BJA

British Journal of Anaesthesia, 117 (S1): i49–i59 (2016)

doi: 10.1093/bja/aew193
Special Issue

Systematic review of the anaesthetic management of non-iatrogenic acute adult airway trauma

S. J. Mercer[1,2,3,*], C. P. Jones[1], M. Bridge[1], E. Clitheroe[1], B. Morton[1,4] and P. Groom[1]

[1]Anaesthetic Department, Aintree University Hospital NHS Foundation Trust, Longmoor Lane, Aintree, Liverpool L9 7AL, UK, [2]Defence Medical Services, Royal Centre for Defence Medicine, Queen Elizabeth Hospital Birmingham, Mindelsohn Way, Edgbaston, Birmingham B15 2WB, UK, [3]Postgraduate School of Medicine, University of Liverpool, Cedar House, Ashton Street, Liverpool L69 3GE, UK, and [4]Honorary Research Fellow, Liverpool School of Tropical Medicine, Pembroke Place, Liverpool L3 5QA, UK

*Corresponding author. E-mail: simonjmercer@hotmail.com

Abstract

Introduction: Non-iatrogenic trauma to the airway is rare and presents a significant challenge to the anaesthetist. Although guidelines for the management of the unanticipated difficult airway have been published, these do not make provision for the 'anticipated' difficult airway. This systematic review aims to inform best practice and suggest management options for different injury patterns.

Methods: A literature search was conducted using Embase, Medline, and Google Scholar for papers after the year 2000 reporting on the acute airway management of adult patients who suffered airway trauma. Our protocol and search strategy are registered with and published by PROSPERO (http://www.crd.york.ac.uk/PROSPERO, ID: CRD42016032763).

Results: A systematic literature search yielded 578 articles, of which a total of 148 full-text papers were reviewed. We present our results categorized by mechanism of injury: blunt, penetrating, blast, and burns.

Conclusions: The hallmark of airway management with trauma to the airway is the maintenance of spontaneous ventilation, intubation under direct vision to avoid the creation of a false passage, and the avoidance of both intermittent positive pressure ventilation and cricoid pressure (the latter for laryngotracheal trauma only) during a rapid sequence induction. Management depends on available resources and time to perform airway assessment, investigations, and intervention (patients will be classified into one of three categories: no time, some time, or adequate time). Human factors, particularly the development of a shared mental model amongst the trauma team, are vital to mitigate risk and improve patient safety.

Key words: airway management; blast injuries; blunt injuries; burns; wounds, penetrating

Trauma to the airway may cause acutely life-threatening airway laceration, obstruction, haemorrhage, and aspiration of blood; this presents the anaesthetist with a major challenge.[1 2] Fortunately, airway trauma is a relatively infrequent complication of major trauma, in both the UK civilian (National Health Service) and UK Defence Medical Services settings.[3 4] However, complications related to this injury can be catastrophic without optimal management. For example, in a patient with blunt or penetrating airway trauma, advancing a bougie or tracheal tube blindly beyond the vocal cords risks penetration through an airway laceration, leading to airway obstruction, pneumomediastinum, and the creation of a false passage.[1 5] Guidelines for the management of the unanticipated difficult airway have recently been revised by the Difficult Airway Society;[6] however, these do not make provision for an 'anticipated' difficult airway that could be experienced in complex trauma, and if followed, could even worsen

Accepted: May 23, 2016

the traumatic airway. Our aim was to inform best practice for airway trauma and suggest management options for the various injury patterns to reduce serious sequelae.

Methods

Search strategy

We searched Embase, Medline, and Google Scholar for papers reporting on the acute airway management of adult patients who had suffered airway trauma. We limited the search to articles published from the year 2000 onwards to represent contemporary practice. The search included full-text reports of articles from peer-reviewed journals and conference abstracts published in English, and there were no restrictions to the studies reviewed. In addition, the reference lists of the articles reviewed were scrutinized for additional relevant articles and book chapters.

Article selection

Titles and abstracts of the references obtained were reviewed by two independent reviewers (M.B. and C.P.J.). Articles were categorized for inclusion or exclusion. Articles were removed if both reviewers agreed independently to exclude. In the event of agreement to include or a discordant opinion, articles were reviewed in full by one of four independent reviewers (C.P.J., P.G., E.C., and S.J.M.). Inclusion criteria were as follows: adults older than 18 yr of age with airway trauma; papers published on or after 2000; and papers reporting airway trauma (blunt, burn, penetrating, blast, or miscellaneous injuries) and anaesthetic management. The exclusion criteria were as follows: children (<18 yr old); animal studies; papers not dealing with acute trauma and airway trauma; and papers that did not have an airway management focus. Our full protocol and search strategy are registered with and published by PROSPERO (http://www.crd.york.ac.uk/PROSPERO, ID: CRD42016032763); this includes the search terms and keywords used.

Results

Our systematic literature search yielded 578 articles (see Fig. 1). Two hundred and sixteen were excluded after title review. After abstract review, a further 214 articles were excluded. A total of 148 full-text papers were reviewed, of which we included 35 in this review. Figure 1 details reasons for inclusion and exclusion. We present our results categorized by mechanism of injury, as follows: blunt, penetrating, blast, and burns.

Blunt injury

Blunt airway trauma usually involves high-energy transfer; examples include assault, crush, fall from height, road traffic collision, pedestrian *vs* vehicle, hanging, accidental strangulation, and the 'clothesline' mechanism. Table 1 describes the various mechanisms of injury in blunt trauma and their associated injuries.

Patients who suffer blunt injury develop complex airway injuries, often as part of severe multisystem trauma. Failure to intubate, secure, and protect the airway in these patients are common factors that lead to an increase in morbidity and mortality.[7–9] Blunt airway trauma includes maxillofacial trauma, laryngotracheal trauma (LTT), and disruption of the trachea and bronchi. The sternum, cervical spine, and mandible shield the airway during trauma such that the incidence of blunt airway injury is low (~0.4%).[7–9] Despite being a rare pathology, the impact can be significant, with mortality rates of traumatic lesions below the vocal cords quoted as high as 63%.[10] Bronchial disruption occurs in 1% of chest trauma; most of these patients die at the scene.[11]

Maxillofacial trauma is the most common type of blunt airway trauma but does not usually present a problem because trismus is usually attributable to pain and therefore resolves on induction. The main issues to consider are then airway haemorrhage, hypoxia, and the risk of aspiration. Very rarely, trismus is the result of impaction of a condylar head fracture, causing a physical obstruction to mouth opening, which becomes apparent only after rapid sequence induction.[12]

The cricoid cartilage and cricothyroid membrane are involved in 50% of instances of blunt airway trauma with airway compromise; injury to the thyrohyoid membrane, thyroid cartilage, and extrathoracic trachea account for the remainder.[1 13] Laryngotracheal separation occurs in up to 63% of instances, usually between the cricoid and fourth tracheal cartilage.[14 15] The airway can remain patent if spontaneous respiration is maintained by splinting of peritracheal connective tissue.[16] This situation is precarious and can deteriorate rapidly.[17]

