecedents, perception of their own health and interest in and knowledge of healthy behaviours and toxic habits.

In these patients, we may find a lack of knowledge about their disease and about the technique to be applied (NIV), which may condition the success of the therapy.

They will also be susceptible to infections due to therapeutic devices, the risk of aspiration inherent to NIV, decreased ciliary action and the possibility of pressure injuries (NIV, prolonged bed rest).

Once this pattern has been assessed, the following nursing diagnoses can be found:

- 00126 Poor knowledge
- 00004 Risk of infection

Pattern 2: Nutritional—Metabolic

This standard is responsible for assessing whether the amount of liquids and food ingested by the individual is sufficient to cover his/her metabolic needs, swallowing problems, anthropometric measurements, body temperature and the condition of the skin, mucous membranes and mucous membranes.

In the case of patients undergoing NIV for acute respiratory failure, we will focus on assessing whether the intake of food and liquids is recommended or whether, due to the patient's condition, an absolute diet, enteral nutrition via nasogastric tube or parenteral nutrition has been prescribed. In the case of being able to ingest food, the patient's ability to chew and swallow must be assessed. We must also be on the lookout for food allergies and intolerances.

Constant assessment of mucous membranes, membranes and tissues will be necessary, focusing on areas of support of interfaces and other therapeutic devices, areas of pressure against the bed, the state of the oral cavity and corneas. Validated scales such as the Norton scale for stratifying the risk of pressure injuries or the Walt scale for assessing the state of the mouth and lips can be used to assess these.

Many of these patients will be in this situation due to a respiratory infectious process, so fever may be found when analysing this pattern.

Once the data have been collected, the following nursing diagnoses can be made:

- 00304 Risk of pressure injury in adults
- 00002 Risk of nutritional imbalance: less than body requirements
- 00028 Risk of fluid volume deficit
- 00047 Risk of deterioration of skin integrity
- 00044 Risk of deterioration of tissue integrity
- 00247 Risk of oral mucosal damage
- 00039 Aspiration risk
- 00219 Dry eye risk
- 00245 Risk of corneal injury
- 00261 Risk of dry mouth

Pattern 3: Elimination

This pattern assesses intestinal, urinary and cutaneous excretory functions.

Constipation related to prolonged immobilisation is to be expected in these patients. It is also possible that, due to their critical or semi-critical condition, they may need a bladder catheter to control diuresis.

The nursing diagnoses we can find related to this pattern are

- 00015 Constipation

Pattern 4: Activity—Exercise

This pattern is responsible for assessing the patient's functional capacity, exercise, activity level and leisure time activities.

In these patients, we will focus on the assessment of blood pressure, heart rate, oxygen saturation, respiratory pattern, sensation of dyspnoea and its variations in response to activity (small efforts such as mobilisation in bed). This will give us an idea of the patient's activity tolerance.

In cases of prolonged bed rest, the degree of joint mobility, strength and muscle tone should also be assessed.

The nursing diagnoses that we can foreseeably find after the assessment of this pattern will be

- 00299 Risk of impaired activity tolerance
- 00091 Impaired mobility in bed
- 00291 Risk of thrombosis
- 00030 Deterioration of gas exchange
- 00093 Fatigue
- 00032 Ineffective breathing pattern
- 00031 Ineffective airway clearance
- 00033 Spontaneous ventilatory impairment
- 00108 Self-care deficits: bathing and hygiene
- 00110 Self-care deficit: toileting

Pattern 5: Sleep—Rest

This pattern describes the person's ability to achieve sleep, rest or relaxation, the patient's assessment of the quality of their sleep, whether or not they require pharmacological sleep aids and their perception of their energy level.

We have to take into account that these patients will generally be admitted to extraordinarily complex hospital units, where there is never silence or total darkness and where procedures are constantly being performed, so their sleep will be very difficult.

In addition, being away from their families and the perceived seriousness of their own state of health can induce states of anxiety or depression.

Nor will pain or discomfort related to therapeutic devices help the patient's rest.

The following nursing diagnosis is expected to be found:

- 00095 Sleep pattern impairment

Pattern 6: Cognitive—Perceptual

This pattern is responsible for the assessment of the patient's level of consciousness, cognitive status, adequacy of the sense organs, pain perception and management, language and the need for communication aids.

The assessment will collect data such as the level of consciousness and orientation in time and space, knowledge of language, hearing, communication or vision problems, existence, location, type and intensity of pain and behavioural alterations such as agitation.

Hypercapnia is frequently present in these patients, which may affect their level of consciousness, cognitive status or agitation.

They will also have communication problems related to the different interfaces. For example with the helmet, it will be difficult for the patient to hear us and with the interfaces covering the mouth, it will be difficult for us to understand what the patient wants to express.

Following the assessment of this pattern, it will be possible for us to make the following nursing diagnoses:

- 00051 Verbal communication impairment
- 00132 Acute pain
- 00173 Risk of acute confusion

Pattern 7: Self-Perception—Self-Concept

Assesses self-concept and perceptions of self, body image, identity, general sense of life, emotional pattern, eye contact, voice and conversation patterns.

In this case, the patient may experience moments of low situational self-esteem due to feeling unable to cope with the situation or events, feeling hopelessness, mistrust and worthlessness. This may be motivated by the functional impairment suffered or by changes in the social or family role.

The nursing diagnoses that can be found after the assessment of this pattern are as follows:

- 00153 Situational low self-esteem risk
- 00124 Despair

Pattern 8: Role—Relationships

This pattern analyses the patient's relationships with his or her environment, family, society in general, self-satisfaction with these relationships and the usual responsibilities he or she carries out.

For the assessment of this pattern, we will have to inquire about who the patient lives with, his or her family structure, whether he or she has dependents and the presence or absence of social support.

It is clear that the situation of illness and hospital admission may condition a change in social and work relationships as well as in the role that the patient had been occupying in his or her family until that moment and may also mean an increase in the need for social support for the patient.

In the context of this pattern, we can state the following nursing diagnoses:

- 00053 Social isolation
- 00054 Risk of loneliness
- 00152 Risk of impotence

Pattern 9: Sexuality and Reproduction

It assesses satisfaction or not with one's own sexuality, alterations in sexuality or sexual relations, security in sexual relations, reproductive pattern, pre- and post-menopause and problems perceived by the person.

In these cases, the hospital admission itself represents a limitation of their sexual activity. If the patient perceives this situation as a concern, we will make the following diagnosis:

- 00059 Sexual dysfunction

Pattern 10: Adaptation—Stress Tolerance

This pattern takes into account the forms and strategies of coping that the person possesses, his or her habitual responses to stressful situations, the capacity to adapt to change and the individual and family support that the individual has.

The patient will be asked about whether they are tense or relaxed, what usually helps them when they are tense and whether this approach has been successful.

Patients requiring noninvasive mechanical ventilation are experiencing a serious health problem and are located in extraordinarily complex hospital units where the presence of loved ones is not always possible, and which constitute a hostile environment for the patient. All this means that we can find the following nursing diagnoses after assessing this pattern:

- 00146 Anxiety
- 00147 Death anxiety
- 00148 Fear

Pattern 11: Values and Beliefs

This pattern identifies the values and beliefs that guide choices or decisions, what is considered right or appropriate, what is perceived as important in life, health-related expectations, decisions about treatment, health priorities, life or death, and religious practices.

In order to assess this, future plans, concerns related to life, death, pain or illness, and membership of any religion that prohibits or limits prescribed treatments, should be asked.

The assessment of this pattern takes on special relevance when NIV is used in the context of palliative care. This will allow us to respect the wishes of patients and relatives when deciding on therapeutic ceilings or limiting the therapeutic effort when necessary.

Within the framework of this pattern, we can find the following nursing diagnosis:

- 00067 Risk of spiritual suffering [31]

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Part VI

Education, Ethics and Cost Noninvasive Ventilation Outside Intensive Care Unit

Education and Training Programs in Noninvasive Ventilation: Clinical Practice and Evidence

36

Isabelle Piazza and Roberto Cosentini

Abstract

Noninvasive ventilation (NIV) is a worldwide approved and expanding method of respiratory support even outside intensive care unit (ICU) with an increasing practical importance due to the spreading of Coronavirus-19 disease (COVID-19). The education and training of medical and nurse staff is essential in order to reduce failures and complications of NIV and improve outcomes in patients with respiratory failure; but currently, organized training in NIV is available only in a few developed countries. In emergency situations, such as when ventilation is needed, a cooperative and close approach is essential in maximizing the performance of the team. This aim is only achievable through structured and organized education and training of all members of the NIV team. There is a lack of high-grade experimental evidence, but recently an international consensus on NIV education and training based on opinions from experts across different countries of the world was formulated. This consensus summarizes the minimum content of training and education programs for health-care staff using NIV and stated some new proposals. A good method to learn and practice in NIV management is simulation-based training that has become increasingly widespread in medical education. The simulation can be an opportunity for sharing fears and mistakes, and it can play an additional formative and relational role. There is a need to develop structured, organized NIV education, and training programs. Based on these data, training in NIV can be considered the upcoming more compelling challenge of health-care education, due to a significant heterogeneity among local training programs.

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Keywords

Noninvasive ventilation · Training · Education · Simulation · Residents

Introduction

Noninvasive ventilation (NIV) is a worldwide approved and expanding method of respiratory support for a range of cardiopulmonary conditions even outside intensive care unit (ICU).

Because of the spreading of Coronavirus-19 disease (COVID-19), NIV had a new and ever-increasing practical relevance, due to the progressive arterial hypoxemia, which rapidly leads to acute respiratory distress syndrome (ARDS) as a main clinical feature of the disease. Intensive care and invasive or noninvasive ventilation were in these scenarios almost inevitable and the need for adequate training in NIV management also outside the ICU became even more necessary for all operators working in the emergency setting [1]. The education and training of medical and nurse staff is essential in order to reduce failures and complications of NIV and to improve outcomes in patients with respiratory failure [2]. Proper training might optimize NIV therapy success in patients with ARDS, SarS-CoV2 related or not, acute decompensated chronic obstructive pulmonary disease (COPD) even in busy and stressful environments [3].

Relevance and Influence of Staff Training and Teamwork on the Outcome

Nowadays, the use of NIV is widespread, and it is routinely employed not only in ICU or ED, but also in intermediate-care units, wards, rehabilitation, and palliative care units. A careful patient selection as well as the skills of physicians, nurses, and therapists are the basis of a safe and effective NIV treatment. In this context, different levels of care and set-up of NIV require a different degree of expertise and training for safe initiation, management, and, if necessary, discontinuation of NIV and/or escalation to invasive mechanical ventilation. The adequate education and skills acquired thanks to specific and advanced training would allow medical and nurse staff to face acute life-threatening conditions associated to respiratory failure with the best expertise, with the intention of delaying or even avoiding invasive ventilation. In addition, the proper use of NIV in association to an appropriate management and monitoring by the staff allows the reduction of costs and time of hospitalization and may prevent disease exacerbations [4]. Another positive implication is the improvement of the clinical staff's job satisfaction, which would consequently lead the senior staff to teach the younger ones with more commitment and would lead to a more close-knit group. Clearly, a proper training period for NIV should be part of the education of a multidisciplinary respiratory team and, indeed, all health-care professionals (pulmonology, emergency medicine (EM), anesthesia, perioperative,

and ICU physicians, nurses, and respiratory therapists) who might handle patients with respiratory insufficiency.

All these health-care professionals are key players of the multidisciplinary NIV team and a good interaction between all of them and patients is crucial for the success of NIV and good outcomes. Nurses' roles include technical and empathic skills aiming to improve patients' compliance. Furthermore, they also detect problems of the NIV equipment and inform physicians whether the patients are responding well to the NIV treatment [5].

Physicians and medicine residents have to decide who may benefit from the therapy and to establish the most appropriate timing and duration of the NIV trial. In emergency rooms and in all situations where there is a possibility to come across life-threatening patients, teamwork is crucial. In this case, a cooperative and close approach is essential in maximizing the performance of the team; this is only achievable through structured and organized education and training of all members of the NIV team [5].

The initiation of NIV has been reported to be time-consuming in the hands of inexperienced people [6]. The providers also need to be constantly updated with the ever new and advanced technologies and equipment. It is not to be forgotten, however, that staff with the skill of using airway equipment to establish invasive ventilation should be readily available in case of rapid deterioration despite NIV. This issue is becoming more important as NIV is increasingly used to delay invasive ventilation, sometimes as bailout use, in patients with severe respiratory failure, such as in COVID-19 patients.

The COVID Experience

With the spread of COVID-19 pandemic, NIV systems have been diffusely employed outside the ICU to face the high request of ventilatory support and the lack of mechanical support and ICU beds for patients with acute respiratory failure caused by COVID-19. [1] Especially in the first waves, the rapidly rising numbers of COVID-19 patients forced the reorganization of the ED and the entire hospital. In particular, because of the high prevalence of critically ill patients needing intensive care resources, many patients were treated with NIV in the ED or in improvised areas, as a bailout alternative to mechanical ventilation.

Respiratory failure due to COVID-19 is now well known to be rapidly progressive and severe. Therefore, because of the high risk of NIV failure, close monitoring must be ensured with trained medical and nursing staff to avoid any delay in endotracheal intubation [7].

In this critical situation all staff, medical or nurse, had to learn the basics of noninvasive ventilation, following video lectures given by experts in NIV or even just learning in a practical way. EM residents, especially, had the opportunity to see a huge number of patients with severe acute respiratory failure and to apply and refine their theoretical knowledge from university lectures. The teamwork once again proved to be essential in these precarious situations.

Evidence of Education and Training Programs of NIV

There is little published scientific evidence concerning the role of education and training programs in NIV. This may be due to the fact that the use of NIV can still be considered a novelty and both structured education and training were not widely approved. This field still has to be explored with clinical trials. However, when a therapeutic intervention replaces the role of a vital organ or function, as is the case in patients with the need of ventilation, conduction controlled study is ethically challenging [8].

Due to a lack of high-grade evidence, an international consensus on NIV education and training based on opinions from 64 experts across the twenty-one different countries of the world was formulated. Literature search was conducted from 1990 to 2018 to identify randomized controlled studies and systematic reviews [2]. No clinical trials examining the impact of education and training in NIV as the primary objective were found, but only a few studies with poor evidence, a simulation-based training study and narrative reviews.

A structured ICU training program in the limited-resourced area of Asia has been shown to be effective in improving the outcome [9]. Similarly, resident training in communication in the ICU has shown to be associated with strongly positive family member outcomes and significant improvements in residents' perceived skills [10].

During COVID-19 pandemic, some countries tried to define a structured program to train health-care providers on NIV. Papa Giovanni XXIII hospital in Bergamo faced the Northern Italy first wave in March 2020 with a special educational program: peer education on Covid-19 management was provided to all hospital personnel; more than 1500 people were trained in 1 week, and shared protocol on treatment was developed and continuously updated [11].

Jackson et al. [12] proposed a multimodal NIV training, which included didactic, simulation, and team-based learning, in Haiti. They stated that this program was feasible and resulted in significant increases in trainee confidence and knowledge of NIV, especially during the ongoing COVID-19 pandemic. Similarly, Osula et al. [13] tried to develop and implement a "low-dose, high-frequency" advanced respiratory care training program for COVID-19 care in Lesotho. This training approach was not feasible during the early emergency pandemic period, and it suggests that health-care workers require alternative educational strategies before higher advanced care like mechanical ventilation is implementable.

Although more studies have to be conducted about this topic, a first step could be to rework and adapt a study protocol already published [14]. The project of these American physicians aimed to compare two educational strategies: online and interprofessional education which targets complex team-based care in NIV delivery. Data that will emerge from this study are highly needed.

The Pivotal Role of Simulations

Nowadays, simulation-based training has become increasingly widespread in medical education. Simulation has been defined by Sullivan et al. as "a technique, not a technology, to replace or amplify real experiences with guided experience, often immersive in nature, that evokes or replicates substantial aspects of the real world in a fully interactive fashion" [10]. They also stated that simulation-based medical teaching can be defined as an educational activity, which uses simulated components to replicate clinical practice [10].

Several systematic reviews [15] and some meta-analyses [16] have investigated the effectiveness of simulation-based education with knowledge and skill as outcomes. There are currently several studies with good evidence demonstrating that simulation-based education is efficient in terms of skills acquisition as well as in translating the skills acquired into practice to improve patient care and clinical outcomes [17].

This new training method has proved its value in improving four important items (i.e., physiology, indications, settings, and failure) in 762 participants in a high-fidelity online simulation-based program for NIV [18].

A prospective randomized single-blind trial by Spadaro et al. [19] compared computer-based and mannequin-based approaches for training residents in mechanical ventilation. It resulted in significantly improved skill scores of only the mannequin group between the training and final session. These data further support the theory that simulation, better if with mannequins, has the potential to improve skills in managing invasive and noninvasive ventilation.

It is also important to underline that simulations can be a chance for sharing fears and mistakes, for this reason they can play an additional educative, as well as relational, role.

Training Programs

Worldwide, many centers and educational institutes offer specific training in NIV within professional education. But even if this is common in European as well as other developed countries (The EUSEM, The European Respiratory Society-ERS, Polish Respiratory Society, SIMEU), such organized education programs are lacking in developing countries like India [20]. It is also crucial that NIV schools and educational programs should be directed not only to senior physicians but also to residents and nurses. As a matter of fact, training done through only workshops during conferences and limited to the doctors has a low impact on changing practice and does not support an unified training perspective for the NIV team.

In Italy, the EM residents association (CoSMEU) has recently published data of a national survey aimed to assess the acquisition of technical skills and clinical knowledge by EM residents during the academic year 2019–2020 [21]. They declared that they feel reasonably comfortable in NIV and air management thanks

to good training and the NIV courses provided by SIMEU (Italian EM Physician Society) [1].

Based on these data, training in NIV can be considered the upcoming more compelling challenge of health-care education, due to a significant heterogeneity among local training programs.

Contents of the Education and Training Program

Training programs aim at gradually growing and improving the learners' knowledge until high standards are reached and at ensuring understanding of the various NIV topics.

A comprehensive understanding of the different causes of hypoxaemic or hypercapnic acute respiratory failure, as well as the indications, contraindications, limitations, and techniques of NIV is essential.

A general knowledge and experience in intensive care medicine, including agitation management and invasive hemodynamic monitoring, is also necessary. Table 36.1 summarizes the minimum content of training and education programs for health-care staff using NIV. The experts stated that an ideal NIV training course should consist of 30% lectures, 20% interaction and questions for the participants, and 50% practical exercises. The total duration of the course and the time to be devoted to theoretical and practical sessions should be decided according to the characteristics of the participants, the types of equipment, and the complexity of the NIV modalities [2]. Some authors have suggested that an initial session of 2 hours three times a month can provide an initial basis to start using NIV safely [2]. These sessions may be less frequent as the staff's experience improves.

Regular in-service training and refresher courses would help maintain staff competence and keep them updated on new developments.

NIV Education: A Practical Approach

1. Select patients likely to respond to NIV successfully and prepare the appropriate monitor setting.
2. Promptly identify those who are likely to fail or those showing signs of failed NIV.
3. Optimize patient comfort, reduce air leak, prevent skin lesion, and adjust the ventilator to efficiently alleviate respiratory distress by selecting the most appropriate and best fitted mask.
4. The learners should play the role of "the patient": the fitting of a mask/helmet, and a direct experience of receiving PEEP and pressure support ventilation. It provides a unique opportunity to appreciate the patients NIV experience and would help them to manage real NIV situations at the patients bedside.

