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Radiology findings and non-invasive ventilation response

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Abstract

Although NIV is a simple and useful method, considerable variation in its use across countries, regions and hospitals may be noted. The patient should be evaluated according to subjective response (respiratory distress, consciousness, problems related to mask and airflow), physiological responses (respiration rate, respiratory effort, air leakage) and patient-ventilator compliance (gas exchange, pulse oximetry, arterial blood gases). Normalization in respiration rate within 1 or 2 hours after initiation of treatment is one of the most important markers for recovery. The goal is to maintain respiration rate between 20 and 30 breaths/minute. Reduction in intercostal and supraclavicular retractions, paradoxical respiration and sympathetic activity indicate success of treatment. Arterial blood gases are measured within first 2 hours in order to assess pH and CO_2; and as needed thereafter. In general, NIV is assessed by arterial blood gases, hemodynamic parameters and several laboratory tests. There is limited number of studies in NIV. Here, we aimed to assess radiological implications of gas distribution within lung tissue during NIV therapy.

Key words: non-invasive ventilation, NIV, radiology findings

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Introduction

Non-invasive ventilation (NIV) is an established method of treatment in type 2 respiratory failure. NIV refers to the use of ventilator support without an endotracheal or tracheostomy tube. Its popularity is increasing in different countries, also in Europe. It can be used both in acute and chronic respiratory failure, as well as in home-care end-expiratory intensive care settings. It tends to be an alternative to invasive methods due to its flexibility and ease of use.

NIV plays an important role in the treatment of acute respiratory failure. It alters the disease process in such disorders as an acute exacerbation of chronic obstructive pulmonary disease (COPD) and shortens the duration of invasive mechanical ventilation (IMV), moreover, it decreases the need for intubation and invasive ventilation, reducing IMV-related complications and risks. NIV is relatively easy to use and well-tolerated by patients. It may change the disease process and severity when used in an accurate and timely manner.

NIV can be applied in two different approaches: non-invasive positive pressure ventilation (NIPPV) and continuous positive airway pressure (CPAP). NIPPV is the combination of inspiratory positive airway pressure (IPAP) and positive and in-expiratory pressure/expiratory positive airway pressure (PEEP/EPAP) provided via a mask. Biphasic positive airway pressure (BiPAP) or non-invasive pressure-supported ventilation (NIPSV) is also used to define NIV. CPAP provides positive airway pressure during both inspiration and expiration while BiPAP ensures differential pressure at 2 levels: IPAP in inspiration and EPAP in expiration.

Profound understanding of technique and accurate patient selection are essential for successful administration. NIV therapy is assessed within first 48 hours (early response) according to objec-

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tive and subjective criteria [1]. Delayed response is permanent respiratory acidosis with a clinical improvement despite facial mask-delivered NIV for 48 hours. Permanent respiratory acidosis is ≥ 15 mm Hg increase in $PaCO_2$ (when compared to baseline $PaCO_2$) or pH > 7.30 following 2 hours of NIV.

Early NIV failure (< 48 hours) after initial improvement is assessed according to major and minor criteria defined in the literature [2]. Major criteria include: respiratory arrest, persistent, besides mechanical ventilation respiratory pauses (that is why we avoid spontaneous modes of application in ARF) or bradycardia (< 50 bpm), hypotension with systolic arterial blood pressure < 70 mm Hg and SaO_2 < 90% despite FiO_2 > 60% (refractory hypoxemia). Minor criteria include tachypnea with the respiration rate > 35 breaths/min or the increased respiration rate when compared to baseline, pH < 7.30 or a decrease in pH when compared to baseline, increased encephalopathy score (as rated by Kelly and Matthay scale) when compared to previous assessment. NIV failure is defined as the presence of one major and 2 minor criteria above 24 hours of NIV. If no recovery is achieved in the respiration rate, encephalopathy score, $PaCO_2$ and pH *via* facial mask-delivered NIV, the patient is repositioned to a sitting posture . If minor criteria are present despite NIV, endotracheal intubation should be considered unless it is contraindicated [3].

Although NIV is a simple and useful method, considerable variation in its use across countries, regions and hospitals may be noted. The patient should be evaluated according to subjective response (respiratory distress, consciousness, problems related to a mask and airflow), physiological responses (respiration rate, respiratory effort, air leakage) and patient-ventilator compliance (gas exchange, pulse oximetry, arterial blood gases). Normalization in the respiration rate within 1 or 2 hours after initiation of treatment is one of the most important markers for recovery. The goal is to maintain the respiration rate between 20 and 30 breaths/minute [4]. A reduction in intercostal and supraclavicular retractions, paradoxical respiration and sympathetic activity indicate the success of treatment. Arterial blood gases are measured within first 2 hours in order to assess pH and CO_2; and as needed thereafter [5].

In general, NIV should be assessed by arterial blood gases, hemodynamic parameters and several laboratory tests. Here, we aimed to assess radiological implications of gas distribution within lung tissue during NIV therapy.

