Pediatr Surg Int (1990) 5: 322–326

Pediatric Surgery International

Successful early management of adolescent inhalation injuries

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Abstract. We recently cared for 12 adolescents with inhalation injuries who were involved in a bus accident and subsequent fire. These patients arrived at our trauma center between 2 and 8 h following injury. Need for early intubation was mandated by hoarseness, stridor, and respiratory distress. There were 27 scene deaths attributed to smoke inhalation and thermal burns by postmortem examination in combination with carboxyhemoglobin values of 18% to 69%. There were no deaths among our 12 patients, whose carboxyhemoglobin values ranged from 3.2% to 18.8%. Seven patients required emergency endotracheal intubation, and 5 others were electively intubated in the operating room due to signs and symptoms of respiratory injury. All 12 patients were subsequently bronchoscoped. One patient who underwent bronchoscopy did not require continued intubation, but the other 11 all had dense soot lining the entire visible tracheobronchial tree. One patient developed clinical pneumonia while intubated. Patients required intubation for from 2 to 10 days and pre-extubation bronchoscopic examination was performed in 8 patients, documenting improvement. Five patients with severe facial burns underwent laryngoscopy, and vocal cord edema in 4 delayed extubation despite an improved lower airway. Two patients required late tracheotomy for glottic and interarytenoid scarring. One patient who required reintubation due to cord edema and 1 other who had been intubated emergently in the field required late tracheostomies for glottic and interarytenoid scarring. We had no mortality and low morbidity in a group of young patients with severe inhalation injuries. Rather than the more common complications of pneumonia and adult respiratory distress syndrome, glottic and supraglottic injuries caused the most disability. Periodic evaluation with bronchoscopy and laryngoscopy prior to extubation may have helped to minimize further airway trauma and contributed to our early good results.

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Key words: Pulmonary burns – Smoke inhalation

Introduction

A recent review of the literature [8] revealed that between 3% and 15% of thermally injured patients admitted to burn units have associated inhalation injuries. Many patients with inhalation injuries have associated severe cutaneous burns [5], but the inhalation injury has been found to be the most important determinant of mortality, increasing the risk of death more than age or total body surface area of cutaneous burn involved [4, 6, 23]. The pulmonary pathology occurring primarily as a result of inhalation injury accounts for between 20% and 84% of burn mortality in various series [8]. We report the preliminary results of a series of adolescents who were involved in a bus accident and subsequent fire, 11 of which had severe inhalation injuries mandating endotracheal intubation and ventilatory support.

Materials and methods

On 14 May 1988, a church bus carrying 67 passengers returning from an amusement park collided head-on with a pickup truck traveling on the incorrect side of the median of an interstate highway. Four passengers were adults and the remainder were children and adolescents. Soon after the crash the front of the bus caught fire, presumably due to a puncture in the fuel tank, which was located at the front of the bus. The fire spread rapidly through the passenger compartment. The only usable exit on the bus was the rear emergency door. The survivors included most of the children at the back of the bus and those passengers who were able to exit through windows or climb over the seats on either side of the narrow aisle to the rear emergency door.

There were 27 scene deaths; 25 additional patients were relatively uninjured, and were seen and released at local hospitals in the county in which the accident occurred. Fifteen patients were triaged at the scene by the local emergency medical service units, and many had immediate care at the local county hospital. All of these patients were transported by either helicopter or ground to the University of Louisville Level I Trauma

