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Ultimately, the goal of airway management in trauma is to establish and/or maintain adequate oxygenation, ventilation, and airway protection. It is the first priority in the acute phase of care of the trauma patient and consists of evaluation and, when indicated, intervention using various techniques and devices. It involves the recognition of any trauma to the airway or surrounding tissues, anticipation of their respiratory consequences, and planning and application of management, keeping in mind the potential for exacerbation of existing airway or other injuries by the contemplated strategies. It also involves prediction and prevention of progression of airway or surrounding tissue injury with increasing airway compromise.

Although with certain modifications, the American Society of Anesthesiologists (ASA) difficult airway algorithm can be applied to various trauma-induced airway issues [1], it may not be applicable in some clinical scenarios. For example, cancellation of airway management when difficulty arises may not be an option in the acute trauma setting. Likewise, awake rather than asleep intubation or a surgical airway from the outset may be the preferred choice in some situations. Modifications of the ASA

difficult airway algorithm are available for various trauma-induced clinical situations [2].

Frequently Encountered Clinical Conditions

Full Stomach

Commonly, the unknown time of the last food intake, the frequent presence of alcohol and/or illicit drugs, and trauma-induced reduction or absence of gastrointestinal motility imply that almost all acute trauma victims have a full stomach and are at risk for pulmonary aspiration. Pharyngeal blood, secretions, and foreign bodies in some maxillofacial and neck injuries are additional factors for aspiration after trauma. It is generally considered, although without much proof, that at least 24 h are needed after injury to decrease the risk of aspiration from a full stomach. In most instances, the urgency of securing the airway does not permit adequate time for pharmacologic measures such as bicarbonate or H₂ blockers to reduce gastric volume and acidity, and indeed these agents may be unreliable. Thus, rather than depending on pharmacology, emphasis should be placed on selection of a safe technique for securing the airway when necessary. Rapid-sequence induction (RSI) is recommended for those patients without serious airway problems. Awake intubation, with sedation and topical anesthesia, if possible, should be performed in

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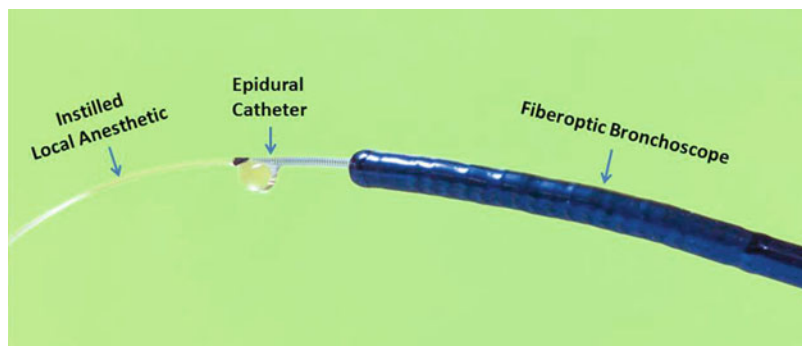


Fig. 2.1 Local anesthetic solution injected via the epidural catheter introduced through the working channel of the fiberoptic bronchoscope provides topical anesthesia of the

larynx and trachea under direct vision with minimal stimulation during intubation attempt

those with anticipated serious airway difficulties, in whom taking irretrievable steps such as administering intravenous anesthetics and muscle relaxants may be associated with uncorrectable airway obstruction and severe hypoxia.

Rapid sequence induction should be achieved with the following objectives in mind: (a) adequate sedation and paralysis, (b) adequate oxygenation, (c) optimal hemodynamics and perfusion, (d) avoidance of intracranial hypertension, and (e) prevention of vomiting and aspiration. Any of the intravenous agents including propofol, etomidate, ketamine, or midazolam can be used provided that their doses are adjusted to satisfy the above objectives [3]. Although even a single dose of etomidate has been shown to cause adrenocortical suppression [4], increased likelihood of adult respiratory distress syndrome (ARDS), and multiple organ failure (MOF) [5], it is still used for emergency airway management because of its rapid onset and relatively lower risk of hypotension in comparison to propofol. Succinylcholine is still the preferred agent for muscle relaxation, because it has the shortest time to effect in relation to other agents. Large doses (1.2–1.5 mg/kg) of rocuronium may provide an onset of action comparable to succinylcholine, but its long duration may represent a disadvantage in patients with difficult mask ventilation or tracheal intubation, since return of spontaneous breathing may be excessively delayed. As in any tracheal intubation the use of pulse oximetry, end tidal

CO₂ monitoring, and an available experienced operator is essential. Additionally, the neck must be maintained in neutral position and equipment and personnel for invasive airway management must be present.

