CHEST

Original Research

CRITICAL CARE MEDICINE

Noninvasive Ventilation Reduces Intubation in Chest Trauma-Related Hypoxemia

A Randomized Clinical Trial

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Background: **Guidelines for noninvasive mechanical ventilation (NIMV) recommend continuous positive airway pressure in patients with thoracic trauma who remain hypoxic despite regional anesthesia. This recommendation is rated only by level C evidence because randomized controlled trials in this specific population are lacking. Our aim was to determine whether NIMV reduces intubation in severe trauma-related hypoxemia.**

Methods: **This was a single-center randomized clinical trial in a nine-bed ICU of a level I trauma hospital. Inclusion criteria were patients with $Pao_2/Fio_2 < 200$ for > 8 h while receiving oxygen by high-flow mask within the first 48 h after thoracic trauma. Patients were randomized to remain on high-flow oxygen mask or to receive NIMV. The interface was selected based on the associated injuries. Thoracic anesthesia was universally supplied unless contraindicated. The primary end point was intubation; secondary end points included length of hospital stay and survival. Statistical analysis was based on multivariate analysis.**

Results: **After 25 patients were enrolled in each group, the trial was prematurely stopped for efficacy because the intubation rate was much higher in controls than in NIMV patients (10 [40%] vs 3 [12%], *P* = .02). Multivariate analysis adjusted for age, gender, chronic heart failure, and Acute Physiology and Chronic Health Evaluation II at admission revealed NIMV as the only variable independently related to intubation (odds ratio, 0.12; 95% CI, 0.02-0.61; *P* = .01). Length of hospital stay was shorter in NIMV patients (14 vs 21 days *P* = .001), but no differences were observed in survival or other secondary end points.**

Conclusion: **NIMV reduced intubation compared with oxygen therapy in severe thoracic trauma-related hypoxemia.**

Trial registration: **clinicaltrials.gov; identifier: NCT 00557752.** ***CHEST 2010; 137(1):74–80***

Abbreviation: APACHE II = Acute Physiology and Chronic Health Evaluation; EPAP = expiratory positive airway pressure; IPAP = inspiratory positive airway pressure; LOS = length of hospital stay; NIMV = noninvasive mechanical ventilation; RR = respiratory rate; Spo_2 = oxygen saturation as measured by pulse oximetry

Intubation rates reported in patients with chest trauma range from 23% to 75%, mainly depending on trauma severity, the presence of underlying pulmonary disease, associated injuries, and the intensity of ICU monitoring and management.[1,2] However, in a multicenter survey, posttraumatic hypoxemic respiratory failure responded favorably to noninvasive mechanical ventilation (NIMV), with a moderate rate of NIMV failure (18%).[3]

The critical care management of these patients has focused on surgical stabilization, fluid management, pulmonary toilet, and control of chest wall pain; ventilatory management has received little attention,[4-8] and this is reflected in the low-grade recommendation for NIMV in trauma patients in the British Thoracic Society guidelines.[9]

Previous studies focused on NIMV in hypoxemic patients include a mixed population with a low percentage of trauma patients or are limited to comparisons with invasive ventilation.[10] Moreover, to our knowledge, no studies have explored the potential usefulness of NIMV in preventing intubation when hypoxemia develops after chest trauma. One randomized clinical trial[11] examined ventilatory management but excluded

patients with severe hypoxia ($Pao_2/Fio_2 < 150$); furthermore, the bias induced by higher injury severity scores in intubated patients in that study precludes useful clinical conclusions. Finally, the safety profile of NIMV was reinforced by a lack of pneumothorax when NIMV plus systemic analgesia was applied in trauma patients with a high incidence of flail chest.[12]

Another multicenter randomized trial carried out in a mixed population (16% trauma patients) of patients with acute hypoxemic respiratory failure[13] can only partly elucidate the potential role of NIMV in avoiding intubation in hypoxic trauma patients, because the cause of the respiratory failure was not randomized. We hypothesized that early and continuous NIMV may improve clinically important end points, such as the intubation rate.

