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Noninvasive ventilation failure in thoracic trauma: A retrospective study on predictive scores, ventilatory strategies and pain management'

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ABSTRACT

Background: Blunt thoracic trauma is a major cause of respiratory failure. While most patients recover, some deteriorate, requiring invasive ventilation. The HACOR score (Heart rate, Acidosis, Consciousness, Oxygenation, Respiratory rate) and ROX index (SpO_2/FiO_2 to respiratory rate) have been used to assess the risk of non-invasive ventilatory support (NIV) failure in hypoxemic respiratory failure but have not been validated in trauma patients. Pain control and NIV strategy are key to management, yet optimal approaches remain unclear. This study assesses HACOR and ROX scores in predicting NIV failure in ICU patients with blunt thoracic trauma and explores the impact of NIV strategy and analgesia.

Methods: This single-center, retrospective study included 93 patients with blunt thoracic trauma admitted to S. Chiara Hospital (Trento, Italy). The primary outcome was NIV failure, defined as the need for invasive mechanical ventilation.

Results: NIV succeeded in 73 patients (78.5 %), while 20 (21.5 %) required intubation. NIV failure patients had higher HACOR scores and lower ROX index at ICU admission (5 vs. 2, $p = 0.002$; 8.5 vs. 14.4, $p = 0.006$). The lowest failure rate (13 %) was observed in patients alternating helmet CPAP and HFNC, compared to helmet CPAP alone (31 %, $p = 0.05$). Epidural analgesia was more common in NIV success (46.6 %; $p = 0.004$), while opioids predominated in NIV failure (90 %; $p = 0.016$).

Conclusions: Higher HACOR and lower ROX scores at ICU admission were associated with NIV failure in blunt thoracic trauma patients. Alternating HFNC and CPAP showed lower NIV failure rates, as was epidural analgesia.

1. Introduction

Blunt thoracic trauma accounts for 30–50 % of major trauma cases, with road accidents, falls, and pedestrian collisions being the most common causes [1,2]. A significant proportion of patients with severe post-traumatic injuries requires endotracheal intubation and mechanical ventilation before hospital arrival. However, a subset of patients presents to the emergency department awake and spontaneously breathing [3,4]. While most of these patients recover without the need for invasive respiratory support, a smaller but significant group develops severe respiratory failure requiring intubation and invasive support [5,6]. The clinical trajectory of thoracic trauma is mainly influenced by the severity of the injuries. Factors such as extensive pulmonary contusions, pneumothorax, hemothorax, and multiple rib fractures are strong predictors of poorer outcomes [7]. Severity scoring systems like the Thoracic Trauma Severity (TTS) score and the Injury Severity Score (ISS) are widely used to quantify trauma severity but were not developed to predict need for invasive ventilation [8,9]. Conversely, scores such as HACOR (Heart rate, Acidosis, Consciousness, Oxygenation, Respiratory rate) and ROX (ratio of peripheral oxygen saturation and inspiratory oxygen fraction to respiratory rate) have demonstrated good sensitivity for predicting noninvasive ventilatory support (NIV) failure, but were validated mainly respiratory failure from infectious causes [10-12]. NIV techniques such as high flow nasal cannula (HFNC), continuous positive airway pressure (CPAP), and bi-level positive airway pressure (BIPAP) are increasingly used in patients with major thoracic trauma [13]. The primary goals of NIV are to maintain lung recruitment, improve respiratory mechanics and oxygenation, and prevent the need for endotracheal intubation [14]. Several studies support its effectiveness in major thoracic trauma [13,15], while others highlight potential

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risks: some patients may experience hemodynamic instability, worsening respiratory failure, or self-inflicted lung injury (SILI) [14,16]. Therefore, it is crucial to select the most effective support strategy, considering the available ventilatory options and interfaces, and to identify patients who fail NIV and may require endotracheal intubation [17]. In this context, indicators such as HACOR and ROX may play a role [18], but the evidence in thoracic trauma patients remains limited.

Futhermore, factors such as pain control may impact the progression of thoracic trauma. Some studies have highlighted the importance of an effective pain management strategy in improving patient outcomes [19,20], but further evidence is required.

Hence, we designed a retrospective study to evaluate the association between HACOR and ROX scores and NIV failure in awake and spontaneously breathing patients admitted to the ICU for blunt thoracic trauma, assessing their predictive value in this specific population.

Moreover, we explored the relationship between pain management strategies and NIV failure rate.

2. Material and methods

2.1. Study design, setting, and participants

This retrospective cohort study was conducted at Santa Chiara Hospital, Trento, Italy, on patients admitted from September 2018 to July 2024. Ethical approval (Number of registration A556) was obtained from the *Comitato Etico per le Sperimentazioni Cliniche* of the *Azienda Provinciale per i Servizi Sanitari di Trento*. The study was reported in accordance with the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) guidelines [21].

