Paediatric Respiratory Reviews xxx (2015) xxx–xxx

Contents lists available at ScienceDirect

Paediatric Respiratory Reviews

Mini-Symposium: Ventilation Strategies in the Paediatric Intensive Care Unit

Ventilation strategies in paediatric inhalation injury

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EDUCATIONAL AIMS

After reading this article the reader will be able to recognise:

- the significance of inhalation injuries in children
- ventilatory management strategies suitable for children with inhalation injuries
- the potential role of additional pharmacological adjuncts that are sometimes used in inhalation injury

ARTICLE INFO

Keywords:
Inhalation injury
Treatment
Children

SUMMARY

Inhalation injury increases morbidity and mortality in burns victims. While the diagnosis remains largely clinical, bronchoscopy is also helpful to diagnose and grade the severity of any injury. Inhalation injury results from direct thermal injury or chemical irritation of the respiratory tract, systemic toxicity from inhaled substances, or a combination of these factors. While endotracheal intubation is essential in cases where upper airway obstruction may occur, it has its own risks and should not be performed prophylactically in all cases of inhalation injury. The evidence-base informing the selection of optimal ventilation strategy in inhalation injury is sparse, and most recommendations are based on extrapolation from (largely adult) studies in acute respiratory distress syndrome (ARDS). Conventional ventilation using a lung-protective approach (i.e. low tidal volume, limited plateau pressure, and permissive hypercarbia) is recommended as the initial approach if invasive ventilation is required; various rescue strategies may become necessary if there is a poor response. The efficacy of many widely used pharmacologic adjuncts in inhalation injury remains uncertain. Further research is urgently required to address these gaps in our knowledge.

INTRODUCTION

Approximately 10-30% of patients hospitalised with burn injury have a concomitant inhalation injury, and inhalation injury is a significant risk factor for increased mortality and morbidity in adult and paediatric burns patients [1–8]. A recent large series of 850 children with inhalation injury admitted to a Shriners Children's Hospital in the U.S.A. over a 10-year period found these children required mechanical ventilation for a mean of 15.2 days and the overall mortality rate was approximately 16%, with most deaths due to pulmonary dysfunction [9]. Mortality was significantly related to the size and depth of the burn.

Inhalation injury increases the risk for pneumonia, and the contributions of inhalation injury and pneumonia to mortality are independent and additive [6]. A recent meta-analysis found the risk of death doubled with inhalational injury (13.9% vs 27.6%) [5]. While inhalation injury is associated with increased morbidity in the acute phase, a study of paediatric burn survivors found it did not affect long-term quality of life [10].

Unfortunately, a universally recognised definition of inhalation injury is currently lacking, and specific evidence-based treatment options are largely lacking.

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http://dx.doi.org/10.1016/j.prrv.2015.10.005
1526-0542/

Please cite this article in press as: Goh CT, Jacobe S. Ventilation strategies in paediatric inhalation injury. Paediatr. Respir. Rev. (2015), http://dx.doi.org/10.1016/j.prrv.2015.10.005

The lung injury seen following inhalation associated with burns results from direct thermal injury to the airways, local chemical irritation to the respiratory tract, or systemic toxicity due to inhalation of carbon monoxide, cyanide, or other toxins [11]. In addition, the systemic inflammatory response to burns, sepsis, pneumonia, and ventilator-induced lung injury (VILI) may contribute to additional lung injury.

Inhalation injury may often be associated with pneumonia and ARDS, however burn victims without inhalation injury can also develop these, and it should not be assumed that the presence of pulmonary complications signifies that an inhalation injury has been sustained.

While some studies found patients with inhalation injury required increased fluid volume for resuscitation compared to those without [12,13], others have not confirmed this [14].

Unlike damaged skin that can be dressed and grafted, the management of inhalation injury is mainly supportive, with care taken to protect the lung from secondary injury. This review will focus on the respiratory support strategies, and in particular, ventilation strategies, for children with inhalation injuries.

PATHOPHYSIOLOGY

Inhalation injury can cause damage by a combination of: 1) direct thermal damage to the upper airways; 2) local chemical irritation of the respiratory tract, and; 3) systemic toxicity due to inhalation of toxic substances. Lee et al. [15] recently reviewed this topic.