Materials and Methods

Patients

This prospective randomized controlled study was conducted in a 700-bed level I trauma center that works as regional referral center for traumatic brain injury. From September 2005 to June 2008, we screened all patients admitted for severe thoracic trauma to our nine-bed closed trauma ICU without out-of-hospital intubation. The study was approved by the Institutional Review Board. Informed consent was obtained from patients or relatives in all cases.

Inclusion criteria were: age older than 18 years, and early (first 48 h after trauma) and persistent (> 8 h) severe hypoxemic respiratory failure ($Pao_2/Fio_2 < 200$ mm Hg while receiving oxygen by high-flow [≥ 10 L/min] mask).

Patients meeting any of the following criteria were excluded from the study: (1) hypercapnia ($Paco_2 > 45$ mm Hg) on study entry; (2) orotracheal intubation indicated for another reason; (3) need for emergency intubation; (4) standard contraindications for NIMV (active gastrointestinal bleeding, low level of consciousness, multiorgan failure, airway patency problems, lack of cooperation, or hemodynamic instability); (5) severe traumatic brain injury; (6) facial trauma with pneumocephalus, skull base fracture, orbit base fracture, or any facial fracture involving a sinus; (7) cervical injury when treatment contraindicated a facial mask; (8) bronchopleural fistula; or (9) gastrointestinal trauma.

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Randomization

Within 6 h of fulfilling the inclusion criteria, patients were randomly allocated (concealed allocation) either to receive NIMV or to remain on high-flow oxygen mask (control group). Randomization was done with a random number generator using a constant block size of 10 and was assigned through a phone-call center. To minimize the risk of bias resulting from the obvious difficulty of maintaining blinding in the study, both groups were treated by the same members of the medical, nursing, and respiratory therapy staffs (excluding investigators) and the medical management of the acute respiratory failure was similar in both groups.

Protocol

In the NIMV group, patients were ventilated using the bilevel positive airway pressure mode (BiPAP Vision; Respironics Inc.; Murrysville, PA). The interface, either a face mask (Spectrum Reusable Full Face Mask; Respironics Inc.) or a total face mask (Total Face Mask; Respironics Inc.), was selected based on the associated injuries and patient's tolerance. Patients remained in semi-seated 45° position unless contraindicated. Nasogastric tubes for gastric drainage were placed in all patients during the first 24 h and passed through a seal connector.

Ventilation Protocol: Inspiratory positive airway pressure (IPAP) was initially set at 10 to 12 cm H_2O and expiratory positive airway pressure (EPAP) at 6 cm H_2O with enough Fio_2 to achieve oxygen saturation as measured by pulse oximetry (Spo_2) greater than 92% or Pao_2 greater than 65 mm Hg. After checking for tolerance, NIMV support was sequentially increased in 2-cm H_2O steps for IPAP and in 1-cm H_2O steps for EPAP. The clinical targets were respiratory rate (RR) less than 25 breaths/min and tidal volume greater than or equal to 8 mL/kg for IPAP and lowest Fio_2 with Spo_2 greater than or equal to 92% for EPAP titration, while minimizing patients' intolerance and leaks around the mask. Disconnections from NIMV were minimized in the first 24 h, but short intervals to increase the patient's tolerance or to allow coughing and clearing of respiratory secretions were allowed at the attending physician's discretion.

Weaning from NIMV: When patients tolerated $Fio_2 \leq 0.5$ with EPAP ≤ 8 cm H_2O and IPAP ≤ 14 cm H_2O for > 6 consecutive hours, withdrawal from NIMV was attempted daily in 30-min spontaneous breathing trials. Predefined criteria for failure of the spontaneous breathing trial were: $Spo_2 < 92\%$ or $Pao_2 < 65$ mm Hg with $Fio_2 > 0.5$, RR > 30 breaths/min, or activation of the accessory respiratory muscles.