Inclusion Criteria: Patients with thoracic trauma—whether isolated or associated with other injuries—and respiratory failure (defined as a PaO_2/FiO_2 ratio ⟨300), who received helmet CPAP and/or HFNC as non-invasive ventilatory support for at least six hours following ICU admission.

Exclusion Criteria: Patients were excluded if they had a traumatic brain injury identified during the post-traumatic assessment, required mechanical ventilation within six hours of ICU admission, were pregnant, or under 18 years of age.

The primary outcome was NIV failure, defined as the requirement for endotracheal intubation and invasive mechanical ventilation. Patients intubated for surgery and ventilated for less than 24 h afterwards were not considered to have failed NIV. Secondary outcomes included ICU and hospital length of stay (LOS) and overall ICU and hospital mortality.

Given the retrospective nature of the study criteria for endotracheal intubation were not pre-specified, but dependent from clinical judgment, which usually includes worsening respiratory failure despite NIV (e.g., increasing oxygen requirement, PaO_2/FiO_2 ⟨100), respiratory acidosis (pH <7.25), decreased level of consciousness, inability to clear secretions, or hemodynamic instability unresponsive to medical therapy.

2.2. Data collection

Descriptive Variables: Collected variables included patient demographics [age, gender, Body Mass Index (BMI) and comorbidities] and severity scores at hospital arrival, such as the Thoracic Abbreviated Injury Scale (T-AIS), ISS, TTSS, and Sequential Organ Failure Assessment (SOFA).

Clinical and Laboratory Data: Physiological parameters, including Glasgow Coma Scale, respiratory rate, blood pressure, heart rate, and peripheral oxygen saturation (SpO_2), were recorded at hospital and ICU admission. Blood gas parameters (arterial pH, PaO_2, $PaCO_2$, lactate, and arterial to inspired oxygen fraction ration - PaO_2/FiO_2 ratio) were collected at hospital arrival, ICU admission, and two and six hours after the initiation of NIV.

NIV Treatment setting and Variables: NIV treatment was administered using a helmet CPAP system with PEEP set at 8 ± 1 cmH_2O, airflow at 50 $\pm$ 10 L/min, and FiO_2 titrated to maintain a minimum SpO_2 of 92 %. HFNC was delivered via nasal cannula with airflow set at 40 ± 10 L/min and FiO_2 similarly adjusted to achieve an SpO_2 of at least 92 %. Key variables included the proportion of ICU time spent on NIV, the settings for helmet CPAP (PEEP, gas flow, and FiO_2), and the use of HFNC.

NIV-Related Scores: HACOR and ROX scores were assessed prior to the start of NIV and at two and six hours after NIV initiation. The HACOR score (Heart rate, Acidosis [pH], Consciousness [GCS], Oxygenation [PaO_2/FiO_2], Respiratory rate) ranges from 0 to 25, with higher scores indicating greater likelihood of NIV failure. A score > 5 has been associated with increased risk of failure in previous literature [10]. The ROX index—calculated as SpO_2/FiO_2 divided by respiratory rate—reflects oxygenation efficiency and respiratory effort, with lower values indicating worse oxygenation and greater respiratory distress. A ROX index $<$4.88 has been associated with increased risk of failure in hypoxemic respiratory failure [11]. Both scores were calculated at ICU admission (at the NIV initiation) and at 2 and 6 h after starting NIV. All parameters were extracted retrospectively from the electronic medical record.

Pain Management: Pain management strategies, including the use of opioids, epidural catheters, or regional anesthesia (e.g., chest wall blocks), were recorded. Chest pain was evaluated using the Numerical Rating Scale (NRS) at ICU admission and at 24- and 48-h post-admission. Epidural catheters were typically placed at the thoracic level (T6–T8). Regional anesthesia included serratus anterior plane blocks, erector spinae plane block, and paravertebral blocks performed by trained anesthesiologists.

2.3. Statistical analysis

Data are presented as mean $\pm$ standard deviation (SD) for normally distributed variables and as median with interquartile range (IQR) for non-normally distributed variables. Statistical analysis was performed using R Studio (version 4.3.3). Group comparisons—NIV success vs NIV failure - were conducted using the Kruskal-Wallis, the Fisher's exact test or the Wilcoxon rank sum exact test for non-parametric data and ANOVA for parametric data. Assuming a NIV failure rate of 20 %, we estimated that a sample size of 90 patients would be sufficient to achieve adequate statistical power.