NIV and radiological assessment in chronic obstructive pulmonary disease

COPD is a disease that is characterized by irreversible airway obstruction usually caused by an exposure to inspired toxic particles [6]. The disease severity can be classified according to pulmonary function test. It may have symptoms of the disease and exacerbation risk. Emphysematous changes, lung cancer, remodeling in the airway and vasculature, heart failure, cachexia and bone demineralization — all of them can be seen in COPD [7].

Significant reductions in the length of ICU and hospital stay, mortality with prevention of intubation have been observed by the NIV use in acute exacerbations of COPD and hypercapneic respiratory failure. During acute exacerbations, the respiration rate is increased while diaphragm motions are restricted; positive end-expiratory pressure is elevated; and ineffective and insufficient tidal volume is created- all which causes hyperinflation by complicating sufficient ventilation. NIV therapy relieves respiratory muscles effectively, increases tidal volume; reduces the respiration rate, decreases hypercapnia by improving oxygenation and improves shortness of breath by lowering load on the diaphragm [8, 9].

In studies suggesting that baseline X-ray and CT findings can predict a necessity for ventilator support in COPD, it was seen that the need for NIV was 2.4-fold higher in the presence of multilobar involvement in X-ray and 47-fold higher in the presence of consolidation in CT scan; however, further evidence to confirm the usefulness of radiological assessment in this terms is needed [10–14].

Hypercapnia may develop on a long-term basis in patients with severe COPD. To assess NIV therapy in such individuals, high-resolution CT scans were obtained at baseline and in 1 and 6-month follow-up. CT scans were processed by functional respiratory imaging (FRI) technique. This method estimates lobar volumes (ivLobes), airway volume (iVaw), airway resistance (iRaw) and volume of blood vessels (iVbv). It provides information about functional properties of the lung such as ventilation-perfusion (VQ), allowing us to correlate them with clinical findings [11]. NIV therapy during exacerbation of hypercapneic COPD results in lower $PaCO_2$ without a need for pharmacological therapy, which maintains over several months. In addition, exercise tolerance is also ameliorated due to improvement in VQ.

Decreased hyperinflation is associated with better blood gas values. Presumably, the advance in VQ results from amelioration of VQ [12].

There is an evidence that sonographic assessment of diaphragm thickness may be useful to show diaphragm function and its contribution to respiratory workload. Girou *at al.* [13] reported the measurement of the diaphragm thickening fraction ([thickness at inspiration-thickness at expiration]/thickness at expiration) in this term.

The Vibration Response Imaging (VRI) is a new and non-invasive imaging modality that is used to assess initial therapeutic effect of NIV in exacerbation of COPD. The VRI objectively records lung sounds by computer assistance in a 2-dimensional manner [14]. Functional alterations are rapidly visualized in patients receiving NIPPV. It is more sensitive than widely used arterial blood gas result such as $PaCO_2$. It is a promising, novel non-invasive modality to assess initial therapeutic effect of NIV and to predict success of NIV at early phase [14].

Other modalities

The COPD is a heterogeneous systemic condition. Thus, pulmonary functions as rated by spirometric measurements alone are inadequate to assess and classify disease severity. Today, pulmonary imaging methods and quantitative imaging techniques can provide temporal findings about disease *in vivo* and potentially allow monitoring response to treatment. In his textbook, George R. Washko discussed major imaging modalities including computed tomography (CT), magnetic resonance imaging (MRI), positron emission tomography (PET) and optical coherence tomography (OCT) [6]. MR imaging can assess tissue movements more comprehensively and in real time. However, tissue architecture is a limiting factor for the use in the lung. To increase its appliance, there is a need for an inhaler and intravenous contrast materials. Although PET scan is used extensively for screening, diagnosis and follow-up in malignancy, it may provide new perspectives to pathology and pathogenesis of disease in pulmonary disorders such as COPD. In a study by Vidal Melo *et al*. [15], it was shown that lung perfusion is markedly heterogeneous in mild and moderate COPD. In the study by Alford *et al*. [16], emphysematous changes (a regional perfusion defect) are a component of parenchymal disease accompanied by vascular remodeling.

Radiological assessment in patients with cardiogenic pulmonary edema/congestive heart failure undergoing NIV

Respiratory failure resulting from cardiogenic pulmonary edema or congestive heart failure (CHF) is a condition that can be treated effectively by using non-invasive ventilation (NIV) [17–22]. In CHF, pathophysiological changes include congestion in pulmonary vascular bed, interstitial edema and fluid accumulation in the alveoli. This initially causes hypoxemic respiratory failure; followed by hypercapneic respiratory failure [19, 20].

It was seen that there was a significant difference in the total number of B lines on lung ultrasound at mid-axillary line. Transthoracic ultrasound was performed to monitor therapeutic effectiveness of CPAP applied in addition to standard therapy in patients with decompensated heart failure [21].

In a study on assessment of NIV failure in neonatal infants by using lung ultrasound, Raimondi *et al.* [22] showed that the presence of hyperechogenic, "white lung" appearance is associated with NIV failure.