In the control group, patients continued to receive oxygen from high concentration sources (High concentration oxygen mask; Intersurgical CRS; Berkshire, UK) with a high oxygen flow (≥ 10 L/min). The Fio_2 was set to achieve $Spo_2 > 92\%$ or $Pao_2 >$ 65 mm Hg. NIMV was not allowed in this group.

All aspects of patients' clinical management except ventilatory support remained at the attending physician's discretion excluding the investigators. Unless contraindicated, our standard treatment included regional anesthesia,[14] which was based mainly on epidural analgesia with fentanyl plus bupivacaine targeted by the attending physician. Contraindications of regional analgesia were: acute spine fracture or preexisting spinal deformity, spinal cord injury, altered mental status precluding pain assessment, unstable pelvic fracture, skin injury at the puncture site precluding epidural access, and ongoing cardiac instability or coagulopathy. Under these circumstances, analgesia was based on intravenous remifentanil and the dosage was determined using pain scales. Our hospital protocol for thoracic trauma includes a thoracic CT scan in patients with a thoracic Abbreviated Injury Scale score ≥ 3 derived from plain chest radiographs.

Predefined criteria for intubation for both groups were: (1) respiratory or cardiac arrest; (2) respiratory pauses or heart rate less than 50 beats/min with loss of consciousness or gasping for air; (3) major agitation inadequately controlled by sedation; (4) unequivocal clinical signs suggestive of respiratory-muscle fatigue, such as maintained active contraction of the expiratory muscles, asynchronous and paradoxical motion of the rib cage and abdomen, or respiratory alternans; (5) massive aspiration or inability to manage respiratory secretions appropriately; (6) hemodynamic instability without response to fluids and vasoactive agents; (7) refractory hypoxemia ($Spo_2 < 85\%$ despite the use of a high fraction of inspired oxygen); or (8) respiratory acidosis (persistent pH < 7.25 under optimal management). Patients fulfilling one of these criteria were intubated, but the final decision to intubate was evaluated by a consensus decision excluding the investigators.

We recorded RR, heart rate, blood pressure, and arterial blood gases at randomization and after 1 to 2 h, 3 to 4 h, 6 to 8 h, 12 h, 24 h, 48 h, and 72 h. Diagnoses of hospital-acquired pneumonia, septic shock, ARDS, and multiple organ failure were defined by published criteria.[15-17] In brief, diagnosis of hospital-acquired pneumonia was defined as new or progressive pulmonary infiltrates in plain chest radiographs, and at least two of the following criteria: persistent fever (≥ 38.3°C) or hypothermia (< 35°C); leukopenia or leukocytosis (WBC ≤ 4,000 or ≥ 12,000/μL); and purulent bronchial secretions. Cardiogenic pulmonary edema was diagnosed if patients had dyspnea of sudden onset with physical findings consistent with pulmonary edema.[18] ARDS was defined as the presence of bilateral pulmonary infiltrates with a $Pao_2/Fio_2 < 200$ mm Hg in the absence of cardiogenic pulmonary edema.[18] Patients were followed to hospital discharge or death.

End Points

The primary end point was intubation rate. The secondary end points were pneumothorax, pneumonia, and sepsis rates; ICU and hospital stays; and mortality.

Statistical Analysis

Sample Size and Interim Analyses: With an expected intubation rate of 45% in the control group and 16% in the NIMV group for a confidence level $[1-\alpha]$ 95% and power level $[1-\beta]$ 80%, the calculated sample size was 43 patients in each group. Two interim analyses at 18-month intervals were planned by the safety monitoring board. The predefined stopping rule (α spending function) was a significant difference in intubation rate in any group with a $P < .016$ in the first analysis and $P < .033$ in the second analysis.

Comparison Between the Two Groups: All prespecified analyses were conducted according to the intention-to-treat principle. Categorical variables were compared using Fisher exact tests. Continuous variables were compared using Mann-Whitney tests. The time courses of RR, heart rate, blood pressure, and arterial blood gas variables were compared using two-way analysis of variance for repeated measures with *post hoc* Student *t* test with Bonferroni adjustment. The Kaplan-Meier estimate of survival and the log-rank test were used to compare the cumulative probability of remaining on spontaneous breathing for the two groups. The level of significance was set at 0.05.