A p-value of $\leq$0.05 was considered statistically significant.

3. Results

From September 2018 to July 2024, a total of 239 patients with chest trauma were admitted in the ICU and 93 of these were included in our study. Among these, 20 patients (21.5 %) failed NIV (Fig. 1). Table 1 summarizes the population characteristics.

3.1. Baseline characteristics

In the univariate analysis, there were no significant differences between NIV failure and NIV success in terms of age, sex, or BMI (Table 1). The two groups did not differ in regard to chronic cardiovascular, renal, hepatic, or respiratory diseases. NIV failure occurred on average, 48 h after ICU admission. NIV failure patients had significantly longer ICU and hospital LOS (15 [11-22] days, $p < 0.001$ and 29 [14–36] days, $p = 0.001$, respectively), and higher ICU and in hospital mortality rates (2 (10 %), $p = 0.043$ and 3 (15 %) $p = 0.029$, respectively).

At hospital admission (shock room) NIV failure patients had presented worse trauma and organ failure scores with significantly higher ISS ($p < 0.001$), AIS ($p = 0.007$), and SOFA ($p = 0.003$) (Table 2). Moreover, these patients showed lower mean arterial pressure and higher lactate levels with no difference in respiratory parameters. However, at ICU admission, NIV failure patients had significantly lower PaO_2/FiO_2 ratios ($p = 0.001$, Table 2).

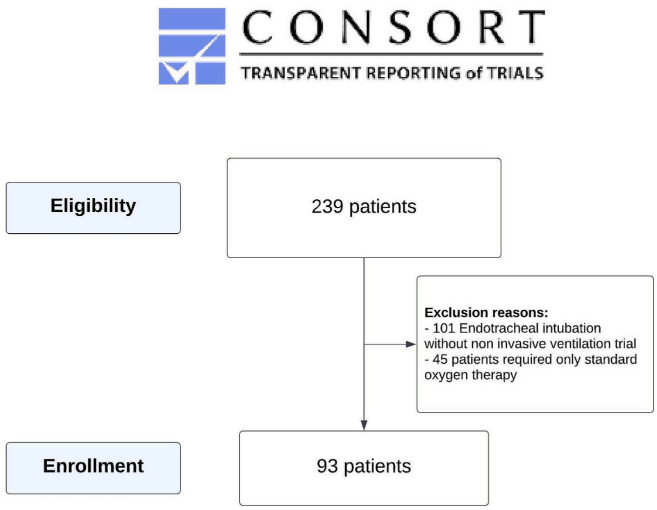

Fig. 1. CONSORT flow chart of the included and enrolled population in the study.

Table 1
Demographic and clinical characteristics of the study population, including age, sex, BMI, comorbidities, and baseline severity scores.

	Total	NIV success	NIV failure	P-value[1]
Number of patients, N (%)	93	73 (78.5 %)	20 (21.5 %)	
Age, years	59 (50–69)	59 (50–67)	62 (54–76)	0.284
Male sex, N (%)	75 (79.8 %)	59 (79.8 %)	16 (20.3 %)	0.001
BMI, kg/m^2	26 (24–29)	26 (24–29)	26 (24–24)	0.775
Comorbidities				
Arterial hypertension, N (%)	29 (31.2 %)	23 (31.5 %)	6 (30 %)	0.001
Diabetes mellitus, N (%)	7 (7.5 %)	6 (8.2 %)	1 (5 %)	0.001
Chronic kidney Injury, N (%)	6 (6.5 %)	4 (5.5 %)	2 (10 %)	0.606
Cardiovascular disease, N (%)	4 (4.3 %)	3 (4.1 %)	1 (5 %)	0.001
Chronic Hepatic disease, N (%)	1 (1.1 %)	1 (1.4 %)	0 (0 %)	0.001
Active smokers, N (%)	11 (11.8 %)	8 (11 %)	3 (15 %)	0.697
Immune disease, N (%)	3 (3.2 %)	2 (2.7 %)	1 (5 %)	0.521
Chronic Obstructive Pulmonary Disease, N (%)	10 (10.8 %)	9 (12.3 %)	1 (5.0 %)	0.684
ICU Outcome				
Time from ICU admission to endotracheal intubation, hours			48 (33–89)	
Tracheostomy, N (%)	6 (6,4 %)	0 (0 %)	6 (30 %)	<0.001
ICU length of stay, days	6 (3–10)	4 (2–8)	15 (11−22)	<0.001
Hospital length of stay, days	14 (9–23)	13 (9–20)	29 (140–36)	0.001
ICU mortality, N (%)	2 (2,1 %)	0 (0 %)	2 (10 %)	0.043
Hospital mortality, N (%)	4 (4.3 %)	1 (1.4 %)	3 (15.0 %)	0.029

Baseline characteristics and clinical outcomes in the overall study population and stratified by NIV outcome (success vs. failure). Continuous variables are expressed as median (interquartile range) and compared using the Kruskal–Wallis test; categorical variables are presented as number (percentage) and compared using Fisher's exact test. NIV failure was defined as the requirement for endotracheal intubation. Time to intubation is reported only for patients who experienced NIV failure.
Abbreviations: BMI: body mass index; ICU: intensive care unit; NIV: noninvasive ventilation.