Table 1. Patient profile of respiratory parameters in injured patients

Patient	Tube Placement	Symptoms	Initial ABG (pH, pCO_2, pO_2)	CoHB %	TBSA % burn	Facial burns	Initial ventilator settings Rate/FiO_2/PEEP	No. of days on ventilator	Compli-cations	Colonizing organisms
DJ	Community hosp. ER	drowsy hypoventilation	7.36/42/272[a] (3L nc)	3.3	8%	yes	IMV14/40%/2.5	3	mild hoarseness	*Hemophilus influenzae*
KF	ER	hoarseness respiratory distress	7.37/38/77[a] (3L nc)	6.5	6%	yes	IMV18/40%/2.5	3	no	β-Streptococcus *Staphylococcus aureus*
JP	ER	stridor hoarseness	7.42/34/298[a] (6L nc)	4.7	3%	yes	IMV14/50%/0	2	no	–
CA	ER	resp. distress	7.41/24/221[a] 100% FM	12.1	58%	yes	AC20/40%/5	8	hoarse	*S. aureus*
CP	scene	resp. distress	7.34/34/382 (ventilator)	16.2	22%	yes	AC20/100%/2.5	3	reintubation; late fusion anterior vocal cords; tracheotomy	*H. influenzae Streptococcus pneumoniae*
CF	Community hosp. ER	resp. distress	7.26/41/266 (ventilator)	5.9	19%	yes	AC20/100%/5	10	severe hoarseness; interarytenoid scarring; tracheotomy	*S. aureus enterococcus*
KD	OR	hoarseness throat pain	7.4/35/90[a] (4L nc)	8.4	3%	minor	IMV6/70%/4	3	hoarse	α-streptococcus
KM	OR	carbonaceous sputum hoarseness	7.32/39/172[a] (10L nc)	7.2	16%	yes	IMV10/100%/5	4	hoarse	*S. aureus*
AC	ER	severe facial burns and swelling hoarseness	7.50/19/529 (ventilator)	3.2	22%	yes	IMV20/100%/2.5	8	hoarse	*S. aureus S. pneumoniae*
HD	OR	stridor severe facial burns and swelling	7.37/23/171 (ventilator)	18.8	15%	yes	IMV16/50%/6	7	pneumonia hoarse	*S. aureus S. pneumoniae*
QH	OR	hoarseness carbonaceous sputum	7.35/41/165[a] (3L nc)	8.9	7%	yes	IMV6/80%/5	3	hoarse	*S. aureus*
MJ'	OR	hoarseness carbonaceous sputum	7.4/36/136[a] (3L nc)	5.0	4%	yes	extubated to face tent	0	no	–

[a] Pre-intubation ABG

Abbreviations: ABG, arterial blood gas; COHB, Carboxyhemoglobin; TBSA, Total body surface area; PEEP, Positive end-expiratory pressure; ER, Emergency room; OR, Operating room; IMV, intermittent mandatory ventilation; AC, assist control; L, liters; nc, nasal cannula; FM, face mask

Center 60 miles southwest of the accident, arriving between 2 and 8 h after injury. Two hospitals were involved in caring for these patients, the Kosair Children's Hospital, which is a 227-bed pediatric tertiary-care referral center and has a burn unit with7 beds; and the Humana Hospital, University of Louisville, which is a 404-bed adult hospital with an 8-bed burn unit. The patients were equally distributed between the two hospitals, which are both staffed by the University of Louisville Department of Surgery faculty and residents.

Results

The 27 scene deaths were attributed to smoke inhalation and thermal injuries. Carboxyhemoglobin values in the non-survivors ranged from 18% to 69%. Cyanide levels in non-survivors did not reveal toxic levels. The 15 patients triaged to the University of Louisville Trauma Center had carboxyhemoglobin values ranging from 3.2% to 18.8%. Two of these 15 patients were found to have only minor cutaneous burns in conjunction with no apparent respiratory injury and were hospitalized only briefly. One additional patient had a carboxyhemoglobin level of 5.2% but no immediate signs of respiratory compromise, and his 2-week hospital stay was necessitated by cutaneous burns. The remaining 12 patients form the basis for this report. Six were boys and 6 were girls, and ages ranged from 13 to 17 years with a mean of 14 years.