Risk Factors for Intubation: We used logistic regression for univariate and multivariate analyses of risk factors for intubation. Normally distributed continuous variables were described by means and standard deviations, whereas non-normally distributed variables were described by medians and 25th to 75th percentiles. Continuous variables were compared using Kruskal-Wallis and Mann-Whitney *U* tests. Categorical data were compared using χ^2 tests with Yates correction or two-tailed Fisher exact tests. A Cox multiple variable model was designed to assess the probability of being intubated using forward stepwise logistic regression of variables that were significant in the univariate analysis ($P < .05$) or that could act as confounding factors, and the results were expressed as odds ratios. All analyses were performed using SPSS statistical software version 13.0 (SPSS Inc.; Chicago, IL).

Results

At the second interim analysis, after enrollment of 50 patients, a significantly reduced intubation rate in the NIMV group led the safety monitoring board to stop the study. The Consolidated Standards of Reporting Trials study flow is summarized in Figure 1. During the 3-year study period, 79 patients were screened, but only 50 were finally included in the study, 25 randomized to each treatment group. The baseline characteristics of patients in each group are summarized in Table 1. In the univariate analysis, the only differences between groups were a higher Acute Physiology and Chronic Health Evaluation (APACHE) II score at ICU admission in the NIMV group and a trend toward more chronic heart failure in the NIMV group. Patients in the NIMV group received NIMV for a median of 3 days (range 2-14), whereas patients in the control group received high-flow oxygen mask for a median of 5 days (range 3-16).

Compared with controls, NIMV patients needed intubation less frequently (3/25 vs 10/25 $P = .02$) and later (median 168 [72-182] h vs 33 [24-52] h, $P < .01$) (Fig 2). The number of hours per day receiving NIMV was similar in patients who were eventually intubated and in those that did not require intubation (23 ± 1 vs 22 ± 2.5 h, $P = .6$ for the first day and 20 ± 4.3 vs 14 ± 6.9 h, $P = .09$ for the second day).

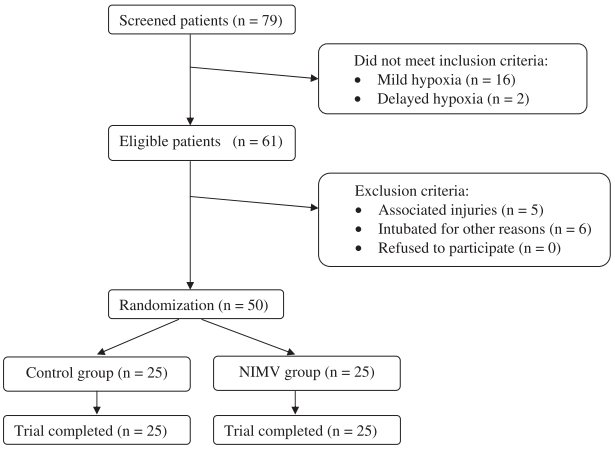

Figure 1. CONSORT flowchart of the study. CONSORT = Consolidated Standards of Reporting Trials; NIMV = noninvasive mechanical ventilation.