[1] Fisher's exact test; Wilcoxon rank sum test; Wilcoxon rank sum exact test. Values are expressed as Median (25 IQR-75 IQR); n (%).

Table 2
Trauma severity and organ failure scores at hospital admission, including Injury Severity Score (ISS), Thoracic Abbreviated Injury Scale (T-AIS), and Sequential Organ Failure Assessment (SOFA) score.

	Total	NIV success	NIV failure	P-value[1]
Trauma scores				
ISS	15 (9–21)	13 (9–17)	24 (17–29)	<0.001
AIS (Chest Trauma)	3 (2–3)	3 (2–3)	3 (3–4)	0.007
TTS	11 (9–13)	10 (9–13)	12 (10–15)	0.059
SOFA score	3 (2–4)	3 (2–3)	4 (3–5)	0.003
Shock Room Admission				
SpO_2, %	96 (93–98)	96 (93–98)	94 (92–96)	0.097
Mean arterial pressure, mmHg	95 (85–108)	97 (87–109)	87 (83–98)	0.043
pH	7.36 (7.34–7.40)	7.37 (7.34–7.40)	7.36 (7.31–7.40)	0.304
$PaCO_2$, mmHg	38 (34–42)	39 (34–42)	37 (34–40)	0.813
PaO_2/FiO_2 ratio	271 (152–318)	275 (175–318)	215 (97–312)	0.180
Lactate, mmol/L	1.8 (1.3–2.3)	1.7 (1.3–2.1)	2.2 (0.2–3.0)	0.001
Respiratory rate, breaths per minute	20 (16–22)	20 (16–22)	18 (17–24)	0.867
Heart rate, bpm	88 (75–100)	86 (75–99)	95 (75–100)	0.353
ICU Admission				
SpO_2, %	97 (94–99)	97 (95–99)	97 (94–98)	0.720
Mean arterial pressure, mmHg	90 (78–102)	92 (80–104)	77 (62–92)	0.001
pH	7.35 (7.33–7.38)	7.35 (7.33–7.38)	7.33 (7.31–7.35)	0.008
$PaCO_2$. mmHg	40 (36–48)	40 (36–44)	41 (37–43)	0.435
PaO_2/FiO_2 ratio	261 (203−332)	276 (213–360)	190 (119–259)	0.001
Lactate, mmol/L	1.6 (1.1–2.1)	1.5 (0.9–2.0)	2.1 (1.8–2.7)	<0.001
Respiratory rate, breaths per minute	22 (17–25)	21 (17–25)	23 (18–24)	0.900
Heart rate, bpm	22 (17–25)	83 (75–97)	92 (78–106)	0.221

Trauma severity scores and physiologic parameters at emergency department (shock room) and ICU admission, stratified by NIV outcome (success vs. failure). Continuous variables are presented as median (interquartile range) and compared using the Wilcoxon rank-sum test; categorical variables are shown as number (percentage) and compared using Fisher's exact test. NIV failure was defined as the need for endotracheal intubation.
Abbreviations: AIS: Abbreviated Injury Scale; ICU: intensive care unit; IQR: interquartile range; ISS: Injury Severity Score; MAP: mean arterial pressure; NIV: noninvasive ventilation; PaO_2/FiO_2: arterial partial pressure of oxygen/inspired oxygen fraction ratio; bpm: beats per minute; SOFA: Sequential Organ Failure Assessment; SpO_2: peripheral oxygen saturation; TTS: Thoracic Trauma Severity score.

3.2. *NIV strategies and predictors of failure*

At ICU admission, NIV failure patients had higher HACOR scores [5 (1.5–7.2) vs. 2 (0–3) respectively; $p = 0.002$] and lower ROX index [8.5 (5.8–13.4) vs. 14.4 (9.4–19.2) respectively; $p = 0.006$]. These differences became less pronounced at two and six hours after ICU admission, with only the HACOR score at 6 h retaining statistical significance [2 (0–3) vs. 0 (0–1.7) respectively; $p = 0.013$] (Fig. 2). The Area under the curve (AUC) resulted 0.71 for HACOR score (best cutoff 4.5; 95 % CI: 0.56–0.87) and 0.70 for ROX index (best cutoff: 8.1; 95 % CI: 0.57–0.83). (Supplementary Fig. E1).

