Noninvasive Ventilation and Perioperative Mortality

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3.1 Background

Postoperative pulmonary complications (PPCs) are caused by a variable impairment of respiratory function, whose common responsible are the dysfunction of the abdominal, thoracic, and diaphragmatic muscles, along with reduction in lung parenchyma excursion and derecruitment occurring after anesthesia and surgery. These abnormalities are frequent, following long and high-risk surgical procedures, and may persist for days. Patients affected by any pulmonary abnormality occurring in the postoperative period are at increased risk of developing ventilation perfusion mismatch, hypoxemia, carbon dioxide retention, and respiratory failure. Moreover, PPCs may be associated with prolonged hospital length of stay, long-term poor outcome, and reduced survival rate [1].

As described by the EUSOS study ($N=46,539$) [2], including adult patients undergoing noncardiac surgery, postoperative acute respiratory failure is one of the main causes of increased morbidity and mortality. It affects 5–10 % of all surgical patients and up to 40 % of those undergoing abdominal surgery [3, 4].

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Invasive mechanical ventilation has been considered for many years the unique ventilatory strategy for acute PPCs, despite the associated complications and mortality rate [5]. Nevertheless, in recent years noninvasive ventilation (NIV) has increasingly been considered a simpler and safer alternative to invasive mechanical ventilation to extend optimal respiratory care into the postoperative period. Meta-analysis and original works in this area [6, 7] have demonstrated that NIV in the prevention or treatment of perioperative respiratory failure is associated with a reduction in the rates of pneumonia, reintubation, and overall morbidity. NIV effects on survival come mainly from few works presenting a small number of patients and/or a poor quality, as recently confirmed by the update of the web-based International Consensus Conference on mortality reduction after adult surgery [8, 9]. Notably, NIV is currently underutilized in the perioperative setting as few centers have the possibility to employ NIV in the surgical wards [10] or even in the surgical ICU.

3.2 Published Evidence

NIV is increasingly used either to prevent acute respiratory failure after surgery (prophylactic use) or to treat acute respiratory failure once it has occurred (therapeutic use). Two recent meta-analyses [7, 11] of randomized clinical trials on NIV in the perioperative period were performed in the setting of abdominal surgery (nine studies), thoracic surgery (three), cardiac surgery (eight), thoracoabdominal surgery (three), bariatric surgery (four), and solid organ transplantation surgery (two). They found that both prophylactic and therapeutic NIV is beneficial in reducing in-hospital stay and incidence of pneumonia and reintubation. ICU stay was reduced in postsurgical patients who received NIV after extubation. However, there was insufficient data to assess whether NIV affected patients' survival when compared with standard therapy.

3.2.1 Thoracic Surgery

Evidences of benefit in terms of gas exchange and lung volumes are well established when NIV is employed as preventive or therapeutic treatment after lung surgery, even in the case of high-risk patients [12, 13]. Lefebvre et al. analyzed the preventive approach showing how NIV approach for acute respiratory failure after lung surgery presents a reduction in the need for invasive mechanical ventilation and overall severe complications, as those affecting the surgical site (bronchial stump disruption, bronchopleural fistula, persistent air leakage, and pneumonia) [14]. However, these data was not confirmed by Lorut et al. [15] who focused on COPD patients in a randomized trial of early prophylactic NIV vs. conventional postoperative treatment following major lung surgery. They found no difference between the groups in the rate of acute respiratory events, intubation rate, infectious and noninfectious complications, duration of ICU and hospital stay, and 30-day mortality rate.

The only evidence of reduction in mortality comes from a randomized single-center trial (48 patients) in which patients with acute hypoxemic respiratory failure after lung resection were randomly assigned to NIV or standard treatment [16]. NIV was provided with nasal mask in pressure support mode to achieve an 8–10-mL/kg exhaled tidal volume and to obtain a saturation of peripheral oxygen (SpO2) above 90 %. Standard treatment consisted of oxygen supplementation to achieve SpO2 >90 %, bronchodilators, patient-controlled analgesia, and chest physiotherapy. Nine patients in the standard treatment group (37.5 %) versus three (12.5 %) in the NIV group died ($p = 0.045$). A significant decrease in in-hospital stay and 3-month mortality rate in the NIV group emerged. Intubation and invasive ventilation was significantly lower in the NIV group.

