Turk J Anaesthesiol Reanim 2018; 46: 88-95 DOI: 10.5152/TJAR.2018.46762

Review

Non-Invasive Mechanical Ventilation in Critically Ill Trauma Patients: A Systematic Review

Annia Schreiber[1], Fatma Yıldırım[2], Giovanni Ferrari[3], Andrea Antonelli[4], Pablo Bayoumy Delis[5], Murat Gündüz[6], Marcin Karcz[7], Peter Papadakos[8], Roberto Cosentini[9], Yalım Dikmen[10], Antonio M. Esquinas[5]

[1]*Fondazione Salvatore Maugeri, IRCCS, Respiratory Intensive Care Unit and Pulmonary Rehabilitation Unit, Pavia, Italy*

[2]*Ankara Dışkapı Yıldırım Beyazıt Research and Education Hospital, Intensive Care Unit, Ankara, Turkey*

[3]*Ospedale Mauriziano, Department of Respiratory Medicine, Turin Italy*

[4]*Allergologia e Fisiopatologia Respiratoria, ASO S. Croce e Carle Cuneo, Cuneo, Italy*

[5]*Hospital Morales Meseguer, Intensive Care Unit, Murcia, Spain*

[6]*Department of Anaesthesiology and Reanimation, Intensive Care Unit, Çukurova University School of Medicine, Adana, Turkey*

[7]*University of Rochester, Department of Anesthesiology, Critical Care Medicine, Rochester, New York, USA*

[8]*University of Rochester, Department of Anesthesiology, Surgery and Neurosurgery, Critical Care Medicine, Rochester, New York, USA*

[9]*Emergency Medicine Department, Gruppo NIV, Fondazione IRCCS Ca' Granda Ospedale Maggiore Policlinico, Milan, Italy*

[10]*Department of Anaesthesiology and Reanimation, Intensive Care Unit, İstanbul University, Cerrahpaşa School of Medicine, İstanbul, Turkey*

Cite this article as: Schreiber A, Yıldırım F, Ferrari G, Antonelli A, Delis PB, Gündüz M, et al. Non-Invasive Mechanical Ventilation in Critically Ill Trauma Patients: A Systematic Review. Turk J Anaesthesiol Reanim 2018; 46: 88-95.

ORCID IDs of the authors: A.S. 0000-0003-4073-4001; F.Y. 0000-0003-3715-3097; G.F. 0000-0002-8863-2496; A.A. 0000-0002-1288-3184; P.B.D. 0000-0002-6116-1954; M.G. 0000-0003-0006-8796; M.K. 0000-0003-2153-3343; P.P. 0000-0002-7065-7775; R.C. 0000-0003-3407-3630; Y.D. 0000-0002-0814-2439; A.M.E. 0000-0003-0571-2050

Abstract

There is limited literature on non-invasive mechanical ventilation (NIMV) in patients with polytrauma-related acute respiratory failure (ARF). Despite an increasing worldwide application, there is still scarce evidence of significant NIMV benefits in this specific setting, and no clear recommendations are provided. We performed a systematic review, and a search of clinical databases including MEDLINE and EMBASE was conducted from the beginning of 1990 until today. Although the benefits in reducing the intubation rate, morbidity and mortality are unclear, NIMV may be useful and does not appear to be associated with harm when applied in properly selected patients with moderate ARF at an earlier stage of injury by experienced teams and in appropriate settings under strict monitoring. In the presence of these criteria, NIMV is worth attempting, but only if endotracheal intubation is promptly available because non-responders to NIMV are burdened by an increased mortality when intubation is delayed.

Keywords: Non-invasive mechanical ventilation, continuous positive airway pressure, acute lung injury, acute respiratory distress syndrome, acute respiratory failure, transfusion-associated circulatory overload

Introduction

Trauma patients are a heterogeneous patient population with different respiratory needs. The intensity and modality of respiratory and ventilatory supports mainly depend on the severity of respiratory dysfunction, the degree of gas exchange impairment, associated injuries and the feasibility of non-invasive mechanical ventilation (NIMV) as the first-line approach.

The usefulness of NIMV (either non-invasive positive pressure ventilation [NPPV] or continuous positive airway pressure [CPAP]) in the respiratory management of trauma patients has still not been sufficiently investigated on a large scale.

According to the British Thoracic Society guidelines from 2002 (1), the indications and efficacy of NIMV in trauma-induced respiratory insufficiency were inconsistent and merely received a low-grade recommendation. In the last 20 years, several reports have demonstrated that NIMV may be effective in trauma patients as a means of preventing or treating

Corresponding Author: Annia Schreiber E-mail: annia.schreiber@fsm.it

©Copyright 2018 by Turkish Anaesthesiology and Intensive Care Society - Available online at www.jtaics.org

Received : 28.02.2017
Accepted : 20.12.2017

impending or evident respiratory failure. However, despite increasing worldwide application, there are still no specific recommendations on the NIMV use in such a setting.