Fig. 3 shows the rate of NIV failure according to the different interfaces applied. The lowest incidence of failure (13 %) was observed in patients who received an alternation of helmet CPAP and HFNC compared to those treated with helmet CPAP alone ($p = 0.05$).

There were no significant differences in helmet-CPAP settings or treatment duration between the groups, except for a lower FiO_2 delivered to NIV success patients (0.35 vs. 0.45; $p = 0.027$).

The interface use changed over the years pre- and post-COVID, suggesting variations in clinical practice (Supplementary fig. E2) while

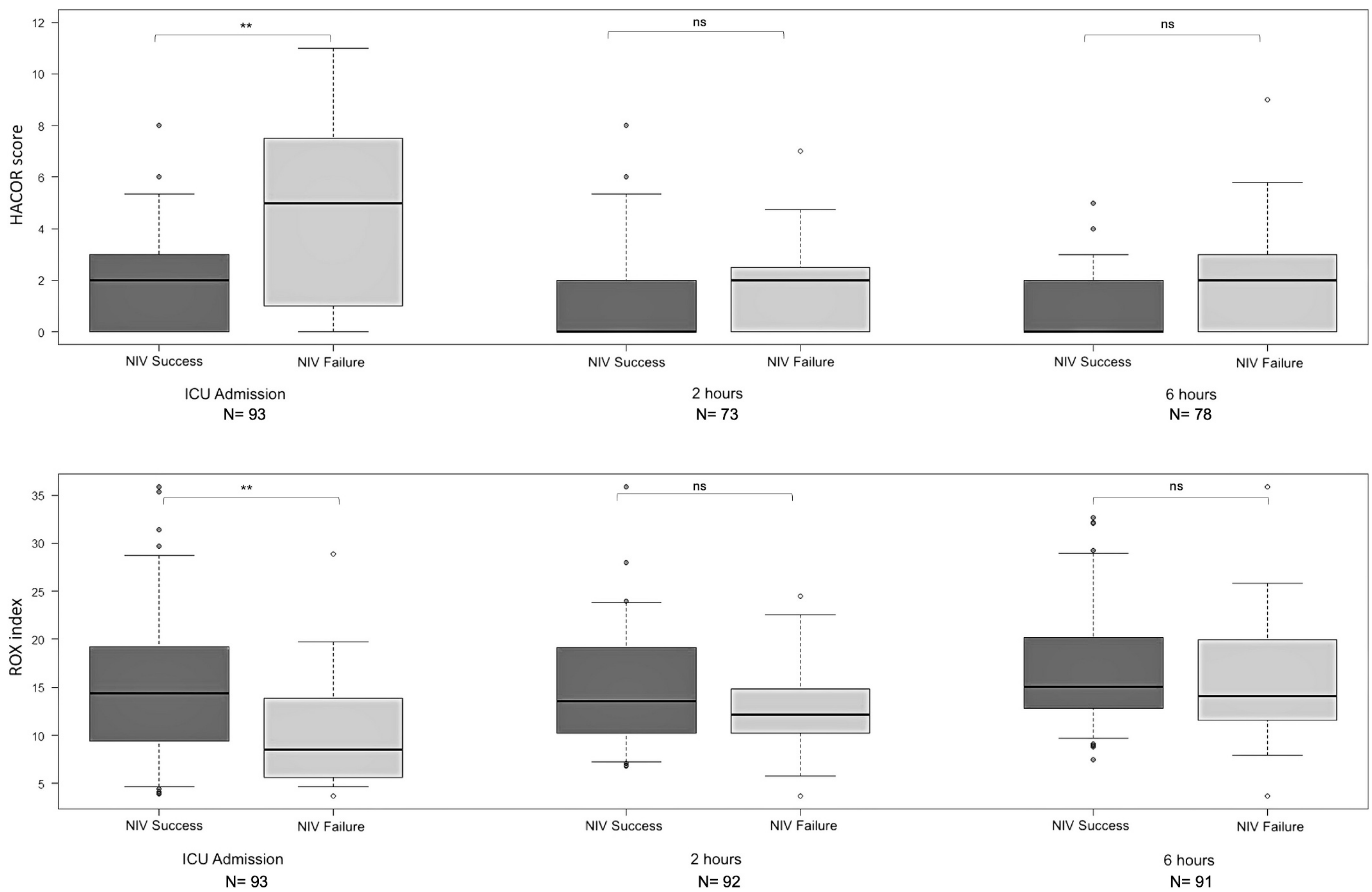

Fig. 2. Boxplots of HACOR score (top panel) and ROX index (bottom panel) at ICU admission, 2 h, and 6 h after the initiation of non-invasive ventilation (NIV). Data are shown separately for patients with NIV success and NIV failure. The boxes represent the interquartile range (IQR), the horizontal line within each box indicates the median values. Asterisks indicate levels of statistical significance: $p < 0.05$ (*), $p < 0.01$ (**), $p < 0.001$ (***); ns = not significant.

the incidence of the NIV failure did not change.