Blunt trauma at the level of the larynx or below can be difficult to diagnose and life threatening if managed poorly. Patients can present with non-specific signs and symptoms, such as cough, dyspnoea, aphonia, stridor, laryngeal crepitus, haemoptysis, and subcutaneous emphysema. These symptoms do not correlate well with the anatomical site of the lesion;[14 15] however, complaints of haemoptysis and stridor at presentation have been associated with severity of injury.[16 18]

In view of the poor relation between signs and severity of injury, the clinician must have both a high index of suspicion and a low threshold for further investigations, including plain X-rays (chest and lateral cervical spine) to rule out surgical emphysema, pneumothorax, or both. Nasendoscopy is useful and permits assessment of vocal cord movement, integrity of the laryngeal mucosa, and airway patency.[13] Computed tomography is the gold standard and detects the site of injury in 94% of blunt trauma.[19] Bronchoscopy is considered the best diagnostic tool for suspected lesions below the vocal cords,[11 14 20] but utility in acute airway compromise is limited because it is a skilled technique and access to equipment may be limited. The severity of blunt airway trauma has been classified by Schaefer and Close[21] (Table 2).

Trauma to the upper and lower respiratory tract should be managed on a patient-by-patient basis. Minor instances of blunt airway trauma should be observed in the critical care unit, with reassessment of the airway at regular intervals for at least 48 h. The management of major blunt airway trauma is governed by the degree of patient cooperation and a risk–benefit analysis. The safest approach to patients requiring intubation is to instrument the trachea under direct vision to avoid entering a tear, creating a false passage, or disrupting the airway completely.[1] It is preferable to do this with the patient awake and breathing spontaneously.

Following these principles, there are three judicious approaches to airway management . First, performing an awake tracheostomy under local anaesthesia is a common intervention of choice for LTT.[18] However, this technique requires a high degree of operator skill, may be difficult, and is limited by patient cooperation and teh time taken to assemble skilled assistance.[16 22 23] It is important to note that surgical cricothyroidotomy and percutaneous cricothyroidotomy are contraindicated in these patients because they may lead to further airway disruption.[11 18 24] This is not the case for tracheobronchial trauma because the lesion is commonly more distal, with 76% of injuries occurring within 2 cm of the carina, and 43% occurring within the first 2 cm of the right main bronchus.[25 26]

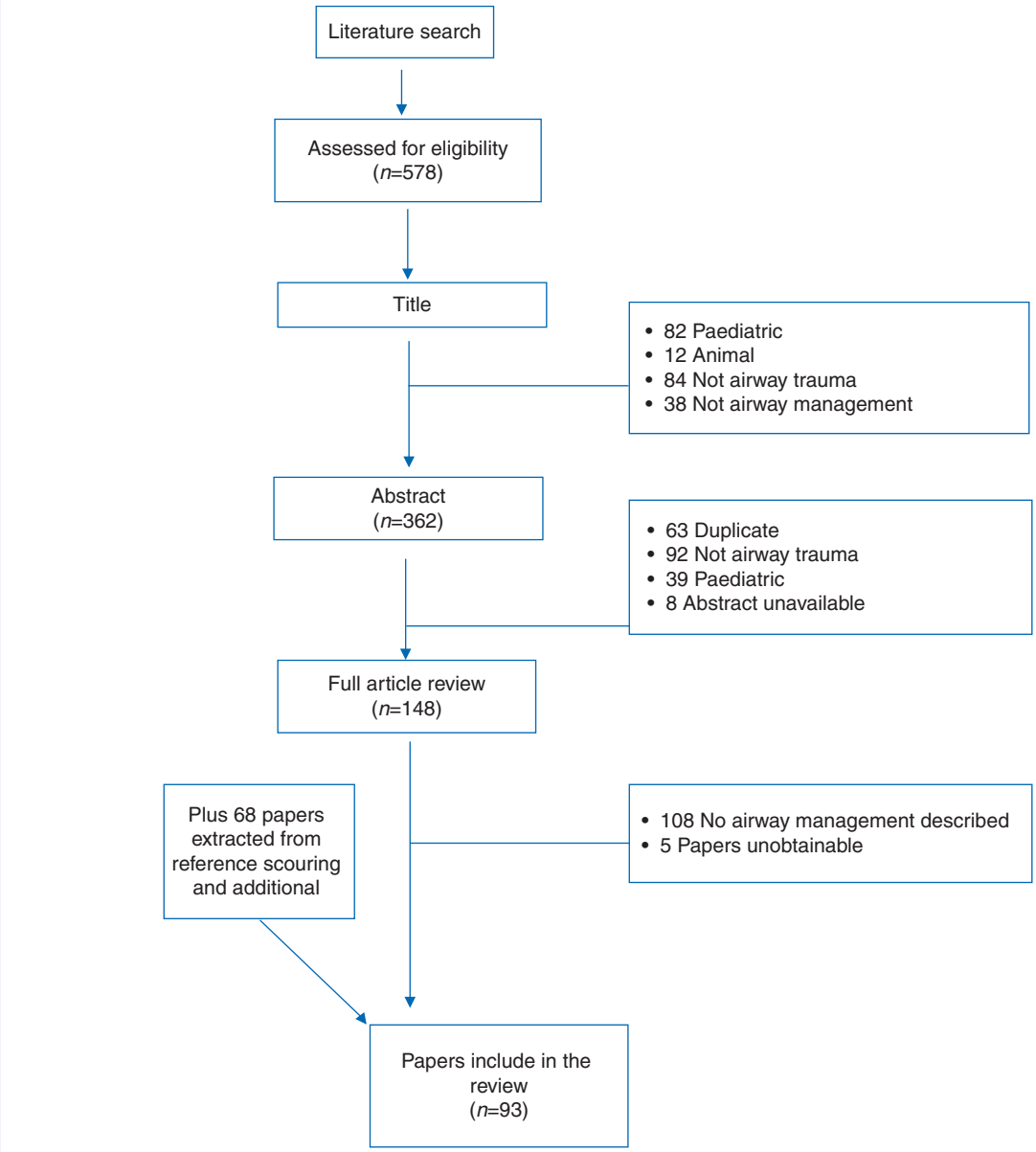


Fig 1 Systemic review literature search flow chart.