3.2.2 Cardiac Surgery

A recent systematic review and meta-analysis of randomized trials [17] included 14 studies and 1,211 patients, mainly after cardiac or vascular surgery. NIV reduced the reintubation rate (risk ratio [RR], 0.29; 95 % CI, 0.16–0.53; P for efficacy <0.0001; I 2 = 0), hospital length of stay, and mortality. Subgroup analyses suggested that the benefits of NIV are more important in patients with ongoing acute respiratory failure and in those at high risk of developing postoperative pulmonary complications. Analyses including prophylactic studies in patients at low risk did not show a significant effect of NIV on reintubation rate nor on any of the outcomes considered except for oxygenation. Despite a growing amount of data, adequately powered randomized trials on NIV are still limited. NIV seems effective both in early and in severe Acute Respiratory Failure (ARF), improving hospital length of stay and survival. NIV efficacy when applied as a preventive tool in unselected patients is not demonstrated, and it is likely that NIV should be reserved to patients who are at high risk for postoperative ARF.

Thereafter, Al Jaaly et al. [18] randomized 129 patients to NIV versus standard care to prevent PPC after coronary artery bypass. Respiratory complications were significantly lower in the NIV group although length of stay and mortality were not different.

In a recent randomized controlled trial (RCT) by Zhu et al. [19], 95 patients who developed acute respiratory failure after cardiac surgery were randomized to positive pressure NIV vs. standard medical care and oxygen therapy as needed. The group undergoing NIV therapy displayed a lower rate of reintubation, tracheotomy, ventilation-associated pneumonia, and a reduced duration of both mechanical ventilation and ICU stay. The mortality rate in this group was significantly lower than in the standard treatment group: 18.8 % vs. 38.3 %, respectively.

3.2.3 Abdominal Surgery

The benefits of prophylactic NIV are well described in abdominal surgery. Therapeutic NIV is associated with better gas exchange, lower intubation rate, and reduction in ICU length of stay [20–25]. Squadrone et al. [26] conducted a large randomized controlled study across 15 ICUs in Italy: 209 patients who underwent laparotomy and developed postoperative hypoxemia were randomized in two groups (CPAP 7.5 cm H_2O via helmet vs. standard care). CPAP was associated with a lower intubation rate (1 % vs. 10 %; $p = 0.005$) and a lower occurrence rate of pneumonia, sepsis, anastomotic leaks, and infections. None of the patients treated with CPAP died in the hospital, while three deaths occurred among those treated with oxygen alone.

Narita and coworkers [25] applied NIV in 16 patients who developed respiratory failure and/or a massive atelectasis after liver resection. In the NIV group, respiratory-cause mortality was significantly lower (0.0 % vs. 40.0 %; $p = 0.007$) than in conventional treatment without NIV (oxygen supplementation to achieve SpO2 above 90 %, inhaled bronchodilators, continuous epidural analgesia, physiotherapy). Rate of reintubation was significantly lower in the NIV group (12.5 % vs. 50.0 %; $p = 0.040$), and all-cause mortality was lower after NIV treatment (18.8 % vs. 50.0 %; $p = 0.100$).

3.2.4 Solid Organ Transplantation

Acute respiratory failure still represents the most frequent cause of postoperative mortality after solid organ transplantation.

Antonelli et al. [27] enrolled 40 consecutive adults recipients of solid organ transplantation, admitted to the ICU because of acute respiratory distress. Twenty patients were assigned to receive NIV through a face mask and 20 to standard treatment with oxygen supplementation via a Venturi mask. The use of NIV was associated with a significant reduction in the rate of endotracheal intubation (20 % vs. 70 %; $p = 0.002$) and length of stay in the intensive care unit (mean days, 5.5 vs. 9; $p = 0.03$). Moreover, a significant reduction in ICU mortality was observed with early NIV implementation, while in-hospital mortality was similar in the two groups.

3.3 Therapeutic Use

The positive pressure can be delivered as continuous positive end-expiratory pressure (CPAP) or, if an inspiratory pressure is added, as pressure support ventilation (PSV).