Table 36.1 Minimum content of training and education program for health-care using NIV

Theoretical contents
Scientific principles of respiratory failure and respiratory system
– Physiology and pathophysiology
– Symptoms and signs of respiratory failure
– Common respiratory diseases requiring NIV
– Hypoxic vs. hypercapnic respiratory failure
Goals and strategies of NIV
Analysis of flow and pressure curve
Recognition of patient-ventilator synchronization/ desyncronization
Open issues and update on NIV research development
Recognition of complication of NIV
Recognition of failure of NIV
Discontinuation of NIV and/or upgrading to mechanical ventilation mode
Recognition and management of secretions
Problem solution
Airways management
– Air stacking, assisted cough, cough assist devices
– Aerosol delivering during NIV
– Optimal gas humidification during NIV
– Bronchoscopy (before or during NIV)
– Nasogastric tube insertion and enteral feeding during NIV
Patient's sedation during NIV
Patient's needs and comfort measures

5. Know the interaction of flow, leakage, and interface with supplemental oxygen therapy and their management.
6. Learn the proper method of applying and of removing the mask/interface.
7. Advanced educational NIV programs should also contain some skills in the interpretation of physiological waveforms (pressure-time/flow-time) assessing patient-ventilator synchrony [3].
8. Learn the different treatment settings: (1) Setting the mode, e.g., spontaneous/timed mode; (2) pressure setting, e.g., expiratory or inspiratory positive airway pressure; (3) inspiratory duration (applicable only in spontaneous/timed mode).
9. Modules should be audited and updated as per feedback (Fig. 36.1).

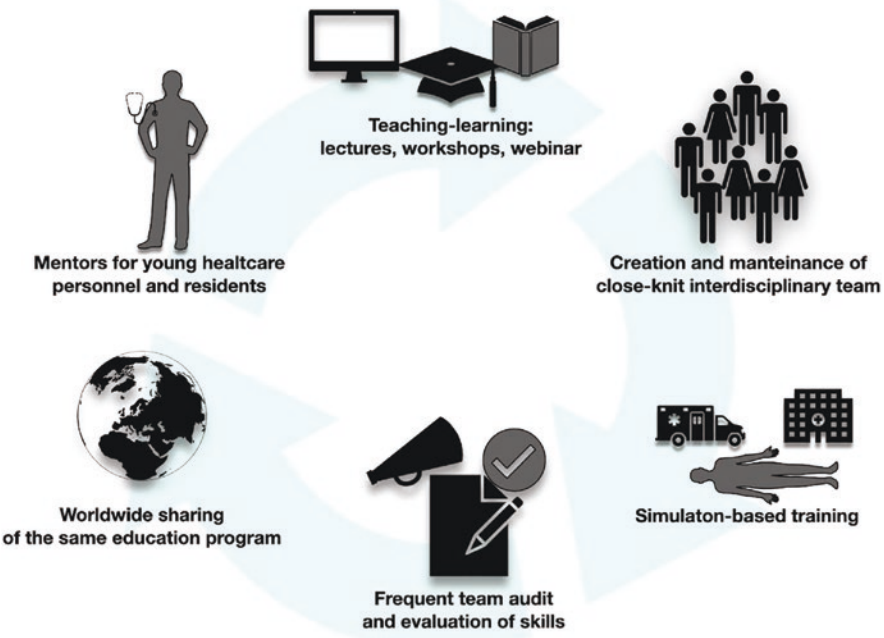

Fig. 36.1 Practical approach for NIV education and training

Conclusion

NIV education and training of medical, nursing, and all the health-care personnel have the potential to increase the knowledge and skills essential to improve outcomes, reduce failures, and avoid complications associated with the use of NIV.

Currently, there is little experimental evidence supporting the best way to train and educate NIV practitioners. Moreover, the COVID-19 pandemic highlighted the need for a structured program, shared by the different countries and also by the different health-care figures working in the emergency system. Several countries around the world have started to meet this need with structured and organized education and training programs.

This is what nurses and physician, but especially residents, need in order to work to their best potential.

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Education Skills Accreditation Program Recommendations for Noninvasive Ventilation Outside the ICU

37

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Abstract

Noninvasive Ventilation (NIV) is a form of ventilatory support through the patient's upper airway using a mask or similar device. With the COVID-19 pandemic, intensive care units (ICUs) have become overwhelmed, leading to patients requiring NIV to be treated outside the ICU. This has led to a major predicament as NIV requires multiple different professionals all invested in the care of the patient, but not all having the experience or education to conduct such treatment at the highest level necessary. Along with this conundrum, there have been limited studies published or universal guidelines established about NIV education outside of the ICU. Multidisciplinary teams must be employed to provide such a treatment, including, but not limited to physicians, nurses, respiratory therapists, and technicians. To execute an excellent level of care, these providers must know how and when to use NIV, how to address any technical issues with the machinery, how to cope with complications, and how to monitor the progress. They should know the relevant importance of clinical status and gas exchange, and correlation to change in severity of illness. Education techniques should include lectures, and handouts regarding all pertinent information at the level of understanding each provider can reach. Following this, hands-on simulation-based training should be utilized for maximum efficiency of translating theoretical information to practical. The education of health-care providers outside of the ICU in techniques of NIV is highly recommended to keep with the changing medical landscape.

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Noninvasive ventilation · Education · General floors · Lectures · Simulation based

Introduction

Noninvasive Ventilation (NIV) refers to the administration of positive pressure and oxygen through various methods, primarily through nasal cannulas, CPAP, or BI-PAP. Although seen as a means of step-down from invasive mechanical ventilation or step-up from low flow or hi-flow oxygen via mask or cannula, noninvasive ventilation has its own significant indications. Patients requiring ventilatory support typically require ICU setting. Due to shortage of ICU beds globally, physicians are forced to utilize NIV outside the ICU areas. Even transfer to ICU may be delayed for extended period necessitating treating the patient with noninvasively ventilatory support. The COVID-19 pandemic led to a drastic change in this thought process. The Cybersecurity & Infrastructure Security Agency (CISA) COVID Task Force formulated a study in which they observed the relationship of the overwhelming of ICUs and excessive hospital deaths between July 2020 and July 2021. It is important to note that during this time, the highly virulent Delta strain of COVID-19 was primarily causing hospitalizations and deaths. The study used a negative binomial regression model to calculate deaths from COVID-19 during this time. It found that once ICUs were at 75% capacity, there would be 12,000 excess deaths and when ICUs were at 100%, there would be 80,000 excess deaths [1]. Noninvasive ventilation has been widely accepted as one of the primary alternative treatments for patients suffering from acute respiratory distress syndrome (ARDS) due to COVID-19 [2]. The study performed by CISA clearly illustrates a correlation between ICU capacity and unnecessary deaths. Simply put, the further overrun that ICUs get, the more deaths occur. Ultimately, in the likely case of emergency situations, such as another pandemic or a spike in COVID-19 cases, more and more patients will need ventilatory support outside of the ICU.

Despite being a vital aspect in patient care, NIV use outside of the ICU is underutilized. Inadequate knowledge and skills have been shown as reasons for the underutilization as there are limited studies regarding standardization of NIV outside of the ICU. Studies show that the education and proper training of individuals concerned in the care of patients requiring NIV would not only be cost-effective, by reducing costs and length of hospitalizations and may prevent need for escalation of care to ICU, but it would also bring more satisfaction to healthcare workers [3, 4]. The NIV team consists not only of intensivists but includes a multidisciplinary team comprising of ICU and emergency room nurses, and respiratory therapists. In the event of overcrowding of ICUs, critically ill patients who require ICU care are forced onto other levels of care, such as the step-down unit or the medicine wards. Internists and medicine wards nurses are now a part of the previously described multidisciplinary team. Each component of this team

must undergo various levels of training, suiting various purposes. Physicians determine whether NIV is indicated for the level of severity of acute respiratory failure, contraindications for NIV, and level of monitoring required. Nurses, who are trained in ventilator care, monitor signs of response or failure of NIV, and have the ability to detect and troubleshoot equipment. Respiratory therapists assist with setting adjustments, troubleshooting, and secretion clearance, with the goal to improve dyspnea and work of breathing [3]. This illustrates the importance of the multidisciplinary team and the vital role that nurses and respiratory therapists play in the foreground of patient care.

The next question that comes into play is how further intensive education on noninvasive ventilation is carried out. The answer is more complex than simple, but one of the main upcoming methods is simulation. Simulation in healthcare describes how simulation has been thoroughly developed over the last 20 years and has ramped up use in recent years [5, 6]. Simulations utilize machinery or actors posing as patients that interact and respond to the person participating in the simulation. Simulations can be used regardless of experience, thus allowing all members of the team to participate. Meta-analytic reviews of simulation-based training compared to traditional medical education find that training done via simulation is more beneficial and effective [6]. Although the review is statistically significant, the sample size of the number of studies is notably small. Simulation-based education for noninvasive ventilation is a growing field and is a potential source of education for treating patients with respiratory failure outside of the ICU.

The feasibility of utilizing NIV outside of the ICU has been brought into the spotlight due to the COVID-19 pandemic. During COVID-19 outbreak, NIV was utilized outside ICU, in a percentage of patients ranging from 11% to 62% despite the lack of recommendations and guidelines. [7–9]. There was no significant change in mortality related to use of NIV outside the ICU. In one study, the 30-day unadjusted mortality rate was 30% for NIV and CPAP and 16% for High Flow Nasal Cannula (HFNC). The endotracheal intubation rate for HFNC was 29%, for CPAP was 25%, and 28% for NIV. After adjustments for confounders, the relative probability of death was unrelated neither to the NIV used nor endotracheal intubation. Length of stay was not different among the different mode of ventilation used [10]. A single-day observational study of patients with COVID-19 in Italy, 10% of patients received NIV outside the ICU, reported an overall intra-hospital mortality of 36% with 26% of the patients failing NIV and requiring intubation [11]. In another study of NIV use outside the ICU, over a 10-year period, 22% of patients were transferred to the ICU for escalation of care with 67% of those escalated requiring intubation [12]. If done correctly with appropriate guidance and training, NIV use outside of the ICU may be a feasible strategy during times of increased demand for ventilatory assistance.

As ICUs become crowded and patients begin to be shifted elsewhere, it is of paramount importance that treating healthcare providers aknowledge when and when not to use NIV, and monitoring tools for success or failure of NIV.

Indications and Monitoring

It is essential to evaluate the indication of NIV if applied outside the ICU area, and if the patient will benefit for ventilatory support (Tables 37.1 and 37.2). Majority of patients will meet the requirement of NIV according to their respiratory parameters and work of breathing. Examples of such patients: patients with noncardiogenic pulmonary edema, acute exacerbation of COPD, and COVID-19 pneumonia who are not responding to pharmacological and standard oxygen therapy via nasal cannula or face mask. It is imperative to remember that certain conditions, such as pancreatitis or septic shock, could precipitate ARDS and thus require NIV. Indications for NIV include both hypoxic and hypercapnic respiratory failure with increased A-a gradient and respiratory acidosis who have failed oxygen therapy complicated by increase of work of breathing. The goal is to avoid endotracheal intubation and invasive mechanical ventilation. COPD exacerbations leading to respiratory acidosis, ARDS, acute or chronic respiratory failure, patients with respiratory failure due to neuromuscular causes or chest wall deformities, decompensated obstructive sleep apnea and cardiogenic pulmonary edema are examples of such conditions [13]. One study noted that the number of affected quadrants in a chest x-ray, tachyarrhythmia, and hypoxemia may be useful in the initial decision to determine use of NIV outside of the ICU [12].

Table 37.1 Important factors in monitoring NIV

• Systolic blood pressure
• Respiratory rate
• Heart rate
• $PaCO_2$
• Arterial pH
• SpO_2
• PaO_2/FiO_2 ratio
• Claustrophobia
• Abdominal distension
• Skin erythema
• Dry mouth
• Nasal congestion

Table 37.2 Criteria for NIV use

• Moderate to severe dyspnea with signs of increased work of breathing, accessory muscle use, and abdominal paradoxical movement
• History of COPD, CHF, cardiogenic pulmonary edema, OSA, or neuromuscular disorders with acute or exacerbated hypercapnic respiratory failure
• Patient with do-not-intubate status
• Early intubation (within the hour) if there is no improvement
• Tachypnea >30 bpm
• Acute hypercapnic respiratory failure (pH <7.35 with $PaCO_2$ >45 mmHg)

Contraindications

Health-care providers should be knowledgeable with the contraindications for NIV even in the setting of respiratory failure secondary to commonly treatable causes (Table 37.3). NIV should never be used in patients who are not breathing spontaneously or in patients with poor respiratory drive [14]. These patients require invasive ventilation, such as intubation [14]. Other contraindications include patients who are uncooperative, unstable cardiopulmonary status, facial trauma or burns, and surgery on the face, stomach, or esophagus. Patients who have severe continuous vomiting or extensive respiratory secretions are not fit for NIV. Another specific contraindication to Noninvasive Ventilation is Air Leak Syndrome (pneumothorax with a bronchopleural fistula) [14].

Indication for invasive mechanical ventilation, cardiopulmonary arrest, unable to fit mask, unable to protect airway, agitated/uncooperative, swallowing impairment, multiple organ failure, recent upper airway or upper gastrointestinal surgery, severe hypoxemia, or acidosis (pH < 7.1), pneumothorax, pleural effusion, pulmonary embolism.

NIV Failure

When administering NIV, it is important to recognize its futility, or improper application (Table 37.4). To secure success of NIV, proper mask type and size need to be utilized with proper fitting to avoid leakage and tolerance by the patients. Face masks and nasal masks were shown to have similar efficacy, but the nasal masks had

Table 37.3 Contraindications for NIV

• Indication for invasive mechanical ventilation
• Cardiopulmonary arrest
• Hemodynamic instability and cardiac arrhythmias
• Altered mental status or encephalopathy
• Swallowing impairment
• Multiple organ failure
• Recent facial trauma or facial surgery
• Recent upper airway or upper gastrointestinal surgery
• Severe hypoxemia or acidosis (pH <7.1)
• Pneumothorax, pleural effusion, pulmonary embolism

Table 37.4 Criteria for failure of NIV outside of ICU [15]

• Persistence of hypercapnic ventilatory failure as evidenced by increase in basal $PaCO_2$ and persistence of low pH
• Persistent hypoxemia PaO_2 <70 mmHg with SaO_2 <90%
• Severe dyspnea (RR 30–40 bpm) with the use of accessory muscles
• Presence of cardiac arrythmia (atrial fibrillation or atrial flutter)

a higher likelihood of oral air leak when not used with a chinstrap [16]. When patients are using NIV with non-ICU ventilators and have supplemental oxygen added, often, it is added with a preset flow. When leak port circuits are used and interface leakage is present with the facial masks, oxygen concentration is drastically diminished, and the gas exchange is immensely impaired [17]. High values of IPAP (inspiratory positive airway pressure), persistence of elevated $PaCO_2$, arterial hypotension, and age could be useful to screen for NIV failure outside of the ICU [12]. Elevations in systolic blood pressure and heart rate, as well as alterations in $PaCO_2$, arterial pH, and PaO_2/FiO_2 ratio are all indicators NIV failure. Various complications of NIV include claustrophobia, abdominal distension, skin erythema, dry mouth, and nasal congestion. All these issues could occur due to patient discomfort, agitation, aspiration, or aggravated patient condition [18]. These are all various means of gauging whether NIV is working, and all the possible obstacles providers might face when conducting the use of NIV outside of the ICU.

Criteria for failure of NIV outside of ICU are as follows: persistence of hypercapnic ventilatory failure as evidenced by increase in basal PaCO2 and persistence of low pH, worsening of respiratory acidosis with rise in PCO_2, persistent hypoxemia PaO_2 <70 mmHg with SaO_2 < 90%, severe dyspnea (RR 30–40 bpm) with the use of accessory muscles, presence of cardiac arrhythmia (atrial fibrillation or atrial flutter). Certain scoring systems can be utilized outside the ICU to monitor response to NIV such as HACOR score >5 and mROX score <3 in 2 h (Need reference).

Effectiveness of NIV

Identifying successful NIV usage is paramount in proper patient care and is equivalent to exposing failure of the same (Table 37.4). In conjunction with this, delineating which patients are most likely to fail NIV is also essential. Patients who have a low pH and an elevated $PaCO_2$, especially in the first 4 h of presentation, are far more likely to require intubation [15]. After 1 h, if patients show stabilization of heart rate, respiratory rate, $PaCO_2$, and pH, it is far more probable that they will succeed with NIV and not need further escalation of treatment; 54% of patients in this study who failed to improve their stats required endotracheal intubation [19]. Certain variables can be determining factors in the success of NIV outside of the ICU. Decreasing values of IPAP (inspiratory positive airway pressure) required, clearance of elevated $PaCO_2$, and resolution of arterial hypotension could be useful indicators for NIV success outside of the ICU [12]. Pacilli et al. [20] found that the predictive variables included age, pH, albumin, quality of life as measured on the Barthel scale, and the SPAS II score. Regarding both successful and unsuccessful NIV usage, early changes in patient vitals and arterial blood gas analysis are key to identifying whether or not NIV is the correct methodology. Nursing staff outside of the ICU should be taught that along with strict vital monitoring, an ABG should be taken and analyzed immediately. If patients are not faring well on NIV or their Acid/Base imbalance is not improving, then escalation of care should be considered. Being able to determine which vitals are relevant to NIV success and realizing

which patients will succeed in their treatment should invariably be part of the education of those in the teams treating patients outside of the ICU. Patients who had a successful NIV trial will be able to be weaned to standard oxygen supplementation.

Palliative Noninvasive Ventilation

Noninvasive ventilation has reduced the need for endotracheal intubation, decreased the rate of ventilation-induced complication, and is increasingly used as a palliative strategy when endotracheal intubation is deemed inappropriate. This includes those who are do-not-intubate or if interventions contradict the patient's values and goal. Together with pain, dyspnea is among the most common symptoms in palliative care patients. Palliative NIV provides the opportunity of survival or can be offered to alleviate the symptoms of respiratory distress and can be applied outside the ICU. In the UK, in a survey among physicians specialized in Duchenne's muscular dystrophy, nearly 80% reported discussing palliative NIV with the patients and families [21–23]. In another survey done in Canada and USA among intensivists and pulmonologists, nearly half perceived palliative NIV as a component of comfort care and nearly 80% had used palliative NIV in patients with end-stage COPD and heart failure.[24] However, the use of NIV in patients with terminal dyspnea such as in cancer patients is controversial and has been described as both futile care and as a tool for improving quality of life. Studies are needed to identify benefits from palliative NIV that are not related to survival.