Second, awake fibreoptic intubation is an alternative technique, which maintains spontaneous ventilation and allows simultaneous airway assessment and placement of a tracheal tube distal to any pericarinal defect.[22 23] Care must be taken when railroading the tracheal tube so that its bevel does not catch on a tear, extending the injury.[27] This can be avoided by using a lubricated small-diameter tube, fitting snuggly onto the scope, and twisting the tube so that its bevel faces any lesion during its advancement into the trachea. The use of the Lightwand in blunt trauma has also been described.[28]

Third, conventional intubation is a rapid way of securing the airway but risks intubating a tear, creating a false passage, or disruption of the larynx or trachea.[21 29] Consequently, we recommend fibrescope-assisted direct or videolaryngoscopy as part of a modified rapid sequence induction (with no cricoid pressure or positive pressure ventilation because both may aggravate the injury).[30 31] A small-diameter tracheal tube should be placed at the introitus of the larynx under direct vision, and then a fibrescope is passed through the tube and into the trachea. The tracheal tube can then be delivered past the lesion safely if the bevel is orientated to face the lesion. Modified rapid sequence induction and rigid bronchoscopy is an alternative choice, because airway inspection is simultaneous with intubation. This technique requires a high degree of operator skill and needs appropriately trained personnel but can deal effectively with distal tracheal or bronchial disruption.[11 18 32] A summary of the associated problems and cautions in relation to the anatomical territory is presented in Table 3. The technique of choice depends upon the patient's condition, urgency, and the experience of the anaesthetist and surgeon.[33]

Table 1 The mechanisms of injury associated with blunt trauma to the airway[7]

Type of trauma	Mechanisim of injury	Airway injury
Road traffic collision	Severe flexion/extension	Tracheal tears
Fall	Rapid deceleration	Fractures of the larynx Laryngotracheal separation
Hanging Accidental strangulation 'Clothesline' mechanism Assault	Direct blows	Fractured thyroid or cricoid cartilages, or both Layrngotrachael separation
Crush Pedestrian *vs* vehicle	Crush injuries to chest	Tracheobronchial disruption
	Sudden, explosive increase in intrathoracic pressure against a relatively closed glottis	
	Rapid deceleration shears airways at fixed points: cricoid cartilage and carina	Transection at carina or cricotracheal junction
	Pulmonary compression tears the airway at the level of the carina	Carinal tear

Table 2 Classification of the severity of blunt airway injury (adapted from Schaefer and Close)[21]

Group 1	Minor endolaryngeal haemotoma, laceration, or both No detectable laryngeal fracture
Group 2	Laryngeal oedema, haemotoma, or both Minor mucosal disruption, but no exposed cartilage
Group 3	Massive oedema, large mucosal lacerations, exposed cartilage, displaced fracture, vocal cord immobility
Group 4	As group 3 plus comminuted or unstable fracture

Penetrating and blast injury

Penetrating injuries to the face and neck are uncommon in both civilian[25 34] and military[3 35] populations. However, the incidence is increasing in military personnel because modern body armour does not protect the face and neck.[26 34 36–38] Airway wounds can cause immediate life-threatening compromise[34] because of the density of vital structures within the neck.[1 2 39 40] Indeed, on exploration, a clinically superficial stab wound may reveal a vascular or aerodigestive injury.[3 4 32] Blast-induced injuries result from direct or indirect exposure to an explosion and have high potential for an associated upper airway injury,[5 34 41] the most severe of which is complete disruption of the airway.[1 35 42]

The causes of penetrating airway trauma are diverse and include assault or self-inflicted injuries with firearms or knives.[36–38 40] Facial wounds are usually the result of gunshot[2 7 9 38 39 43–45] or blast injuries.[4 10 46–53] Objects or projectiles can transfix the mouth and limit mouth opening.[11–15 25 34 40–45 54 55] Patients may also present with neck lacerations and open wounds to the airway.[2 16 38 40] Gunshot and blast injuries result in penetrating neck trauma,[25 46–53] so the clinician must always consider the likely trajectory of projectiles or fragments and their potential airway effects. The location of great vessels in the neck adjacent to the airway means that haemorrhage can impact airway patency,[14 15 54 56] with high mortality.[16 18 34 43 44 45 54]

When assessing these patients, an effective approach is to divide the structures of the head and neck into three zones.[13 39 55] Zone 1 is from the clavicles to the cricoid cartilage, zone 2 from the cricoid cartilage to the angle of the mandible, and zone 3 from the angle of the mandible to the base of the skull. Zone analysis predicts potential injuries and the need for urgent airway management solutions.[5 19 25] Blood loss and upper airway obstruction are the major determinants of injury severity.[14 38 40]

Wounds in the anterior and lateral aspects of the neck compromise the airway more often than those in the posterior region.[11 20 25 40 42] The clinician should also consider the presence of blood and debris within the lumen of the airway, injury within the airway wall itself, or injury outside the wall (e.g. expanding haematoma or surgical emphysema). If possible, computed tomography is the first-line investigation in stable patients with penetrating neck injuries[21 35 56] in order to identify the location of an airway injury.

As with blunt injuries, major penetrating and blast airway trauma management is governed by the degree of patient cooperation and a risk–benefit analysis. Potential difficulties to consider are neck haematoma or subcutaneous emphysema around the airway that can distort anatomy and impair tracheostomy. Fibreoptic intubation is difficult if blood or debris is present within the airway. Regardless, awake fibreoptic intubation in skilled hands has proved effective.[1 18 39 41 43–45 54 57]

The literature suggests that the safest approach to patients requiring intubation is to instrument the trachea under direct vision in order to avoid entering a tear, creating a false passage, or disrupting the airway completely.[5 16 22 23 50 58] It is preferable to do this with the patient awake and breathing spontaneously. Similar to blunt trauma, awake tracheostomy is the intervention of choice,[5 11 18 22 23 25 26 35 38 40 42 59–64] and surgical or percutaneous cricothyroidotomy are contraindicated.[27 59] It is important to consider thoracotomy if a patient presents with chest trauma, and low tracheal or bronchial transection standard tracheostomy in this situation will result in malposition distal to the defect. Awake fibreoptic intubation is an alternative option to permit simultaneous airway assessment and placement of a tracheal tube distal to any laceration.[21 29 41 45 57 65 66] As emphasized already, great care must be taken when railroading the tracheal tube so that its bevel does not extend a laceration. A modified

Table 3 A summary of the the associated problems and cautions in relation to the anatomical territory in blunt injury. LTT, laryngotracheal trauma