In spite of the crash situation, minor lacerations were the only additional injuries incurred besides burns. Many patients also had corneal burns. One patient required emergency endotracheal intubation at the scene and 6 were intubated emergently on arrival in emergency departments, 2 at local hospitals and 4 in Louisville. Need for early intubation was dictated in most cases by hoarseness, stridor, carbonaceous sputum, and respiratory distress. Five additional patients were electively intubated in the operating room.

Eleven of 12 admission chest radiographs were normal. All 12 patients underwent flexible bronchoscopy soon after intubation, and all but 1 had dense soot lining the entire visible tracheobronchial tree down to the secondary bronchi. The soot was adherent to the walls of the airway and saline irrigation was ineffective. At the time of bronchoscopy, there was a marked lack of secretions in the airway and mild to moderate edema was noted. In 1 patient with a carboxyhemoglobin of 5%, the absence of significant findings on bronchoscopy allowed endotracheal tube removal immediately and the patient was observed in the intensive care unit overnight. He did not have subsequent serious respiratory problems.

The patients are profiled in Table 1. The first arterial blood gas in some cases was obtained following intubation due to significant respiratory distress; pre-intubation gases are indicated. Ventilatory management in each case consisted of high inspired oxygen concentrations for at least 24 h following the injury, in conjunction with positive end-expiratory pressure (PEEP) ranging from 2.5 to 6 cm of water. PEEP compliance studies were done in the patients at Kosair Children's Hospital to establish the best level of PEEP. Six patients required fluid resuscitation for cutaneous burns and required an average of 1.9 ml/kg per percent burn of crystalloid above the expected needs according to the Parkland formula.

Endotracheal intubation was required in 11 patients for a duration of 2 to 10 days. Vigorous pulmonary toilet was employed both pre- and postextubation. Pre-extubation bronchoscopic examination was performed in 8 patients, documenting improvement in each case. The 5 patients with severe facial burns underwent laryngoscopy prior to extubation, and vocal cord edema in 4 patients delayed extubation despite an improved lower airway. One patient extubated on post-burn day 2 required reintubation for stridor and on subsequent direct laryngoscopy was found to have a supraglottic eschar at the false vocal cords, which was debrided. In 2 patients, in spite of airway improvement that would have allowed extubation 2 days earlier, the endotracheal tube was left in place pending skin grafts for cutaneous burns so as not to retraumatize the airway with repeated intubation.

There have been no deaths in the group of patients who were transported from the scene. Although airways became colonized with organisms, primarily *Staphylococcus aureus* and *Streptococcus pneumoniae*, only a single patient developed clinical pneumonia requiring antibiotics while intubated. Two patients required tracheotomy at 7 weeks and 9 weeks following injury; both had been discharged from the hospital. One was the patient who had been intubated emergently in the field, who required reintubation following early extubation and later debridement of a supraglottic eschar. She presented at 9 weeks with tracheal stenosis due to fusion of the true cords with only a small opening posteriorly. Following tracheotomy she required a laryngotomy and stent placement. She is now decannulated and laryngoscopy 9 months after injury demonstrated normal cord movement although she remains hoarse. The other patient was originally intubated in a local emergency department prior to transport to the University of Louisville. She required tracheotomy at 7 weeks for interarytenoid scarring involving mainly the left true vocal cord. Four months after injury she underwent laser excision of interarytenoid scar tissue and placement of a translaryngeal stent. She has been successfully decannulated. Her right vocal cord moves normally, but the left remains sluggish and she also continues to be hoarse. One additional patient has mild arytenoid scarring that has not required intervention to this date. Many of the other patients continue to report relative hoarseness, but there has not been an increased incidence of respiratory-related infections in these patients subsequent to the injury.