3.3. Pain management

Both groups reported similar pain scores at ICU admission and at 24- and 48-h post-ICU admission ($p = 0.295$, 0.968, and 0.263, respectively) (Fig. 4). However, this was achieved by different analgesic strategies between the groups.

Fig. 4 shows that analgesic strategies differed between the two groups: opioids use was associated with a greater incidence of NIV failure (37 %) as opposed to epidural and regional anesthesia (0 %) and the combination of epidural anesthesia or regional anesthesia and opioids (10 %) ($p = 0.001$), despite similar severity of trauma among the different analgesic strategies.

4. Discussion

The main findings of this study can be summarized as follows: patients who failed NIV after major thoracic trauma had, as expected, significantly more severe clinical presentations than those who succeeded as well as worse ROX and HACOR scores. Alternation of helmet CPAP and HFNC were associated with a lower incidence of NIV failure. Analgesic strategies based on neuraxial and regional anesthesia were similarly associated with lower occurrence of NIV failure.

The HACOR score, introduced by Duan et al. in 2017, has been widely used to predict NIV failure in hypoxemic respiratory failure [10]. To our knowledge, its use in thoracic trauma has not been previously investigated. In our cohort, patients who failed NIV presented a significantly higher HACOR score at ICU admission, reaching the critical threshold of 5 out of 25 points. Interestingly, the initial difference in HACOR scores between the two groups nearly disappeared after two hours of ICU treatment. Similarly, the ROX index, introduced by Roca et al. as a reliable predictor for HFNC success [11], was significantly lower in NIV failure patients. However, like the HACOR score, the ROX index's predictive difference decreased after two hours of ICU treatment. These findings suggest that while HACOR and ROX are associated and might be predictive of NIV failure in traumatic patients, their reliability may be limited to pre-intervention assessments, prior to ICU medical treatments such as sedatives, analgesics, or other therapies that can impact the clinical presentation of patients, potentially altering the predictive value of these scores.

The highest NIV success rates were observed in patients receiving combined HFNC and CPAP helmet therapy. NIV failure and success groups did not differ in time spent on helmet CPAP or PEEP levels. Thoracic trauma frequently leads to pulmonary contusions and increased lung permeability, which predispose the lungs to collapse and contribute to respiratory failure [22,23]. The application of CPAP through a helmet favors lung's expansion, possibly preventing collapse and decruitment [24,25]. However, procedures and/or patient intolerance may lead to interruptions in CPAP treatment, exposing the lungs to collapse [26]. In such cases, HFNC might serve as a complementary support mechanism, maintaining some positive airway pressure during helmet CPAP interruptions, thereby mitigating lung collapse. In a meta-analysis of 10 studies involving 368 chest trauma patients overall, Chiumello et al. found that NIV significantly improved oxygenation while reducing mortality and intubation rates [15]. However, only two of these 10 studies directly compared NIV (as the experimental intervention) to HFNC (as standard care) [27,28], and none explored the

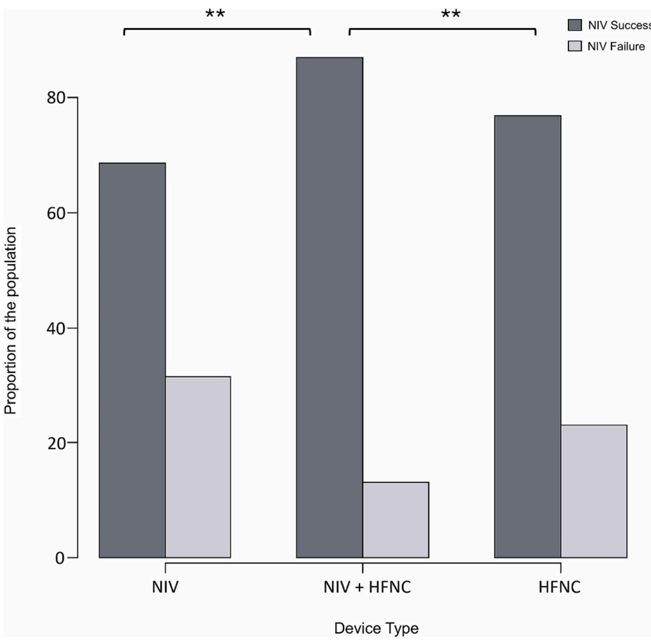

Fig. 3. Bar chart displaying the distribution of different respiratory support strategies in NIV success and failure groups. The categories include non-invasive ventilation (NIV) alone, a combination of NIV and high-flow nasal cannula (HFNC), and HFNC alone.
Asterisks indicate levels of statistical significance: $p < 0.05$ (*), $p < 0.01$ (**), $p < 0.001$ (***); ns = not significant.