	Anatomical territory	Associated problems	Caution: red flag signs and symptoms
	Maxillofacial	Traumatic brain injury and base of skull fracture Cervical spine fracture Ophthalmic injury Vascular injury Aspiration of blood and debris	Signs of elevated intracranial presssure Neurological deficit Neurogenic shock Significant bleeding from fracture displacement Bilateral anterior mandible fractures and airway obstruction Ventilatory failure
	Laryngotracheal	Cervical fracture Vascular injury Oesophageal injury Rib fractures and flail segment Pneumothorax Haemothorax Pneumomediastinum Pulmonary contusion	Haemoptysis and stridor have previously been reported as cardinal features of severe LTT Massive surgical emphysema Ventilatory failure Cardiovascular collapse
	Trachea and bronchi	Vascular injury Oesophageal injury Rib fractures and flail segment Pneumothorax Haemothorax Pneumomediastinum Pulmonary contusion	Haemoptysis Massive surgical emphysema Ventilatory failure Cardiovascular collapse

rapid sequence induction and fibreoptic-assisted direct or videolaryngoscopy may be undertaken if a general anaesthetic must be administered immediately. However, the clinician should avoid neuromuscular blocking agents (muscle tone may be important for airway integrity in airway transection)[30 50 58 67] and be cognizant that conventional intubation risks intubating a tear.[5 31 68] We suggest that this may be mediated by fibrescope-assisted direct or videolaryngoscopy as part of a modified rapid sequence induction (with no cricoid pressure or positive pressure ventilation). A tracheal tube should be placed above the vocal cords under direct vision and then a fibrescope passed through the tube and into the trachea. The tracheal tube can then be delivered safely as described above. Large neck wounds can be intubated directly over a fibrescope in this manner. Combined usage of an Airway Scope and gum elastic bougie for emergency airway management in a patient with a neck stab wound has also been described,[69] as has the use of the AirTraq in traumatic asphyxiation,[70] and the use of the Lightwand.[28] A summary of the associated problems and cautions in relation to the anatomical territory for non-iatrogenic injury to the airway caused by penetrating injury is presented in Table 4.

Burns

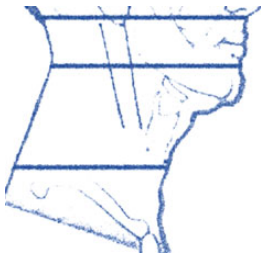
Burns to the upper airway caused by direct heat and steam injury, electrocution, or contact with corrosive chemicals can lead to marked swelling of the face, tongue, epiglottis, and glottis and result in airway obstruction.[11 18 25 32 34 60–64 71] Airway swelling may not occur immediately but may develop over a period of hours (exacerbated by fluid resuscitation). Therefore, a high index of suspicion and frequent re-evaluation of the airway are essential.[3 35 65 72–74] Thermal injury is primarily restricted to structures above the vocal cords, unless steam is inhaled, because the oropharynx and nasopharynx act as an efficient heat sink.[26 34 36–38 66 74] Smoke inhalation delivers a pathological insult to the lungs as a result of the particulates, respiratory irritants, and systemic toxins that it contains.[34 75] In this context, it is necessary to look for and treat carbon monoxide[76] and cyanide poisoning.[77]

Inhalation injury is a greater contributor to overall morbidity and mortality than either body surface area percentage or age[57 67] and is present in 60% of central facial burns.[61 68] Burns patients without smoke inhalation have a mortality of 2%, compared with a mortality of 30% with this type of injury.[78]

Patients who present acutely with facial and neck burns have two predominant airway issues: airway obstruction and smoke inhalation. These risks prompt the early intubation of high-risk patients,[75 79 80] because the rate of difficult intubation increases from 11.2 to 16.9% if delayed (owing to the development of airway oedema).[61 62 71 81] However, intubation is not without risk, and the clinician should carefully evaluate individual patients.[72–74 82] Nasendoscopy is an important tool to diagnose the extent and severity of an airway burn, and serial nasendoscopy of vocal fold oedema has been used to predict the need for intubation in patients at risk.[66 74] Fibreoptic bronchoscopy supports the diagnosis of smoke inhalation and may reveal carbonaceous debris, erythema, or ulceration.

Intubation is mandated in instances of heat and smoke inhalation injury combined with facial, neck, or extensive body burns. In contrast, physiologically stable patients with smoke inhalation injury but no facial or neck burns may be monitored by nasal endoscopy and intubated later.[57] In addition to airway oedema, other causes of difficulty include limited mouth opening and intractable trismus in electrical burns.[61] Mask ventilation may also be challenging because of the presence of dressings and exudates,[42 78] and the application of nasal oxygen should be

Table 4 A summary of the the associated problems and cautions in relation to the anatomical territory for non-iatrogenic injury to the airway caused by penetrating injury

	Anatomical territory	Associated problems	Caution: red flag signs and symptoms
	Zone 3	Cranial nerve injury Oesophageal injury Vascular injury (to branches of the external carotid artery, internal carotid artery, vertebral artery, and internal jugular and facial veins)	Neurological deficit Neurogenic shock Odynophagia Haematemesis Air bubbling from wound
	Zone 2	Oesophageal injury Vascular injury (to common carotid, carotid bifurcation, vertebral arteries, and jugular veins)	Massive surgical emphysema Expanding or pulsatile haematoma Active bleeding Cardiovascular collapse
	Zone 1	Oesophageal injury Vascular injury (to subclavian and innominate vessels, common carotid and lower vertebral arteries, and jugular veins)	Haemoptysis

considered. This can significantly boost the effective inspired oxygen and can be left on during tracheal intubation attempts. The application of additional nasal oxygen during intubation has been termed NO DESAT).[83]

For an anticipated difficult airway, clinical examination and nasendoscopy will provide vital information; however, this does depend on the degree of patient cooperation and the severity of the injury. Minor injuries can be managed conservatively in a monitored (high-dependency unit) setting. For major burns requiring immediate treatment, for cooperative patients awake fibreoptic intubation should be considered if the preoperative evaluation reveals concern for upper airway patency or difficult mask ventilation.[79] For severe injuries or non-compliant patients, a primary surgical airway is mandated.[61 62 81] Tracheostomy may also be indicated if a laryngeal injury is suspected.[82 84] In uncooperative patients or those with less severe pathology on clinical examination and nasendoscopy, rapid sequence induction followed by videolaryngoscopy is appropriate. One article described the use of the Combitube in the airway management of burns patients.[85]

After intubation, the tube should be secured carefully because accidental extubation may have fatal consequences.[86] Fixation methods include wiring the tube to a tooth and the use of archbars. The tracheal tube should be left uncut because facial swelling can cause it to retreat into the oropharynx, requiring re-intubation at the worst possible time. A summary of the associated problems and cautions in relation to the anatomical territory for non-iatrogenic injury to the airway caused by burn injuries is presented in Table 5.

Conclusion

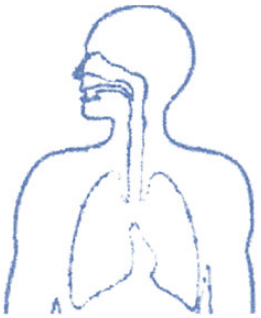
Our systematic review of the literature on acute adult non-iatrogenic airway trauma has highlighted common themes that should guide the clinician. The hallmark of airway management in these patients is the maintenance of spontaneous ventilation if at all possible, intubation under direct vision to avoid the creation of a false passage, and the avoidance of both intermittent positive pressure ventilation and cricoid pressure during a rapid sequence induction. This situation is distinct from the management of an unanticipated difficult airway. Here, adherence to the Difficult Airway Society 2015 guidelines[6] could even worsen the situation in this patient population because cricoid pressure, positive pressure ventilation either via a face mask or a supraglottic airway device, and surgical cricothyroidotomy are all contraindicated.