Factors that may account for the scarce evidence of the significant benefit of NIMV in trauma patients include the lack of uniformity, standardisation and design of various NIMV trials, the wide range of different traumatic events after which it was attempted and the low number of patients with significant hypoxemia included in the trials. Different conclusions likely emerge because of different objectives and comparisons of the investigations. For example, some trials compared NIMV with conventional ventilation, some compared it with high-flow nasal oxygen, and some assessed its ability to improve gas exchange, prevent tracheal intubation or reduce mortality (2-5).

When evaluating the benefits of NIMV, the aetiology of acute respiratory failure (ARF) may become an important determinant of the final outcome, which likely explains the variable outcomes of NIMV application in various diseases and severities of lung injury.

Given the lack of a clear consensus on the use of NIMV in patients with trauma-related ARF, we performed a systematic review on clinical experience, recommendations, technical aspects and final results of its use in this setting.

Methods

Study design and literature search

By selecting several major key topics, our aim was to investigate the indications for NIMV in polytrauma as well as its foremost effects.

We included data only from studies that enrolled adults (aged >18 years) who developed ARF as a consequence of blunt or penetrating trauma and who were admitted to the emergency department, trauma service or intensive care unit (ICU) and treated with NIMV.

Randomised and non-randomised controlled trials, as well as observational studies including cohort, case-control and case series, were searched from previously published systematic reviews and meta-analyses. The list of studies was updated by a number of clinical databases, including MEDLINE and EMBASE, from January 1990 until the day when the search strategy was developed to maximise the sensitivity of article identification, and it was not restricted by language. The selected keywords were non-invasive mechanical ventilation, CPAP and polytrauma, which were cross-referenced with flail chest, pulmonary contusion, chest injury, blunt chest trauma, acute lung injury (ALI), acute respiratory distress syndrome (ARDS), transfusion-related acute lung injury (TRALI), and transfusion-associated circulatory overload (TACO). Because this was a retrospective review, ethical approval was deemed not necessary for data collection.

Results

ARF in trauma

Two major mechanisms are responsible for ARF following trauma: (a) the direct involvement of the thoracic cage or lung parenchyma, such as in the case of multiple rib fractures, pulmonary contusions, pneumothorax and injury to airway structures, major vessels, heart and pericardium, diaphragm and other structures of the mediastinum and (b) the leakage of oedema fluid into the lung and inflammatory cellular infiltrates associated with altered surfactant composition and diffusion abnormalities. The latter mechanism is the typical feature of lung involvement from non-thoracic trauma associated with shock, disseminated intravascular coagulation, sepsis syndrome, large transfusion of blood products and acute pancreatitis. Both pathogenic events may converge on a common pathophysiological pathway and cause differing degrees of ARDS severity.

In spontaneously breathing patients, the trauma-induced alteration of the chest wall mechanics decreases the tidal volume interfering with the cough reflex, predisposing to the retention of secretions, atelectasis and pneumonia. An associated pulmonary contusion can dramatically contribute to intrapulmonary shunt and the worsening of gas exchange.

Non-invasive ventilation in flail chest

There has been an increasing use of NIMV in patients with ARF to avoid endotracheal intubation (ETI) and its complications (5).

Chest injury and its relevant complications are responsible for as much as 25% of blunt trauma mortality. Flail chest occurs in almost 20% of patients hospitalised for blunt chest trauma, and the overall mortality may be as high as 35% (6, 7).

Flail chest is defined as fractures of more than three consecutive ribs at two separate sites. When adjacent ribs are fractured, that segment of the thorax becomes disconnected from the remaining of the rib cage, resulting in a paradoxical movement of the involved part. During inspiration, the flail segment moves inwards, pulled by the negative intra-thoracic pressure, whereas during expiration, it moves outwards due to the positive intra-thoracic pressure, causing a variable degree of disarrangement in ventilation and gas exchange (7). This is particularly evident in patients with flail chest who present with hypoxemic ARF and are at high risk for respiratory impairment (8). The causes of respiratory failure in these patients include shunt (secondary to lung contusion), ventilation-perfusion mismatch, atelectasis, pneumothorax or haemothorax. After an appropriate pain management, the goal should be to avoid ETI (9). The application of positive pressure to the airways, either by NPPV or CPAP, may reduce the need to intubate such patients.