Approaching Education

Multidisciplinary teams should be educated on every pervasive and multifaceted issue (Fig. 37.1). An advanced search on Pubmed, using the terms "NIV," "noninvasive ventilation," "education," and "training" during the time of 2000–2022, revealed few studies of note indicating that there have been few recommendations for NIV education for both physicians and nonphysicians, particularly those providers outside of the ICU. Habib et al have described a particular recommendation that describes "30% of lectures; 20% of dedicated interaction and questions for the participants followed by 50% of hands-on training." These education courses should be tailored to the knowledge level of those taking part, whether they be physicians, nurses, or respiratory therapists. They should be able to understand the various modalities of the ventilator and be able to identify and fix any issues with either the patient or the machinery [3]. Once theoretical knowledge has been learned, the physical use of simulators is one of the more realistic and useful methods of hands-on training. There are various international issues that come into play when attempting to uniformly derive principles of NIV. For example, in the USA, respiratory therapists are much more hands-on with NIV, whereas in India, physicians are more likely to apply the NIV [25]. The European Respiratory Society has a project called

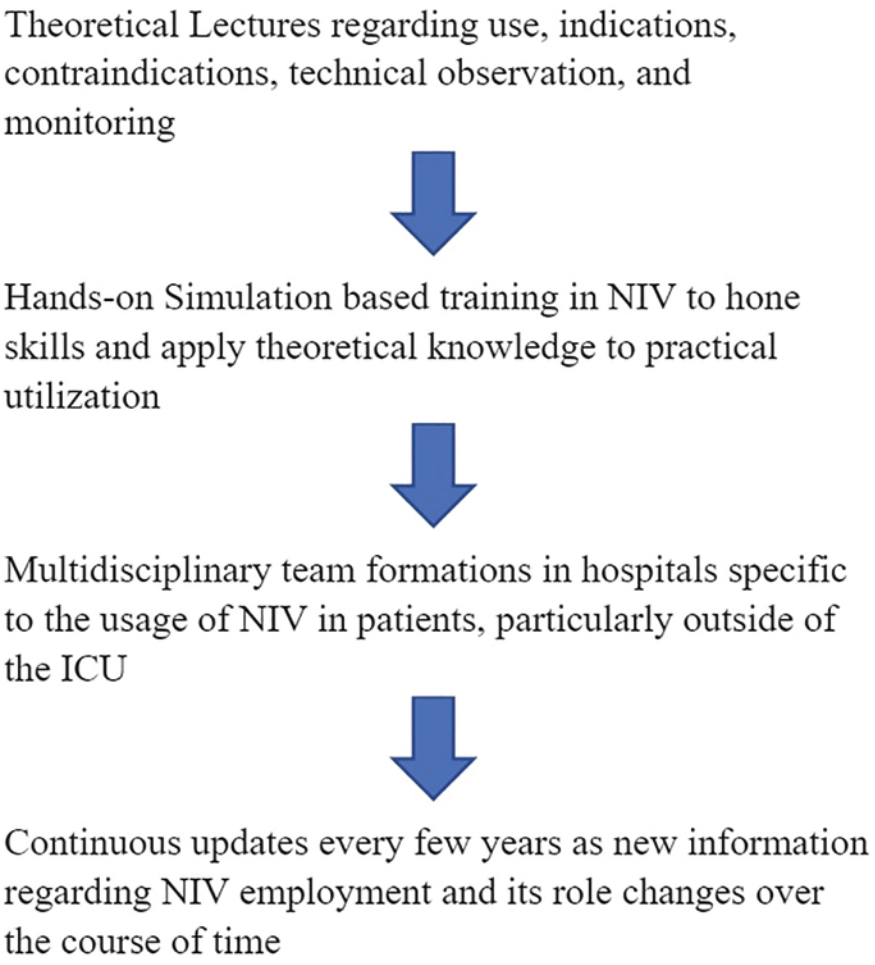

Fig. 37.1 Process of education for NIV

Harmonized Education in Respiratory Medicine for European Specialists, which contains holistic training in NIV. India, on the other hand, utilizes NIV at a high rate, but does not have such an organized education program [25]. Initiation of any education for those utilizing NIV should be encouraged with some suggesting sessions to be started at 2 hours for 3 sessions a month [25]. The European Respiratory Society has held a course on NIV in Hannover, Germany, periodically, starting in 2007. This is a 2-day course for doctors, nurses, therapists, technicians, and anyone who takes part in administering NIV. The course provides current evidence and physical skills of applying the treatment. The initial lectures guide who needs NIV and why they need it, who will have the greatest benefit, how to use the proper setup, how to monitor NIV setups, and how to troubleshoot issues such as air leak. This is followed by a hands-on physical workshop. These courses have been

attended by various providers in over 20 countries [26]. It is important to update the knowledge of the multidisciplinary team, whenever necessary, as new evidence regarding NIV emerges. Although the differences in the international scenario are varied, these programs provide helpful resources to provide the necessary education and training for NIV use.

Conclusion

As the scope of noninvasive ventilation expands, the amount of health-care providers using and treating patients with it will follow. As of now, there have not been any universal guidelines as to how to educate health-care professionals regarding NIV outside of the ICU. As the need for NIV outside of the ICU increases in the age of COVID-19, this quandary becomes very pressing. The European Respiratory Society has provided a base of how to potentially tackle this issue, but the lack of standardization over different parts of the world provides the greatest issue with NIV education. Even with such dilemmas, a comprehensive and ubiquitous set of standards is immensely pertinent to the ever-changing landscape of the medical field and is recommended as such. Some relevant and possible answers to this difficult question include

- Provide mandatory lectures regarding NIV usage, indications, contraindications, troubleshooting techniques, and NIV monitoring to all health-care providers, including physicians, nurses, respiratory therapists, and technicians.
- Tailoring of education standard and intensity to the provider's role.
- Use of simulations to practice theoretical techniques and knowledge.
- Frequent updates such as every 2 years as newer evidence arises.
- Dedicated time should be given to participants by each hospital to undergo such training.

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Ethics and Palliative Aspects of Noninvasive Mechanical Ventilation Outside ICU

38

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Abstract

Many studies showed that NIV can be useful in palliative care, because it might be a valid alternative to relieve dyspnea in the terminal stages of many diseases. The decision whether to use NIV cannot be separated from a global assessment of the patient that considers two aspects, both important and closely connected, which are the ethical and the clinical evaluation. In very advanced or rapidly progressing chronic respiratory failure, patients and their relatives must be informed as early as possible about the potential imminent respiratory emergencies and the therapeutic options for the end stage of the disease. A partner-like relationship must take place among patient, physician, and nurse, even in the final phase of life, whereby medical competence but also clear statements about the prognosis, particularly in relation to questions about the end of life, and the duty of medical care remains indispensable. A selection decision-making process is necessary in the clinical path and this process includes inquiring about the patient's wishes and the expectations of family members. In the absence of advance directives already formulated, an "Individual Care Plan" (ICP) is configured as the only adequate tool to prepare a shared path of palliative care. You may have better symptoms management in older patients in hospital or in home-care setting if the case is followed by a multidisciplinary team, which uses the comprehensive geriatric assessment, the involvement of caregiver, and the attention of quality of life.

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NIV in Palliative Care

Death is a biological phenomenon that represents the last phase of life for persons, and, at the same time, it is an integral part of life on a physical, psychic, and social level. Death can be fast or slow. If death is sudden and fast, it does not constitute a problem of care for the individual who disappears. On the other hand, when there is a long waiting period and death is expected within a certain period of time, we are facing the terminal phase of the disease. This phase concerns individuals affected by an incurable disease that determines in a more or less rapid way the progressive deterioration of the state of health and the loss of personal and social autonomy [1].

In a context of this type in which it is no longer possible to "heal," the need to "cure" the person as a "whole" (body, mind, and spirit) becomes preponderant, shifting the perspective of the intervention from treating the disease to taking care of the person. Death is not the defeat of medicine but on the contrary medicine with its continuous progress can effectively help people to face this important phase of life in the best possible way.

Palliative care is a measure for improving the quality of life in patients and their families who are facing the problems that accompany a life-threatening illness. This is achieved by prevention and relief of complaints via early detection measures, and careful evaluation and treatment of pain, as well as physical, psychosocial, and spiritual issues [2].

Recently noninvasive ventilation (NIV) has been found to have a useful application in palliative care, because there are many suggestions that this procedure might be a valid alternative to relieve dyspnea in advanced stages of diseases such as cancer, COPD, and neurodegenerative disorders [2, 3].

In fact, dyspnea is one of the most distressing symptoms experienced by patients at the end of life and it is a frequent reason for such patients to seek emergency care [4].

NIV is increasingly used as a palliative strategy when endotracheal ventilation is inappropriate (patients with "Do Not Intubate Order") although its effectiveness for relieving symptoms in end-of-life care is controversial [5]. Some authors claim that the palliative use of NIV in the palliative scenario may relieve respiratory symptoms and/or to allow the communication and/or to provide additional time to finalize personal affairs and to come to the acceptance of death [6]. Conversely, other authors considered the use of NIV inappropriate in this context as it may cause discomfort and may prolong uselessly the dying process [7–9]. While the role of NIV as a palliative strategy against dyspnea in end-of-life neoplastic is well known, the use of NIV in end-stage chronic diseases is unclear [10].

Palliative ventilation can be administered to alleviate the symptoms of respiratory distress in advanced stages of diseases and to manage patients with respiratory failure who present suffering from severe dyspnea not respondent to usual pharmacological strategies.

However, the prescription of NIV in this context (palliative care and older patient with advanced stages of diseases) requires further studies, because these patients have many problems and comorbidities that can complicate the management of acute respiratory failure.

Some studies have shown a better management of symptoms in very elderly hospitalized patients in a nonintensive care unit setting followed by a multidisciplinary medical staff conforming to principles of comprehensive geriatric assessment and treatment, the involvement of family caregiver, and the attention to quality of life [11–13].

Ethical Evaluation

The decision whether to proceed with the use of NIV cannot be separated from a global assessment of the patient that considers two aspects, both important and closely connected, which are the ethical and the clinical evaluation. In accordance with all international documents [14, 15] an ethical evaluation must take into consideration the following ethical principles: autonomy, beneficence, non-maleficence, and justice [14, 15].

The first ethical principle is "autonomy" concerning the patient's right to self-determination regarding the own health choices. Patient involvement in decisions can only take place in the face of precise and detailed information from the care team regarding the clinical conditions, therapeutic possibilities, and realistic expected results through the acquisition of informed consent. Therefore, a dialogue between health professionals and patient/family is necessary in order to explain the health and care objectives. The informed consent is strongly related to the assessment of patient's decision-making capacity (DMC) for treatment. In fact, the concept of "mental capacity" refers to the ability of an individual to make decisions. The mental capacity of a person may vary depending on different factors such as the environment, level of education, personality, health status, and communication problems [15].

In the absence of advance directives from the patient, it is essential to reconstruct the patient's will through the testimony of family members (substitute judgment or delegate) and seeking the best interest of the patient through the balance between the expected benefits and the severity of the treatment.

In all situations of chronic diseases, the formulation of an advance planning of care should therefore always be encouraged, thanks also to the intervention of the doctor or other specialists who treat the patient, so that his wishes are respected in the event that a mental incapacity should occur due to the worsening of the clinical conditions.

In Italy this is possible thanks to Law 219 of 2017, which defines the rules on informed consent and advanced directives (AHCD) [16]. The objectives of the AHCD are to ensure that the care programs reflect the patient's will as much as possible, reducing the risk of insufficient or excess treatments and also the emotional burden of decisions that would otherwise weigh on family members, ultimately preventing conflicts, decision-making between family members or between them and care staff.

Another important issue is the communication of the truth. Very often, even today, the diagnostic reality is shamefully hidden from the patient by doctors and family members. According to the philosopher-ethicist JF Malherbe, "telling the truth to the person concerned is a moral rule that should govern all human relationships. The truth is not always convenient, but if it is not told it must be kept silent with everyone. Telling everyone, except the person concerned, is the worst that can be done" [9].

The principle of "beneficence" refers to the moral obligation to act for the good of others through the prevention-removal of evil or damage and the promotion of good. This principle is the basis of medicine, whose mission is precisely preventing, diagnosing, and treating diseases in order to promote patient health. This means that doctors can act in the best interest of the patient even by refraining from acting and /or acting with caution, always from the point of view of the benefit for the patient and his needs. However, cultural and ethical developments have gradually led to the addition of autonomy to this principle, supporting one more subjective interpretation of the patient's "best interest."

The principle of "non-maleficence" was well known to doctors ever since of the Hippocratic precept of primum non nocere. Non-maleficence includes the following principles: do not harm the patient and the need to assess the risks and the benefit/risks ratio balance of a treatment that, although effective, could be harmful to the patient. The principle of non-maleficence is reflected in a number of legal provisions with respect to intentional medical negligence, in which the patient has been intentionally injured, or negligent negligence, where the damage was caused by negligence, inexperience, recklessness, or failure to comply with laws, regulations, or standards of care correctly.

The principle of "justice" refers to the obligation to treat all patients without limitations related to age, sex, social status, or religious belief. The only criteria to be used are related to clinical appropriateness and ethical lawfulness. However, the concept of justice is not limited only to the patient's right to access available treatments, but also to the correct distribution of resources, especially in a context of their scarcity. Performing treatments that are unlikely to be beneficial for the patient makes it impossible to offer effective therapies to other patients who could benefit from them [17]. These four principles are then closely connected with another important concept, related to the "proportionality of care," which defines the appropriateness of a treatment based on some elements: improvement of the quality of life, prolongation of survival, probability of success, and burdens (in terms of stress and suffering) related to the treatment itself. Ultimately, the appropriateness of care is inversely proportional to the burden and directly proportional to the improvement in the quality of life and probability of success. A treatment should be applied if it can reasonably lead to a benefit.

Communication Between the Physician and Patient and the Modern Doctor-Patient Relationship

A patient-oriented clarification and information process is of central importance in advanced-stage diseases and/or rapidly progressing chronic respiratory failure [2]. A dialogue should take place in which the physician informs the patient and his/her relatives about impending respiratory emergencies and therapeutic options for the final stage of the disease. The inclusion of the patient's caregivers in this communication process assumes the consent of the patient. If carers or health attorneys are appointed, they should then be involved in this dialogue. A one-off discussion at the time of diagnosis is generally not adequate; ongoing regular informative and advisory conversations should also be made possible as the situation progresses, in order to create an atmosphere of trust and commitment. A practical approach on how to proceed can be devised, bearing in mind the actual/presumed wishes of the patient. Appraisals from the therapy team, the patient's caregivers, and (if available) the patient's representative should also be included in this process.

From a medical perspective, the critical final stage of life is no longer about managing organ disease or technical challenges associated with medical devices, but rather about social competence and the ability to communicate. Regarding the communication between the physician and patient, a paradigm shift has recently taken place, but has not yet fully been put into effect. The earlier prevailing paternalistic concept of the doctor-patient relationship, including the heteronomous control of the patient by the treating physician, is increasingly being replaced by a dialogue between the physician and the responsible, autonomous patient and his/her family, with priority given to the interests of the patient [18]. The modern doctor-patient relationship is based on a partnership, even in the final phase of life, where not only medical competence but also clear statements about the prognosis—especially in relation to end-of-life questions—and the duty of medical care remain inescapable. The physician should also critically check that his/her own reservations about such a conversation do not influence the presumption of overtaxing the patient. The basic prerequisite for the mutual decision-making process is the exchange of information and transfer of knowledge between doctor and patient. Communication should correspond to the cognitive and intellectual abilities of the patient. However, successful communication is not only based on knowledge transfer, but should also address the patient's fears [19].

Competence and Decision-Making Capacity

Ideally, decisions regarding the use of NIV should be made first by the patient in the course of a chronic terminal illness through the tool of advance directives. When a patient (or his delegate such as a family member or surrogate) clearly understands their current health status (diagnosis, treatment options and prognosis) and he is able to agree on the goals of care according to his health conditions and life expectancy, the treatments are more adequate and relevant to the patient's wishes. This

would not only improve the patient's quality of life but would also relieve physicians of ethical dilemmas relating to the best choice of treatment.

This ideal situation unfortunately clashes with the dynamic nature of the chronic pathology (episodes of exacerbation alternating with periods of stability), the uncertain prognosis and the tendency for people to talk little about advance directives for treatment. Furthermore, the situation becomes complicated when these decisions must be made in the presence of crises (such as exacerbations of respiratory failure) that increase the possibility of imminent death.

An emerging issue is the management of elderly patients with respiratory failure and dementia.

Family members of older patients with dementia in critical illness play an essential role in the decision-making process relating to treatment. For the physicians may be difficult to know the patient's wishes and preferences. Informed consent for clinical treatment has become a strategic component of contemporary medical practice, because it is directly related to the health activities [20, 21]. The informed consent is strongly related to the assessment of patient's decision-making capacity (DMC) for treatment. In fact, the concept of "mental capacity" refers to the ability of an individual to make decisions. The mental capacity of a person may vary depending on different factors such as the environment, level of education, personality, health status, communication problems, etc. A person's decision-making capacity can also be temporarily affected by shock, confusion, fatigue, or medication. There is a strong relationship between the ability to make decisions and the cognitive status [15]. The prevalence of the cognitive impairment without dementia steadily increases with age and affects a large part of the elderly population [22]. Furthermore, there are many causes frequently associated with cognitive impairment in hospitalized older patients, including the presence of delirium [23], acute illnesses [24] and dementia [25]. The "competence" of a person allows to perform a defined task in the specific context in which it must be performed. The competence (or "capacity") to consent requires the following features: (a) the capacity to make a choice about a proposed course of action; (b) knows about the risks, benefits, alternatives; (c) understands that consent is 'voluntary and continuing permission"; (d) understands that consent 'can be withdrawn at any time' [26]. The concept of competence is a multidimensional construct with important clinical, legal, ethical, social, and policy aspects. The terms "capacity" and "competency" occur frequently and are often used interchangeably in the clinical practice. It referred to the mental ability and cognitive capabilities required to execute a legally recognized act rationally [9]. The competence is determined by the judge. A known legal incompetence determines a lack of decision-making capacity, even if a patient may retain his legal "competence" regarding medical matters, but not, for example, financial decisions or perform complex tasks (such as driving or planning an event). A judicial declaration of incompetence may be global, or it may be limited (e.g., to financial matters, personal care, or medical decisions) [27]. Competence is reduced already starting from the mild stage of cognitive impairment in variable and selective way; during the course of neurocognitive disorders (due to degenerative, traumatic, or vascular diseases), the competence of the individual certainly evolves in a pejorative sense

and becomes "total incapacity" in the severe stages [28], but the person can maintain for a long time the ability to communicate desires, interests, and emotions [29]. Therefore, a diagnosis of "cognitive impairment" is not enough to completely exclude the person from the decision-making process regarding his health status and his life. Unlike competence, the decision-making capacity can change over time. The consent process involving the patient, or the surrogate, is directed at establishing reasonable expectations for a medically indicated treatment's outcome. However, the decision-making capacity is a process consisting of cognitive abilities typically divided into four subcapacities: understanding, appreciation, reasoning, and choice. The ability to understand information includes general cognitive skills to understand knowledge about the medical condition, treatment, and outcome of care. Recognition of one's situation refers to the ability to realize and evaluate the consequences of different alternatives. Reasoning covers the ability to use and process information to reach a decision, including the ability to take different viewpoints in one's decision-making. The choice guarantees aspects of the selection itself, for example, to be able to settle for a decision and communicate it [30]. For an older patient, the assessment of the decisional capacity should also consider the ability to control his/her emotions, the daily life activities, and the size of expressing his/her preferences and wishes consistently [31]. A comprehensive assessment of ability would include most all of the following components: (1) a clinical and diagnostic interview; (2) neuropsychological testing; (3) functional ability assessment; (4) review of legal standards [32]. The decision-making capacity is usually assessed by a medical professional such as an expert doctor appointed by the court or physicians with experience to assess the multidimensional aspects of competence. The assessment of patient capacity to consent to treatment has been described in an integrative review on instruments and tools published in 2012 [33]. Although there are many capacity-assessment instruments and tools available to health-care professionals, a comprehensive assessment requires adequate time and is often difficult in the acute care setting and capacity assessment instruments should support, but not replace, experienced clinical judgment.