Consequently, if the primary intubation plan fails, there is only one rescue plan to avoid making the situation worse, namely surgical tracheostomy. The management of burns patients is broadly similar but with the caveat that the Difficult Airway Society 2015 guidelines[6] apply throughout because the clinician is not faced with the problem of an airway laceration or transection.

Ultimately, when considering all these types of airway traumas, the clinician is faced with a time-management issue, with a patient being classified into one of three groups: no time, some time, or adequate time for airway assessment, investigation, and intervention. If the patient is in extremis and there is no time for assessment, the anaesthetist must manage the patient urgently while planning for the worst-case scenario; a false passage in blunt, penetrating, and blast trauma, for example. If the airway appears stable then there is adequate time for assessment, planning, and intervention in optimal conditions. Most patients are somewhere between these two extremes, such that informed decision making is crucial for the anaesthetist because the situation can be worsened or stabilized by their subsequent actions. For example, allowing a patient to assume their most comfortable position, be that sitting, lateral, or prone, may 'buy enough time' to undertake nasal endoscopy or computed tomography.[4] Objects that impale the patient should be trimmed carefully so they do not impede subsequent airway interventions.[42 87] Finally, location is very important; it could be safer to transfer the patient to theatre to secure the airway, especially if a tracheostomy is required, because there is more space, better lighting, and staff more familiar with the intervention.

Human factors are key to the management of a complex anticipated airway problem.[88 89] The recently revised Difficult Airway Society Guidelines for the management of an unanticipated difficult airway[6] devote a significant section to these. Leadership, followership, teamwork, and situational awareness and communication amongst the team are all vital to ensure that the airway is safely secured. A trauma team will often have 10–15 min to prepare to receive a patient once they have been activated.[84] During this period, the anaesthetist should consider the likelihood of airway trauma and the possible investigations

Table 5 A summary of the the associated problems and cautions in relation to the anatomical territory for non-iatrogenic injury to the airway caused by burn injuries

	Anatomical territory	Associated problems	Caution: red flag signs and symptoms
	Face, tongue, and oropharynx	Pulmonary oedema Cardiovascular dysfunction Carbon monoxide and cyanide poisoning	Evidence of thermal or chemical injury to face, lips, mouth, pharynx, or nasal mucosa Inflammation, blistering, oedema, and mucosal lesions Hair singeing Soot in mouth
	Larynx		Stridor Hoarseness
	Trachea, bronchi, and distal airways		Carbonaceous sputum Dyspnoea Hypoxaemia Increased concentrations of carbon monoxide and cyanide may not cause cyanosis Decreased level of consciousness, confusion, or signs of cerebellar dysfunction Mortality increases significantly with inhalation injury
Ensure primary survey completed to assess for other traumatic injuries Avoid task fixation with burns			

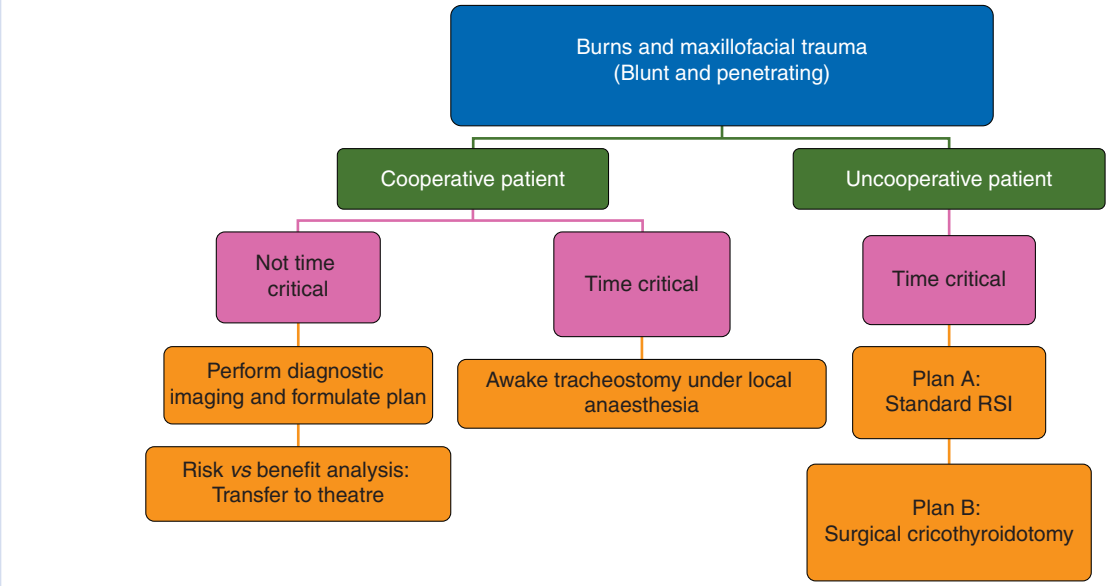


Fig 2 An example of shared mental model maps for burns and maxilliofacial trauma. RSI, rapid sequence induction.

and airway interventions required. This includes consideration of what personnel and equipment are needed and specifically who will perform a tracheostomy or surgical cricothyroidotomy if required. The UK Defence Medical Services have developed the concept of a 'command huddle',[90] where decisions are made by a senior team about further management after the primary survey. A conversation around airway management (if it has not already taken place) should occur here, with a discussion around the airway technique of choice.

The majority of anaesthetists have limited exposure to complex airway trauma and need to develop shared mental models to optimize management techniques; examples of these are included in Figs 2 and 3. Our review presents contemporary evidence in management of airway trauma to inform clinical practice. The clinician should also consolidate knowledge through mechanisms such as high-fidelity simulation scenarios[91] and by attending workshops specifically for the management of airway trauma.