Table 1—*Baseline Clinical Characteristics of Patients*

	NIMV Group (n = 25)	Control Group (n = 25)	*P* Value
Epidemiologic variables			
Age, y	44.5 ± 16.8	42.3 ± 19	.7
Male gender	19 (76%)	21 (84%)	.5
Comorbidities			
Chronic heart failure	5 (20%)	1 (4%)	.08
Chronic airflow limitation	4 (16%)	2 (8%)	.4
Mechanism of trauma			
Thoracic compression	5 (20%)	4 (16%)	.8
Pedestrian road traffic injury	0 (0%)	1 (4%)	
Car crash	10 (40%)	11 (44%)	
Motorbike accident	3 (12%)	4 (16%)	
Fall	7 (28%)	5 (20%)	
Severity scores and associated injuries			
APACHE II on admission, points	17.5 ± 4.7	14.1 ± 5	.02
Shock on admission	7 (28%)	8 (32%)	.7
≥ 2 units RBC transfused (first 48 h)	4 (16%)	3 (12%)	.9
Thoracic AIS, points	4.1 ± 0.7	3.8 ± 0.6	.2
ISS, points	34 ± 11.4	31 ± 12.2	.4
Lung contusion, quadrants	2.3 ± 1.1	2 ± 1.2	.4
Thoracolumbar vertebral trauma	10 (40%)	8 (32%)	.4
Flail chest	4 (16%)	3 (12%)	.7
Pain control			
Regional anesthesia	10 (40%)	10 (40%)	1.0
Length of regional anesthesia, d	9 (5-15)	13 (7-19)	.1
Gasometric variables at randomization			
Pao_2/Fio_2, mm Hg	108 ± 34.5	110 ± 34.5	.8
$Paco_2$, mm Hg	36 ± 8.4	36 ± 6.7	.8
Arterial pH	7.3 ± 0.3	7.4 ± 0.3	.6

AIS = Abbreviated Injury Scale; APACHE = Acute Physiology and Chronic Health Evaluation; ISS = Injury Severity Score; NIMV = noninvasive mechanical ventilation.

Total face masks were needed in 11 patients: in 5 patients as a first choice and in the other 6 patients as an alternative to replace face masks to avoid facial ulcers or patient intolerance. The length of ICU stay did not differ between NIMV patients and controls (Table 2), but the length of hospital stay (LOS) was lower in the NIMV group (median 14 [9-146] days vs 21 [11-154] days, $P = .001$). The Cox regression multivariate analysis adjusted for age, gender, APACHE II at study entry, and chronic heart failure showed that NIMV was the only variable significantly associated with the reduced intubation rate (Table 3).

The time course of Pao_2/Fio_2 and respiratory rate is shown in Figure 3. The low number of intubated patients in the NIMV group precluded further analysis of early predictors of NIMV failure.

Discussion

The major finding of this study is that early and continuous NIMV prevents intubation and reduces

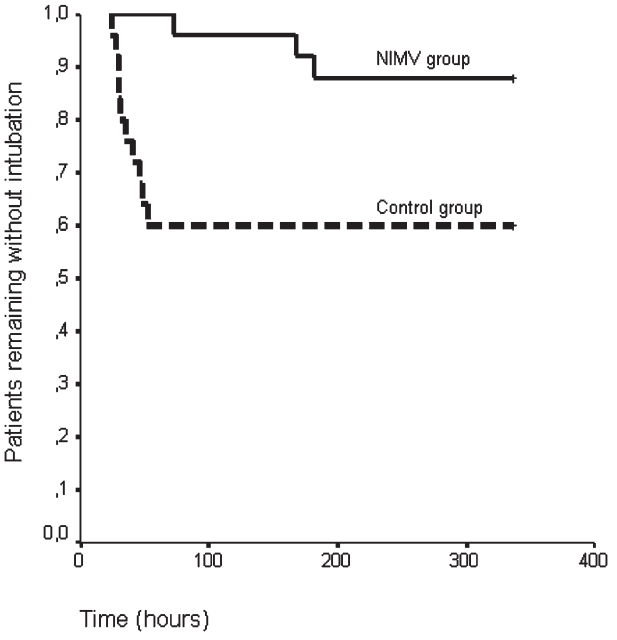

Figure 2. Kaplan-Meier curve for the probability of remaining without intubation in both groups. See Figure 1 legend for expansion of abbreviation.