3.3.1 Ventilation Strategies

NIV increases functional residual capacity and oxygenation and reduces the respiratory work by increasing intrathoracic pressure. A progressive increase of pressure support and PEEP level is a good strategy to relieve dyspnea and improve gas exchange. The duration of NIV trial in the postoperative setting is difficult to standardize; practical experience and individual tolerance may determine the total daily use. Overall, the length of NIV cycles (1 to 3–4 h) is progressively reduced as gas exchange, respiratory patterns, and clinical conditions improve. Optimal noninvasive approach is based on individual patients and local feasibility and protocols, available devices, and expertise. Notably, postoperative lung dysfunction should also be treated with a proper pain control (i.e., epidural analgesia).

3.3.2 Patient Ventilator Interface

Nasal masks, oronasal (full-face) masks, and the "total face" helmets remain the most common interfaces for postoperative NIV. The advantages of nasal masks include less dead space, less claustrophobia, and minimum complications especially if vomiting occurs. Full-face masks are nowadays more common and more suitable for a moderately dyspneic patient. However, they tend to lead to discomfort and intolerance in case of prolonged use and to be more claustrophobic. Although it has been stated that helmets are less effective than face masks in delivering NIV, the very high tolerability of the helmet makes it a better interface when prolonged and continuous assistance is needed or in case of claustrophobic patients [23].

3.3.3 Complications

Failure of NIV therapy can be considered the worst complication due to the risk of prolonged time to intubation. Lefebvre et al. [14] described a successful rate after lung resection of 85.3 %. The mortality rate in "nonresponders" to NIV was 46.1 %. Factors significantly associated with NIV failure were previous cardiac comorbidities, postoperative pneumonia, and no initial response to NIV. Other predictive factors of NIV failure were age, admission in the surgical intensive care unit (ICU), and occurrence of noninfectious complications. Riviere et al. [28] reported a rate of 30 % of NIV failure after thoracic surgery. According to the authors, four independent variables were associated with NIV failure during the first 48 h of application: an increased respiratory rate, an increased Sequential Organ Failure Assessment (SOFA) score, an increased number of fiber-optic bronchoscopies performed, and the number of hours spent on NIV. Similarly, Wallet et al. [29] found that 58 % of patients with postsurgical respiratory failure treated with NIV avoided intubation. Factors associated with postoperative NIV failure were a decrease in the paO2/FiO2 ratio after 1 h of NIV, the need for tracheal intubation because of nosocomial pneumonia, and an increased Simplified Acute Physiology Score (SAPS).

Major NIV complications as barotrauma and hemodynamic effects, although uncommon, may be potentially life-threatening and are usually correlated with pulmonary and cardiovascular involvement. Minor complications are usually related to NIV interfaces or airflow patterns. Besides the shortcomings related to mask, pressure, and airflow, NIV requires caution regarding aspiration risk. Arm edema, deep venous thrombosis, discomfort, facial skin lesions, nasal or oral dryness, nasal congestion and gastric insufflation are common after prolonged use [30].

Conclusion

NIV is a safe and effective mean of reducing postoperative pulmonary complications, improving alveolar ventilation and gas exchange, decreasing infectious complications and even improving survival in selected patient populations with acute postoperative respiratory failure.

Summary Table

Clinical summary					
Technique	Indications	Cautions	Side effects	Dosage	Notes
Noninvasive ventilation	Postoperative acute respiratory failure	Failure of NIV therapy can be considered the worse complication due to the risk of prolonged time to intubation and should be early detected	Major complications (uncommon): barotrauma and hemodynamic effects Minor complications (common after prolonged use): aspiration risk, arm edema, deep venous thrombosis, discomfort, facial skin lesions, nasal or oral dryness, nasal congestion, and gastric insufflations	Progressive increase of pressure support and PEEP level to relieve dyspnea and improve gas exchange Optimal duration of NIV trial is unclear	Evidences of survival benefits come from lung resection surgery [16], liver resection surgery [24], solid organ transplantation [26]

NIV noninvasive ventilation, *PEEP* positive end-expiratory pressure

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