Cutaneous burns ranged from 3% to 58% of total body surface area. Most burns involved the upper extremities and face, although 1 of the most seriously injured patients incurred a fourth-degree burn of the right lower extremity requiring a below-knee amputation. The average hospital stay was 19 days and several patients required skin grafts. Three children required temporary homografts, but all had their burns completely covered with autografts within 21 days of injury. All children received topical antimicrobial therapy, and all received preoperative intravenous prophylactic antibiotics at the time of skin grafting. Five patients required aggressive support with parenteral and enteral nutrition.

Discussion

This report profiles a group of young patients involved in a bus accident and subsequent fire at which there were 27 scene deaths. All patients who died had severe cutaneous burns and inhalation injuries. The accident occurred over 60 miles from a Level I trauma center with a burn unit, necessitating appropriate triage of survivors. Despite the gravity of the respiratory injuries, only 1 patient required intubation in the field. Within the 1 to 8 h it took for the 15 more seriously injured patients to arrive in emergency departments, 11 additional patients were exhibiting signs and symptoms of respiratory embarrassment, in some cases mandating intubation prior to blood gas determination.

Stone [22] described three temporal stages of pulmonary injury: (1) respiratory insufficiency with bronchospasm occurring at 1–12 h following injury; (2) pulmonary edema at 6–72 h; and (3) bronchopneumonia after 60 h; and noted that the child who appears symptom-free a few hours post-injury may go on to develop significant respiratory distress within a matter of hours. Herndon et al. [8] described 22 patients who developed severe pulmonary complications from smoke inhalation, and only 2 had increased carboxyhemoglobin levels on admission. The relatively low values in our patients reflect the fact that they arrived at our institutions 2–8 h following injury, but at that time the majority were showing progressive signs of respiratory distress. Parish [16] and Zikria et al. [24] have listed the many symptoms and signs associated with respiratory burns, and the former author notes that initial arterial blood gases often show a normal or slight decrease in PaO_2 and a normal pH. This was true in some but not all patients discussed here, as indicated in Table 1.

Carbon monoxide poisoning is the most immediate cause of death from fire. The injury to the respiratory tract is usually the result of irritation and inflammation caused by noxious gases and smoke in combination with asphyxia due to carbon monoxide poisoning [17]. Although cyanide has been implicated in inhalation injuries [20], there was no evidence of cyanide toxicity in our patients. The bus seats were composed of vinyl and polyurethane.

Blinn et al. [1] studied 86 consecutive patients with a combination of inhalation injuries and cutaneous burns, of which 88% required an endotracheal tube. There was a 62% mortality in this group of patients, yet admission chest radiographs, paO_2, and lung auscultation were normal in 90%. They also classified bronchoscopic findings into mild, moderate, and severe categories. A severe injury was denoted by marked coating of the trachea and mainstem bronchi with soot particles, as well as edema and ulceration.

The majority of the patients profiled in this series had normal admission chest radiographs, and 11 of the 12 had dense soot lining the entire tracheobronchial tree to the level of the secondary bronchi. All patients underwent bronchoscopy within 16 h of injury, and edema of the airway was a finding in most cases at that time, with maximal edema occurring 2 to 3 days following the injury. As the soot cleared from the airway, striking erythema of the mucosa was noted.

Herndon et al. [7] studied extravascular lung water (EVLW) changes following burn injuries, and found that inhalation injuries were associated with an increase in EVLW during the first 24 h after injury. The lung edema was attributed to the toxic effects of smoke inhalation. The increase in lung microvascular permeability is attenuated by increasing cardiac output to normal levels with appropriate fluid resuscitation, which is increased on the order of 2 ml/kg per percent body surface area burned *above* calculated resuscitation volumes [15]. Fluid restriction may lead to excessive pulmonary fluid formation and hypoxia [9]. The 5 patients in this series who did not require fluid resuscitation (cutaneous burns less than 15%) required only maintenance crystalloid volumes to maintain adequate urine output. The 6 patients with significant cutaneous burns required an average of 1.9 ml/kg per percent burn in addition to calculated resuscitation volumes.