Administrator Support (AdS), Advanced Dispositions of Treatment (AD), and Individual Care Plan (ICP)

Many patients with cognitive impairment and/or intellectual disabilities may be deprived of their legal capacity and subject to some form of protection or guardianship. Mounting evidence and emerging awareness exists concerning the nature and extent of the abuse of vulnerable and frail older people. In fact, the need to invoke guardianship—a legal act that grants one person the power to make personal or property decisions for an apparently incapacitated person—has grown. The Convention for the Protection of Human Rights and Dignity of the Human Being about the Application of Biology and Medicine [34] is the most critical and prominent legislative basis for all European member states to guarantee the protection of human rights in the biomedical field [35]. It was opened for signature on 4 April

1997 in Oviedo, Spain, and is thus otherwise known as the Oviedo Convention. This convention is a unique legal instrument with the power to hold responsible the ratifying states about the minimum level of protection conferred to human rights regarding biology, medicine, and healthcare. The Convention recommended that "where an adult cannot consent to an intervention because of a mental disability, a disease or for similar reasons, the intervention may only be carried out with the authorization of his or her representative or an authority or a person or body provided by law." This treaty specifies that "the previously expressed wishes relating to a medical intervention in a state to express his or her wishes shall be taken into account". Two main guardianship models are common practice: plenary and partial guardianship. Persons under partial guardianship keep the main part of their civil rights, but specific and particular capacities are transferred to a legal representative, most commonly the power to manage financial affairs or ability to make a will. Those under full or plenary guardianship, on the other hand, lose all or almost all of their civil rights [36]. In the Italian legal System [37] before the approval of Law 6/2004 that instituted the supporting administrator, the only possible legal representative for an incompetent adult was the legal guardian. Following the interdiction procedure, the interdicted person was thereby completely and permanently deprived of the possibility to act. Interdiction and disqualification are nonetheless often excessive and disproportionate measures. In fact, this law has introduced a flexible instrument, able to adapt to the needs of fragile subjects, to protecting them as well as to promote their residual skills, unlike the traditional legal measures to protect individuals, interdiction, and disqualification, very often disproportionate to the subject's need for protection. For this reason, the Law 6 on 9 January 2004 established the possibility of a supporting administrator and offers a new protective measure that can be modeled by specific and unexpected situations and needs. The Italian law establishing the support administrator is very important for the possible designation in advance (on the part of the beneficiary in anticipation) of a potential situation of incapacity and it can be considered as a tool to enforce advance care directives, showing that beneficence and respect for autonomy are both essential elements in the choices of the legal system aimed at promoting the health and the well-being of its citizens. The court management model would provide a sort of protection for the incapacitated patients. The limit of this model is the possible lack of a therapeutic alliance between the family members and doctors. The adoption of advance directives allows overcoming this limit. The instructional directive refers to the wishes and the preferences for treatment decisions as well as underlined by the new Italian Law (Act number 219/2017) containing "Rules on informant consent and advance dispositions of treatment ") [38]. The advance care planning is a more extensive health-care concept whereby a patient, in consultation with health-care providers, family members, and significant others, makes decisions about his or her future healthcare, should he or she become incapable of participating in medical treatment decisions [39]. Many studies have shown that the impact of advance care planning improves end-of-life care in elderly patients including a reduction of hospital death and increased use of hospice. It improves the patient and family satisfaction and reduces stress, anxiety, and depression in surviving relatives [40, 41]. The

publication of the Law of 22 December 2017, n. 219, "Rules on informant consent (IC) and advance dispositions of treatment (AD)" has filled a regulatory delay in the Italian health scenario. However, crucial questions remain in the application of the law in the context of people with dementia. To have legal value, in fact, both the CI and the AD must be issued by a person capable of discernment and in case of dementia, it can be challenging to determine the level of capacity of the person. In general, at the national level, there is a critical situation in the application of the law: poor knowledge, inhomogeneity in the application of the institute of Guardian (in Italy Ads: Administrator Support), long time for the appointment of an AdS, if no advance directive has been arranged, fragmented and inhomogeneous responses from institutions, structures and reference professionals that might disengage the vulnerable person and his family [16]. Clinical ethics implies "the identification, analysis, and solution of conflicts of value or uncertainties that emerge in the course of medical care provided in the clinical field" and is a necessary tool particularly in the case of clinical choices involving the sphere of individual values [42, 43]. Particularly, in the cases of absence of AD already formulated, an "individual care plan" (ICP) is configured as the only adequate instrument to prepare a shared accompanying path. The ICP identifies the acts of care and assistance that the multidisciplinary team considers ethical and appropriate to pursue and must be understood as a flexible instrument whose objectives are subject to periodic verification and adjustment. The ICP approach to the end-of-life phase is particularly important. The European Association of Palliative Care (EAPC) has drafted a consensus statement trying to define some practical principles to use along the path of caring for people at the end of life. Great emphasis is given to preventive planning (AD) as a dynamic process of reflection and dialogue among the individual, his/her family members, and health professionals regarding preferences for future care and assistance [44].

Conclusion

At the end of life and in elderly with advanced respiratory diseases (persistent hypercapnic respiratory failure), NIV may be effective in alleviating breathlessness and to avoid hospitalization [3]. Although age should be not considered a limiting parameter for NIV use, factors such as chronic health status, cognitive impairment, and collaboration of family members may influence NIV efficacy. The communication about the goals of NIV treatment in this phase of care and alliance between patients, family members and health professional are crucial. Breathlessness causes distress not only for the patient but also for families and other careers. In every care setting (Hospital, Nursing Home, and home care), both patients and their carers need this symptom to be relieved and support strategies (such as information, coping, or efficacy communication) should be explained. NIV is increasingly used as a palliative strategy when endotracheal ventilation is inappropriate (patients with "Do Not Intubate Order") although its effectiveness for relieving symptoms in end-of-life care is controversial [5].

Palliative ventilation can be administered to alleviate the symptoms of respiratory distress in advanced stages of diseases and to manage patients with respiratory failure who present suffering from severe dyspnea not respondent to usual pharmacological strategies. For elderly patients with severe illness and dementia treated on long-term NIV at home, the main goal is to optimize their daily quality of life and to obtain a collaboration of family regarding the better "choice" to minimize distress and suffering of patient and to reduce "caregiver burden" consequently [45]. An important prerequisite before palliative ventilation is to assess the benefits for the patient as well as the skills and experiences of family caregivers; palliative ventilation should not cause patient discomfort and caregiver anxiety (due to concerns about symptom management or difficulty dealing with crises), if it is included (in case of person with cognitive impairment) in shared care plan between health professionals (doctors, nurse) and family member (or legal guardian or surrogate). The plan should address all aspects of care including the reduction of complications (agitation, pain, skin lesions) and monitoring of specific clinical characteristics of these patients (cognitive and behavioral problems, "poor" therapy compliance, atypical presentations of associated diseases, "frailty," and vulnerability to adverse events such as drugs side effects). Any information required for management of care plan may be obtained through comprehensive geriatric assessment [46], family collaboration, and a good communication [47]. There is currently a great debate on the opportunity to enter into the issues of end-of-life care from the beginning of a terminally ill diagnostic process (such as neurodegenerative disorders), even if the current legislation establishes its obligation (Italian Law on AD) [48]. Not all professionals have the necessary communication tools to face a shared information and decision-making process. However, the planning of end-of-life care should take place soon when the person has sufficient mental capacity to consider their preferences and make decisions for their future. An approach of this type should be structured in such a way as to involve all reference persons (family member or surrogates) and supported by adequate training initiatives for health professionals.

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Noninvasive Ventilation Cost Outside Intensive Care Unit

39

Bruno Matos Gomes

Abstract

The most commonly reported locations for starting NIV outside ICUs and high-dependency units were in the emergency department. A cost-effective analysis is important in all public health decision-making, taking in mind the application of mechanical ventilation accounts for a significant share of this cost. The main goals of this therapy imply a good balance between cost and benefit. A recent study concluded that the use of NIV in general wards was effective, common, and gradually increasing. Improvements in staff training and introduction of protocols could help to make this technique safer and more common when applied in a general ward setting.

Keywords

Noninvasive ventilation · Cost · Outside intensive care unit · Ward

Introduction

Noninvasive ventilation (NIV) is the process of supporting respiration using devices that do not require an artificial airway. It has repeatedly been proven effective in patients with acute respiratory failure (ARF) from different etiologies, such as exacerbation of chronic obstructive pulmonary disease (COPD), acute hypoxemic respiratory failure, community-acquired pneumonia, cardiogenic pulmonary edema, and immunosuppressed patients with pulmonary infiltrates.

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The application of mechanical ventilation in an Intensive Care Unit (ICU) environment started in 1953, when Bjorn Ibsen suggested that positive pressure ventilation should be the treatment of choice during the polio epidemic in Denmark [1].

During many years, all forms of ventilatory assistance have been managed in ICU due to ICU personnel knowledge, skills, and monitoring capabilities that amply exceed that of a general ward. However, with the shortage of intensive care beds and the growing ease of application, NIV is frequently started outside the ICU.

NIV Outside ICU

The most commonly reported locations for starting NIV outside ICUs and high-dependency units were in the emergency department. However, to optimize the efficacy and avoid harm to patients, each hospital should have a specific, designated area staffed by personnel with appropriate experience. There should also be structures to ensure that patients requiring NIV can be transferred to this area with minimum delay.

In 2009, Cabrini et al. published the first report regarding the use of NIV outside the ICU, their goal was to report data about "real-life" treatments with NIV for ARF, managed by the medical emergency team outsider the ICU. Besides the lack of resources and sometimes in apparently inadequate setting, they had a high success rate and few complications [2]. Despite this conclusion, the author emphasizes that this experience may not be extrapolated to other hospitals, and patients to be treated outside an ICU should be selected and monitored with caution.

NIV Costs

A cost-effective analysis is important in all public health decision-making, taking in mind the application of mechanical ventilation accounts for a significant share of this cost. In a study published in 2020 by Kaier et al., they found out that the daily nonventilated costs were €999, and ventilated costs were €1590, a 59% increase [3]. However, the results showed that the ICU costs for patients with different underlying diseases and underlying mechanical ventilation were an important driver of ICU costs.

Nicolini et al. in 2017 claimed that NIV was a medical procedure with financial costs. As so, the therapy aims were achieving a good balance between cost and benefit [4]. It includes improvement of symptoms, such as dyspnea, and clinical parameters, such as the parameters of arterial blood gases, avoidance of intubation, reducing the need for invasive mechanical ventilation, and a reduction in the duration of ICU and hospital stay.

In the same article, Nicolini et al. described the main factors that influence the cost of NIV therapy. In resume, the main factors were related with human resources, equipment, organization and severity of the diseases treated.

Regarding the costs, there is a study from Babcock et al. published in 2015 and they found that NIV ventilation treatment was cost-effective at 61 (USD, 2012)/QALYs, substantially less than 1 xGDP/QALY, which in India is 1489 (USD, 2012) [1]. They concluded that taking in mind that 40% of the hospitals in India have no ICU, ward-based NIV may become a crucial new option to provide some life-saving respiratory support.

Final Thoughts

In 2017, Nicolini et al. referred that there are few studies that investigate the cost-effectiveness of NIV for ARF. Most are focused on COPD and the rest on prehospital NIV for ARF [5].

Although Mukherjee et al. in 2018 published that early ward-based NIV has been the bedrock for the expansion of acute NIV services across countries, 15 years after the publication of YONIV, an international survey including a sample of hospitals from five continents focusing on ward-based NIV for AHRF has shown that acute exacerbations of COPD are the most common indication for NIV use outside the ICU (94%) and that NIV outside the ICU has become a growing phenomenon [6]. The survey concluded that the use of NIV in general wards was effective, common, and gradually increasing. Improvements in staff training and introduction of protocols could help to make this technique safer and more common when applied in a general ward setting.

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Part VII

Noninvasive Ventilation Outside Intensive Care Unit: Discharge Plan from Hospital to Home Care

Hospital Discharge Planning for Patients Requiring NIMV Support at Home

40

Szymon Skoczynski and Patrycja Rzepka-Wrona

Abstract

The most common indication for hospital use of noninvasive mechanical ventilation (NIMV) was to threat to exacerbations of chronic type two respiratory failure. This indication is supported by numerous publications and therefore is endorsed by the European Respiratory Society (ERS) guideline as the strongest indication (Rochwerg et al., Eur Respir J 50(2):1602426, 2017). It has to be underlined that revealing acute conditions is not the end of medical problem causing patients increased risk, but mostly a chronic condition, which leads to gradual deterioration and disability. Most patients with chronic respiratory failure are subject to frequent readmissions and/or prolonged hospital stay. The readmission risk is especially high when the patient is discharged too fast (before he/she is clinically stabile—this generates short-term increased readmission risk), but also when the patient is discharged too late (this facilitates contamination with multidrug-resistant pathogens and secondary risk of hospital acquired infections) (Toledo et al., BMJ Open 8(3):e020243, 2018). In numerous cases, the clinical worsening may be important for several weeks after acute exacerbation. Those are known to be responsible for increased death risk, hospital readmissions, and quality-of-life impairment. This is especially important for high-risk patient requiring NIMV during acute episode of respiratory failure but

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previously not treated with chronic NIMV. The chapter describes most common clinical situations. The given descriptions are based on most important clinical scenarios and will not describe legal issues, which may be different in distinct countries and are frequently due to rapid changes not necessarily related to clinical indications.

Keywords

Noninvasive ventilation · Hospital discharge · Planning · Home ventilation

Introduction

It has been accepted for many years now that prolonged hospitalization is due to several factors such as hospital-acquired infections and death as well as of increased rehospitalization risk. This accounts especially for elderly subjects with numerous comorbidities, chronic conditions leading to muscle weakness and disability and usually those who present severe dyspnea and/or respiratory failure. Unfortunately, this group of subjects is being excessively admitted to the hospitals, and the readmission rate after pneumonia in elderly patients is >10% [1]. Physicians treating respiratory failure at hospital are less kin for fast home discharge because these patients are due to frequent rehospitalizations and are known to be at risk of early deterioration. In recent days, this situation is being more and more exposed to lawyers. In some circumstances, the family members are not willing to take their relative back home. Due to these reasons, elderly population, which is frequently at risk of chronic diseases such as COPD, OHS is usually kept for longer in hospitals. In some cases, these patients are not aware of severe chronic respiratory condition, which may be easily unrevealed especially when the subject is being hospitalized in other than respiratory wards. The chapter will describe the most commonly observed problems, which may occur in patients with respiratory failure risk, which are requiring NIMV support at home.

Acute Type One Respiratory Failure

In general, acute respiratory failure (ARF) is not a reason for qualification to chronic NIMV or oxygen treatment; however, some patients may require prolonged postexacerbation oxygen therapy [2]. This accounts both for type one, as well as for type two respiratory failure. In general, till the advent of recent pandemics, type one respiratory failure was almost never considered as an indication for NIVM; however, the recent years of new experiences with COVID-19 pneumonia patients have taught us a new lesson. COVID-19, which is a disease in which in general there is a severe hypoxemia, patients who developed type two respiratory failure usually die during hospital treatment [3]. Unfortunately, in those patients with severe hypoxemic respiratory failure, the hospitalization time is frequently

extremely long, because the patients had excessive oxygen demand even when the viral replication was terminated. Those patients required frequently oxygen therapy at home; however, not for all subjects, especially during pandemics, it was possible to deliver home oxygen supplementation. Based on disease pathophysiology, it was found that those subjects improved significantly after administration of positive airway pressure treatment. The positive pressure recruited atelectatic alveoli and improved blood oxygenation. This was possible to achieve at lower FiO_2, which is important, because prolonged oxygen exposition when not clinically justified may be harmful. Therefore, on numerous occasions, patients without type two respiratory treatment, which were on NIMV during the hospital stay, were transferred home on bridging NIMV. The mode of ventilatory support could have been based on the overall patient alert and preserved respiratory muscle strength. In general, patients with serious lung damage were on CPAP with oxygen supplementation, whereas those with respiratory muscle weakness were rather candidates for NIVM with oxygen supplementation. This approach gave time for patient rehabilitation, lung healing, and respiratory pattern improvement. In general, severe post COVID-19 respiratory failure lasted for no more than 3–6 months. This was found to be the perfect time for hospital reassessment, addressed to decision making on whether the patient will require prolonged ventilation (usually in cases in which earlier severe chronic condition), or whether the patient has improved enough to be taken off ventilator.

Acute on Chronic Respiratory Failure

Having a proof, that a patient suffered already from type two respiratory failure before hospitalization (data with previous hospital documentation) proving that there were indications for chronic NIMV treatment represents one of the easiest to handle scenarios. After patient's clinical stabilization, the intensity of NIMV settings may be decreased in patients without respiratory effort and on NIMV arterial blood gas improvement. But this should be done in patients in whom it is evident that respiratory effort has decreased. In optimal circumstances, the patients have arterial blood gases (ABG) normalization or at least significant reduction of respiratory acidosis. In case NIMV treatment is poorly tolerated, it has to be discussed with the patient what is the main reason for NIMV intolerance, and what are the ventilations recordings (e.g., TV, pressures, leakage, and asynchrony). This is important because patient intolerance may be caused by high-pressures: usually, it is a reason to decrease the pressure, leakage (the mask should be adjusted or changed into another model), but it may be also caused by insufficient effectiveness, which may create an indication to increase intensity of patient NIMV settings. Finally, when NIMV is introduced into home treatment, the patient should be reassessed after complete recovery to confirm that the diagnosis and treatment are accurate for his clinical condition. This scenario is optimal, because it facilities patient's safety, which is crucial especially at the first weeks post patient discharge.