The use of cricoid pressure for RSI is controversial. Although standard since Sellick's recommendation in 1960s [6], recent findings from 402 trauma patients suggest that its use actually decreases the view of the larynx during direct laryngoscopy and does not seem to prevent regurgitation and aspiration [7, 8]. Although it is difficult to recommend elimination of cricoid pressure during RSI at this time, its removal when the laryngeal view is compromised during direct laryngoscopy or when mask ventilation is hindered appears to be an appropriate maneuver.

Awake intubation with preservation of spontaneous breathing should be performed, if at all, with minimal sedation and topical anesthesia of the tongue, pharynx, epiglottis, and the superior surface of the vocal cords. Topical anesthesia of the trachea can be obtained just before introduction of the tracheal tube during direct laryngoscopy or fiberoptic bronchoscopy (FOB) using a tracheal local anesthetic applicator or the working channel of the FOB. Advancement of an epidural catheter that fits the working channel of the FOB, beyond the tip of the device and into the laryngotracheal opening, decreases laryngeal stimulation, minimizing cough and patient movement (Fig. 2.1).



Fig. 2.2 Laryngeal airways. Laryngeal Mask Airway Supreme (LMA Supreme) on the *left*, and I-Gel Airway on the *right*

The high probability of a full stomach precludes the use of any supraglottic device, such as the Laryngeal Mask Airway (LMA) (Fig. 2.2), Combitube (Fig. 2.3), or King's airway (LT, LTS, LTS-D) (Fig. 2.4), which does not protect the trachea from aspiration of gastric or pharyngeal contents, as a definitive airway in trauma patients. However, these devices can serve as a bridge for a brief period to establish airway patency or to facilitate intubation. In patients with maxillofacial injuries, aspiration of pharyngeal blood or secretions is more likely than aspiration of gastric contents. If they can be inserted in these circumstances, supraglottic airways may protect the lungs. Although positive-pressure ventilation may be used with supraglottic airways, patients with pulmonary contusion, edema, or aspiration may be difficult to ventilate with these devices. Supraglottic airways may permit rapid blind or FOB-guided tracheal intubation while temporarily allowing ventilation. An important disadvantage of the original intubating LMA is its metal stem that may exert considerable pressure against the cervical vertebrae, potentially exacerbating an unstable injury in this region [9].

Many trauma victims with abdominal injuries return to the operating room several times after damage control surgery performed during the acute stage of injury. These repeat procedures are performed to debride and wash the abdominal cavity and to close the abdomen when the initial

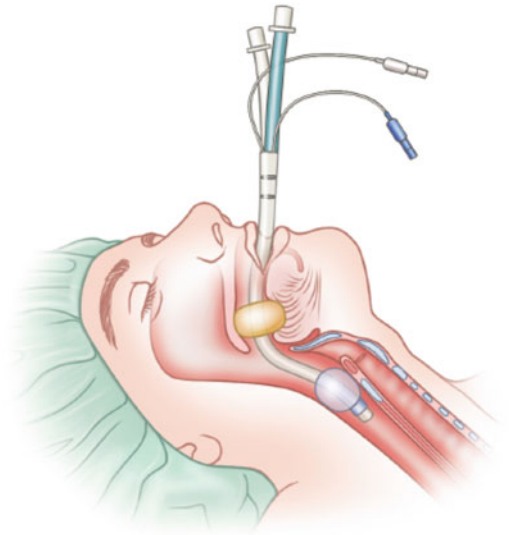


Fig. 2.3 Combitube. In this position of the tube with distal cuff in the esophagus, ventilation takes place by the air delivered through the openings below the proximal cuff

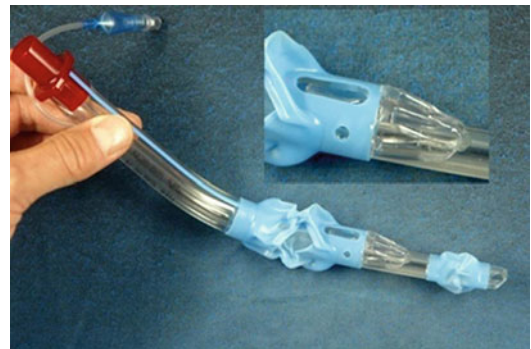


Fig. 2.4 King Airway. The tube with distal cuff enters into the esophagus and permits nasogastric tube introduced from a proximal port to proceed into the stomach. Ventilation takes place by the air exiting through the openings below the proximal cuff. Detailed view of the openings below the proximal cuff is shown in the *inset*

edema subsides. Many of these patients present with a vacuum dressing placed over the open abdomen. They are often extubated and many have been fed with a feeding tube which allows one-way entry of formula into the stomach owing to an internal valve that prevents drainage of gastric contents. These tubes, unlike sump nasogastric tubes, do not decompress the stomach. Even when the feeding tube is removed

and the patient is kept NPO for several hours, these patients should be considered to have full stomachs because of hypoactive bowel function, the open abdomen, continuous accumulation of gastroduodenal fluid, and remaining feeding solution in the stomach. Airway management in these patients necessitates using rapid sequence induction with cricoid pressure.