LOS in patients who develop severe hypoxia early in the course of thoracic trauma. It seems that the time course of oxygenation does not predict NIMV failure, as Pao_2/Fio_2 also improved in the first 24 h in the group of patients who were eventually intubated (see Fig 3). However, the difference in the Pao_2/Fio_2 ratio in NIMV vs control patients when comparing patients who were intubated with those who were not intubated suggests

Table 2—*Intubation and Secondary Outcome Variables of Patients*

	NIMV Group (n = 25)	Control Group (n = 25)	*P* Value
Intubation rate	3 (12%)	10 (40%)	.02
Causes of intubation			
Signs of exhaustion	2 (8%)	6 (24%)	.1
Refractory hypoxemia	0 (0%)	2 (8%)	
Inability to clear respiratory secretions	1 (4%)	1 (4%)	
Major agitation	0 (0%)	1 (4%)	
Pneumothorax post randomization	6 (24%)	3 (12%)	.3
Ventilator-associated pneumonia	2 (8%)	3 (12%)	.6
ARDS	3 (12%)	4 (16%)	.7
Sepsis	3 (12%)	2 (8%)	.6
Multiorgan failure	2 (8%)	1 (4%)	.8
ICU stay, d[a]	6 (5-10)	8 (6-13)	.4
ICU mortality	1 (4%)	1 (4%)	1.0
Hospital stay, d[a]	14 (10-17)	21 (17-29)	.001
Hospital mortality	1 (4%)	1 (4%)	1.0

See Table 1 for expansion of abbreviations.
[a]Expressed as median (25th-75th percentiles).

Table 3—*Cox Regression Multivariate Analysis of the Risk Factors for Intubation*

	Constant	OR (95% CI)	*P* Value
NIMV	−2.06	0.12 (0.02 - 0.61)	.01
APACHE II at study entry, points	0.11	1.1 (0.98 - 1.27)	.08
Male	−1.26	0.28 (0.02 - 2.87)	.3
Age, y	−0.01	0.98 (0.95 - 1.02)	.4
Chronic heart failure	0.65	1.9 (0.18 - 20.41)	.6

OR = odds ratio. See Table 1 for expansion of other abbreviations.

that control patients are more likely failing due to hypoxia, whereas other mechanisms must be more prominent in NIMV patients.

The small sample of NIMV failure patients and the low mortality rate preclude any speculation about morbidity and mortality when NIMV fails. Nevertheless, pneumothorax tended to be higher in the NIMV group, although this difference did not reach statistical significance. Our results disagree with those of Bollinger and Van Eeden[11]; the higher rate of pneumothorax in our NIMV patients probably results from our clinical targets, using slightly higher airway pressures for longer periods.

Some details of our trauma management deserve mention: The severity of pulmonary contusions in the present study was similar to that reported in studies with a higher rate of intubation (75%).[2] There are two possible explanations for our lower intubation rate: (1) our exclusion of patients intubated in the field when a long transfer to the hospital was anticipated due to our wide rural referral area; and (2) the specific pattern of injuries in our patients, who had a higher incidence of thoracic compression and falls than reported elsewhere,[19] more thoracic and lumbar vertebral fractures contraindicating epidural catheter, and a lower rate of associated facial injuries.[20] Case-mix definition is also modulated by our intense protocol of thoracic imaging, because injury severity score and abbreviated injury scale scores derived from thoracic CT scans are higher than those derived from plain chest radiographs.[21]

In a survey study, Antonelli et al[3] reported an 18% intubation rate in 72 trauma patients with hypoxia treated with NIMV, and Ferrer et al[13] reported a similar intubation rate (17%). Our slightly lower intubation rate in the NIMV group (12%) can be explained by three different factors: the inclusion of patients who develop hypoxia within 48 h after trauma; the high prevalence of lung contusion, not only at admission but within 24 h after trauma; and the extended length of NIMV. Hypoxia in our patients was mainly due to lung contusion, and the high NIMV success rate mirrors the ease of recruitment of contused lung regions when positive pressure is applied early. The 40% intubation rate in our control group was similar to the 45% reported by Ferrer et al,[13] but their nonselected population precluded analysis of specific factors related to intubation in trauma patients.