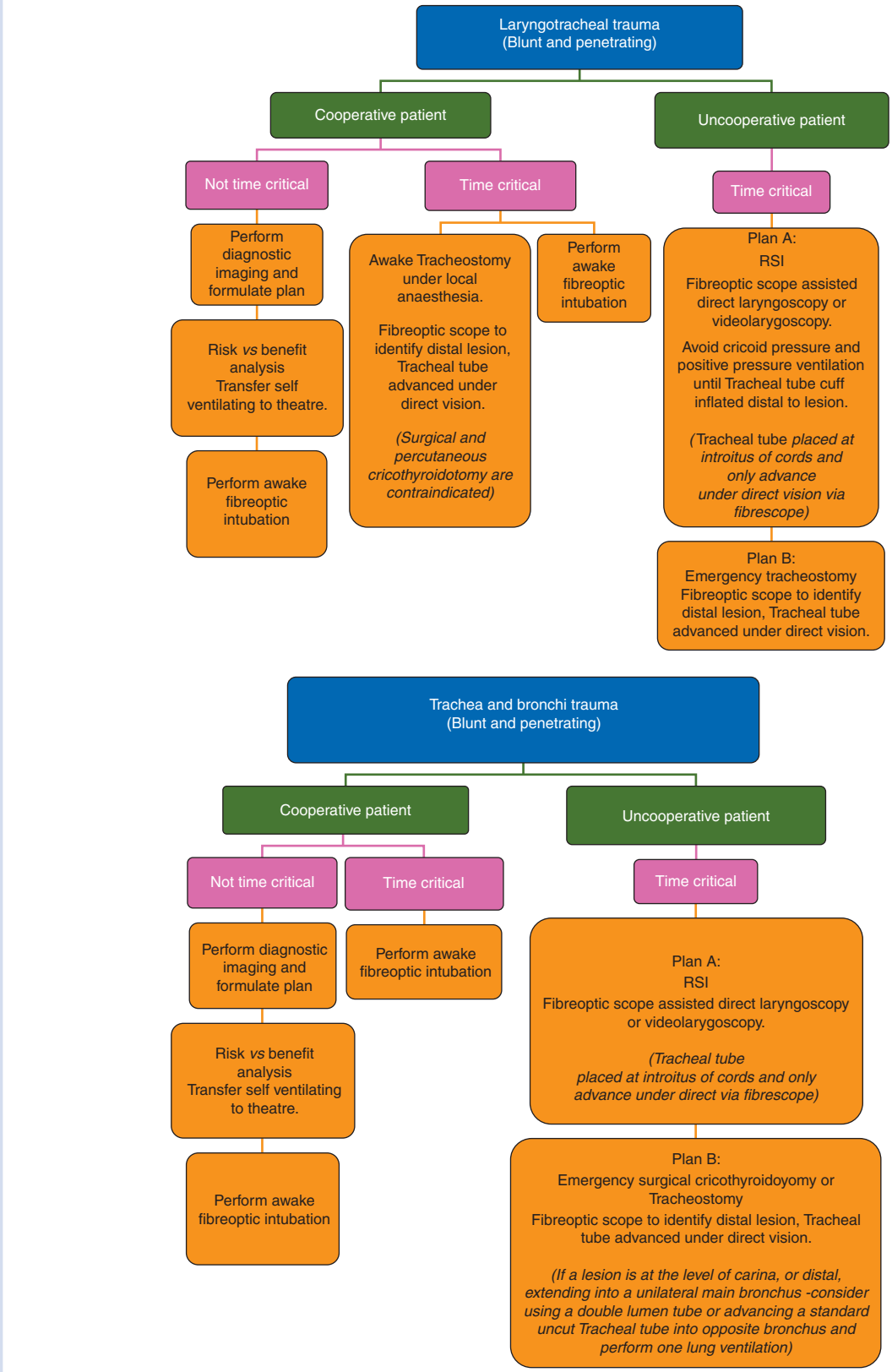


Fig 3 A shared mental model map for laryngotracheal trauma (blunt and penetrating). RSI, rapid sequence induction.

Authors' contributions

Substantial contributions to the conception or design of the work: B.M., S.J.M., P.G.
Acquisition of data: S.J.M., P.G., M.B., C.P.J., E.C.
Analysis of data: B.M., S.J.M., P.G., M.B., C.P.J., E.C.
Interpretation of data: B.M., S.J.M., P.G., M.B., C.P.J., E.C.
Drafting work for important intellectual content: B.M., S.J.M., P.G., C.P.J.

Declaration of interest

B.M. has received an honorarium for a lecture by Grifols, Inc.; this represents no conflict of interest for the submitted manuscript. S.J.M., C.P.J., M.B., E.C. and P.G. have no conflict of interest to declare.