Tzelepis et al. (10) investigated the physiological role of CPAP in the treatment of flail chest-related respiratory failure by as-

sessing chest wall distortion in patients with flail chest on various ventilatory modes. The results of their study showed that there was less chest wall distortion during a high-flow CPAP than during intermittent mandatory ventilation. Moreover, CPAP produced the least overall distortion, which was likely related to the effect of positive pleural pressure and the minimal ventilator-imposed load of this system. Therefore, CPAP may provide enough pneumatic force to stabilise the flail segments, thereby providing a true "internal pneumatic stabilisation" (11).

Mechanical ventilatory support is not always mandatory for the treatment of flail chest (12); its need depends on the severity of ARF and existing co-morbidities, such as pulmonary contusion and post-traumatic ALI. In 1975, Trinkle et al. (13) showed that flail chest-associated ARF was mainly due to the underlying pulmonary contusion, rather than paradoxical respiration due to the flail chest itself. There is a lack of scientific evidence for the treatment of flail chest; recent guidelines (14) made no level 1 recommendations for the management of flail chest and pulmonary contusion.

In a prospective study, patients with flail chest had a higher rate of mechanical ventilation use, greater incidence of respiratory complications and longer length of hospital stay than those with rib fractures only, despite similar clinical severity, age and rates of lung contusion and extrathoracic injury (15).

Only two randomised controlled trials (RCTs) have compared NIMV with ETI in patients with flail chest or multiple rib fractures, and only one has evaluated NPPV as opposed to oxygen therapy to prevent ETI. The first RCT comparing CPAP with ETI was published in 1990 by Bolliger *and* Van Eeden (16). In 69 patients with more than three rib fractures and hypoxemia, CPAP with regional analgesia was compared with ETI, NPPV with positive end expiratory pressure (PEEP) and systemic analgesia. The CPAP group had a shorter duration of treatment and length of ICU stay and a lower rate of complications (28% vs. 73%). The main difference in complications was the incidence of infections, primarily pneumonia, which occurred in 14% as opposed to 48%.

In another RCT, Gunduz et al. (17) compared CPAP with ETI and NPPV in patients with flail chest. In the CPAP group, pain control was achieved with morphine sulphate patient-controlled analgesia. In the NPPV group, propofol plus fentanyl were infused continuously. PaO_2 was higher in the NPPV group in the first 2 days, but no differences were observed over the following days. There were no differences in the mean ICU or hospital length of stay. Differences were observed in the incidence of nosocomial infections (47.6% in the NPPV group vs. 18.2% in the CPAP group) and mortality directly or indirectly linked to infection (seven vs. two patients).

In a retrospective study by Tanaka et al. (11), CPAP was applied in patients with flail chest trauma. These patients were compared with historical controls who were primarily treated with mechanical ventilation. The patients treated with CPAP had a lower rate of pulmonary complications (atelectasis 47% *vs.* 95%; pneumonia 27% *vs.* 70%) than the historical controls.

Hernandez et al. (18) performed an RCT to assess if NPPV, as compared to high-flow nasal oxygen, could reduce the intubation rate in patients with severe chest trauma-related hypoxemia. They also enrolled patients with flail chest (seven of 50 patients). The primary end-point was the intubation rate, which was higher in the control group, even for the seven patients hadflail chest.

NIMV in non-flail chest trauma

Gregoretti et al. (19) evaluated 22 trauma patients who were weaned from invasive mechanical ventilation and switched to NIMV at similar levels of both inspiratory and expiratory pressures. They found that all patients tolerated NIMV and had a similar improvement in gas exchange and respiratory pattern, but nine (40.9%) patients required re-intubation. In this study, gas exchange improved earlier with invasive mechanical ventilation.

In 2005, a prospective observational study was conducted to evaluate the safety and efficacy of NIV in patients with ARF due to blunt thoracic trauma (20). Twenty-two patients were enrolled and treated with NIMV combined with regional anaesthesia. Gas exchange and heart and respiratory rates improved 1 h after starting NIMV. Eighteen of the 22 patients avoided ETI and four required intubation, of whom one developed septic shock and died.

Table 1 summarises some studies that investigated NIMV in patients with chest trauma and fail chest.

Vidhani et al. (21) conducted a retrospective review of 75 adults with blunt traumatic pulmonary contusions and found that patients with significant pulmonary contusion, as indicated by $PaO_2/FiO_2<300$, were safely managed with NPPV.

The trial by Hernandez et al. (18) was prematurely interrupted because the intubation rate was much higher in controls than in patients who underwent NIMV (40% vs. 12%, $p<0.02$). Furthermore, the length of hospital stay was shorter in patients who underwent NIMV (14 vs. 21 days $p<0.001$), but no differences were observed in survival or other secondary end-points.

