Archives of Anesthesiology and Critical Care (In Press); x(x): xx-xx.

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Case Report

# Managing Refractory Hypoxemia in Trauma-Induced ARDS Complicated by Right Hemothorax: The Role of Inverse Ratio Ventilation

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**ARTICLE INFO**

**Article history:**
Received 15 June 2026
Revised 06 July 2026
Accepted 20 July 2026

**Keywords:**
Acute respiratory distress syndrome;
Inverse ratio ventilation;
Refractory hypoxemia;
Trauma;
Hemothorax;
Mechanical ventilation

**ABSTRACT**

Trauma-associated acute respiratory distress syndrome (ARDS) with refractory hypoxemia remains difficult to manage, especially when conventional lung-protective ventilation fails. Inverse ratio ventilation (IRV) may improve oxygenation by increasing mean airway pressure and alveolar recruitment. A patient with spinal cord injury and massive hemothorax developed severe hypoxemia and low lung compliance despite conventional mechanical ventilation. Ventilation was escalated to pressure-controlled ventilation with prolonged inspiratory time, higher PEEP, deep sedation, and IRV-oriented settings. Oxygenation and lung compliance improved progressively without significant hemodynamic instability or ventilator-related complications. Prone positioning was not feasible because of spinal trauma. IRV-oriented ventilation may serve as an effective rescue strategy in trauma-induced ARDS with refractory hypoxemia when standard lung-protective ventilation is insufficient. Careful titration and monitoring are essential to optimize oxygenation while minimizing complications.

## Introduction

Management of trauma-associated acute respiratory distress syndrome (ARDS) becomes particularly difficult when refractory hypoxemia persists despite lung-protective ventilation. In such patients, the need to improve oxygenation while avoiding further ventilator-induced lung injury creates a significant therapeutic dilemma.

Inverse ratio ventilation (IRV) is not a conventional first-line approach in ARDS, yet it may be considered in selected patients as a rescue strategy to improve oxygenation through prolongation of inspiratory time and elevation of mean airway pressure. This potential benefit, however, must be weighed against the risks of auto-PEEP and hemodynamic compromise. We present a case of trauma-related ARDS with right-sided hemothorax in which IRV was used as a rescue modality, highlighting the physiological basis of this approach and the patient's subsequent clinical response.

## Case Report

The patient was referred to Dr. Soetomo General Hospital with a spinal cord injury, presenting with paraplegia below the umbilical level with stable hemodynamics. Following primary trauma assessment, the cardiothoracic surgery team identified a massive left-sided hemothorax. A chest tube was inserted; however, during the procedure, approximately 700 mL of blood was rapidly evacuated. Consequently, the water-seal

The authors declare no conflicts of interest.
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DOI:

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drainage (WSD) system was temporarily clamped. Subsequently, the patient developed desaturation and appeared distressed, primarily due to pain. The patient was then transferred to the resuscitation room for close monitoring.

Upon arrival in the resuscitation unit, the patient was receiving oxygen via a simple face mask at 5 L/min, with a respiratory rate of 20 breaths per minute and an $SpO_2$ of 99%. The pain score was 5 on the Numeric Rating Scale (NRS). Physical examination revealed absent breath sounds over the left hemithorax and crackles over the right lung field. Intravenous fentanyl (50 mcg) was administered with careful monitoring, resulting in adequate pain relief.

Despite analgesia, the cardiothoracic surgeon continued to evaluate the chest tube output, as breath sounds over the left lung remained absent. The patient subsequently developed worsening respiratory distress, with desaturation and an increased respiratory rate of 22–24 breaths per minute. Endotracheal intubation was therefore indicated. After informed consent, assisted ventilation was attempted for ~15 minutes but failed to correct hypoxemia ($SpO_2$ 70%). Endotracheal intubation was then performed successfully. Post-intubation auscultation revealed bilateral breath sounds, reduced on the right, and CXR confirmed the ETT position at 2.6 cm above the carina.

Mechanical ventilation was initiated using synchronized intermittent mandatory ventilation with pressure support (SIMV-PS) mode, with the following settings: inspiratory pressure (Pinsp) of 8 $cmH_2O$, positive end-expiratory pressure (PEEP) of 5 $cmH_2O$, inspiratory-to-expiratory (I:E) ratio of 1:2, and $FiO_2$ of 50%. However, tidal volume did not reach the target range of 4–6 mL/kg body weight, and oxygen saturation remained at 80%. Given persistent hypoxemia and inadequate ventilation, deep sedation was initiated, and the ventilator mode was changed to pressure-controlled ventilation (PCV). Ventilator settings were adjusted to Pinsp 15 $cmH_2O$, PEEP 12 $cmH_2O$, $FiO_2$ 100%, and inspiratory time (Ti) 1.40 seconds. These settings resulted in a peak airway pressure (Ppeak) of 26 $cmH_2O$, expired tidal volume (VTe) of 260–295 mL, minute ventilation (MV) of 5.9–6.4 L/min, and respiratory rate of 24 breaths per minute. After 15 min, compliance improved (Cstat 23.5 mL/$cmH_2O$) and VTe reached 275 mL. Ventilation was adjusted (Pinsp 14, PEEP 10, $FiO_2$ 60%), yielding Ppeak 24 $cmH_2O$, VTe 245–310 mL, and MV 5.9–6.3 L/min. Ventilator parameters were carefully titrated with targets of maintaining $SpO_2 \geq 89\%$, improving static lung compliance, and achieving tidal volumes of 4–6 mL/kg body weight. Intravenous dexamethasone was administered at a dose of 20 mg daily for 5 days, followed by a reduced dose of 10 mg daily for an additional 5 days.