References

1. Gussack GS, Jurkovich GJ, Luterman A. Laryngotracheal trauma: a protocol approach to a rare injury. *Laryngoscope* 1986; **96**: 660–5
2. Bhattacharya P, Mandal MC, Das S, Mukhopadhyay S, Basu SR. Airway management of two patients with penetrating neck trauma. *Indian J Anaesth* 2009; **53**: 348–51
3. Breeze J, Gibbons AJ, Shieff C, Banfield G, Bryant DG, Midwinter MJ. Combat-related craniofacial and cervical injuries: a 5-year review from the British military. *J Trauma* 2011; **71**: 108–13
4. Mercer S, Lewis S, Wilson S, Groom P, Mahoney P. Creating airway management guidelines for casualties with penetrating airway injuries. *J R Army Med Corps* 2010; **156**: S355–60
5. Abernathy JH 3rd, Reeves ST. Airway catastrophes. *Curr Opin Anaesthesiol* 2010; **23**: 41
6. Frerk C, Mitchell VS, McNarry AF, *et al*. Difficult Airway Society 2015 guidelines for management of unanticipated difficult intubation in adults. *Br J Anaesth* 2015; **115**: 827–48
7. Mohan R, Iyer R, Thaller S. Airway management in patients with facial trauma. *J Craniofac Surg* 2009; **20**: 21–3
8. Kummer C, Netto FS, Rizoli S, Yee D. A review of traumatic airway injuries: potential implications for airway assessment and management. *Injury* 2007; **38**: 27–33
9. Gruen RL, Jurkovich GJ, McIntyre LK, Foy HM, Maier RV. Patterns of errors contributing to trauma mortality: lessons learned from 2594 deaths. *Ann Surg* 2006; **244**: 371
10. Bhojani RA, Rosenbaum DH, Dikmen E, *et al*. Contemporary assessment of laryngotracheal trauma. *J Thorac Cardiovasc Surg* 2005; **130**: 426–32
11. Kayani AG, Pervaiz AA, Umair B, Siddique K, Khalique K. Right main bronchial disruption due to blunt trauma. *J Col L Physicians Surg Pak* 2009; **19**: 249–51
12. Smith CE, Fallon WF. Sevoflurane mask anesthesia for urgent tracheostomy in an uncooperative trauma patient with a difficult airway. *Can J Anaesth* 2000; **47**: 242–5
13. Francis S, Gaspard DJ, Rogers N, Stain SC. Diagnosis and management of laryngotracheal trauma. *J Natl Med Assoc* 2002; **94**: 21
14. Valerio P, Ivan M, Francisco R, *et al*. Survival after traumatic complete laryngotracheal transection. *Am J Emerg Med* 2008; **26**: 837.e3–.e4
15. Lee WT, Eliashar R, Eliachar I. Acute external laryngotracheal trauma: diagnosis and management. *Ear Nose Throat J* 2006; **85**: 179–84
16. Peadey C. Initial airway management of blunt upper airway injuries: a case report and literature review. *Australas Anaesthesia* 2005. Available at: http://www.anzca.edu.au/documents/05_peady.pdf (accessed 24 June 2016)
17. Edwards WH Jr, Morris JA Jr, DeLozier JB 3rd, Adkins RB Jr. Airway injuries. The first priority in trauma. *Am Surg* 1987; **53**: 192–7
18. Akhtar S, Awan S. Laryngotracheal trauma: its management and sequelae. *J Pak Med Assoc* 2008; **58**: 241–3
19. Scaglione M, Romano S, Pinto A, Sparano A, Scialpi M, Rotondo A. Acute tracheobronchial injuries: impact of imaging on diagnosis and management implications. *Eur J Radiol* 2006; **59**: 336–43
20. Shimizu J, Hirano Y, Ishida Y, Kinoshita T, Tatsuzawa Y, Kawaura Y. Use of a silicone T-tube for management of a tracheal injury in a patient with cervical blunt trauma. *Jpn J Thorac Cardiovasc* 2003; **51**: 541–4
21. Schaefer SD, Close LG. Acute management of laryngeal trauma update. *Ann Otol Rhinol Laryngol* 1989; **98**: 98–104
22. Perdikis G, Schmitt T, Chait D, Richards AT. Blunt laryngeal fracture: another airbag injury. *J Trauma Acute Care Surg* 2000; **48**: 544–6
23. Demetriades D, Velmahos GG, Asensio JA. Cervical pharyngoesophageal and laryngotracheal injuries. *World J Surg* 2001; **25**: 1044–8
24. Atkins BZ, Abbate S, Fisher SR, Vaslef SN. Current management of laryngotracheal trauma: case-report and literature review. *J Trauma Acute Care Surg* 2004; **56**: 185–90
25. Desjardins G, Varon AJ. Airway management for penetrating neck injuries: the Miami experience. *Resuscitation* 2001; **48**: 71–5
26. Kiser AC, O'Brien SM, Detterbeck FC. Blunt tracheobronchial injuries: treatment and outcomes. *Ann Thorac Surg* 2001; **71**: 2059–65
27. Wu M-H, Tsai Y-F, Lin M-Y, Hsu I-L, Fong Y. Complete laryngotracheal disruption caused by blunt injury. *Ann Thorac Surg* 2004; **77**: 1211–5
28. Jain S, Bhadani U. Lightwand: a useful aid in faciomaxillary trauma. *J Anesth* 2011; **25**: 291–1
29. Fuhrman GM, Stieg FH 3rd, Buerk CA. Blunt laryngeal trauma: classification and management protocol. *J Trauma Acute Care Surg* 1990; **30**: 87–92
30. Cicala RS, Kudsk KA, Butts A, Nguyen H, Fabian TC. Initial evaluation and management of upper airway injuries in trauma patients. *J Clin Anesth* 1991; **3**: 91–8
31. Gold SM, Gerber ME, Shott SR, Myer CM. Blunt laryngotracheal trauma in children. *Arch Otolaryngol Head Neck Surg* 1997; **123**: 83–7
32. Nabeel A, Irfan M. Near fatal fall complicated by penetrating neck injury with uneventful outcome: a case report. *Bangladesh J Med Sci* 2011; **10**: 125–8
33. Mohammed S, Biyani G, Bhatia PK, Chauhan DS. Airway management in a patient with blunt trauma neck: a concern for anesthesiologist. *Eg J Anaest* 2014; **30**: 431–3
34. Keller W, Han P, Galarneau R, Brigger T. Airway management in severe combat maxillofacial trauma. *Otolaryngol Head Neck* 2015; **153**: 532–7
35. Kumar V, Kumar P, Prasad V, *et al*. Blast injury face: an exemplified review of management. *Natl J Maxillofac Surg* 2013; **4**: 33–9
36. Sheffy N, Chemsian RV, Grabinsky A. Anaesthesia considerations in penetrating trauma. *Br J Anaesth* 2014; **113**: 276–85
37. Daniel Y, de Regloix S, Kaiser E. Use of a gum elastic bougie in a penetrating neck trauma. *Prehosp Disaster Med* 2014; **29**: 212–3