Chronic But Undiagnosed Previously Respiratory Failure

Usually, those patients have a history of frequent deteriorations, and frequent hospital admissions. In this situation the state of art treatment would be to use NIMV in acute indications. In case of such scenario the treatment is being carried out according to current ERS guidelines [4]. However, it has to be remembered that patient with chronic hypoxemia may have shifted respiratory drive into hypoxemic, which may cause hypoventilation and subsequent respiratory failure exacerbation. On many occasions this patient has to be assessed with ABG after clinical stabilization. In case of permissive hypercapnia temporary qualification for NIV treatment should be considered. Those patients if qualified to NIV should be reassessed after 3–6 months, to confirm whether they may be still managed on Home Oxygen Therapy (HOT), or whether they would require treatment amplification from oxygen therapy to more advanced/supportive methods [3, 5]. Currently, in increasing number of countries, in mild to moderate hypercapnia but mainly in hypoxemic respiratory failure patients may be also effectively treated with the use of home High Flow Nasal Cannula (HFNC). This may be equally effective as NIMV in the treatment of why mild hypercapnic respiratory failure, but it is also usually better tolerated as long-term treatment method. Although HFNC is available in some countries like Italy, more frequently the patients may not have this opportunity. Therefore, a choice between oxygen therapy and NIMV should be made. This scenario was tested in several research projects. In one study the time to readmission or death was 4.3 months (IQR, 1.3–13.8 months) in the NIVM group, whereas 1.4 months (IQR, 0.5–3.9 months) in the HOT group, with adjusted hazard ratio of 0.49 (95% CI, 0.31–0.77; $P = 0.002$). This resulted in the 12-month readmission or death risk of 63.4% in home NIMV group vs 80.4% in the HOT group, giving a relative risk reduction of 17.0% (95% CI, 0.1–34.0%) with add-on NIMV post discharge [6]. This mirrors results provided by other studies which in general support the thesis that in patients with persistent hypercapnia implementation of post-exacerbation NIMV not only reduces the frequency of hospital readmissions, but also reduces death risk. This accounts for COPD population with body mass index (BMI) within normal range but should be even more evident in the obese subpopulation of COPD patients. Nowadays, the implementation of at home NIMV therapy in COPD patients following NIMV used to treat an acute exacerbation (AE) is therefore supported by European guidelines.

Chronic Respiratory Failure in a Patient Previously Treated with NIMV

It is supported by the European Respiratory Society guidelines on home NIMV for management of stable hypercapnic COPD [5]. If a significant reduction in carbon dioxide partial arterial pressure is achieved, a beneficial effect on outcomes including quality of life, rate of hospital readmissions, life expectancy is noted. Therefore,

in this setting, a clinician mask answers the following question: what is the current reason for patient exacerbation?

1. Typical infectious AE requires only confirmation that NIV treatment is still effective and is tailored to patient's needs according to the GOLD guidelines. Treatment efficacy should be confirmed before hospital discharge. The baseline treatment should be adjusted if the current clinical situation calls for a change.
2. Patient decompensation caused by previously ineffective NIV settings or by patient's intolerance, which results in worsening of patient's compliance. In both situations, the NIMV settings and /or patient's interface should be readjusted or exchanged to improve postdischarge treatment effectiveness. The best way to achieve this is is to reassess the recordings from patient's ventilator (e.g., daily treatment time, average minute ventilation, and average leak). If possible, historical arterial blood gases should be assessed. Based on this assessment, NIMV settings may be readjusted to achieve a reduction of carbon dioxide partial pressure. Currently, it is recommended to use fixed pressure support as first choice ventilator mode.
3. Aspiration pneumonia usually caused by gastric distension may result from aggressive treatment (high PEEP). These patients require ventilator settings readjustment. In this case, usually, it is crucial to reveal whether the abdominal situation was primary abdominal problem. Aspiration may result from abdominal surgery or inappropriate ventilator setting, namely, too high PEEP, or inspiration time. To address this problem, PEEP and/or inspiration time should be reduced. This is especially important in patients with gastroesophageal reflux disease. After such adjustments, apnea hypopnea index (AHI) should be assessed, as PEEP reduction may result in occurrence of upper airway obstruction.
4. Finally, if the scenarios mentioned above were excluded, the patient must be revaluated for underlying diseases, which might be responsible for current clinical deterioration. These include pulmonary embolism, lung cancer, or heart failure with pleural effusion. This applies especially to elderly patients with tobacco smoke exposure history and numerous comorbidities, as the increase in arterial carbon dioxide pressure may not be the only reason for AE. In this situation, a complex assessment of health status is required, as in the elderly population, symptoms may be less apparent. Bronchofiberoscopy may reveal the underlying cause for deterioration of clinical status [7].

Patient Weaned from IMV But Still Requiring NIMV

This is a high-risk patient population with significant in likelihood of clinical state deterioration. This calls for 3–6 months of bridging at home NIMV therapy to stabilize the patient's clinical state. After rehabilitation program, the patient should be

reassessed to decide whether weaning from NIMV can be achieved or long-term ventilation should be continued.

Extubated patients should be subjected to long-term observation due to the risk of postintubation tracheal stenosis, which is proportionate to duration of invasive ventilation [7]. Tracheal stenosis occurrence is also associated with the type of intubation (both technique and the tube), and on individual predisposition to develop granulomatous tissue. Because of these challenges, these individuals should be managed in experienced multidisciplinary ventilation centers, where both ABG and endoscopic procedures are available. When the clinical situation is stabilized, these patients should undergo pulmonary function tests with assessment of flow-volume curves, exercise testing, and frequent bronchoscopy assessments.

Legal and Technical Problems

Patients with chronic respiratory failure may be hospitalized due to various reasons. NIMV has been proven to have a positive effect on patients' with type two respiratory failure outcomes (prognosis and quality of life both in hospital and outpatient setting) provided proper qualification for NIMV. The balance or cost-effectiveness of this NIMV may vary based on localization, but it depends also on the underlying disease and health-care costs. On the other hand, NIMV should not be implemented in patients who will not benefit from this method (precocious qualification may not generate favorable outcomes). Locally, the health-care reimbursement system regulations define the qualification requirements for posthospital NIMV (e.g., illness severity, age, disease, and comorbidities). This chapter concentrates solely on medical indications.

In chronic type two respiratory failure, the safest discharge method is to qualify the patient for NIMV support at home (if this is possible based on the national health-care funding). Although this approach seems to be optimal, it requires support from the family members. If it is impossible, a dependent patient should be moved to a chronic care facility. In many countries, social workers provide guardian help 24/7. Unfortunately, availability of such services is limited, and sometimes depends on patients' copayment, which further limits the access. This is responsible for discrepancies in NIMV accessibility worldwide.

Nevertheless, the diagnosis of chronic respiratory failure should be made in a clinically stable patient, no sooner than 3 months from the last AE, just as it is the case during qualification for home oxygen therapy [2]. The qualification should be performed in a pulmonary department, with background in the diagnostic and therapeutic work-up of respiratory failure. During hospitalization, ABG should be the staple of the diagnostic process. Moreover, progressive character of the disease and optimal therapeutic approach should be confirmed to ensure optimal qualification for chronic NIMV [5]. In general, in COPD or OHS, treatment's beneficial effects will depend on the severity of type two respiratory failure and on the capacity to improve patient's respiratory pattern, which will be revealed as significant reduction

or normalization of carbon dioxide partial pressure. Hypoxemia should be generally managed with oxygen supplementation.

Key Practical and Clinical Recommendations

At the time of home discharge, check whether the patient has at-risk factors for type two respiratory failure. Patients discharged previously from the ICU, treated with mechanical ventilation (invasive or noninvasive), or treated due to diseases, which contribute to development of respiratory failure, should undergo arterial blood gas assessment. All subjects with permissive hypercapnia should be considered for three months bridging NIMV treatment. We consider that in areas where it is not possible to introduce temporary NIMV in discharged patients, indications for home ventilation should be reassessed in an experienced respiratory medicine center.

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Role of Respiratory Technicians in Discharge Program from Hospital to Home

41

Marta Paiva da Silva, Catia Milene Esteves, and Cátia Caneiras

Abstract

There is a significant increase in the number of patients who need noninvasive ventilation after hospital admission and treatment in the home care environment. However, this step involves important logistics and the need for coordinated human and technical resources for adequate monitoring and effectiveness. In this control program the role of respiratory technicians (RT) is essential, a health-care professional specialized in this type of therapies that will follow the patient in the hospital discharge and at home.

Keywords

Home respiratory care · Chronic respiratory failure · Home noninvasive ventilation · Respiratory technicians · Home monitoring · Telemonitoring · Patient-ventilator asynchronies

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Introduction

Due to the significant growth of the elderly population and respiratory diseases, noninvasive ventilation (NIV) has become over time the most common and effective treatment in situations of acute and chronic respiratory failure [1]. Most of these patients arrive in an acute stage in hospital environments and after their clinical stabilization with NIV, it is important to define their home monitoring: either at the patient's home address or in other integrated support units, such as nursing homes, rehabilitation centers, or long-term care units [2].

Therefore, it's important to ensure a long-term, personalized home support network for these patients, which allows the supply of medical devices, their consumables, a telephone, and face-to-face technical control, according to the guidelines provided for the patient's degree of ventilator dependence [1]. It is in this sense that the respiratory technicians (RTs) appears, a health-care professional specialized in this type of therapies that will follow the patient in the hospital discharge and at home, and ensure that the NIV is performed as planned, empowering the autonomy of patients, when possible, training and supporting health-care professionals and/or family members in all the necessary considerations for this type of patients [3].

The challenges imposed by the prolonged use of NIV in patients with chronic respiratory failure pose significant challenges to the health-care system and requires that communication between the follow-up hospital team and the home respiratory technician is indispensable for successful therapy, disease control, and consequently reduced exacerbations and hospital admissions [2–4].

Respiratory Technicians (RTs)

Since the mid-1980s, noninvasive home mechanical ventilation has become a well-established treatment for patients with chronic hypercapnia respiratory failure. The main goal of NIV is to reduce hypoventilation, relieve symptoms, and reduce hospitalizations, thereby improving health-related quality of life and surviva [5]. Few data on the prevalence of home NIV use have been reported. Over 15 years ago, this prevalence was estimated at 6.6 per 100,000 population in Europe [6]. Since then, the number of patients using home NIV has inevitably grown, although indications and practices differ between countries [7]. Aging populations, increasing prevalence of obesity, and recent evidence for the benefits of NIV in patients with severe hypercapnia chronic obstructive pulmonary disease (COLD) have a contributed to this growth [8].

The increase in the number of patients receiving Home Respiratory Therapies (HRTs) has been reported not only in Europe, but also worldwide [9]. The need to alleviate hospital services for patients with acute respiratory failure is imminent and has led over the years to cost containment measures, with a consequent increase in the frequency of home healthcare associated with home respiratory

care providers [10]. Therefore, the concept of moving patients as their response to treatment reduces the exacerbation of their condition has rapidly over the years gained support [11].

The home respiratory health-care providers, through their qualified home care workers (nurses, physiotherapists, clinical physiologists), must ensure that patients under noninvasive mechanical ventilation remain stable after discharge from hospital. They must be competent not only in the handling of the mechanical ventilator, but also in all aspects related to ventilator support and the patient's clinical stabilization [4, 12].

The HRT job emerged in the 1940s and 1950s to meet the specific needs of home healthcare. At that time, with vastly different skills from those required today. In fact, these professionals are referred to as Oxygen Technicians and effectively reflected the function they had at the time: they installed home oxygen, administered aerosolized pharmacological agents, and performed pulmonary function tests and blood gas analysis [13].

The curriculum of respiratory technicians was created for certified nurses and respiratory therapists with the goal of becoming experts in assessing, treating, documenting, and caring for patients with pulmonary disorders. Under proper supervision, a licensed RP performed some of the work previously performed by physicians with the same responsibility and quality of care [12].

Today, the skills required of the respiratory technicians (RT) in mechanical ventilation thematic far exceed those of the oxygen technician of the past, presenting as a licensed health-care professional who specializes in mechanical ventilators and the indications and physiology leading to their necessity. They are well-qualified professionals who can provide home respiratory care, reduce misallocation of respiratory services, assess the patient's respiratory status, identify problems and needs, assess the effect of the home environment, educate the patient on the proper use of equipment, monitor patient’s response and complications of therapy, monitor the functioning of other therapies adjunct to mechanical ventilation, monitor proper infection control procedures, make recommendations for changes in the therapy regimen, and adjust therapy under the direction of the physician [12, 14].

Depending on their specific practice, they should be basic life support, certified advanced life support, and be able to act and perform resuscitation techniques necessary for mechanically ventilated patients. The home RT should be the individual that all professions look to when issues arise with home mechanical ventilation [12].

The RT is positioned to optimize teamwork, to be able to personalize his/her type of care, taking into account what is requested of him/her upon discharge from the hospital and the evolution of the pathology, to identify and convey the patient’s degree of disability, his/her social status, and the hygiene and living conditions in which he/she resides. It must be the health-care professional who answers the patient’s questions at home, keeping the patient safe and motivated to comply with the treatment to consequently minimize hospitalizations among patients receiving respiratory home care [14, 15].

Communication and Teamwork

Today's society is characterized by change at various levels (social, economic, and political, among others), in which knowledge considered by professionals to be up to date at the present time can quickly become outdated [5].

It is indisputable that RT together with home mechanical ventilation (HMV) have developed a remarkable path, in successive readjustment, within our ever-changing social context, where technical-scientific knowledge is increasing in quantity and complexity and attitudes and values are also changing, in order to have comfortable and clinically stable patients [9, 15].

Strategies for professional development show that experience provides professionals with technical and relational skills. Thus, training/knowledge is related to the effectiveness and success of noninvasive ventilation use. In the patient's adaptation strategy to HMV, teamwork between health professionals (nurses, doctors and home respiratory therapist, social worker, speech therapist, occupational therapist) in the hospital environment and in the preparation for hospital discharge is shown to be crucial for the success of therapy at home. It benefits all sides and ensures reduced hospital costs and time, better data collection and communication, increased job satisfaction, and better patient monitoring, education, and quality of life [14]. Also, the literature argues that patient acceptance, an involved family, and a well-developed care plan significantly influence the success of RT, as well as patient autonomy and prior patient experience [8, 12].

The home caregivers, through the RT, thus provide full care to the patient days before discharge: to adapt to the portable mechanical ventilator, the respective ventilator mode, and the most appropriate interface, facilitating the transition from hospital follow-up to the home or to a long-term care unit. The RT will be responsible for conveying the information to the hospital team any anomaly that may occur at the patient's home and that may jeopardize the success of the therapy [8].

Two situations that are also very important for the RT, who will follow up the patient at home, to know when deciding the hospital discharge of a patient dependent on NIV are: the reason that led to respiratory worsening and consequently hospital admission and if the patient already had a history of mechanical ventilator use/dependence at home or if it is a beginning of therapy. This information will allow us to define the type of approach at home and the most appropriate health prevention and disease stabilization measures [14, 16].

Since this is a patient with a history of HMV, it is important to understand, together with the hospital team and caregivers/family members, what motivated the worsening of the respiratory disease, to redefine joint, personalized strategies that promote better therapy optimization. Evaluating the patient's state of consciousness after hospitalization, promoting the reteaching of respiratory therapy, promoting increased adherence to therapy, changing the home ventilator, and modifying the ventilator mode and/or interfaces may be some of the measures to be considered [8, 14].

When we are facing the beginning of therapy, the RT approach should follow certain guidelines, including [8]:

1. Inform and explain to the patient the procedures that will be performed and the expected result, requesting their cooperation, promoting confidence and safety in the use of HMV.
2. Demystify the complexity of therapy, showing availability, and permanent help at home, to reduce the anxiety associated with the daily loss of hospital care.
3. Train the patient to ask for help in case of pain, discomfort, mask displacement, nausea, vomiting, bloating sensation, difficulty breathing, or expelling secretions.
4. Defining the ventilator best suited to the patient's ventilator needs and daily life, considering the parameters prescribed in a hospital environment.
5. To present the most adequate interface to the patient's face anatomy, which enables the maximization of the results, considering the models available in the market, because the correct selection of the interface is extremely important and significantly influences the patient's tolerance to ventilation.
6. Involve the patient and his family and/or caregivers in all the explanation of the therapy, since the assembly and disassembly of the mechanical ventilator and its components to the manufacturer's washing, disinfection, and sterilization principles.
7. Registering and checking that the ventilator parameters are adjusted to the patient's needs and according to the medical prescription.

As these and other modalities become more firmly established both scientifically and in clinical practice, and as technological advances continue to be introduced, home respiratory care will likely be made available to more patients and in an increasing number of countries [15]. Physicians, other health-care professionals, industry representatives, administrative agencies, and those responsible for payment or reimbursement must work together to provide the best possible care for patients with chronic respiratory failure [4, 7].

Choice of the Home Ventilator

The increasing number of patients on HMV has driven considerable progress in the performance and functionality of ventilators and, currently, there are several existing and used models, where the general principles are similar to the equipment used in Intensive Care Units (ICU) [17].

A better knowledge by RTs of the technical performance of home ventilators (pressure capacity, volumes, and cycling profile) is essential in deciding which equipment is best suited for the patient's demand and respiratory mechanics at hospital discharge. Clinical algorithms presented by certain equipment may help to improve patient-ventilator synchrony, therapy optimization, and consequently disease control [18].

Besides the parameters of pressure, volume, inspiratory times, cycling, among others, the patient's degree of dependence on NIV (number of hours that the patient must use NIV at home to control the disease) must be defined in the medical prescription at the time of hospital discharge, because it will also determine the type of

home mechanical ventilator to be used. Thus, for better understanding, in clinical practice at home, 3 levels of equipment can be considered [19]:

Level 1: Equipment that can go up to 12 h/day of use, with no integrated battery.
Level 2: Equipment that can go up to 16 h/day of use, with an integrated battery that can last up to 4 h, depending on the programming of the equipment. The higher the programmed pressures, the more energy consumption of the equipment and, consequently, less battery autonomy.
Level 3: Equipment that can be used 24 h/day, having an integrated battery that can last up to 8 h, depending on the equipment's programming. The higher the programmed pressures, the more energy consumption of the equipment and consequently less battery autonomy. In this equipment, an external battery can also be integrated, which can give a total of 15 h of autonomy to the equipment. In these dependence levels, the patients always have at their disposal another piece of equipment with the same programming, called the back-up ventilator, which must be activated whenever the main ventilator presents some anomaly and waits to be checked and/or replaced by the RP.

The promotion of patient autonomy should also be considered when choosing the home ventilator. More accessible software for patients and/or caregivers with less physical and/or cognitive capacity may dictate greater adherence to therapy, effectiveness, with significant improvements in their quality of life. More portable, lighter equipment that allows patients to maintain their integration into social and/or professional life, which enables them to ambulate without significant restrictions and not see the therapy as life-limiting, is also crucial when choosing the home ventilator [8, 20].

All home mechanical ventilators have the capacity to store in their internal memory all the data related to the use of the ventilator, namely: compliance, leaks, AHI, delivered pressures, flow, percentage of respiratory cycles triggered by the patient, inspiratory and expiratory times, tidal volume and minute ventilation, which allow the RTs and the hospital team to understand the behavior of the patient mechanically ventilated at home [21]. The data that today's ventilators give us are very similar, regardless of the manufacturer; however, the graphic and detailed way in which the data is presented to us has some differences depending on the brands and it is in this sense important to define the choice of ventilator also based on these particularities of clinical analysis [17, 21].

It is important to keep in mind that the parameters and the ventilator defined at hospital discharge do not necessarily have to remain the same throughout home treatment. The constant monitoring performed by the RT at the beginning of home treatment and during the ventilator's long-term use and the physician's clinical analysis may dictate changes in parameters and/or ventilator, with the objective of therapeutic optimization, patient comfort and consequent disease control [1]. However, there is still little published information regarding the assessment and comparison of each ventilator's performance, considering the characteristics defined by the

manufacturers [17]. Clinical algorithms to help define cycling criteria, improving patient-ventilator synchrony and patient comfort, should be considered when choosing a mechanical home ventilator [8].

