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**Review Article**

# Management of inhalation injuries in emergency and critical care: immediate interventions and long-term outcomes

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## ABSTRACT

Inhalation injury is respiratory injury caused by inhalation of substances such as toxic gas, fire fumes and chemical products. It can lead to hypoxia, ventilation dysfunction, increased airway resistance, and massive pulmonary edema. Immediate intervention is crucial for inhalation injuries. Current management strategies include endotracheal intubation, tracheostomy, fluid resuscitation, mechanical ventilation, and treatment of systemic toxicity. Many factors can affect the outcomes of inhalation injury such as age, severity of inhalation injury, and total body surface area burned. The following databases were used in systematic research: Medline (PubMed), Web of Science, and Scopus till 22 December 2024. Inclusion criteria is any study that discusses management of inhalation injuries in emergency and critical care and their outcomes and published in peer-reviewed journals was included with the inclusion of full-text articles, abstracts, and case series with the related topics are included. All languages are included. Animal studies, case reports, letters and comments were excluded. Endotracheal intubation, mechanical ventilation, and tracheostomy are considered important interventions in the inhalation injury emergency setting. However, studies reported poor long-term outcomes of these interventions. The objective of this review is to discuss the different approaches of management of inhalation injuries in emergency department and the obtained outcomes.

**Keywords:** Inhalation injury, Smoke inhalation injury, Emergency treatment, Critical care, Long-term outcomes

## INTRODUCTION

Inhalation injury is respiratory injury caused by inhalation of substances such as toxic gas, fire fumes and chemical products.[1] It occurs in 3.5% to 15% of burn patients.[2] There are three categories of inhalation injuries, injuries restricted to upper airway structures, injuries at lower airways and lung parenchyma, and systemic toxicity such as inhalation of carbon monoxide (CO).[3]

Inhalation injury involves different pathophysiology's, including hypoxia, ventilation dysfunction, increased airway resistance, and massive pulmonary edema.[4] Burns inhalation injury is considered a risk factor of mortality and

morbidity.[5-7] In addition, it is associated with increased risk of acute respiratory distress syndrome and pneumonia.[3,8]

Immediate intervention is crucial for inhalation injuries. A study noted that improvement in treatment for inhalation injuries have lagged behind those for cutaneous burns.[9] Current management strategies include endotracheal intubation, tracheostomy, fluid resuscitation, mechanical ventilation, and treatment of systemic toxicity.[4] Many factors can affect the outcomes of inhalation injury such as age, severity of inhalation injury, and total body surface area burned.

The objective of this review is to discuss the different approaches of management of inhalation injuries in emergency and critical care and to demonstrate the long-term outcomes of inhalation injuries and their management strategies.

## METHODS

The following databases were used in systematic research: Medline (PubMed), Web of Science, and Scopus till 22 December 2024. MeSH database was used to retrieve the synonyms of search strategy. Search terms were then combined by ("AND" and "OR") Boolean operators according to the Cochrane Handbook for Systematic Reviews of Interventions as follows: "inhalation injury" "inhalation injuries" "inhalation injuries, smoke" "injury, smoke inhalation AND "emergency treatment" "emergency therapy" "critical care" "care, critical" "critical care outcome".[10] Summaries of the found studies were exported by EndNoteX8, and duplicate studies were removed. Inclusion criteria is any study that discusses management of inhalation injuries in emergency and critical care and their outcomes and published in peer-reviewed journals was included with the inclusion of full-text articles, abstracts, and case series with the related topics are included. All languages are included. Animal studies, case reports, letters and comments were excluded.

## DISCUSSION

### *Management of inhalation injury*

While specific strategies for treating inhalation injuries are limited, appropriate initial management can significantly improve outcomes. Before any intervention, the first thing to do is to evacuate the victim from the fire or the toxic site and to decontaminate with full isolation precaution. It is necessary to remove all clothing, watch, and jewellery as soon as possible, as they may carry toxins like HCN, retain heat, leading to a tourniquet-like effect during swelling.[11]

An immediate assessment of the respiratory and circulatory status of patients with smoke inhalation should be done similar to standard assessment for all trauma patients. To ensure an airway allowing adequate oxygenation and ventilation, and to prevent ventilator-induced lung injury and substances that may complicate further care are the goals of initial management.[12] Then a secondary survey should be carried out, information regarding medical history, allergies, concomitant injuries, and medications should be obtained. A thorough physical examination should be performed.