In a study by Antonelli et al. (22), NIMV significantly reduced the intubation rate in patients with severe thoracic trauma compared with the rate in the control group (12% vs. 18%). The benefit of NIMV was attributed to the inclusion of patients within 48 h after trauma, high prevalence of lung contusions as the major underlying cause of hypoxia and extended length of NIMV use. The authors concluded that in patients with severe thoracic trauma-related hypoxia, an early and continuous application of NIMV is effective in reducing the need for intubation.

Table 1. Summaries of some studies investigating the effect of NIMV in patients with chest trauma and flail chest

Study	Patient number	Patient population	Comparison parameters	Primary end-point	Secondary end-point	Reference
Tzelepis et al. (1989, case series)	13	Flail chest (n=9) Normal (n=4)	Mechanical ventilation vs. CPAP or CPAP spontaneous high-flow or breathing with T-piece	Chest wall distortion: greater during spontaneous breaths	Differences in mean $Pa0_2$:CPAP high flow (–3.3±–1.5 cm H_2O), being less loaded than MV (–7.2±2.8 cm H_2O) or CPAP (–7.1±2.4 cm H_20) (p<0.01)	10
Tanaka et al. (2001, case series)	59	Flail chest	CPAP vs. spontaneous breathing	Incidence and duration of endotracheal entubation: not istatistically significant	Mortality rate: 51% vs. 25%, p=0.0531	11
Bolliger and Van Eeden (1990, RCT)	69	>3 rib fractures, pulmonary contusion	CPAP vs. MV	Duration of treatment, CPAP vs. MV (4.5±2.3 vs. 7.3±3.7 days, p=0.0003) Intensive care days (5.3±2.9 vs. 9.5±4.4 days, p<0.0001); hospitalisation days (8.4±7.1 vs. 14.6±8.6 days, p=0.0019)	Nosocomial infection: 13.8% Pneumothorax: 5.5% Mortality: 0%	16
Xirouchaki et al. (2005, case series)	22	Blunt thoracic trauma	NPPV vs. standard care NIMV: 18%	Need for intubation due to failure of	Nosocomial infection: 13.6% Mortality: 0%	20
Gunduz et al. (2005, RCT)	43	≥5 rib fractures in a row, ≥3 segmental rib fractures, flail chest	CPAP vs. MV	Need for intubation due to failure of NIMV: 17%	Nosocomial infection: 9% Mortality: 9%	17
Hernandez et al. (2010, RCT)	50	Lung contusions/ quadrant, thoracolumbar vertebral trauma, flail chest	NPPV vs. high-flow nasal oxygen	Need for intubation: 12% in the NIMV group vs. 40% in the high-flow nasal oxygen group	Nosocomial infection: 8% vs. 12% Pneumothorax: 24% vs. 12% Mortality: 4% vs. 4%	18

RCT: randomized controlled trial; CPAP: continuous positive airway pressure; MV: mechanical ventilation; NPPV: non-invasive positive pressure ventilation; NIMV: non-invasive mechanical ventilation; PaO_2: partial pressure of oxygen

NIMV in trauma-induced ARF and ARDS

Although the use of NIMV strategies has not gained universal approval in this setting because of the increased transpulmonary pressure and the uncontrolled overdistention of the alveoli, the commonly advocated advantages include the preservation of airway defence mechanisms, the decreased need for sedation and improvements in gas exchange.

One of the first randomised trials investigating the use of CPAP in trauma patients was conducted by Hurst et al. (23). Patients presenting with hypoxemia despite supplemental oxygen administration, and normo- or hypocarbia were treated with CPAP via a facemask. In 32 of 33 patients with isolated chest trauma, the therapeutic end-point of PaO_2/FiO_2>300 mm Hg was achieved. ETI was required in only two patients for reasons other than an elevation in $PaCO_2$.

Although the number of studies in this field is limited, CPAP alone, compared with NPPV, does not appear to decrease respiratory fatigue or dyspnoea or have substantial effects on oxygenation. In various reports, the addition of pressure support (PS) to PEEP was more effective than CPAP alone in unloading the inspiratory muscles, reducing neuromuscular drive and alleviating dyspnoea (24-26).

In the paper by Antonelli et al. (27), four of 32 patients who were assigned to NPPV had respiratory distress due to trauma-induced pulmonary contusion or atelectasis. This treatment was associated with a rapid and significant improvement in the PaO_2-to-FiO_2 ratio, and ETI was avoided in all

four patients and no mortality occurred. In contrast, one of the four patients assigned to the conventional mechanical ventilation group died.

In a retrospective clinical study, Beltrame et al. (28) evaluated NPPV treatment in 46 patients with trauma-related ARF. Thirty-three (72%) patients were successfully weaned to spontaneous breathing. The effectiveness of NPPV was demonstrated by an improvement in the PaO_2-to-FiO_2 ratio, an increase in the tidal volume and a decrease in the respiratory rate. The failure group included nine patients with hypercapnia and four with hypoxemic respiratory failure; all required invasive mechanical ventilation.