Home Interface(s) and Accessories

The success of NIV is correlated with the application of the "best ingredients" of the patient's "tailored recipe," including the proper choice of the selected candidate, the ventilator configuration, the interface, the experience of the team, and the training of the caregiver. The choice of interface is crucial to the success of the NIV [8].

The interfaces presented can be of the type, nasal, nasal pillows, facial or orinasal, full facial and mouthpiece. Except for the mouthpiece, they are made up of three parts: cushion made of soft material (gel or silicone) that contact with the patient's face; mask frame made of a hard material, usually transparent with several attachment points, and headgear or cap to adjust the mask to the patient's head. They can have different designs, materials and sizes that can affect the patient's comfort in many ways, such as air leakage, claustrophobia, skin erythema, eye irritation, skin breakdown and craniofacial deformity [22].

For a perfect balance between comfort and efficacy of the NIV technique, the interface should have the following characteristics: correct adaptation to the patient's anatomical constitution, comfortable and lightweight material, no leaks, quick and easy removal of components, no significant complications, minimal dead space, and no re-breathing [8, 23].

According to Scala et al., the ideal characteristics of the interface for IVN are leak-free, good seal and stability, nontraumatic, light-weight, low dead space, long-lasting and nondeformable, range of sizes, made of nonallergenic and latex-free material, low resistance to airflow, easy to secure, easy to clean, low cost, transparent, quickly removable, and with antiasphyxia valve [22].

An effective home NIV program must pay attention to detail and provide training for patients and caregivers in monitoring NIV, choose a ventilatory strategy in agreement with the appropriate hospital team for each condition, and use the appropriate mask for each patient. Although the continuous development of new products, geared toward greater comfort and leak reduction, conducted by interface marketers has increased, the availability of models and the likelihood of meeting different requirements, in patients especially requiring several hours of NIV daily is not always easy to manage by RTs, who follow these patients at home. The rotational use of different interfaces remains one of the most effective strategies in decreasing the risk of skin breakdown, with increased patient tolerance and efficacy to NIV [22]. It is mainly the responsibility of the RT to be constantly updated about home mask technology and materials, in order to improve his/her "knowledge" in making the right recommendation of the interface to apply in a given patient, both at the time of hospital discharge and at home, taking into account the different clinical scenarios [24].

Mask Classification and Materials

Nasal masks (covers the whole nose) are normally used at home, in chronic respiratory insufficiency situations, namely obstructive sleep apnea syndrome and hypoventilation-obesity syndrome, as they are less claustrophobic, more comfortable and tolerated by the patient. It allows the necessary positive airway pressures to be maintained (less dead space) without compromising communication, feeding, and the elimination of secretions. In this case, there is less risk of aspiration of vomit or aerophagia and, in addition, the possibility of injuries to the patient's face are less frequent, since it allows for a softer fixation due to the lower pressures used [22].

The **full-face mask or oronasal mask** (covers both the nose and the mouth) is usually used in acute situations, in anxious patients, polypneic and mouth breathers, because it allows the application of higher pressures, with less leak, requiring less collaboration from the patient compared to the previous mask. It should be noted that this type of mask, as well as the total-face mask, are often poorly tolerated by the patient due to the feeling of claustrophobia, increased risk of aspiration of vomit and aerophagia, hindering the elimination of secretions and preventing communication and feeding. In this case, there is a greater likelihood of skin damage, especially to the nose, malar and chin due to the often excessive pressure of the mask [22].

There are then other types of interfaces, namely the nasal pillow or nasal slings (applied externally to the nares) and the oral Interface which are presented as an alternative to the nasal or face mask, these are normally used in the context of long-term ventilation and within a more specific framework. As for nasal pillows, they are especially indicated for situations of skin damage caused by the use of face mask, but these have the condition of not allowing the application of high pressures and the existence of a greater probability of air leakage [22].

The mouthpiece (MPV) is rarely applied in the acute setting: it is primarily intended for patients with a high degree of ventilator dependence, greater than 16 h/day, such as neuromuscular diseases, cystic fibrosis, and COPD [22]. With disease progression, nocturnal NIV needs to be extended during the day and mouthpiece ventilation is an option for daytime NIV, promoting rest of the patient's face during the day, thus maintaining therapy [25]. It does, however, have some unwanted effects, such as orthodontic deformities when used for a prolonged time, increased salivation, and increased vomiting reflex. The MPV mode also represents a challenging task for home ventilators due to rapidly changing load conditions resulting from intermittent connections and disconnections of the MPV circuit [26].

The total face mask covers the entire facial perimeter (mouth, nose, and eyes), avoiding direct pressure on the various anatomical structures and reducing skin lesions; however, it conditions the increase of dead space and may present disadvantages with the risk of ineffective CO_2 elimination, ocular irritation, and inability to eliminate sputum [22].

All interfaces, regardless of the model and brand, have their advantages and disadvantages that should be considered by professionals. In this sense, it is also

important to inform patients of their existence in order to optimize the use of NIV, also understanding what may be more advantageous considering the patient's tolerance [27]. Most patients with acute and/or chronic respiratory failure use Full face mask with NIV in the hospital and keep it at home, for the greater comfort and tolerance to higher pressures, compared to other types of masks [28]. They are known to impair communication, but their popularity and benefit has led many providers to accept communication impairment [24].

Expiratory Valves

The expiratory valves also play their role in this technique, so they influence the ventilation of the "dead space," which is physiological dead space (static) and dynamic dead space (related to the ventilator circuit and mask). Dynamic dead space is reduced by positive expiratory pressures and using the expiratory valve, as this influences its ventilation and minimizes rebreathing. This valve (CO_2 exhalation valve) can be incorporated into the mask itself (through holes in the mask) or else be placed externally, and there are three types on the market today, the so-called Swivel Whisper expiratory valve, "Simple exhalation Swivel," or "Plateau valve." The antiasphyxia valve makes it possible for the patient, even if the ventilator fails, to continue breathing ambient air. Dual-circuit ventilators do not require the antiasphyxia and exhalation valves [8, 27].

Hygiene

Teaching interface hygiene to the patient, family and/or caregivers is essential at hospital discharge and at home. Regardless of the type and model of interface, we can only achieve maximum performance of its function if it is in its full cleaning condition. The lack of daily interface hygiene leads to air leakage and consequent mask adjustments that may lead to lacerations, pressure ulcers, thus jeopardizing the use of therapy and consequently disease exacerbation [27]. Although home ventilators feature leak compensation algorithms, if the leaks are too high the effectiveness of therapy is called into question. Therefore, leak analysis by RTs is so important in determining the reliability of the clinical data presented by the ventilator. Uncontrolled leaks reduce the optimization of therapy [28].

In summary, it is fundamental for the RT, considering all his/her knowledge and experience, to reinforce with the patient, relatives, and/or caregivers all the criteria associated to a good interface placement, and it is hygienization, using practical examples and allowing room for the patient's experimentation. Comfort is one of the main determinants of successful NIV. All strategies aimed at increasing comfort during NIV should be pursued [23].

Patient and/or Caregiver Training in NIV Management

The growing shift toward home care services assumes that "being home is good" and that this is the most desirable option. Although ethical issues in medical decision making are analyzed when preparing for the hospital discharge of these patients. In many settings, home care decisions for technology-dependent patients, and the moral dilemmas that this population presents, continue to be a daily challenge for physicians and home care RTs [29].

Identifying the individual learning needs of patients and caregivers, as well as understanding their reactions to the reality of receiving mechanical ventilation at home, should be among the RTs priorities in home care. A variety of strategies should be presented to patients and families in order to manage the presence of the NIV, including problem solving and mobilizing the help of friends, family, society and beliefs [30]. The RT must be seen by the patient and caregiver, as an element that enhances therapy, available to help and be the link with the hospital team, whenever there are doubts about the effectiveness of therapy. At home, it is fundamental that patients are informed and confident in the therapy, that they know how to manage the ventilator, the circuit, the interface, that they know how to sanitize them, and above all that they know how to ask for help whenever a situation is not as expected. The importance of a mutual collaboration (patient-RT-physician) allows a better control of the disease at home, thus reducing exacerbations and consequently hospital interventions [30].

It is up to patients and their caregivers to define strategies that allow them to balance the positive aspects of being in the home environment with the challenges of managing complex therapies at home. More dependent patients and caregivers should plan for additional supports at home to reduce the physical, emotional, social, and financial burdens that are often associated [31]. Preventive interventions to improve sleepiness, depression, and physical health of caregivers may be critical to improve quality of life for patients and caregivers and thus reduce health-care costs associated with these conditions [32, 33].

More research is needed to address effective interventions, reducing patient and caregiver concerns, consequently improving therapy optimization outcomes. A higher level of preparedness for managing problems related to home technology and home care can improve the quality of life not only for the patient but for everyone around [31].

Home NIV Monitoring

NIV represents an effective treatment for chronic respiratory failure. However, empirically determined NIV settings may not achieve optimal ventilator support in the short and/or long term. Therefore, the effectiveness of NIV should be systematically monitored, especially at discharge from the hospital and at home. The minimum recommended monitoring strategy includes clinical assessment

of arterial blood gases and nocturnal transcutaneous oxygen saturation (SpO_2) [2].

When NIV is started, ventilator settings are empirically determined in the inpatient setting, based on the underlying disease, the patient's tolerance to therapy, and diurnal changes in arterial blood gases[2]. Adjustment of ventilator settings is usually performed during the day in the inpatient setting and NIV is usually applied at night; thus, optimal ventilator support cannot always be achieved, which may be explained by sleep-related changes in breathing. Sleep induces changes in ventilator control, respiratory muscle recruitment, and upper airway patency, which may affect ventilator function [34].

Asynchronies are frequent during NIV and are often associated with poor outcomes such as therapy dropout. The patient-ventilator interaction is of paramount importance in spontaneous breathing in patients, and therefore, the ventilator must be able to adapt to changes in patient demand and respiratory mechanics. However, lack of coordination between patient and ventilator, due to a mismatch between neural time and ventilator, throughout the respiratory cycle can hinder weaning and lead to prolonged mechanical ventilation. Therefore, adequate monitoring of asynchronies is critical to improve the strategies applied and thus facilitate patient-ventilator interaction [3].

Home NIV monitoring is necessary and essential to assess ventilator effectiveness and therapy compliance, resolve potential adverse effects, enhance patient's knowledge, provide equipment maintenance, and readjust ventilator settings according to the patient's changing condition [35].

Advances in sleep medicine have led manufacturers to build monitoring systems into NIV devices to record data on compliance and leakage, as well as respiratory parameters (respiratory rate, tidal volume, minute ventilation, and respiratory events). These technological advances are considered useful, because they provide the RT and physicians with additional information about ventilation effectiveness and potential causes of inadequate ventilation. Moreover, recent studies have shown that changes in the values of certain parameters recorded by NIV devices may be associated with changes in clinical status [1]. Thus, it is up to the CA following the patient at home to be able to analyze all systems of monitoring of NIV, with the aim of improving the quality and effectiveness of care, facilitating the exchange of information between professionals involved in the monitoring of NIV [36].

Currently, all home mechanical ventilators have built-in monitoring tools, most displayed on screens that can be viewed directly by the RT and/or physicians. The first tool developed was the ventilator timer that provides an estimate of the number of hours of daily ventilator use. In addition to ventilator usage, the integrated pneumotachograph provides physicians with a summary of delivered pressures, flow, the percentage of cycles triggered by the patient, inspiratory and expiratory time, tidal volume, minute ventilation, and the level of leakage [1]. Persistent oxygen desaturation is considered a major determinant of inadequate NIV adaptation and experts recommend that average oxygenation at night should be greater than 90% [36]. Thus, most of the current ventilators already have

specific ports dedicated to oximeters or oximeter adapters to monitor SpO_2, to simplify its interpretation considering ventilator behavior and respiratory events. Although less frequent in the home setting, monitoring CO_2 in specific cases is also essential to evaluate favorable outcomes resulting from reduced hypoventilation.

The expansion of home ventilator-monitoring-capabilities has also required the parallel development of software dedicated to data retrieval and analysis. The use of such software requires, in most cases, the manual transfer of ventilator data to a computer using a memory card or universal serial flash storage. Most ventilation software displays continuous signals such as flow, pressure, and leakage, for curve analysis of ventilator mechanics, as well as automatic detection of residual IAH events. In addition to the data recorded by the ventilator, the software can integrate and synchronize the signals communicated by each port, for example, providing a simultaneous display of pressure and flow curves and oximetry or, capnography or cardiorespiratory polygraphy recordings [21]. However, each home ventilator manufacturer has developed its own software, so it is up to the RT and medical specialists to adapt to each model in order to correctly evaluate the data presented [1].

Telemonitoring platforms are the latest technological development aimed at simplifying home monitoring [37]. They are platforms that are automatically fed with data sent from home ventilators, avoiding laborious manual transfer by home respiratory care RTs. They allow patients to be monitored even more closely, with the possibility of remote adjustment of ventilator settings by both home respiratory care companies and hospital staff. Currently, all new equipment is equipped with tele monitoring systems and it is expected that all ventilators will have this tool in the near future [1, 38]. This type of technological development is a good response to the growing needs for home NIV and increasingly restricted hospital resources and will change the future management of patients under home NIV by health organizations. It is even believed that many of the problems associated with low compliance, poor technique in performing the therapy, and queries can be resolved remotely [39].

Continuous monitoring of these patients, either in person or remotely, including analysis of the data provided by the ventilators, is essential to determine the need to optimize ventilation settings. It is therefore crucial that the data provided by NIV systems are reliable, clinically useful, and lead to improvements in patient outcomes [36, 37].

Complications of Home NIV

Positive pressure mechanical ventilation differs from normal physiological breathing, and this can lead to several negative physiological consequences, both at the level of the lungs and in peripheral organs that need to be analyzed [40].

The main complications encountered are facial skin erythema, claustrophobia, nasal congestion, facial pain, eye irritation, aspiration pneumonia, hypotension,

pneumothorax, aerophagia, hypercapnia, gastric insufficiency, vomiting, broncho aspiration, morning headaches, facial injuries, air embolism, and patient discomfort. However, it is up to the home RT to be aware not only of these physical changes, but also of the social changes that can equally call into question the use of NIV [8, 22].

Physical Changes

Skin trauma caused by prolonged use of masks is the most common complication and is primarily related to patient discomfort. There must be awareness in the care to prevent interface-related complications [22]. The actions to prevent pressure ulcers include rotation of interfaces, use of protective skin gel pads, and application of hydrocolloid [41]. If other complications appear on the face associated with the use of the mask, the home care RT should find the reason of its origin and report to the hospital team, to "solve" it.

Eye irritation and/or conjunctivitis may occur because of air leaks from the mask. The leaks are usually conditioned by the adjustment of the mask to the patient's face or by the adaptation of more appropriate sizes. In this sense, the monitoring of the existence of leaks at home should be frequent, in order to prevent hypoventilation and patient-ventilator asynchrony [41].

On the cardiovascular system, NIV can have adverse effects. Positive pressure ventilation alters lung volumes and, more importantly, increases intrathoracic pressure. Intrathoracic pressure has an important influence on venous return, a major determinant of cardiac output. Positive pressure ventilation decreases preload, increases right ventricular posterior load (greater pulmonary vascular resistance), and decreases left ventricular load. Thus, mechanical ventilation can induce right ventricular dysfunction [42].

Lung injury in patients with NIV can also occur and is closely related to ventilator settings [43]. In fact, ventilation at low lung volumes can cause atelectrauma, while ventilation at high lung volumes can lead to excessive distension and barotrauma [42].

The risk of pulmonary aspiration from vomiting and consequently asphyxia, although considered rare complications, can happen and are related to the use of the orinasal mask and total face mask. Gastric distension, gastroesophageal reflux, and food intolerance can be seen and are associated with higher pressures [24, 41].

Social Changes

Social changes are characterized by the limitation of activities of daily living such as eating, drinking, and communicating spontaneously, without considering the use of the NIV.

Critical illness, dependent on NIV, can lead to multimorbidity ranging from functional impairment caused by dyspnea, fatigue to cognitive dysfunction and

mood disorders, associated with decreased quality of life and power of control over it. These problems can lead to NIV failure, which is often associated with worse outcomes than those presented at the time of NIV initiation and consequently can lead to increased hospitalization costs [3, 24]. A personalized follow-up by home care RTs should ensure the identification of patients and caregivers at risk. Exhausted caregivers are at elevated risk for mood disorders and consequently influence the behavior of mechanically dependent patients [15].

Communication impairment for more NIV-dependent patients has also been associated with increased anxiety and patient-ventilator asynchronies [24]. Although often underestimated, lack of effective communication is a significant cause of complications and failure in the use of ventilation. Remote support strategies such as telemonitoring, 24/7 telephone lines for homecare providers, and others should be considered as tools to reduce non-adherence to NIV according to patients identified needs [44].

Humidification and Complementary Therapies to NIV

Over the years, NIV comfort accessories and complementary therapies have been developed to promote ventilator compliance and therapeutic optimization. Humidification, oxygen therapy, cough-assist, and nebulizers are some examples [16].

Humidification and NIV are often used together, despite the lack of precise recommendations on this practice [45]. Humidification devices humidify the air that is delivered to the upper airway through the ventilation circuit. Humidification aims to reduce dryness of the throat and mouth and thus improve patient tolerability of therapy. The humidification is a determining factor in therapy acceptance and comfort, leading to greater compliance and consequent therapeutic optimization. The most frequent complaints are dry mouth, nose, and minor bleeding from the upper airway. Depending on the ventilator, humidification can be accomplished by means of a device integrated into the ventilator or through external equipment, usually located between the circuit going to the ventilator and the circuit going to the interface [46].

Oxygen therapy is usually prescribed for patients with persistent hypoxemia to increase alveolar oxygen pressure and decrease the work of breathing. The use of ventilator support assumes a better ventilation-perfusion combination and therefore better control of blood gases such as O_2 and CO_2. However, patients tend to maintain persistent hypoxemia despite the use of NIV. Oxygen therapy is thus presented as a complementary therapy to control hypoxemia and consequently reduce exacerbations and hospitalizations associated with this decompensation. Oxygen therapy is not often used at the beginning of the patient's adaptation to NIV, unless there is already a history of criteria associated with long-term oxygen therapy (LTOT) as a result of pre-existing chronic respiratory failure with hypoxemia during wakefulness [47–49].

The mechanical insufflator–exsufflator (MI–E) is a device that produces changes in airflow within the bronchial tree to induce an artificial cough. It can be used at home by the patient still autonomous or by the caregiver. It is mainly used in patients with neuromuscular pathologies or respiratory muscle deficiency, who have a diminished or ineffective cough. An ineffective cough causes retained secretions, chronic inflammation and infection, increased airway resistance, decreased lung compliance, and respiratory failure [50].

Disease progression, coupled with ventilator dependence and upper airway involvement, sometimes makes long-term adjustment of NIV difficult, with a major impact on survival. Nonventilator factors, such as accumulation of secretions at the upper airway level, also impact the effectiveness of NIV and various solutions have been described and should be applied, including cough assist techniques and control of excess salivation to avoid the need for tracheostomy. The progressive increase in survival of patients with neuromuscular pathology or respiratory muscle deficiency is associated with the introduction of NIV and complementary therapies such as cough assistance [50, 51].