After the occurrence of inhalation injury, the patency of the airway is at risk with time as is the maintenance of ventilation and oxygenation. Edema is a major threat that can compromise the patent airway. Progressive edema can result from skin burns, local trauma and large volumes of fluid used for resuscitation.[13] Patients with airway edema should be intubated promptly. Endotracheal intubation should be considered if any of the following signs exist: hypoventilation, stridor, respiratory distress, blistering or edema of the oropharynx, or deep burns to the neck or face.[14]

Early intubation is crucial, as delayed intubation becomes increasingly challenging due to swelling of the tongue and epiglottis caused by edematous tissue.[15] After intubation, the endotracheal tube should be kept in place until the upper airway edema has disappeared.[12] The airway should be frequently re-evaluated, and a high index of suspicion for airway compromise should be present. Regardless of initial symptoms, adopting a low threshold for intubation is the optimal approach.[15] Multiple failed intubation attempts can lead to exacerbation of edema, total loss of airway patency, upper airway trauma, and initiation of bleeding.[16]

Patients requiring intubation due to upper airway edema, impaired mental status, or pulmonary dysfunction, typically need mechanical ventilation. A single center report study held in Romania found that among 38 patients with inhalation injuries, mechanical ventilation was required in 76.5% of cases.[17] Indications for mechanical ventilation include: Tachypnea, respiratory rate >30/min, upper airway edema, use of accessory respiratory muscles, sternal retractions, $PaCO_2$ >50 mmHg, $PaO_2$ <65 mmHg, and $PaO_2/FiO_2$ ratio <200.[15]

In smoke inhalation injury, airway resistance (due to edema) and reduced lung compliance can elevate airway pressures, increasing the risk of barotrauma. The primary goal of mechanical ventilation is to keep alveoli open and ensure adequate oxygenation while avoiding alveolar overdistension and barotrauma.[18] Ventilation strategies include: maintaining peak airway pressure <35 mmHg and plateau pressure <30 mmHg, using small tidal volumes (6–8 ml/kg) and a high respiratory rate.[19]

Optimal positive end-expiratory pressure (PEEP) may be applied to prevent alveolar collapse while staying within safe airway pressure limits.[19] Newer ventilation modes, such high-frequency oscillatory ventilation, as high-frequency percussive ventilation, airway pressure release ventilation, and pressure control inverse ratio ventilation have demonstrated benefits in managing patients with smoke inhalation injuries.[13]

High-frequency percussive ventilation has been shown to improve oxygen and carbon dioxide exchange (increased $PaO_2/FiO_2$ ratio), reduce lung inflammation, injury, and infection, enhance lung compliance, and increase survival rates in smoke inhalation injury victims.[20] Additionally, simple prone positioning has proven effective in improving oxygenation by increasing the $PaO_2/FiO_2$ ratio.[21] High-frequency oscillatory ventilation (HFOV) can decrease the secretion of TNF-α in alveolar macrophages and reduce the accumulation and activation of neutrophils, reflecting a true lung-protective ventilation strategy. The effectiveness of HFOV is attributed to small changes in pulmonary pressure and capacity, rather than to the reopening of collapsed alveoli.[4]