In the study by Antonelli et al. (22), 88 patients were admitted to the ICU with trauma-related ARDS. Sixty-one (69%) of the 88 patients avoided intubation following NIMV, whereas 27 (31%) required invasive mechanical ventilation. In the subgroup of patients with pulmonary contusions and multiple trauma, only 18% required intubation.

In 2003, Ferrer et al. (29) compared the efficacy of NPPV to that of Venturi oxygen mask in avoiding intubation and improving the survival in patients with severe hypoxemic ARF. Six patients with thoracic trauma were enrolled in the NIMV group and 12 were enrolled in the control group. No ICU mortality was observed in the NIMV group, whereas three deaths were observed in the control group. Despite the small sample size, the authors observed a non-significant reduction of the intubation rate in patients in the NIMV group.

In a study by Xirouchaki et al. (20), several patients had bilateral lung injuries and were more likely to require intubation and prolonged mechanical ventilation. Within 24 h after starting NPPV, four patients required ETI.

According to the current available evidence, the practical results of NIMV techniques for ALI/ARDS are conflicting.

Despite initial favourable observations of Antonelli et al. (27), more recent trials (30, 31), although not the ones that enrolled trauma patients, have shown that the failure rate of NIMV in ALI/ARDS appears to exceed 50%.

Moreover, a recent meta-analysis (32) has highlighted that the number of RCTs reporting on NIMV in patients with ARDS is very limited and that the results of these studies suggest that these patients were unlikely to have important added outcome benefits from NIMV. The overall intubation rate in the NIMV group was 48%, and the overall mortality rate was 35%. However, patient selection widely differed among the studies, and none of these studies included trauma-associated ARDS, thus making the generalisation of the review's results problematic.

The controversial role of NIMV as a definitive treatment of chest trauma-induced respiratory distress has also been highlighted in the systematic review published by Duggal et al. (33). They concluded that while NIMV may prevent intubation and decrease complications and ICU length of stay in selected patients with chest trauma and without respiratory failure, either no data or low-/moderate-quality data attest to its benefit in patients with severe hypoxemia and ARDS.

NIMV in Massive TRALI

Trauma patients suffering from multiple injuries and haemorrhagic shock necessarily undergo the transfusion of large amounts of blood, plasma and platelets. Almost no data are available on the effectiveness of non-invasive approaches in the management of ALI associated with massive transfusion. Most pertinent studies have emphasised the potential of NIMV in supporting ventilatory fatigue, alleviating dyspnoea and improving oxygenation, but no RCTs have been published that compared its efficacy and clinical outcomes with those of other treatments.

TRALI is characterised by a severe acute reaction, occurring during or within 6 h of transfusion and with no other apparent cause, which may cause pulmonary infiltrates, hypoxemia and respiratory distress. According to the "two hit" pathogenetic mechanism of TRALI, a first event such as sepsis or trauma potentially induces pulmonary endothelial activation, release of cytokines and "neutrophil priming." The subsequent exposure to lipids, cytokines or antibodies associated with massive transfusion would then activate adherent neutrophils and release inflammatory mediators, leading to lung injury (34, 35).

TRALI and ARDS share a common pathophysiologic pathway and clinical definition except that TRALI is temporally and mechanistically related to the transfusion of blood or blood components. In both diseases, the increased pulmonary capillary permeability results in the movement of plasma into the alveolar space, thereby causing pulmonary oedema (36).

In some individuals, such as the elderly or patients with borderline cardiac function, trauma-associated massive transfusion may be responsible for another complication-TACO-which might cause hypoxemia and respiratory distress by itself. Although it can be difficult to differentiate the signs and symptoms of TRALI from those of the other forms of ARDS, patients affected by TACO usually manifest ARF associated with signs of circulatory overload, such as jugular venous distension and elevated pulmonary artery occlusion pressure, sometimes even before the initiation of a transfusion. The B-type natriuretic peptide level has been identified as a valid laboratory adjunct in the differentiation of TRALI from TACO (37).

The treatment of TRALI is identical to that of ARDS: for mild disease, supplemental oxygen and supportive care may be sufficient; for the most serious cases, either NIMV or invasive mechanical ventilation may be necessary, depending on the patient's clinical condition and the severity of respiratory

insufficiency; and for less severe cases, a trial of NIMV could be warranted. Van Stein and associates (38) retrospectively evaluated 49 patients with TRALI and found that 11 (29%) were already on mechanical ventilation during transfusion, 21 (55%) required mechanical ventilation after the onset of TRALI, two (5%) underwent successful NIMV treatment and the remainder required only supplemental oxygen.