Nebulizers are devices that enable the administration of aerosolized medications in the home. Aerosolized drug delivery is a frequent therapy for patients with numerous respiratory tract diseases, including obstructive airway diseases (OADs), cystic fibrosis (CF), and infectious airway diseases [52]. Pulmonary diseases are selectively treated by inhaled drugs, which are considered a priority route of drug administration over the parenteral route due to the rapid drug effect, greater local pulmonary drug delivery with minimal systemic adverse actions and requiring lower drug doses [8].

Conclusion

In conclusion, the key to successful home NIV therapy consists of efficient teamwork among the patient, home RT, and medical specialist, to carefully set up the ventilator, titrate it, and define the appropriate interface. Especially at the home environment, monitoring needs to be noninvasive, reliable, easy to access, and data security needs to be guaranteed. An active participation of the RT of home respiratory care throughout the therapy, thorough analysis about the patient's motivation, goals, home situation including available support from family members, and the current clinical evaluation are essential for reduction of exacerbations, hospital interventions, and death. However, further studies are needed to define effective interventions to reduce patient and caregiver concerns and move forward regarding the definition of Patient-Reported Outcome Measures (PROMs) and Reported Experience Measures (PREMs) for complex patients, of individual's dependent on ventilator, to improve the value of home NIV therapy on real-world evidence.

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Clinical Determinants of In-Hospital Outcome of Noninvasive Ventilatory Support

42

Bruno S. Silva

Abstract

The use of noninvasive ventilatory support (NIVS) in the acute setting has provided physicians with a valuable tool to better care for their patients by providing an additional tool to treat both hypoxemic and hypercapnic respiratory failure. It is very important to recognize its strengths and weaknesses in order to correctly use it.

A correct physical examination, with vital sign monitoring, and measurement of arterial blood gases are invaluable to help clinicians decide when and how to start NIVS, and whether it is being successful or not. Some clinical scores and indexes, such as the HACOR score, may also assist in these decisions.

In the acute in-hospital setting, the only well-established indications for NIVS are acute exacerbations of chronic obstructive pulmonary disease and acute cardiogenic pulmonary edema. However, its role in other conditions has been investigated. It is important to note that there are no universal predictors for NIVS failure or success; understanding the underlying disease is essential.

The aim of this chapter is to help the reader understand the known and possible determinants and predictors of NIVS success or failure to better identify the more at-risk patients who need the closest monitoring.

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Keywords

Noninvasive ventilation · Acute hypoxemic respiratory failure · Acute hypercapnic respiratory failure · Chronic obstructive pulmonary disease · Acute cardiogenic pulmonary edema · Clinical predictors

Introduction

Noninvasive ventilatory support (NIVS), both through continuous positive airway pressure (CPAP) and noninvasive mechanical ventilation with bilevel positive airway pressure (B-PAP), is a widespread, well-recognized treatment in the management of patients presenting to the hospital with acute respiratory failure, both hypoxemic and hypercapnic. Although its use is more widely accepted in hypercapnic respiratory failure, especially in patients with obstructive pulmonary disease, with proven benefit in reduction of mortality and need for invasive mechanical ventilation in the emergency room setting, it has seen a rising use in patients with acute hypoxic respiratory failure (AHRF) of multiple causes [1]. Invasive mechanical ventilation is associated with significant mortality and complications; therefore, it is essential to be able to identify every situation in which we may have an alternative.

In this chapter, we intend to inform the reader of the clinical features we should assess to more accurately predict in-hospital outcome of patients undergoing NIVS.

Defining the Outcome

NIVS failure has been defined in most published papers as the need for endotracheal intubation (ETI) or death following its institution; most cases will occur within the first 48 h of therapy, thus indicating that careful monitoring of the patient is essential in this timeframe to, if necessary, progress to an invasive strategy as quickly as possible.

We should note that most available papers do not distinguish between CPAP therapy and B-PAP, making it more difficult to explore these treatments individually.

Initial Approach

Both in the prehospital and in-hospital setting in patients with acute pathology, introduction of NIVS may be indicated; the most common indications are acute cardiogenic pulmonary edema (ACPE) and acute exacerbation of chronic obstructive pulmonary disease (AECOPD) and acute hypoxemic respiratory failure (AHRF) of multiple etiologies; NIVS's use in other situations, such as pneumonia, status asthmaticus, and others, remains a controversial topic even among ventilation experts.

Most of these patients will present with common respiratory symptoms, such as shortness of breath, wheezes, cough, or chest pain, palpitations, obnubilation, etc. During physical examination, several findings may be noted, which reflect an increased work of breathing (WoB):

1. Rapid and/or shallow breathing, generally with over 22 breathing cycles/min
2. Bradypnea (<12 cycles/min), which is a marker of more severe disease
3. Central cyanosis
4. Lip pursing
5. Accessory muscle use and retraction, including abdominal muscles, intercostal muscles, spinal muscles, sternocleidomastoid muscles, suprasternal retraction
6. Nasal flaring
7. Low oxygen saturation (<92%)
8. Tachycardia or bradycardia
9. Hypertension (more frequent) or hypotension
10. Depressed state of consciousness
11. Pulmonary auscultation abnormalities

An arterial blood gases (ABG) test must be obtained as soon as possible, as it will provide crucial information, such as arterial pH, partial oxygen (PaO_2), and carbon dioxide ($PaCO_2$) pressures and lactate, among others; these parameters will help guide treatment and provide important prognostic implications. A distinction should be made between patients with hypoxic respiratory failure and hypercapnic respiratory failure, and the presence of acidemia (arterial pH <7.35) should also be observed. These factors will aid the clinician in determining whether the patient will benefit from an NIVS trial (which is beyond the scope of this chapter).

Clinical Monitoring: How?

After you have initiated NIVS, it is essential to monitor your patient closely, as the first 2–4 h are critical in determining whether the therapy is successful or not. The patient should ideally be managed in collaboration with an intensive medicine expert in case therapy fails and invasive mechanical ventilation is necessary.

Even before starting NIVS, basic vital sign monitoring is mandatory, including peripheral oximetry, 3-lead electrocardiogram monitoring, and regular noninvasive blood pressure measurements. Moreover, the clinician should regularly assess the patient's respiratory rate (RR) and state of consciousness (for example, using the Glasgow Coma Scale [GCS]).

A more experienced clinician should also be able to identify markers of respiratory distress and excessive accessory muscle use. ABG measurements should be regularly taken, at least once per hour, or earlier if there is a sudden worsening of the patient's condition.

Outcome Determinants

The reason patients must be closely monitored is that NIVS failure should be identified early, as it worsens prognosis and has been associated with increased mortality [2]. It is not yet clear how long an NIVS trial should be, but ABG should be measured once every 1–2 h [3, 4]; a study by Park et al. involving 78 elderly patients advocates for screening at 30 min and 2 h [5]. Studies conducted by Plant et al. have suggested that improvement should be seen after 1–4 h after initiating NIVS, also based on time goals set in previous studies [3, 6–8].

Regarding the timing of failure, Ozyilmaz et al. have proposed the existence of three timings for NIVS failure, all with different causes: immediate (the first hour), early stage (1–48 h), and late stage (beyond 48 h). In their study, failure was most common in the early-stage period [9]. Causes of treatment failure in the immediate period are usually more related to technical factors, which impede adequate institution of therapy, such as copious secretions, inability to cooperate (causing asynchrony), inadequate interface, facial deformities, impaired cough reflex, fixed upper airway obstruction, and bowel obstruction [9, 10].

The early-stage period of NIMV is the most critical and explored. The physiological markers of improvement are widely recognized. Several studies have determined that reduction of RR, improvement of pH, and adequate patient-ventilator synchrony are reliable markers of improvement and are associated with reduced need for ETI and in-hospital death [2, 3, 5]. It has also been shown that patients with hypercapnic respiratory failure have the greatest benefit from this therapy [6, 7, 11, 12].

Clinical monitoring scores, which are widely used both in the ICU and regular wards, such as the Simplified Acute Physiology Score (SAPS) II and the Acute Physiology And Chronic Health Evaluation (APACHE) scores, have also been shown to help predict NIMV failure in a few studies, most likely due to being related to a more severe underlying illness, with associated clinical instability and clinical worsening [13–15]. The obvious downside to these scores is that they involve laboratory results, which will not always be available immediately.

A more recent bedside clinical monitoring score has been proposed in order to simplify approach to the patient under NIVS. The HACOR index is a score proposed by Duan et al. following a test study including 449 patients who were receiving NIVS due to hypoxemia and a validation group of 358 patients [16]. The score is based on monitoring of five variables: heart rate, acidosis, consciousness, oxygenation, and respiratory rate (Table 42.1). In this study, monitoring was conducted at 1, 12, 24 and 48 h following institution of NIVS. The HACOR index was shown to accurately and timely predict NIV failure. A cutoff of 5 points was particularly significant: at 1 h of NIVS, 87.1% of patients with a score above five required ETI, compared to 18.4% of patients with a score of 5 or less. This highlights the importance of close monitoring and may also incentive physicians to not delay intubation

Table 42.1 HACOR index

Parameter	HACOR score
Heart rate	
≤120 beats/min	0
>120 beats/min	1
pH	
≥7.35	0
7.30–7.34	2
7.25–7.29	3
<7.25	4
Glasgow Coma scale	
15	0
13–14	2
11–12	5
≤10	10
PaO_2/FiO_2	
≥201	0
176–200	2
151–175	3
126–150	4
101–125	5
≤100	6
Respiratory rate	
≤30 breaths/min	0
31–35 breaths/min	1
36–40 breaths/min	2
41–45 breaths/min	3
≥46 breaths/min	4

HACOR heart rate, acidosis, consciousness, oxygenation and respiratory rate

Based on: Duan J, Han X, Bai L, Zhou L, Huang S. "Assessment of heart rate, acidosis, consciousness, oxygenation, and respiratory rate to predict noninvasive ventilation failure in hypoxemic patients." Intensive Care Medicine. 2016;43(2):192-199

in patients who will benefit from it [16]. A later derivation study from including 1218 patients with COPD related respiratory failure showed similar results, with good sensitivity (77.8–93.9%) and specificity (74.8–89.9%) for predicting early NIV failure (within the first 1–2 h), using the same cutoff value of 5 [17]. A later study (2021) from the same group of authors was conducted on 148 patients with non- COPD hypercapnic respiratory failure, obtaining similar results; the optimal cutoff values in this cohort, displaying the highest sensitivity and specificity were, respectively, 7, 5, 4, and 2 at initiation and after 1–2, 12, and 24 h of NIVS [18].

Outcome Determinants: Cause

The cause of respiratory failure is an important factor in determining both the rate of treatment failure, which may vary significantly [9], and its indicators. Therefore, we divided this next section into different pathology groups, to better distinguish the available evidence.

COPD

Current optimal medical treatment in AECOPD includes use of short-acting bronchodilators, systemic corticosteroid treatment, and treatment of underlying causes; in more severe cases, this may not be enough, and a trial of NIVS may be indicated, with patients often displaying signs of increased WoB. After the introduction of B-PAP in clinical practice, in-hospital mortality and need for ETI have dramatically decreased. In these patients, in order to unload respiratory muscles, B-PAP is the preferred option, and thus, CPAP is not currently an option in these situations [1].

Regarding use of B-PAP outside of the ICU, it is therefore essential to identify patients who will benefit the most from an early trial of NIVS. A study was performed by Plant and colleagues (2000) to identify clinical factors associated with therapy failure in a cohort of 118 patients; they found that degree of acidemia, hypercapnia and severity of hypoxia were all associated with NIVS failure, with severe acidemia being the greatest risk factor; similarly, improvement of acidemia (47%) and a fall in RR (49%) at 4 h were associated with a reduction in failure risk. Similar results have been observed in other studies [6–8].

A multicenter study conducted by Confalonieri et al. in 2004 enrolled a total of 1,033 patients who presented with AECOPD, with B-PAP being successful in 797. After 2 h of treatment, the variables, which related to NIVS failure, were:

1. pH < 7.25 (odds ratio 21.02)
2. pH 7.25–7.35 (odds ratio 2.92)
3. APACHE-II score ≥29 points (odds ratio 4.79)
4. GCS 12–14 points (odds ratio 1.93)
5. GCS <12 points (odds ratio 5.16)
6. RR 30–34 cycles/min (odds ratio 2.67)
7. RR ≥ 35 cycles/min (odds ratio 4.95)

These variables were found to be very accurate predictors when applied on a different group of 145 patients prospectively enrolled. Although they were also good predictors for failure at admission, they were found to be more accurate at the 2-h mark. A failure risk chart was suggested by them based on their findings [19].

A study by Pacilli et al. enrolled 176 who underwent NIVS and found that, regarding comorbidities of COPD patients, the presence of pneumonia was identified as a risk factor for NIVS failure; common comorbidities, such as obesity, cardiac disease, and diabetes, did not impact NIVS failure [4]. A similar, small-scale study by Soo Hoo and colleagues supports these findings, with the presence of pneumonia and severity of hypoxemia being major predictors of NIVS failure [15].

Acute Hypoxemic Respiratory Failure

AHRF often represents the endpoint of several pathologies with very different mechanisms, such as ACPE, pneumonia, acute respiratory distress syndrome (ARDS), asthma, etc. The role of NIVS is much less explored in these situations than in AECOPD, which is why we will analyze them separately.

Acute Cardiogenic Pulmonary Edema

CPAP has a very important role in ACPE; however, there is a lack of studies analyzing the variables related to CPAP failure.

The rationale for its use in ACPE relates to its ability to reduce functional residual capacity, thus improving oxygenation and reducing WoB, intrathoracic negative pressure swings and left cardiac ventricular afterload [12].

Several studies have documented the physiological benefits associated with CPAP initiation, namely, an improvement in respiratory rate, arterial pH, and partial CO_2 pressure [11, 12, 20–22]. However, the improvement in physiological variables did not consistently predict NIVS therapy success. A meta-analysis conducted by Peter and colleagues consisting of multiple small-scale studies managed to prove the effectiveness of CPAP in reduction of mortality and need for ETI with the reduction of respiratory rate being the only clinical feature consistently shown to determine a more favorable outcome [21]. Patients who presented with hypercapnic respiratory failure (versus hypoxic respiratory failure) showed the greatest benefit from NIVS, with greater reduction in RR, and less likelihood of treatment failure [11, 12]. Patient comorbidities did not influence the clinical outcome.

B-PAP has not been extensively studied in ACPE; one study by Mehta and colleagues showed increased incidence of myocardial infarction in patients subjected to B-PAP compared to patients submitted to CPAP. This may be due to multiple factors, including vasoconstriction due to rapid correction of hypercapnia, patient-ventilator asynchrony triggering increased sympathetic response, or a decrease in cardiac output due to increased intra-thoracic pressure [21, 23]. Further studies did not confirm a relation between B-PAP and myocardial infarction [24].

Pneumonia

The presence of pneumonia represents a particular set of challenges, due to the presence of an inflammatory state, which will not revert immediately even with adequate antibiotics coverage, the management of excessive bronchial secretions, and reduced lung compliance [13]. Even if managed in the ICU, mortality of community-acquired pneumonia (CAP) may reach 54% [25]. As previously noted, the presence of pneumonia in patients with COPD is, in itself, a predictor of NIVS failure.

Carrillo et al. performed a prospective study, applying B-PAP to 116 patients in the ICU setting; 68 experienced NIVS failure. The main predictors for NIVS failure after 1 h of treatment were need for vasopressor support, higher SAPS-II and SOFA scores, pH < 7.35, development of ARDS, higher RR (37 ± 9 vs. 30 ± 5), lower PaO_2/FiO_2 ratio (139 ± 39 vs. 178 ± and lower bicarbonate concentration (19.3 ± 3.7 vs 22.3 ± 2.8) [26].

A study by Confalonieri and colleagues involving 56 patients randomized them to either standard support treatment or B-PAP; patients had similar baseline characteristics. In the B-PAP group, treatment failure occurred in 6 of the 28 patients, whereas in the standard group, treatment failure was observed in 14 of 28 patients. No predictors of failure were identified in either group, but it was observed that COPD patients in the B-PAP group experienced lower failure rates than in the standard group (which reinforces the importance of B-PAP in patients with obstructive pulmonary disease, regardless of etiology) [25].

Acute Respiratory Distress Syndrome

Patients who present with ARDS due to infectious or acute interstitial disease develop AHRF due to the presence of significant alveolar injury and intrapulmonary shunts, and the use of CPAP in this situation seems reasonable enough from a physiological standpoint. Although an early improvement in oxygenation has been consistently reported, the overall clinical deterioration of the patient due to disease progression, patient noncompliance, and technical difficulties are all related to the overall poor prognosis associated with CPAP, warranting the need for ETI in these cases [27]. The development of ARDS precludes poor overall prognosis with high mortality and has been independently associated with need for ETI (odds ratio 28.5) [28].

Despite ETI, mortality in patients with severe ARDS is still around 35–40% [29]. Despite the debatable recommendation, most authors agree that, unless the patient meets criteria for immediate ETI, a trial of NIVS could be attempted if it does not delay life-saving intubation [30].

As for B-PAP, it is preferred over CPAP when respiratory support is needed in AHRF, with different rates of success. The main predictor of failure is the degree of hypoxemia [31]: in a study by Antonelli et al. enrolling 354 patients with AHRF (38 of which with a diagnosis of CAP), the most common indication for ETI was impaired alveolar exchanges after 1 h of treatment (62% of cases), and a PaO_2/FiO_2 ratio below 146 was found to be a strong predictor for treatment failure (Fig. 42.1); the other statistically significant identified factor was persistent acidemia. Age above 40 years old was also shown to be a predictive factor of NIMV failure in the same study [30].

Asthma

The use of NIVS in asthma, specifically in status asthmaticus, is still very controversial, with invasive ventilation being the main alternative for patients who do not respond to optimized medical treatment [32]. Therefore, few studies have been published regarding factors predicting NIVS failure, either by CPAP or B-PAP. One study by Stefan et al. suggests that the main indicators of NIV failure are in-hospital admission in the previous 12 months, diabetes mellitus, and the presence of pneumonia [33]. Overall, there is insufficient evidence for the use of NIVS, and further studies are required in this field [10].