38. Ezeanolue BC. Management of the upper airway in severe cut-throat injuries. *Afr J Med Med Sci* 2001; **30**: 233–5
39. Glapa M, Kourie JF, Doll D, Degiannis E. Early management of gunshot injuries to the face in civilian practice. *World J Surg* 2007; **31**: 2104–10
40. Mohan S, Varghese G, Kumar S, Subramanian DP. Penetrating facial injury by a wooden log. *Natl J Maxillofac Surg* 2014; **5**: 228–31
41. Takaki S, Yamaguchi O, Morimura N, Goto T. Self-inflicted oral penetration injury: an intravenous drip pole advanced from the mouth to the retroperitoneum. *Int J Surg* 2015; **16**: 112–5
42. Shetty S, Gupta S, BalasubramanyaHasan, Cherian S, Srikrishna M. Facio-cervical transfixion by a metallic rod: a case report. *Am J Otolaryngol* 2001; **22**: 160–3
43. Dobson GT. Airway management in a patient with a nail-gun injury to the floor of the mouth. *Ulster Med J* 2000; **69**: 148–51
44. Ban LH, Leone M, Visintini P, *et al*. Craniocerebral penetrating injury caused by a spear gun through the mouth. *J Neurosurg* 2008; **108**: 1021–3
45. Joly L-M, Oswald AM, Disdet M, Raggueneau JL. Difficult endotracheal intubation as a result of penetrating cranio-facial injury by an arrow. *Anesth Analg* 2002; **94**: 231–2
46. Sari M, Baylancicek S, Inanli S. Atypical penetrating laryngeal trauma: a bullet in the larynx. *Eur J Emerg Med* 2007; **14**: 230–2
47. Young O, Watters K, Sheahan P, Hughes J. Penetrating air gun wound in the neck. *Auris Nasus Larynx* 2008; **35**: 426–8
48. O'Connor J, Haan J. Spent bullet in the bronchus. *Am Surg* 2006; **72**: 345–6
49. Mandavia DP, Qualls S, Rokos I. Emergency airway management in penetrating neck injury. *Ann Emerg Med* 2000; **35**: 221–5
50. Tallon JM, Ahmed JM, Sealy B. Airway management in penetrating neck trauma at a Canadian tertiary trauma centre. *CJEM* 2007; **9**: 101–4
51. Weitzel N, Kendall J, Pons P. Blind nasotracheal intubation for patients with penetrating neck trauma. *J Trauma* 2004; **56**: 1097–101
52. Gallo AC, Adams BD. Emergency battlefield cricothyrotomy complicated by tube occlusion. *J Emerg Trauma Shock* 2009; **2**: 54–5
53. Sharma N, De M, Martin T, Pracy P. Laryngeal reconstruction following shrapnel injury in a British soldier: case report. *JLO* 2008; **123**: 253–6
54. Kotsev S. Airway management in a patient with a vascular injury and rapidly expanding neck haematoma. *Eur J Anaesthesiol* 2005; **22**: 556–8
55. Baron BJ. Penetrating and blunt neck trauma. In: Tintinalli JE, Kelen GD, Stapczynski JS, eds. 6th edition. *Emergency Medicine: a Comprehensive Study Guide*. New York: McGraw-Hill, 2004; 1590–5
56. Inaba K, Munera F, McKenney M, *et al*. Prospective evaluation of screening multislice helical computed tomographic angiography in the initial evaluation of penetrating neck injuries. *J Trauma Acute Care Surg* 2006; **61**: 144–9
57. Madnani DD, Steele NP, de Vries E. Factors that predict the need for intubation in patients with smoke inhalation injury. *Ear Nose Throat J* 2006; **85**: 278–80
58. Chow JL, Coady MA, Varner J, Cannon W, Spain D, Brock-Utne JG. Management of acute complete tracheal transection caused by nonpenetrating trauma: report of a case and review of the literature. *J Cardiothorac Vasc Anesth* 2004; **18**: 475–8
59. Atkins BZ, Abbate S, Fisher SR, *et al*. Current management of laryngotracheal trauma: case-report and literature review. *J Trauma Acute Care Surg* 2004; **56**: 185–90
60. Zatriqi V, Arifi H, Zatriqi S, Duci S, Rrecaj S, Martinaj M. Facial burns - our experience. *Materia Socio-Medica* 2013; **25**: 26–6
61. Graham CA, Ada HY, Chan SS, Rainer TH. Primary emergency surgical airway for trismus caused by electrical burn. *Burns* 2006; **32**: 1062–3
62. Huang C-C, Wu H-S, Lee Y-C. Extensive tracheobronchitis and lung perforation after alkaline caustic aspiration. *Ann Thorac Surg* 2010; **89**: 1670–3
63. Yeh CF, Lee TL. Critical airway induced by formalin injection: case report. *JLO* 2014; **128**: 107–9
64. Silberman M, Jeanmonod R. Aerodigestive tract burn from ingestion of microwaved food. *Case Rep Emerg Med* 2013; **2013**: Article ID 781809
65. Bittner EA, Shank E, Woodson L, Martyn JJ. Acute and perioperative care of the burn-injured patient. *Anesthesiology* 2015; **122**: 448–64
66. Miller K, Chang A. Acute inhalation injury. *Emerg Med Clin North Am* 2003; **21**: 533–57
67. Mutlu GM, Budinger GR. Incidence and outcomes of acute lung injury. *N Engl J Med* 2006; **354**: 416–7
68. Fraser DJF, Venkatesh B. Recent advances in the management of burns. *Australas Anaesth* 2005. Available at: http://www.anzca.edu.au/documents/05_fraser.pdf (accessed 24 June 2016)
69. Makino H, Igarashi H, Suzuki Y, *et al*. Combined usage of an Airway Scope and gum elastic bougie for emergency airway management in a patient with neck stab wound. *Eur J Anaesth* 2012; **29**: 238
70. Black JJM. Emergency use of the Airtraq laryngoscope in traumatic asphyxia: case report. *Emerg Med J* 2007; **24**: 509–10
71. Esnault P, Prunet B, Cotte J, *et al*. Tracheal intubation difficulties in the setting of face and neck burns: myth or reality? *Am J Emerg Med* 2014; **32**: 1174–8
72. Eastman AL, Arnoldo BA, Hunt JL, Purdue GF. Pre-burn center management of the burned airway: do we know enough? *J Burn Care Res* 2010; **31**: 701–5
73. Mackie DP, van Dehn F, Knape P, Breederveld RS, Boer C. Increase in early mechanical ventilation of burn patients: an effect of current emergency trauma management? *J Trauma Acute Care Surg* 2011; **70**: 611–5
74. Amani H, Lozano DD, Blome-Eberwein S. Brother, have you got a light? Assessing the need for intubation in patients sustaining burn injury secondary to home oxygen therapy. *J Burn Care Res* 2012; **33**: e280–5
75. Toon MH, Maybauer MO, Greenwood JE, Maybauer DM, Fraser JF. Management of acute smoke inhalation injury. *Crit Care Resusc* 2010; **12**: 267–7
76. Hampson NB, Piantadosi CA, Thom SR, *et al*. Practice recommendations in the diagnosis, management, and prevention of carbon monoxide poisoning. *Am J Respir Crit Care* 2012; **186**: 1095–101
77. Cummings TF. The treatment of cyanide poisoning. *Occ Med* 2004; **54**: 82–5
78. Keldahl M, Sen S, Gamelli RL. Gastric rupture after cardiopulmonary resuscitation in a burn patient. *J Burn Care Res* 2006; **27**: 757–9
79. Mlcak RP, Suman OE, Herndon DN. Respiratory management of inhalation injury. *Burns* 2007; **33**: 2–13
80. Siah S, Wali El A, Ababou K, Sabah TN, Drissi NK, Ihrai I. Intubation difficile chez le brule de la face et du cou a laphase de sequelles. *Ann Burns Fire Disasters* 2006; **19**: 74–7

81. Kerekhanjanarong V, Supiyaphun P, Saengpanich S. Upper aerodigestive tract burn: a case report of firework injury. *J Med Assoc Thai* 2001; **84**: 294–8
82. Valdez TA, Desai U, Ruhl CM, Nigri PT. Early laryngeal inhalation injury and its correlation with late sequelae. *Laryngoscope* 2006; **116**: 283–7
83. Levitan RM. NO DESAT! Nasal oxygen during efforts securing a tube. *Emergency Physicians Monthly* 2010. Available at: http://epmonthly.com/article/no-desat/ (accessed 24 June 2016)
84. Smith J, Russell R, Horne S. Critical decision-making and timelines in the emergency department. *J R Army Med Corps* 2011; **157**: S273–6
85. Hagberg A, Johnson S, Pillai D. Effective use of the esophageal tracheal Combitube following severe burn injury. *J Anesth* 2003; **15**: 463–3
86. Fleissig Y, Rushinek H, Regev E. Intermaxillary fixation screw for endotracheal tube fixation in the edentulous patient with facial burns. *Int J Oral Maxillofac Surg* 2014; **43**: 1257–8
87. Mittal G, Mittal RK, Katyal S, Uppal S, Mittal V. Airway management in maxillofacial trauma: do we really need tracheostomy/submental intubation. *J Clin Diagn Res* 2014; **8**: 77–9
88. Cook TM, Woodall N, Frerk C, on behalf of the Fourth National Audit Project. Major complications of airway management in the UK: results of the Fourth National Audit Project of the Royal College of Anaesthetists and the Difficult Airway Society. Part 1: Anaesthesia. *Br J Anaesth* 2011; **106**: 617–31
89. Gleeson S, Groom P, Mercer S. Human factors in complex airway management. *BJA Education* 2016; **16**: 191–7
90. Arul GS, Pugh H, Mercer SJ, Midwinter MJ. Optimising communication in the damage control resuscitation–damage control surgery sequence in major trauma management. *J R Army Med Corps* 2012; **158**: 82–4
91. Mercer SJ, Tarmey NT, Mahoney PF. Military experience of human factors in airway complications. *Anaesthesia* 2013; **68**: 1080–1

Handling editor: T. Asai