Discussion

Previous statements from the International Consensus Conference (39) have confirmed that in selected patients, the early institution of NIMV may reverse the acute episode and obviate the need for ETI; however, the switch to invasive ventilation has been reported in a high number of patients.

After several years of NIMV application, there are still insufficient RCTs that support the use of NIMV in trauma patients. The available reports have mainly investigated its benefits or harm in small subgroups, with almost no comparisons with controls. A recent summary of clinical practice guidelines' statements (5) made no recommendation on the use of NIMV in chest trauma without respiratory distress because of the lack of RCTs and no recommendation on its use in patients with chest trauma and respiratory distress. The same guidelines specifically recommended that CPAP should not be used.

However, in a recently published meta-analysis (40), the authors suggested that NIMV is useful in the management of patients with ARF due to chest trauma because it is associated with a significant reduction in the intubation rate, in the incidence of overall complications and infections, in the length of ICU stay and in mortality.

As emphasised by Hernandez et al. (18), when NPPV is applied early, the beneficial results can be ascribed to the ease of the recruitment of contused lung regions. By increasing the intra-thoracic pressure, NIMV increases the functional residual capacity, improves oxygenation, reduces the work of breathing and does not significantly alter the haemodynamics.

Given the disappointing results of various trials and meta-analyses, the selection of appropriate patients is crucial for optimising NIMV success rates and resource utilisation; otherwise, the extensive application of NIMV in patients with trauma-associated ARF may be challenging.

Although it has become a part of routine care for several patients with ARF, implementing NIMV for some patients may simply prolong the time to the inevitable intubation. Therefore, close monitoring is mandatory because delaying the time to intubation often leads to further respiratory instability. Non-responders to NIMV are burdened by an increased mortality risk when intubation is delayed (30, 32).

As a result, the role of NIMV in managing moderate respiratory insufficiency associated with trauma or TRALI may become important if applied in properly selected patients at an earlier stage of their lung injury by trained and experienced teams, with optimal choice of devices and in appropriate settings.

Conclusion

1. NIMV for the management of trauma patients may avoid risks associated with ETI-related infections. However, scientific evidence for an appropriate treatment of flail chest is lacking. A recent publication that reviewed management guidelines found no level 1 recommendations for flail chest (14). Level 2 recommendations comprise fluid resuscitation, pain management, avoidance of steroids and ventilatory management. An NIMV trial should be considered in alert and compliant patients with marginal respiratory status (level 3 recommendation), and the discontinuation of mechanical ventilation at the earliest possible time is advisable (40).

2. The optimal non-invasive approach is based on an understanding of the pathophysiology of individual patients with traumatic lung damage and the severity of gas exchange impairment. The main ventilatory goals are to improve oxygenation, unload respiratory muscles and relieve dyspnoea. PEEP added to PS has been shown to potentially recruit and stabilise previously collapsed lung tissue, and gradually adjusting the PS may help relieve dyspnoea.

3. Patients with flail chest-related respiratory failure should be treated early with NPPV and should not be prophylactically intubated. Further investigations are needed to assess which technique (CPAP or NPPV) is the best for the treatment of these patients.

4. Even if not supported by clear evidence, NPPV seems to be more effective than CPAP alone in maximising lung function until the reversal of the precipitating cause. Although the benefits in terms of reducing the intubation rate, morbidity and mortality are unclear, NIMV does not appear associated with harm when applied in properly selected patients in an adequate environment and under strict monitoring. In the presence of reliable selection criteria, it is worth attempting (41).

5. NIMV for patients with moderate trauma-related ARF should be considered as the first-choice treatment in the absence of contraindications; however, it should be implemented only where patients are closely monitored and ETI is promptly available.

6. In the specific setting of lung dysfunction due to chest trauma, the likelihood of success increases if proper measures of adequate pain control are adopted.

Peer-review: Externally peer-reviewed.

Author Contributions: Concept – A.S., F.Y., G.F., A.A., P.B.D., A.M.E.; Design – A.S., F.Y., G.F., A.A., P.B.D., A.M.E.; Supervision – M.G., K.M., P.P., R.C., Y.D., A.M.E.; Resources – A.S., F.Y., G.F., A.A., P.B.D.; Materials – A.S., F.Y., G.F., A.A., P.B.D.; Analysis and/or Interpretation – A.S., F.Y., G.F., A.A., P.B.D., M.G., K.M., P.P., R.C., Y.D., A.M.E.; Literature Search – A.S., F.Y., G.F., A.A., P.B.D.; Writing Manuscript – A.S., F.Y., G.F., A.A., P.B.D., M.G., K.M., P.P., R.C., Y.D., A.M.E.; Critical Review – M.G., K.M., P.P., R.C., Y.D., A.M.E.