Due to the presence of a spinal cord injury, optimal lateral positioning could not be performed. Serial chest radiographs (CXR) (Figure 1) were obtained to monitor lung expansion and tube positioning.

On the following day, bronchoscopy was performed. No evidence of leaks was identified; however, erythematous changes of the airway mucosa were observed.

## Discussion

This case illustrates the challenges of managing acute hypoxemic respiratory failure in traumatic hemothorax complicated by suspected ARDS. Despite initial stabilization, persistent hypoxemia after chest tube insertion, along with low static compliance (19.6 mL/$cmH_2O$) and inadequate tidal volume, indicated significant alveolar collapse and impaired gas exchange, consistent with early ARDS physiology.

ARDS is characterized by diffuse alveolar damage, increased pulmonary capillary permeability, and loss of aerated lung units, resulting in reduced compliance and ventilation–perfusion mismatch [1-2]. In this patient, multiple contributing factors—including thoracic trauma, massive hemothorax, possible re-expansion pulmonary edema, and systemic inflammatory response—likely contributed to the development of lung injury.

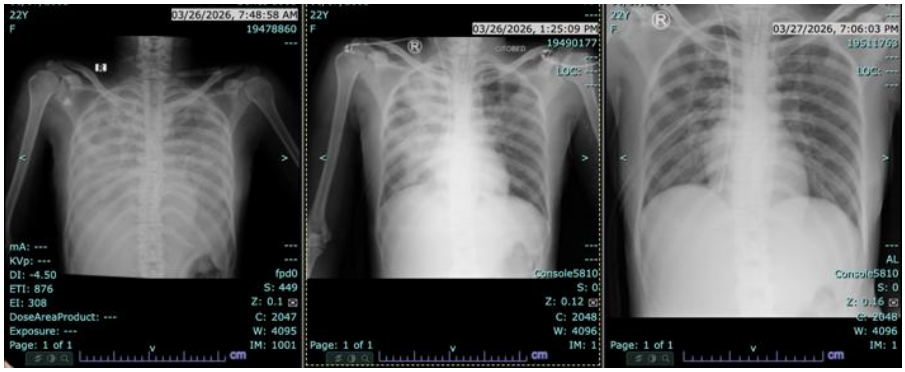



**Figure 1- (a) CXR at the initial phase when the patient came to the resuscitation room; (b) CXR 3 hours after intubation with IRV applied; (c) CXR after a day of intubation and IRV applied.**