To our knowledge, there is little evidence that regional analgesia reduces the intubation rate, although the EAST Pain Management Guidelines[14] consider that there is level 2 evidence that regional analgesia reduces ventilator days and length of ICU stay. Only 40% of our patients were suitable candidates for an epidural catheter, probably because of our case mix; however, epidemiologic studies about the real performance of regional analgesia are lacking. Furthermore, it is possible that the pneumatic stabilization of the thoracic cage in NIMV patients contributed to pain control, favoring the reduction in the intubation rate, as suggested by the trend toward a shorter duration of regional analgesia.

Some limitations of our study merit consideration: our planned sample size was not reached due to the results at an interim analysis, and it has been reported that this may lead to potentially biased results,[22] showing larger treatment effects, particularly when the

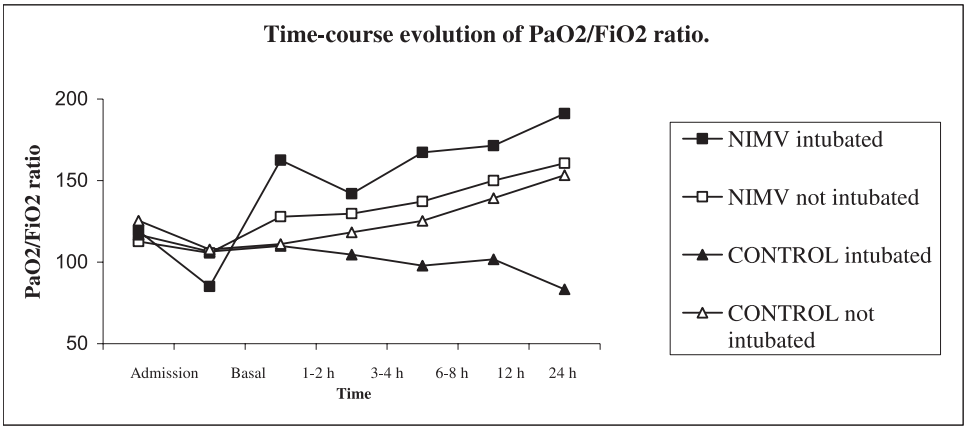

FIGURE 3. Time course evolution of oxygenation and respiratory rate in both groups. See Figure 1 legend for expansion of abbreviation.

number of events is small. However, we assumed the initial sample size because of the weak original data, but using a unilateral contrast hypothesis and an exact binomial method, the calculated sample size is 31 patients per group, with a statistical power of 0.8 and a Cohen effect size of 0.7.

Chronic heart failure, which is highly responsive to NIMV, was four times higher in the NIMV group, but the multivariate analysis found that chronic heart failure was not an independent factor for intubation, and statistical difference persists after excluding these patients. The difficulty of maintaining blinding in NIMV studies can also introduce a treatment bias, even after excluding the investigators in the clinical decision making. For the clinical interpretation of the presence of signs of exhaustion we extrapolated the muscle activation pattern obtained from weaning failure patient's studies, because this is, to our knowledge, the only population studied. However, in the case of thoracic trauma, a direct injury to the thoracic cage including the ventilatory muscles and pain can reproduce the pattern observed in weaning failure patients. Patients undergoing progressive respiratory failure display severe diaphragmatic weakness, which is what finally is clinically interpreted as signs of exhaustion. The signs of exhaustion used in our study have a high specificity of severe diaphragmatic weakness and respiratory exhaustion.[23]

We conclude that, in severe thoracic trauma-related hypoxia, early and continuous application of NIMV reduced the need for intubation and shortened LOS.

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Dr Fernandez: contributed to the conception, design, and interpretation of the study and drafting, critical revision, reading, and approval of the manuscript.
Dr Lopez-Reina: contributed to coordination, design, and interpretation of the study and critical revision, reading, and approval of the manuscript.
Dr Cuena: contributed to performing statistical analyses; design and interpretation of the study; and critical revision, reading, and approval the manuscript.
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Dr Ortiz: contributed to performing statistical analyses; design and interpretation of the study; and critical revision, reading, and approval of the manuscript.
Dr Hiradier: contributed to coordination, design, and interpretation of the study and drafting, critical revision, reading, and approval of the manuscript.
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