Most fire-related deaths are attributed to hypoxia, thermal injuries, and inhalation of toxic combustion byproducts, with cyanide (CN) and carbon monoxide (CO) being the most dangerous components. These gases impair the blood's oxygen-carrying capacity, reducing cellular oxygen uptake and leading to hypoxia and, ultimately, death. Additionally, the damage caused by smoke inhalation injuries significantly increases the risk of mortality and morbidity in fire survivors.[4] CO exposure can cause cardiac injury even in individuals with normal coronary arteries. Cardiac evaluations, including electrocardiograms and cardiac enzyme measurements, may be necessary for exposed patients.[22] The elimination half-life of carboxyhemoglobin (COHb) varies with oxygen concentration: 320 minutes on room air, 74 minutes on 100% oxygen, and 20 minutes with hyperbaric oxygen (HBO) therapy.[23] HBO therapy criteria include COHb levels above 25%, evidence of ongoing end-organ ischemia, loss of consciousness, and pregnant patients with COHb levels above 20% or fetal distress.[24]

However, absolute indications for HBO remain controversial due to the poor correlation between COHb levels and outcome severity. There is no standardized protocol for HBO therapy, and the threshold COHb level for initiating treatment is debated. Moreover, larger multicenter studies have failed to demonstrate a consistent benefit of HBO treatment.[23,25] A Cochrane review of six randomized controlled trials yielded mixed results, with only two studies showing benefits in reducing adverse neurological outcomes.[26] The key determinant for reversing CO poisoning is the speed at which CO elimination begins, rather than the partial pressure of oxygen alone.[27]

Cyanide antidote administration is crucial when cyanide poisoning is clinically suspected. Traditional cyanide antidote kits work by oxidizing hemoglobin to methemoglobin, which binds cyanide to form cyanmethemoglobin. Cyanmethemoglobin gradually dissociates, allowing free cyanide to be converted to thiocyanate in the presence of thiosulfate. Thiocyanate is then excreted in the urine. However, the use of these antidote kits is contraindicated in cases of concurrent CO poisoning, inhalation injury, or both. This is because converting carboxyhemoglobin to methemoglobin can worsen hypoxia. These kits are recommended only for isolated cyanide poisoning.[12]

Hydroxocobalamin, a precursor of vitamin B12, is the preferred first-line treatment for cyanide poisoning 48. It binds cyanide to form cyanocobalamin, a stable and non-toxic compound excreted in the urine 65. The recommended intravenous dose is 70 mg/kg or a standard dose of 5 g administered over 15 minutes. Studies show that hydroxocobalamin improves outcomes in smoke inhalation victims, including lower pneumonia rates, quicker ventilator weaning, and faster discharge from the intensive care unit (ICU). Hydroxocobalamin's efficacy, safety profile, and ability to mitigate morbidity make it a valuable intervention, particularly in settings involving both smoke inhalation and cyanide exposure.[28]

Intravenous (IV) access should be established, and fluid infusion initiated promptly. Ringer's lactate is the fluid of choice for resuscitation. Victims of smoke inhalation injury often require 25% more fluid than others due to increased fluid loss through the injured lungs.[29] However, over-resuscitation can lead to edema formation. The main goal of fluid resuscitation is to maintain adequate urine output (children 1–2 ml/kg/hour, adults 0.5–1 ml/kg/hour).[30] Fluid resuscitation formulas should be used only as a guide and adjusted according to clinical endpoints to improve outcomes and avoid complications.[13] Bronchial hygiene is an important aspect of managing inhalation injuries. It includes various therapeutic interventions aimed to maintain airway patency and minimize complications. Initially, the patient should be positioned with the head elevated 30–45°, this can reduce upper airway edema and decrease the pressure of abdominal contents on the diaphragm.[15]

Retained secretions due to impaired coughing can lead to bronchial obstruction, pneumonia, and atelectasis. Therapeutic coughing aims to clear fibrin casts and excess mucus from the tracheobronchial tree. To effectively clear secretions, regularly therapeutic coughing and deep breathing exercises every two hours should be repeated.[15] Chest physiotherapy helps the drainage of bronchial secretions through techniques like chest vibration and percussion.[31] Repositioning the patient is crucial; they should be turned every four hours as this helps mobilize secretions. Generally, it is encouraged to do early ambulation to prevent respiratory complications.[15]