impact of alternating NIV and HFNC on outcomes. NIV failure rates in blunt chest trauma range from 15 % to 20 % [29,30] and, consistently, our study found a failure rate of 21.5 %. Notably, patients treated with a combination of CPAP helmet and HFNC had a lower NIV failure rate (13 %) compared to patients treated with either CPAP helmet (31 %) or HFNC alone (23 %), possibly emphasizing the synergistic benefits of their combined use.

To the best of our knowledge this is the first report of an association between pain management strategy and NIV failure: despite similar severity of injury (as indicated by TTS), patients who received continuous epidural analgesia had a significantly lower NIV failure rate compared to those treated with intravenous opioids only. Opioid-treated patients may have experienced respiratory drive depression and reduced coughing activity, both of which can contribute to NIV failure [31,32]. These findings underscore the importance of optimizing pain management to avoid impairments in respiratory function [33]. Preserving a natural breathing pattern, characterized by alternating spontaneous tidal volumes, sighs, and coughing, might be essential for preventing the progression to post-traumatic respiratory failure and the need for endotracheal intubation.

This study has several limitations such as its retrospective and monocentric design. The limited number of NIV failure cases precluded a detailed multivariate analysis of risk factors and a precise assessment of predictor sensitivity and specificity. Analgesic strategies were not uniformly standardized. Pain was recorded only at rest, possibly underestimating the effect of different analgesic strategies on incident pain, such as during cough and deeper breaths. This might explain the discrepancy between a similar reported pain, notwithstanding different analgesic strategies between success and failure patients.

5. Conclusions

In spontaneously breathing patients with major thoracic trauma, the HACOR score and ROX index appeared to be associated with an increased likelihood of NIV failure. The combination of HFNC and CPAP helmet therapy, coupled with epidural analgesia for pain management,