Direct thermal damage to upper airways

Air temperature in an enclosed fire can reach in excess of 600 °C. Due to a combination of efficient heat dissipation of the upper airway, reflex closure of the larynx and low heat capacity of air, direct thermal injury is usually confined to airway structures above the carina [16]. Thermal injuries to upper airway structures can, however, lead to massive swelling and partial or even total airway obstruction [16]. Airway swelling develops rapidly over a few hours, particularly as fluid resuscitation is ongoing, and may not peak until ~24 hours post injury. Therefore evaluation immediately following the injury may be an unreliable indicator of the severity of obstruction that may develop, and it is essential that all patients suspected of having significant upper airway burns are carefully assessed by an experienced senior clinician for consideration of early elective intubation for airway protection. Endotracheal intubation has potential complications including the need for heavy sedation and even neuromuscular blockade; hypotension and "fluid creep"; and tube misplacement, dislodgement, or blockage. "Prophylactic" intubation of all patients with inhalation injury should be avoided where safe to do so [17].

Chemical irritation of the respiratory tract

Lower airway injury is usually caused by chemical irritation rather than thermal injury, and the nature and severity depends on the type of materials burnt, the temperature of combustion, and the duration of exposure or 'dose' [15]. Burnt rubber and plastics produce sulphur dioxide, nitrogen dioxide, ammonia and chlorine, which form corrosive acids and alkalis when combined with water in the alveoli. Hydrocarbons, aldehydes, ketones and acids form from polyethylene, while burning cotton or wool produce toxic aldehydes. Carbon monoxide and cyanide are generated from combustion of wood and polyurethane respectively.

Studies using Multiple Inert Gas Elimination Technique (MIGET) suggest that the hypoxia associated with smoke-inhalation-induced small airways injury is predominantly due to V/Q mismatch [18].

The tragic Dellwood fire [19] shed some light on the histological process following smoke inhalation. Autopsy findings of infants who died revealed a combination of bronchial necrosis, alveolar congestion and atelectasis, with vascular engorgement and formation of dense membranes or casts obstructing the lower airways. Bronchiolitis and bronchopneumonia were observed in some.

Pulmonary oedema due to increased vascular permeability plays an important role in the pathophysiological processes leading to lung injury. This is thought to be mediated in part by increased nitric oxide (NO) production, which forms a potent oxidant peroxynitrite (ONOO-), causing cellular injury and lipid peroxidation [20]. Chemicals in smoke promote the formation of neutrophil-generated oxygen radicals and inflammatory radicals which cause bronchial constriction, and exudate and airway cast formation. Impaired chemotactic and phagocytic function of the alveolar macrophage increases the risk of infection. Destruction and damage to the airway's ciliary transport function leads to the accumulation of casts, airway plugging and impaired clearance of bacteria. The end result is progressive respiratory failure over the course of 48 hours due to decreased lung compliance, V/Q mismatch, and increased dead space ventilation.

Systemic toxicity due to inhaled substances

Carbon monoxide (CO) and cyanide inhalation can lead to major morbidity following inhalation injury. Carbon monoxide is an odourless, colourless gas with an affinity ~200 times greater than oxygen for haemoglobin [11]. CO shifts the oxyhaemoglobin dissociation curve to the left, and, following prolonged exposure, binds to cytochrome oxidase, impairing mitochondrial function and reducing adenosine triphosphate production. Carbon monoxide thus reduces both the oxygen-carrying capacity of blood and oxygen dissociation at a tissue level, as well as disrupting cellular respiration. Standard pulse oximetry cannot reliably distinguish between oxyhaemoglobin and carboxyhaemoglobin (COHb), and patients may appear 'cherry pink' rather than cyanosed. Co-oximetry is required to make the diagnosis.

Hydrogen cyanide is produced by combustion of various household materials. Cyanide inhibits the cytochrome oxidase system and may have a synergistic effect with carbon monoxide in producing tissue hypoxia, lactic acidosis and decreased cerebral oxygen consumption [21]. One study of smoke inhalation victims (with burns <15%) found a significant correlation between a lactate level of >10 mmol/L and an elevated blood cyanide level [22]. A lactic acidosis in burn victims may, however, be due to several causes and is not specific for cyanide toxicity. The *in vitro* half-life of cyanide is approximately 1 hour [22]. Although a number of potential "antidotes" for cyanide toxicity are available, a rapid diagnostic test for cyanide poisoning is not widely available, and as a result the accurate evaluation of the efficacy of these therapies remains difficult.

DIAGNOSIS OF INHALATION INJURY

The diagnosis of inhalation injury is suggested by a history of exposure to smoke, flames or super-heated air in an enclosed space, and duration of exposure (trapped or unconscious at the scene), together with physical findings of facial burns, upper airway injury (redness and swelling of the oropharynx, hoarseness, stridor, carbonaceous sputum) and lower airway involvement (tachypnoea, dyspnoea, crackles or wheeze, decreased breath sounds, decreased O_2 saturations) [16,23]. The diagnosis can be confirmed and graded by fiberoptic bronchoscopy (Table 1) [9,24,25].

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