Tracheostomy is a possible intervention in inhalation injuries in the emergency setting. It is preferred in patients who require prolonged intubation. Tracheostomy has shown benefits in trauma patients with severe brain injuries. However, its role in managing burn inhalation injuries is controversial.[5,32,33] 7.5% of patients received tracheostomy in a report, while others reported higher percentage, such as 15.7%.[17,34] One study reports that the presence of inhalation injury is not a definitive predictor of

poor outcomes, however it reports that none of the patients presenting with the condition survived.[35]

***Outcomes***

An analysis found that the risk of mortality in patients with inhalation injury is 12.729 times higher than patients without it.[17] This result is compatible with other reports showing that patients with inhalation injuries have higher mortality.[36] In addition, another study reported that this trauma calls for more surgical interventions.[37] Inhalation injury is associated with higher incidence of pneumonia. However, the effect of pneumonia on mortality among inhalation injury patients is inconsistent between studies.[38,39] The explanations for these differences may in part be due to differing definitions, and the presence or absence of other factors such as associated septic shock. Moreover, it is associated with a significant increase in days on ventilation and higher ICU length of stay, showing how this injury increases the need for more close monitoring and a higher level of care.[40]

With regards to the long-term outcomes after discharge, a 7-year cohort study assessed long-term and in-hospital outcomes for burns patients with inhalation injury in comparison with those without inhalation. Results revealed that in-hospital outcomes were poorer in the inhalation injury group, but that inhalation injury did not provide added risk after discharge.[2] There was no correlation between inhalation injury and readmission for respiratory diagnoses, readmission requiring mechanical ventilation, all-cause readmission, or all-cause death. These findings indicate that poor outcomes following inhalation injury tend to occur acutely. However, if patients survive hospitalization, their long-term risks of mortality or need for inpatient care are consistent with those without inhalation injuries.

Different types of ventilation are linked to mortality risk. Patients require intubation, mechanical ventilation, and tracheostomy are associated with increased risk of mortality.[17]

Ventilator-associated pneumonia (VAP) is an infection that affects the respiratory tract after more than 48 hours of mechanical ventilation. More than 50% of infections in the ICU are attributed to VAP. It also affects approximately 8% to 28% of patients on mechanical ventilation.[41,42] Kim et al evaluating the outcomes of mechanical ventilation, demonstrated that mechanical ventilation is a significant predictor of inhalation injuries mortality.[43] It is also associated with ventilator-associated lung injury (VALI) due to repeated stress of mechanical ventilation on the small airways and alveoli leads to the inflammatory process that occurs in VALI.[44] As a result, Kim et al consider mechanical ventilation to be a risk factor and recommend avoiding it unless necessary. Tracheostomy has been shown to facilitate ventilator weaning by reducing dead space, airway resistance, work of breathing, and the need for sedation.[45]

Although tracheostomy offers some advantages in terms of patient comfort and security, different studies demonstrated that routine performance of early tracheostomy in burns patients did not improve outcomes and did not significantly alter mortality.[46,47] Studies are in conflict regarding the effect of tracheostomy on hospital length of stay and ICU length of stay.[32,46] Tracheostomy, compared with endotracheal tube, improves airway management, patient comfort, and oral hygiene 20. Although it is theorized that bypassing the mouth with a tracheostomy, along with the ease of cannula exchange, may act as a protective factor against the development of VAP, numerous studies have shown that earlier tracheostomy timing is not associated with a reduced incidence of VAP.[48-50] Furthermore, a recent study found that patients undergoing tracheostomy had an increased incidence of VAP compared with the group that did not undergo tracheostomy.[32]

## CONCLUSION

Inhalation injury is considered a risk factor of mortality and morbidity, as it is associated with increased risk of acute respiratory distress syndrome and pneumonia. Currently, management of these injuries is primarily supportive. There are improvements in inhalation injury mortality rates, but this is attributed to general improvements in critical care rather than focused interventions for inhalation injuries. Endotracheal intubation, mechanical ventilation, and tracheostomy are considered important interventions in the inhalation injury emergency setting. However, studies reported poor long-term outcomes of these interventions, prompting the need for more studies focusing on the development of the current strategies in treating inhalation injuries.

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