Conflict of Interest: No conflict of interest was declared by the authors.

Financial Disclosure: The authors declared that this study has received no financial support.

References

1. British Thoracic Society Standards of Care Committee. Non-invasive ventilation in acute respiratory failure. Thorax 2002; 57: 192-211.
2. Bierer GB, Soo Hoo GW. Noninvasive ventilation for acute respiratory failure: a national survey of Veterans Affairs hospitals. Respir Care 2009; 54: 1313-20.
3. Agarwal R, Aggarwal AN, Gupta D. Role of noninvasive ventilation in acute lung injury/acute respiratory distress syndrome: a proportion meta-analysis. Respir Care 2010; 55: 1653-60.
4. Boldrini R, Fasano L, Nava S. Noninvasive mechanical ventilation. Curr Opin Crit Care 2012; 18: 48-53. [CrossRef]
5. Keenan SP, Sinuff T, Burns KE, Muscedere J, Kutsogiannis J, Mehta S, et al. Clinical practice guidelines for the use of noninvasive positive-pressure ventilation and noninvasive continuous positive airway pressure in the acute care setting. CMAJ 2011; 183: E195-214.
6. Gaillard M, Hervé C, Mandin L, Raynaud P. Mortality prognostic factors in chest injury. J Trauma 1990; 30: 93-6. [CrossRef]
7. Davignon K, Kwo J, Bigatello LM, Pathophysiology and management of the flail chest. Minerva Anestesiol 2004; 70: 193-9.
8. Keenan SP, Mehta S. Noninvasive ventilation for patients presenting with acute respiratory failure: the randomized controlled trials. Respir Care 2009; 54: 116-26.
9. Papadakos PJ, Karcz M, Lachmann B. Mechanical ventilation in trauma. Curr Opin Anaesthesiol 2010; 23: 228-32. [CrossRef]
10. Tzelepis GE, McCool FD, Hoppin FG. Chest wall distortion in patients with flail chest. Am Rev Respir Dis 1989; 140: 31-7. [CrossRef]
11. Tanaka H, Tajimi K, Endoh Y, Kobayash K. Pneumatic stabilization for flail chest injury: an 11-year study. Surg Today 2001; 31: 12-7. [CrossRef]
12. Athanassiadi K, Gerazounis M, Theakos N. Management of 150 flail chest injuries: analysis of risk factors affecting outcome. Eur J Cardiothorac Surg 2004; 26: 373-6. [CrossRef]
13. Trinkle JK, Richardson JD, Franz JL, Grover FL, Arom KV, Holmstrom FMG. Management of flail chest without mechanical ventilation. Ann Thorac Surg 1975; 19: 355-63. [CrossRef]
14. Simon B, Ebert J, Bokhari F, Capella J, Emhoff T, Hayward TIII, et al. Management of pulmonary contusion and flail chest: an Eastern Association for the Surgery of Trauma practice management guideline. J Trauma Acute Care Surg 2012; 73(5 Suppl 4): S351-61.
15. Velmahos GC, Vassiliu P, Chan LS, Murray JA, Berne TV, Demetriades D. Influence of flail chest on outcome among patients with severe thoracic cage trauma. Int Surg 2002; 87: 240-4.
16. Bolliger CT, Van Eeden SF. Treatment of multiple rib fractures. Randomized controlled trial comparing ventilatory with non-ventilatory management. Chest 1990; 97: 943-8.
17. Gunduz M. A comparative study of continuous positive airway pressure (CPAP) and intermittent positive pressure ventilation (IPPV) in patients with flail chest. Emerg Med J 2005; 22: 325-9. [CrossRef]
18. Hernandez G, Fernandez R, Lopez-Reina P, Cuena R, Pedrosa A, Ortiz R, et al. Noninvasive ventilation reduces intubation in chest trauma-related hypoxemia: a randomized clinical trial. Chest 2010; 137: 74-80. [CrossRef]
19. Gregoretti C, Beltrame F, Lucangelo U, Burbi L, Conti G, Turello M, et al. Physiologic evaluation of non-invasive pressure support ventilation in trauma patients with acute respiratory failure. Intensive Care Med 1998; 24: 785-90. [CrossRef]
20. Xirouchaki N, Kondoudaki E, Anastasaki M, Alexopoulou C, Koumiotaki S, Georgopoulos D. Noninvasive bilevel positive pressure ventilation in patients with blunt thoracic trauma. Respiration 2005; 72: 517-22. [CrossRef]
21. Vidhani K, Kause J, Parr M. Should we follow ATLS guidelines for the management of traumatic pulmonary contusion: the role of non-invasive ventilatory support. Resuscitation 2002; 52: 265-8. [CrossRef]
22. 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 Med 2001; 27: 1718-28. [CrossRef]
23. Hurst JM, DeHaven CB, Branson RD. Use of CPAP mask as the sole mode of ventilatory support in trauma patients with mild to moderate respiratory insufficiency. J Trauma 1985; 25: 1065-8.
24. Delclaux C, L'Her E, Alberti C, Mancebo J, Abroug F, Conti G, et al. Treatment of acute hypoxemic nonhypercapnic respiratory insufficiency with continuous positive airway pressure delivered by a face mask: A randomized controlled trial. JAMA 2000; 284: 2352-60. [CrossRef]
25. Chadda K, Annane D, Hart N, Gajdos P, Raphaël JC, Lofaso F. Cardiac and respiratory effects of continuous positive airway pressure and noninvasive ventilation in acute cardiac pulmonary edema. Crit Care Med 2002; 30: 2457-61. [CrossRef]
26. L'Her E, Deye N, Lellouche F, Taille S, Demoule A, Fraticelli A, et al. Physiologic effects of noninvasive ventilation during acute lung injury. Am J Respir Crit Care Med 2005; 172: 1112-8. [CrossRef]
27. Antonelli M, Conti G, Rocco M, Bufi M, Alberto De Blasi R, Vivino G, et al. A comparison of noninvasive positive-pressure ventilation and conventional mechanical ventilation in patients with acute respiratory failure. N Engl J Med 1998; 339: 429-35. [CrossRef]
28. Beltrame F, Lucangelo U, Gregori D, Gregoretti C. Noninvasive positive pressure ventilation in trauma patients with