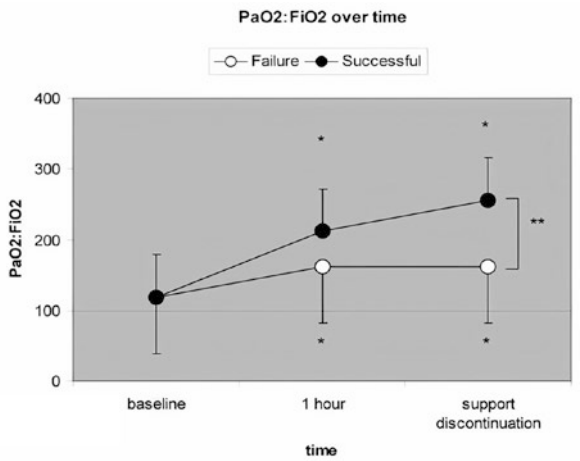

Fig. 42.1 Changes in PaO_2/FiO_2 over time. Support discontinuation refers to the moment when the last arterial blood gas was obtained prior to intubation (failure group) or prior to definitive removal of NIVS (success group). From: Antonelli M, Conti G, Moro M, Esquinas A, Gonzalez-Diaz G, Confalonieri M et al. "Predictors of failure of noninvasive positive pressure ventilation in patients with acute hypoxemic respiratory failure: a multi-center study". Intensive Care Medicine. 2001;27(11):1718-1728

Chest Trauma

Chest trauma develops in about 20% of trauma patients, and development of respiratory failure is more frequent in elderly patients and patients with impaired respiratory function. The mechanisms are multiple and frequently overlapping, including pneumothorax, lung contusion, rib fractures, and hemothorax. The clinical determinants for NIVS failure are not yet well established in this group of patients. A meta-analysis by Chiumello et al. including 219 patients found a relation between NIVS failure and both higher SAPS-II score and persistent hypoxemia after 1 h of treatment, with no distinction made between CPAP and bl-NIVS [34]. Several studies have supported the use of both CPAP and B-PAP in this population, but it has not been determined if one mode is superior to the other [10, 32]. Of note, patients with chest wall trauma who need NIVS should be managed in the ICU, and not in the general ward.

Bronchiectasis

Patients with bronchiectasis may develop respiratory failure during exacerbations, either hypoxic or hypercapnic. NIVS is not usually necessary in this population and is often impractical due to an elevated amount of bronchial secretions, which are extremely difficult to manage in these patients [10]. However, one study by Hadda et al. enrolled initiated NIVS in 81 such patients, and none failed NIVS due to excessive bronchial secretions; a statistical relation was found between NIVS failure and higher APACHE score and lack of improvement in arterial oxygenation at the 2-h mark [14, 35].

Outcome Determinants: Nonclinical Factors

As a final note, we would like to reference non–patient-related factors, which also bear an impact in NIMV failure, such as delay in initiating NIMV, mask intolerance, and staff's lack of experience [9]. The development of internal protocols and adequate staff training should help improve these variables and, therefore, improve patient outcomes.

In Summary

NIVS, both with CPAP and B-PAP, is currently a mainstay in the management of patients with acute respiratory illness and is very useful far beyond the ICU or the emergency department. However, its use requires experienced staff, fully aware of not only its indications and possibilities, but also its limitations. It is important to regularly monitor patients, as they are in a vulnerable state. The use of clinical scores and a correct physical examination are both invaluable in aiding treatment decisions.

Conclusion

NIVS failure usually occurs within the first 4 h; therefore, patients should be closely monitored. The use of bedside clinical scores/indexes can be useful. There are no universal predictors for predicting NIVS failure or success, understanding the underlying disease is essential. Evolution of the patient's respiratory rate, oxygenation, and arterial pH are usually reliable markers, which may be used to predict NIVS failure in most pathologies. Known monitoring scores, such as SAPS-II and APACHE score, may also be useful but are somewhat complex and may not be immediately usable. Outside of AECOPD and ACPE, there is still much doubt regarding the use of NIVS and predictors of failure, and further studies are required in these other pathologies.

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Discharge from Hospital and Long-Term Follow-Up of Patients Receiving Home Noninvasive Mechanical Ventilation

43

Pedro Barros

Abstract

Therapy with home noninvasive mechanical ventilation has grown exponentially worldwide in the last two decades to treat a vast array of diseases, accompanied by notable technological improvements ventilators and interfaces. During the follow-up, there must be a systematic approach for the assessment of these patients, including clinical evaluation, detection and resolution of side effects, analysis of ventilator data, and monitoring tools such as nocturnal oximetry, blood gas analysis, capnography, and polysomnography, while assuring the patient's knowledge of his equipment. In this process, clinicians can evaluate NIV efficacy, aiming to improve signs and symptoms of nocturnal alveolar hypoventilation, resulting in better quality of life and overall survival in some diseases.

Keywords

Home · Ventilation · Follow-up · Monitoring · Nocturnal oximetry · Blood gas · Capnography · Polysomnography · Hypoventilation

Introduction

Home noninvasive mechanical ventilation (NIV) can be defined by the daily application of ventilatory assistance in the patient's home or long-term care facility. The first applications started in the 1980s for patients with chronic respiratory failure, allowing a more convenient treatment with an optimization of resources by

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health-care systems. Since then, the number of patients on home noninvasive mechanical ventilation has grown exponentially worldwide, accompanied by the evolving recommendations, and significant technological improvements in ventilators and interfaces [1].

Leger et al. [2] published in 1994 the first series of patients treated with home NIV, with a 5-year follow-up of 276 patients. This study showed the benefit in terms of survival for patients with kyphoscoliosis, sequelae from tuberculosis, or Duchenne's disease. In this study, patients with chronic obstructive pulmonary disease (COPD) and bronchiectasis also showed benefited from this therapy.

The progress in this area was accompanied by the development of monitoring systems that are reliable and easy to access by the clinician in order to evaluate the efficacy of the home NIV.

During the follow-up, which will be discussed in this chapter, there must be a careful approach to evaluate the efficacy of NIV, and assess the possible side effects related to NIV, so that the ventilator settings and interface can be optimized promptly and achieve successful results with the therapy.

Clinical Follow-Up

There is a lack of scientific evidence on how often a patient on home NIV should be clinically evaluated. The suggested clinical follow-up intervals in the literature range from a few weeks up to one year [3, 4], while some authors advise hospital visits at least twice per year [5].

After the initiation of home NIV, it is important to schedule the first visit within the first few weeks, as this is a crucial phase to ensure the adaptation of the patient, adherence to the therapy, and optimization of the setup ventilator settings [6, 7].

The subsequent frequency of clinical evaluation depends on various factors such as the underlying disorder, the adaptation to the ventilation and potential adverse effects, natural history of the disease, and the ability of the patient to travel to the hospital.

Patients with rapidly progressing neuromuscular diseases such as amyotrophic lateral sclerosis (ALS) may need to be evaluated frequently, in order to adjust the ventilator settings and duration of ventilation as the underlying disease progresses. In some cases, as the disease progresses, there will be a need for continuous NIV or invasive ventilation via tracheostomy, especially in patients with severe bulbar dysfunction [7].

For other patients with restrictive diseases such as kyphoscoliosis, once they are stable, the supervision required is minimal.

Adherence to therapy is essential to ensure its efficacy and that must be reinforced every time the patient visits the hospital. The clinician might be forced to discontinue the therapy if despite optimal setup, the patient is still lacking adherence.

Regarding the location of the follow-up, there has been an increasingly significant transfer toward home. Most ventilators contain sensors and have built-in capability to collect data that can document compliance, settings, and estimated values

of tidal volume, leaks, breathing rate, minute ventilation, percentage of breaths triggered by the patient, and the apnea-hypopnea index. With a close collaboration between homecare providers and the medical team, the information of the ventilator data can be transmitted prior to the outpatient hospital visit and, if requested, overnight recordings of gas exchange using oximetry or capnography, as will be discussed later in this chapter. This allows the hospital team to do some of the necessary adjustments without the need for hospitalization. Nevertheless, the place of medical follow-up remains hospital platform, where the doctor can evaluate the symptoms, quality of life, ventilation-related side effects, and it is possible to do a measurement of vital signs and daytime arterial blood gases. In more complex cases, patients might need to be hospitalized for a closer evaluation and titration of the ventilation settings and setup, with the possibility of using polysomnography for the assessment of NIV during sleep.

NIV Efficacy

The primary goal of ventilation is to achieve improvement of signs and symptoms of nocturnal alveolar hypoventilation once the patient has successfully adapted to the ventilation and is adherent to the therapy, resulting in better sleep, quality of life, daytime gas exchange, and overall survival in some diseases.

Improvement and stabilization of arterial carbon dioxide partial pressure ($PaCO_2$) assessed by arterial blood gases measurement is the most important objective variable to access efficacy and it is associated with improved outcomes [8]. Other objective parameters include improvement in nocturnal oxygen saturation and an increase in diurnal arterial oxygen partial pressure PaO_2. Besides the objective parameters, NIV efficacy needs to be demonstrated with clinical benefit from the treatment.

Evaluation in each clinical visit should include the investigation of common reported symptoms, namely:

- Dyspnea
- *Orthopnea*
- Cough
- Asthenia
- Somnolence
- Cognitive disorders (attention, concentration)
- Cephalea

These symptoms can be assessed through standard patient interview or using validated questionnaires such as Epworth sleepiness scale.

The reduction of nocturnal alveolar hypoventilation can be achieved through different mechanisms, by resting the muscles of the respiratory system, and improving dynamic lung compliance. On the other hand, it is hypothesized that central chemoreceptor sensitivity may be altered with the improvement of nocturnal hypercapnia, which can correct daytime hypoventilation [9].

Hannan et al. [10] published a systematic review in 2014, which examined the effect of NIV on patient-reported outcomes and survival for individuals with or at risk of chronic respiratory failure. In this review, there was consistent evidence supporting NIV for patients with ALS, in survival and measures of somnolence and fatigue. In patients with OHS, NIV also appeared to improve measures of somnolence and fatigue, dyspnoea, and sleep quality, while for those with restrictive thoracic disease, there was a consistent improvement in measures of dyspnoea, sleep quality, physical function and health, mental and emotional health, and social function.

In patients whose symptoms and gas exchange fail to improve or who deteriorate after prior stabilization, further investigations are necessary to detect the mechanisms behind the failure of NIV.

Equipment and Patient Knowledge

It is essential that the patient and his caregivers are educated about the use and maintenance of the ventilator and its entire set of accessories. Homecare providers are responsible for the initial briefing and provide the necessary maintenance.

During home visits, the ventilator, the mask, and other accessories are checked for cleanliness and functionality. Patient knowledge about correct use of the ventilator, interface positioning, humidifier management, and equipment cleaning should be accessed during these visits. During the hospital consultation, setting and positioning of the interface should be checked by asking the patient how the interface is placed and the ventilation started, to ensure that the interface is correctly positioned, and the patient knows how to manage the leaks.

A poorly adapted interface is the main cause of unintentional leaks that impair efficacy and tolerance of NIV [11]. These can be assessed by asking patients and their partner if they feel any leak or are aware of leak noises.

Patients should also be educated about equipment transportation rules and use of internal and external batteries. It's essential that an emergency phone is provided as homecare services should have 24-hour availability for technical problems [12].

Functional checks and safety-related inspections should be carried out in conformity with the manufacturer's suggestions.

Side Effects of NIV

Home NIV can be associated with numerous side effects and, although generally minor, can impair tolerance and compliance in patients and impact overall quality of life. For the success of home NIV, patient's comfort is critical in both the acute [13] and chronic [14] setting.

One study [15] found that side effects occurred in one third of patients and the total number of adverse effects associated with NIV was inversely correlated with the percentage of days on which home NIV was used for. Nevertheless, the

prevalence is dependent in numerous factors and correct adaptation and patient education in an initial phase is crucial to decrease these events.

Side effects are most often related to mask fit, leaks, ventilator air flow or pressure. The main issues that should be explored are mask leaks, facial soreness on pressure points, eye, mouth or nose dryness, conjunctivitis, or gastric distension.

Serious complications such as pneumothorax, hemodynamic compromise, or aspiration pneumonia are rare events [16].

Mask Leaks

Leaks are a common problem in NIV [17]. Although some ventilators can compensate for leaks, their presence can lead to inefficient ventilation and patient discomfort, contributing for sleep arousals [18], oxygen desaturations, and mucosal dryness. The presence of leaks is related to suboptimal selection, setting, or positioning of the interface, high inspiratory pressures, patient's movement during the night, and episodes of upper airway obstruction.

Generally, leaks can be controlled when these causes are addressed. When a nasal mask is used, opening of the mouth during the ventilation can also result in leaks. The addition of a chin strap may help in these cases [19].

Interface-Related Side Effects

The choice of an adequate interface between the patient and the ventilator is crucial for the success of NIV. A poorly fitting interface decreases clinical effectiveness and patient's adherence [20].

The most used interfaces are nasal masks, oronasal masks, or nose-piece masks. In the adaptation phase, the practitioner should ensure that mask fit is optimal, and that minimal strap tension is used to control air leaking. If the patient experiences discomfort, a trial with different types of interfaces may help to resolve the problem. A minority of patients may be unable to tolerate the sensation of a foreign body strapped to the face, leading to an alternative strategy for treatment.

Nasal Bridge Erythema and Ulceration

Excessive mask tension on the nasal bridge can lead to erythema and ulceration, which needs to be addressed promptly, as it is an important cause of discomfort and decreasing adherence. Several strategies can be employed to minimize this side effect. Reducing strap tension usually alleviates the pressure in the nasal bridge and using multiple types of interfaces can allow for a time to unload the harmed areas. Adhesive dressings can also be placed on pressure points to prevent or treat skin lesions. Gel masks may also be an option to alleviate pressure in the harmed areas and have the advantage of moulding to the contours of the face when warmed by the patient's skin.

Pressure or Flow-Related Side Effects

Oronasal Dryness

Dryness of the oronasal mucosa is one of the most common side effects reported by patients, which can improve after a few days of ventilation. It can lead to thirstiness and epistaxis, that can be due to insufficient air humidification [21]. A heated humidification system can be added on the ventilation circuit, as the increased humidity and warmth tend to enhance comfort with the airflow and its efficacy has been demonstrated [22] in reducing the oronasal dryness. In patients with obstructive sleep apnea, the humidifier may also help by decreasing nasal resistance to airflow [23].

It is important to explain to the patient that the heater may be adjusted to increase and decrease the humidity intensity as needed, however being limited by condensation in the ventilation circuit.

Nasal saline and emollients can also be applied to help with the mucosal discomfort.

Conjunctivitis and Eye Dryness

Eye dryness and conjunctivitis are caused mostly by ventilation leaks on the upper region of the interface. It can be avoided by changing or adjusting the interface, while eye drops may help in keeping the eyes more resistant to the sporadic leaks in this area.

Gastric Distension

Many patients report abdominal distention due to the passage of part of the air blown in by the ventilator in the stomach. This phenomenon mainly occurs when the volumes or pressures administered are substantial and there is a patient-ventilator asynchrony, where the patient is swallowing the breaths delivered by the ventilator.

Although usually tolerable and transient, a reduction in inflation pressure might be needed to minimize this problem.

Monitoring Tools

Effectiveness of home NIV should be assessed on a regular basis. The timing of follow-up is not defined, although systematic monitoring should at least be once a year and repeated if the ventilator settings are changed or following an acute respiratory exacerbation.

As described earlier in the chapter, most ventilators provide information that can help identify abnormal nocturnal events and, in some cases, the causes of these events. However, the information provided is insufficient to monitor patient's evolution with the therapy and its usefulness, reliability, and validity of most parameters require further evaluation.

Patient's monitoring tools during follow-up on long-term home NIV include nocturnal oximetry, capnography, blood gas analysis, polygraphy, and polysomnography.

Nocturnal Oximetry

Nocturnal oximetry is a necessary component in the long-term monitoring of all patients on home NIV, also having an important part in the initiation phase to determine ventilator setup.

It is a very simple tool to ensure that the patient has sufficient oxygenation during the night and can detect recurrent or prolonged desaturations. Recurrent drops can represent obstructive or central residual events, and intermittent mask leaks, while prolonged drops are more suggestive of sleep hypoventilation but can also occur because of extended mask leaks [24].

It has the advantage of being conducted in the usual environment and conditions of NIV use by the patient, providing the physician information about the efficacy of the treatment ahead of the medical consultation.

Nevertheless, the information provided should be interpreted with caution, because it lacks specificity and can reflect a wide variety of respiratory events [25]. Furthermore, it is not reliable when patients use supplemental oxygen [26].

Blood Gas Analysis and Capnography

In a ventilated patient, assessing $PaCO_2$ is essential for evaluating alveolar hypoventilation during sleep. If persistent symptoms exist, a residual alveolar hypoventilation can be present despite normal oximetry and can be detected measuring $PaCO_2$.

Repeated sampling of arterial blood from a catheter in the radial artery to measure blood gas would be ideal to record $PaCO_2$ changes, but is not conceivable for routine monitoring. A simpler approach is to collect arterial blood at the end of the night, to document increases in $PaCO_2$ that might indicate hypoventilation. However, normal morning $PaCO_2$ might not reflect the values during the night. Aarrestad et al. [27] evaluated the sensitivity and specificity of a screening test panel for nocturnal hypoventilation, including daytime arterial blood gas, and found that with a daytime $PaCO_2$ <6.0 kPa (<45 mmHg), up to 26% of the cases of nocturnal hypoventilation might be missed.

A noninvasive way to assess PCO_2 continuously is by measuring transcutaneous carbon dioxide tension ($PtcCO_2$) using capnography. With this continuous monitoring, it is possible to observe the trends and effects of NIV. Good agreement between $PtcCO_2$ and $PaCO_2$ has been demonstrated in patients with and without pressure support, and is considered as a reasonable surrogate for $PaCO_2$ by the American Academy of Sleep Medicine [28]. The main limitations of the technique are the price of the equipment, and the requirement for periodic calibration and changes of membrane in order to ensure sufficient precision of transcutaneous measurements.

Sensor drift has also been reported during overnight recordings and could alter the recording.

Coupling capnography to nocturnal oximetry should be considered in patients requiring supplemental oxygen, with unexplained nocturnal hypoxemia, or presenting persistent symptoms of alveolar hypoventilation.

When abnormalities are identified using nocturnal oximetry, capnography, or blood gas analysis, but it is difficult to understand the events involved, polygraphy or polysomnography might be needed to understand the relevant mechanisms and adjust ventilator settings and/or interfaces.

Polygraphy and Polysomnography

While simple tools should be used as first-line monitoring tools, polygraphy or polysomnography may be useful in patients who fail to improve or who deteriorate after prior stabilization.

Polysomnography is the most complete assessment of NIV during sleep, allowing an observation of the different mechanisms involved in desaturations, episodes of hypoventilation, or disrupted sleep structure, and titrate NIV settings if necessary. However, the patient is required to spend a night in a sleep laboratory, which can cause disruption of the sleep habits. Some experts recommend periodic polysomnography in the follow-up of home ventilated patients [29], but this method is expensive, complex, and not available in all centers.

Polygraphy can be used in an outpatient setting and, although it doesn't detect variations in sleep structure, it is still useful for identifying events that impact ventilation.

The interpretation of these sleep studies can be a difficult task, as flow and pressure signals are influenced by the technical specifications of the device and the ventilatory mode and settings. The mechanisms involved in nocturnal respiratory events need to be well understood to adapt the interface or the settings appropriately.

Conclusion

The follow-up of long-term NIV should be carried out according to systematic procedures, enabling a prompt evaluation if the patient is being effectively ventilated. It relies mostly on clinical assessment and data provided by built-in ventilator software, where homecare providers play an important part. Hospital teams can then assess clinical improvement and potential side effects, and evaluate the need for monitoring tools, using nocturnal oximetry, blood gas analysis, capnography, and polysomnography.

Due to the absence of evidence-based guidelines, follow-up strategies vary according to clinical practice, but should aim to move toward building evidence for standardizing practice.

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