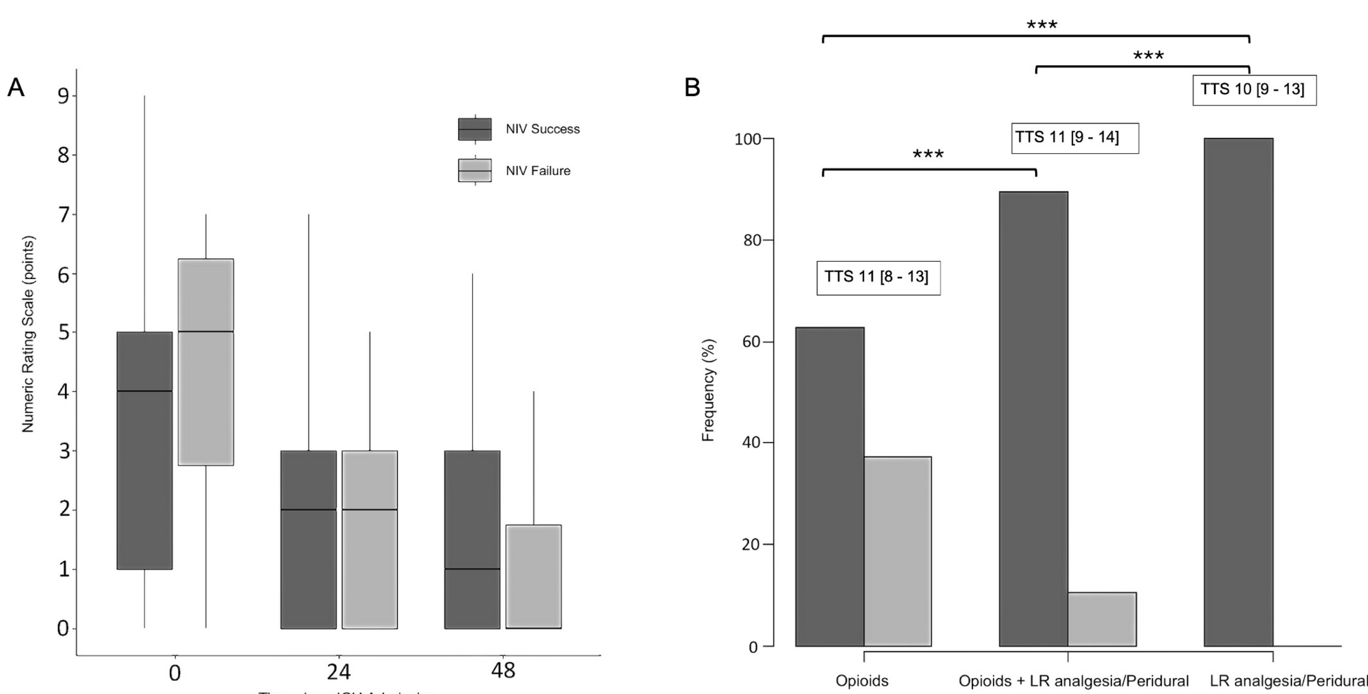

Fig. 4. The figure illustrates in Panel A the variation in the Numeric Rating Scale (NRS) score for pain assessment at 0, 24, and 48 h from ICU admission, stratified by NIV-failure (light gray, defined as the need for intubation) and NIV-success (dark gray), with boxplots representing the median, interquartile range, and 95 % confidence intervals. Panel B shows the frequency of patients receiving analgesia based on opioids alone, opioids combined with locoregional (LR) analgesia, or exclusively LR/epidural analgesia, reporting the median Thoracic Trauma Severity Score (TTS) for each group. Each population is further divided into NIV-failure (light gray) and NIV-success (dark gray). Abbreviations: LR: locoregional; NRS: Numeric Rating Scale; NIV: non-invasive ventilatory support; TTS: Thoracic Trauma Severity Score. Asterisks indicate levels of statistical significance: $p < 0.05$ (*), $p < 0.01$ (**), $p < 0.001$ (***); ns = not significant.

yielded the highest success rates for maintaining spontaneous breathing and avoiding invasive mechanical ventilation.

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Ethical approval and consent to participate

The study was conducted in accordance with [relevant ethical guidelines, e.g., the Declaration of Helsinki] and was approved by the Institutional Review Board of *Comitato Etico per le Sperimentazioni Cliniche* of the *Azienda Provinciale per i Servizi Sanitari di Trento* (Approval Number: [A556]). Due to the retrospective nature of the study, the requirement for informed consent was waived by the Ethics Committee.

CRediT authorship contribution statement

Francesco Cipulli: Writing – review & editing, Writing – original draft, Methodology, Data curation, Conceptualization. **Sara Miori:** Writing – review & editing, Writing – original draft, Methodology, Formal analysis, Data curation, Conceptualization. **Eleonora Balzani:** Writing – review & editing, Visualization, Data curation. **Roberto Zanella:** Visualization, Methodology, Investigation, Data curation. **Francesca Zanon:** Writing – review & editing, Investigation, Data curation. **Giacomo Bellani:** Writing – review & editing, Supervision.

Declaration of competing interest

The authors have no conflict of interest to declare.

Data availability

The Corresponding author has access to all data included into the analysis. Requests should be submitted to the corresponding author in the first instance.

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Not applicable.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jcrc.2025.155137.

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Glossary

- *NIV (Non-Invasive Ventilation):* A method of providing ventilatory support without endotracheal intubation, using interfaces such as masks or helmets.
- *HFNC (High-Flow Nasal Cannula):* A respiratory support system delivering heated, humidified oxygen at high flow rates to improve oxygenation and reduce work of breathing.
- *CPAP (Continuous Positive Airway Pressure):* A non-invasive ventilation mode that maintains positive airway pressure throughout the respiratory cycle to improve lung recruitment.
- *HACOR (Heart rate, Acidosis, Consciousness, Oxygenation, Respiratory rate) Score:* A clinical tool used to predict NIV failure by evaluating key physiological parameters.
- *ROX Index (SpO_2/FiO_2 to Respiratory Rate Ratio):* A score used to assess the likelihood of success with non-invasive ventilation support, helping to predict the need for escalation to invasive ventilation.
- *T-AIS (Thoracic Abbreviated Injury Scale):* A trauma scoring system assessing the severity of thoracic injuries based on anatomical damage.
- *ISS (Injury Severity Score):* A widely used trauma score quantifying overall injury severity based on the three most severely injured body regions.
- *SOFA (Sequential Organ Failure Assessment) Score:* A scoring system evaluating organ dysfunction in critically ill patients, including respiratory, cardiovascular, renal, hepatic, and coagulation function.
- *NRS (Numeric Rating Scale for Pain):* A subjective pain assessment scale ranging from 0 (no pain) to 10 (worst pain imaginable), commonly used in clinical settings.