acute respiratory failure. Monaldi Arch Chest Dis 1999; 54: 109-14.
29. Ferrer M, Esquinas A, Leon M, Gonzalez G, Alarcon A, Torres A. Noninvasive ventilation in severe hypoxemic respiratory failure: a randomized clinical trial. Am J Respir Crit Care Med 2003; 168: 1438-44. [CrossRef]
30. Rana S, Jenad H, Gay PC, Buck CF, Hubmayr RD, Gajic O. Failure of non-invasive ventilation in patients with acute lung injury: observational cohort study. Crit Care 2006; 10: R79.
31. Antonelli M, Conti G, Esquinas A, Montini L, Maggiore SM, Bello G, et al. A multiple-center survey on the use in clinical practice of noninvasive ventilation as a first-line intervention for acute respiratory distress syndrome. Crit Care Med 2007; 35: 18-25. [CrossRef]
32. Agarwal R. Outcomes of noninvasive ventilation in acute hypoxemic respiratory failure in a respiratory intensive care unit in north India. Respir Care 2009; 54(: 1679-87.
33. Duggal A, Perez P, Golan E, Tremblay L, Sinuff T. Safety and efficacy of noninvasive ventilation in patients with blunt chest trauma: a systematic review. Critical Care 2013; 17: R142.
34. Silliman CC. The two-event model of transfusion-related acute lung injury. Crit Care Med 2006; 34(Suppl 5): S124-31.
35. Barrett NA, Kam PC. Transfusion-related acute lung injury: a literature review. Anaesthesia 2006; 61: 777-85. [CrossRef]
36. Triulzi DJ. Transfusion-related acute lung injury: an update. Hematology Am Soc Hematol Educ Program 2006; 1: 497-501. [CrossRef]
37. Gajic O, Gropper MA, Hubmayr RD. Pulmonary edema after transfusion: how to differentiate transfusion-associated circulatory overload from transfusion-related acute lung injury. Crit Care Med 2006; 34(Suppl 5): S109-13.
38. Van Stein D, Beckers EA, Sintnicolaas K, Porcelijn L, Danovic F, Wollersheim JA, et al. Transfusion-related acute lung injury reports in the Netherlands: an observational study. Transfusion 2010; 50: 213-20. [CrossRef]
39. Evans TW. International Consensus Conferences in Intensive Care Medicine: non-invasive positive pressure ventilation in acute respiratory failure. Organised jointly by the American Thoracic Society, the European Respiratory Society, the European Society of Intensive Care Medicine, and the Societe de Reanimation de Langue Francaise, and approved by the ATS Board of Directors, December 2000. Intensive Care Med 2001; 27: 166-78.
40. Chiumello D, Coppola S, Froio S, Gregoretti C, Consonni D. Noninvasive ventilation in chest trauma: systematic review and meta-analysis. Intensive Care Med 2013; 39: 1171-80. [CrossRef]
41. Nava S, Hill N. Non-invasive ventilation in acute respiratory failure. Lancet 2009; 374: 250-9.[CrossRef]