The primary goals of endotracheal intubation and ventilator therapy were to: (1) provide an adequate airway until significant airway edema had subsided; and (2) maintain adequate oxygenation and ventilation during the time of resuscitation and maximum pulmonary edema due to injury. Vigorous suctioning, saline lavage, PEEP compliance studies, humidification of inspired gases, and chest percussion and postural drainage were all adjuncts utilized to optimize respiratory care. Although other innovative techniques of respiratory care have been described in inhalation burn victims, such as high-frequency percussive ventilation [3] and synchronized ventilatory support [13], they were not used in this group.

A few authors have described the microscopic findings that occur following airway injury in smoke inhalation [2]. Judkins and Brander [11] evaluated three children involved in the same fire who died at varying time intervals. One child died 24 days following injury, and epithelial regeneration was progressing well but consisted mainly of squamous epithelium. This was felt likely to render the patient at risk for recurrent chest infections for some weeks due to lack of the normal protection of mucus and ciliary action. Pneumonia complicating respiratory injury poses a significant threat and increased risk of mortality [19], particularly in intubated patients. Adhering to the advice of Stone [22], parenteral antibiotics were employed in our patients only in established cases of pulmonary infection based on sputum smears, cultures, and radiographic evidence of infection. They were never used as prophylaxis for respiratory disease, which is felt to predispose to colonization with more virulent organisms. Only 1 patient in our group developed clinical pneumonia due to *Staphylococcus aureus*.

Bronchoscopy has many advocates in the initial evaluation of inhalation injuries [6, 18]. Hunt et al. [10] showed on serial bronchoscopies that the acute hypopharyngeal and laryngeal edema subsides by the 4th to 6th post-burn day. Miller et al. [12] advocate serial fiberoptic laryngoscopies and recommend that patients showing poor resolution of supraglottic edema and inflammation and/or a need for further mechanical ventilation undergo tracheotomy near the 6th to 8th post-burn day. Alternatively, Stone [22] believed tracheotomy should be reserved for true glottic or supraglottic airway obstructions. In fact, tracheotomy carries a high risk of morbidity: 11% of patients in one reported series remained tracheotomy-dependent following the procedure [6]. Another report [14] describes a 6% incidence of operative complications and a 30% incidence of late complications related to tracheotomies. None of our patients required early tracheotomy, although a few required intubation for 8 to 10 days. Two patients required late elective tracheotomy for progressive glottic scarring, and they are now both decannulated but have persistent hoarseness.

Herndon et al. [8] noted that in patients with inhalation injury who have survived, the long-term pulmonary sequelae are few. Two of our more severely injured patients have had subsequent pulmonary function tests that are normal pre- and post-exercise. Smith and Brandon [21] found a large proportion of patients following carbon monoxide poisoning to have mental disturbances of some sort, including personality deterioration and significant memory impairment. Long-term studies of pediatric smoke-inhalation victims have not been done. Although many of the victims and their families in this report used the services of psychiatrists during and subsequent to hospitalization, it would be difficult at this point to implicate more than the normal grieving process for loss of friends, relatives, and self-image as the indication for any personality or emotional derangements.

In summary, we describe a group of adolescents with respiratory injuries due to a bus crash and subsequent fire in which smoke inhalation was one of the causes of death in non-survivors. There was no mortality and minimal morbidity in the 11 patients requiring endotracheal intubation and mechanical ventilation. Rather than the more common complications of pneumonia and ARDS, glottic and supraglottic injuries caused the most disability. The low incidence of pneumonia may have been due to frequent and vigorous pulmonary toilet and physical therapy in conjunction with the normal gown, glove, and mask technique used in our burn units. Antibiotics were not employed prophylactically. Subglottic stenosis or frequent respiratory infections have not been a problem. Persistent hoarseness affects the majority. Periodic evaluation with bronchoscopy and laryngoscopy prior to extubation may have helped to minimize further airway trauma and contributed to our good early results.

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