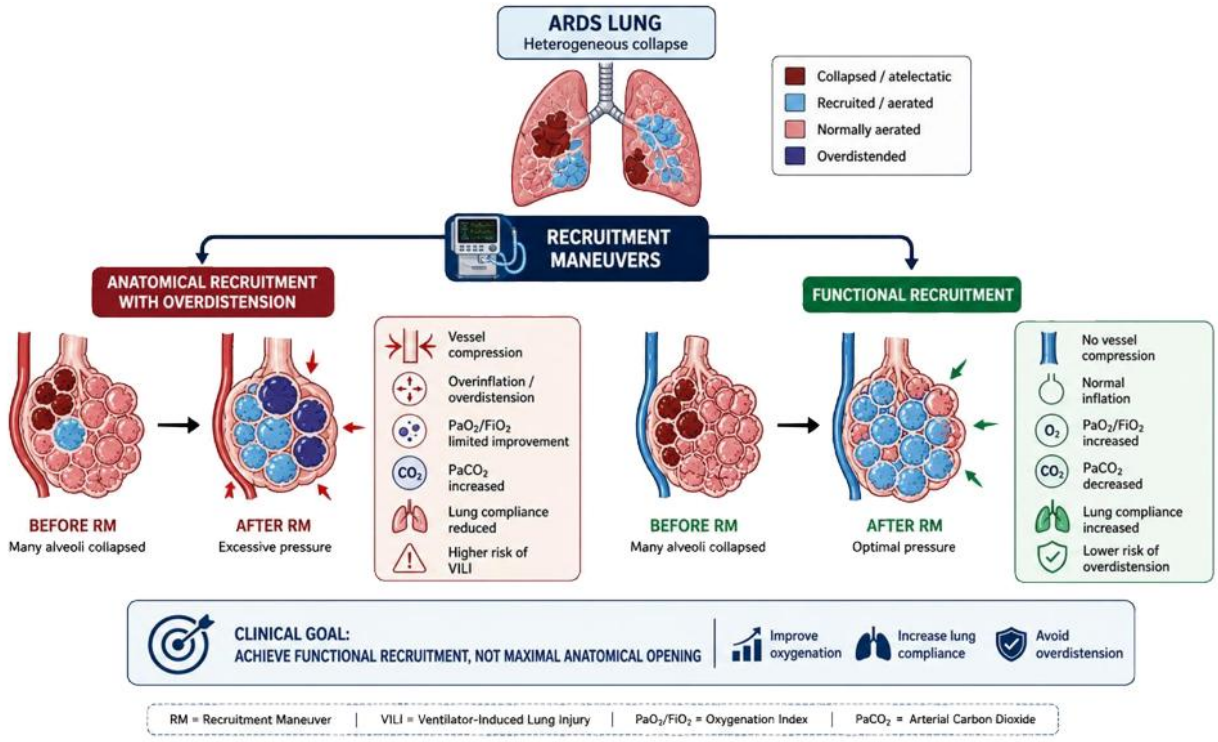



**Figure 2- Pathophysiological Effects of Recruitment Maneuver. Anatomical recruitment may increase aeration but can cause vessel compression, overdistension, and reduced compliance without meaningful oxygenation benefit. Functional recruitment aims to improve gas exchange and compliance without excessive alveolar strain [4-7].**

Initial ventilatory management followed lung-protective strategies (tidal volume 4–6 mL/kg PBW and limited airway pressures) [3]. However, persistent hypoxemia despite increased $FiO_2$ and PEEP required further optimization. Switching to pressure-controlled ventilation improved airway pressure control and tidal volume consistency, with a modest rise in compliance (19.6 → 23.5 mL/cm$H_2O$), suggesting partial recruitment, though significant shunt persisted.

Current guidelines do not recommend routine RM in ARDS, especially prolonged high-pressure maneuvers, because consistent outcome benefit has not been shown and harm may occur. RM should be used selectively, such as in clear derecruitment (e.g., after disconnection, suctioning, or intubation) or persistent hypoxemia despite optimized lung-protective ventilation without contraindications.

It is not initiated routinely in ARDS but considered when a recruitable lung is suspected. In this patient, ongoing hypoxemia and limited positional strategies supported a recruitment-oriented approach as explained in (Figure 2). However, RM carries risks: increased intrathoracic pressure may reduce venous return and cardiac output, impair right ventricular function, and worsen hypotension, especially in trauma patients. Excessive airway pressure also increases the risk of barotrauma, volutrauma, and overdistension [4–6]. Physiologically, RM transiently increases transpulmonary pressure to reopen collapsed alveoli, improving $PaO_2/FiO_2$ and lung compliance. Optimal outcomes occur with functional recruitment (reaeration plus reperfusion), whereas excessive pressure may cause overdistension and vascular compression. Post-RM, appropriate PEEP titration is essential to maintain recruitment and prevent derecruitment, reinforcing the "open the lung and keep it open" strategy [7].

In such cases, inverse ratio ventilation (IRV) may serve as a rescue strategy. IRV prolongs inspiratory time relative to expiratory time (I:E ≥1:1), thereby increasing mean airway pressure and promoting alveolar recruitment [8-9]. This approach enhances ventilation of slow-filling alveoli and improves oxygenation without significantly increasing peak airway pressures. In patients with low compliance and heterogeneous lung injury, IRV can improve oxygenation by redistributing ventilation and reducing intrapulmonary shunt [8].

In the present case, the use of prolonged inspiratory time (Ti 1.40 seconds) and relatively high PEEP reflects a strategy approaching IRV principles. Increasing mean airway pressure is a key determinant of improved oxygenation in ARDS, as it facilitates alveolar recruitment and prevents cyclic collapse [9]. However, IRV must be applied cautiously due to risks of intrinsic PEEP (auto-PEEP), barotrauma, and hemodynamic compromise secondary to elevated intrathoracic pressure [10]. Continuous monitoring of airway pressures, tidal

volume, and lung compliance is essential to minimize ventilator-induced lung injury (VILI).

## Conclusion

Overall, this case underscores the importance of individualized ventilatory strategies in ARDS, particularly when conventional lung-protective ventilation fails to achieve adequate oxygenation. IRV represents a valuable adjunct in such scenarios, especially when other strategies such as prone positioning are not feasible. Nevertheless, its use requires careful titration and close monitoring to balance the benefits of improved oxygenation against potential complications.

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