Pneumonia and NIV

The use of NIV in severe respiratory failure due to community-acquired pneumonia is controversial. Risk factors for NIV failure are unclear in these patients [23]. There were no significant differences at presentation in patients in *de novo* acute respiratory failure group while a reduction in the respiration and heart rate one hour after initiation of NIV in patients responding to NIV therapy was observed. There was a significant increase in alveolar-arterial oxygen gradient (A-a-DO2) even after 24 hours in the group considered to be unresponsive to NIV therapy ($p \leq 0.02$). When the groups were compared, parameters predicting NIV failure after one hour included elevated heart rate, high A-aDO2 after 24 hours and high Opravil score at presentation. However, it should be suggested that the success rate was higher in the group responsive to NIV therapy. Parameters predicting NIV success included less involvement in the lung, early NIV reaction and persistence of clinical response.

In a study, Lowrence *et al*. [9] assessed changes in respiratory failure due to pulmonary and extra-pulmonary causes by using thoracic CT scan. Asymmetrical consolidation and ground glass appearance are seen in respiratory failure due to pulmonary causes while symmetrical ground glass appearance is observed in respiratory failure in extrapulmonary respiratory arrest. In both groups, pleural effusions and air bronchogram are diffuse while Kerley B lines and pneumatoceles are rare.

The number of pulmonary lobes involved, presence of tachyarrhythmia and degree of hypoxemia are major determinants when deciding about the NIV therapy in non-ICU settings; in addition, increased pCO_2, arterial hypotension, age and high IPAP values are other indications for NIV therapy in non-ICU settings [24].

In recent years, electrical impedance tomography (EIT) [24, 25] has become the focus of interest. This is a novel imaging modality used in the assessment of distribution of regional pulmonary ventilation. A new generation, EIT-based technique has also been defined to measure regional pulmonary perfusion at bedside. Although it is a more commonly used method to measure pulmonary artery pulsatility, it isn't appropriate for pulmonary perfusion measurement. Real-time EIT is used to detect, measure and monitor changes in pulmonary ventilation and perfusion during CO_2 insufflation to the pleural cavity. In a study on EIT, regional volumes and distribution of regional ventilation were visualized during combined continuous hyper-gravity and hyper-oxygen exposure in a functional manner. Hyper-gravity together with thoracic compression due to anti-G Trouser inflation lead to decreased regional compression at the xiphoid level; it was also shown that these changes are reversible. These findings suggest air trapping at posterior region of the lung due to closure of the airway during hypergravity. As a result, EIT is an effective method to monitor distinct physiological conditions of the lungs in a real-time manner [26]. The results of the study by Shah *et al.* [25] revealed that EIT is a non-invasive method for monitoring respiratory pattern and changes in distribution of ventilation in infants with spontaneous respiration. It was noted that the differences seen in distribution of ventilation in infants were similar to those observed in adults.

The assessment of NIV therapy was performed by using HRCT in diffuse interstitial lung disease. Although the spectrum of diffuse interstitial lung disease is highly heterogeneous, individual differences can be seen in response to NIV therapy. Treatment success in acute respiratory failure may depend on two factors. Firstly, it leads to poorer results in usual interstitial pneumonia (UIP) when compared to non-specific interstitial pneumonia (NSIP) during application of positive pressure. Secondly, the effectiveness of NIV therapy depends on etiology; it provides better results in potentially reversible conditions (e.g. pneumonia or acute heart failure), whereas poorer outcomes are achieved during acute exacerbation in pulmonary fibrosis. It is assessed by the following parameters at admission: 1) presence of cough and sputum; 2) fever or hypothermia; 3) abnormal leukocyte count (leukocytosis or leucopenia) or elevated C-reactive proteins according to local reference limit. NIV can provide complete recovery in oxygenation if the underlying cause is pneumonia; however, changes are permanent when fibrosis is the underlying cause. As a result, decision regarding NIV should be based on etiology rather than radiological findings in acute respiratory failure due to diffuse interstitial lung disease [27, 28].

In the study by Corral *et al.* [29], the effect of NIV therapy on cardiac dysfunction was assessed by echocardiography in patients with obesity hypoventilation syndrome (OHS). It was seen than mid-term NIV therapy was more effective regarding pulmonary hypertension, left ventricular hypertrophy and functional results when compared to CPAP and lifestyle changes.

Although NIV has been increasingly used, success isn't growing consistently. This may be caused by the lack of experience and patient-ventilator mismatch; however, the patency of the upper respiratory tract also makes significant contribution [25]. The patency of the upper respiratory tract may be diminished in response to positive pressure, resulting in decreased minute-ventilation. There is a complex interaction between genioglossus muscle activity and soft tissues. Electromyography can provide information regarding movements of the laryngeal muscles (genioglossus or cricothyroid muscles) but no data can be obtained regarding movements of soft tissues. Additional methods are needed to assess the patency of the upper respiratory tract. MR imaging can provide such information; however, it is expensive and cumbersome in patients receiving NIV. In recent years, it has been suggested that sonography can visualize the patency of the upper respiratory tract. Endoscopy was used for this purpose but the ideal method hasn't been established [29].

Conclusion

We hypothesize that in the future, approaches to clinical care and evaluation of NIV therapy will include some of the above-mentioned imaging modalities and standard severity assessment methods of covered diseases.

Conflict of interest

The authors declare no conflict of interest.

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