The Agitated Uncooperative Patient

Pain, anxiety, alcohol intoxication, and illicit drug use may cause agitation and uncooperative behavior in many acutely injured patients. In these patients, topical anesthesia of the airway may be impossible, whereas administration of sedative agents may result in apnea or airway obstruction, with an increased risk of aspiration of gastric contents and inadequate conditions for tracheal intubation. These patients are best managed with RSI with direct laryngoscopy, provided that the cricothyroid membrane is located, the lung is denitrogenated, and personnel and material necessary to perform translaryngeal ventilation or cricothyroidotomy are prepared and ready to provide a rapid surgical airway if intubation with RSI fails.

Airway Obstruction

Airway obstruction is probably the most frequent cause of asphyxia; it may result from pharyngeal soft tissue edema, laceration, hematoma, bleeding, secretions, foreign bodies, or displaced bone or cartilage fragments. Bleeding into the cervical region may produce airway obstruction not only because of compression by the hematoma, but also from venous congestion and upper airway edema as a result of neck vein compression. Signs of upper and lower airway obstruction include dyspnea, cyanosis, hoarseness, stridor, dysphonia, subcutaneous emphysema, and hemoptysis. Cervical deformity, edema, crepitation, tracheal tug and/or deviation, or jugular venous distention may be present before these

symptoms appear and may help indicate that specialized techniques are required to secure the airway.

The initial steps in airway management are chin lift, jaw thrust, clearing of the oropharyngeal cavity, placement of an oropharyngeal or nasopharyngeal airway and, in inadequately breathing patients, ventilation with a self-inflating bag/mask assembly. Cervical spine immobilization and administration of oxygen are essential. Blind passage of a nasopharyngeal airway or a nasogastric or nasotracheal tube should be avoided if a basilar skull or maxillary sinus fracture is suspected; it may enter the cranial cavity or the periocular fat pad. Supraglottic airways may permit ventilation with a self-inflating bag, although they do not provide protection against aspiration of gastric contents. They may be used as temporary measures, and if they do not provide adequate ventilation, the trachea must be intubated immediately using either direct laryngoscopy or videolaryngoscopy. Cricothyroidotomy may have to be performed if mask or supraglottic airway ventilation fails to overcome airway obstruction, tracheal intubation is unsuccessful, and hypoxia is severe and cannot be corrected. In all trauma patients airway assessment should include a rapid examination of the anterior neck for feasibility of access to the cricothyroid membrane. Between 0.3 % and 2.7 % of airway management attempts fail in the trauma population, necessitating cricothyroidotomy [10, 11]. Tracheostomy is not desirable during initial management because it takes longer to perform than a cricothyroidotomy and requires neck extension, which may cause or exacerbate cord trauma in patients with cervical spine injuries. Conversion to a tracheostomy should be considered later to prevent laryngeal damage if a cricothyroidotomy will be in place for more than 2–3 days. Possible contraindications to cricothyroidotomy include age younger than 12 years and suspected laryngeal trauma; permanent laryngeal damage may result in the former, and uncorrectable airway obstruction may occur in the latter situation.

Airway Evaluation in the Trauma Patient

As in any patient requiring airway management, airway evaluation in trauma victims is of crucial importance for optimal preparation and thus prevention of undesirable outcomes. Assessment should be made for mask ventilation, tracheal intubation, and a surgical airway. The LEMON score, an airway assessment tool for trauma patients, is included in the current version (8th edition) of the Advanced Trauma Life Support Manual (ATLS) [12, 13]. The components of the score are similar to those used in routine airway assessment, but it is more organized and standardized for trauma patients. Following are the criteria that may indicate difficulty:

L stands for **Look** at the cervicofacial region for evaluation of facial or neck trauma, large incisors, presence of beard, large tongue, or orofacial soft tissue stiffness such as the effect of radiation therapy. One point is assigned for each of four conditions present that can possibly cause difficulty. Thus, this criteria leads to a maximum of four points.

E stands for **Evaluate**. The 3-3-2 rule is used for this purpose to specify an interincisor distance <3 fingers, mentum to hyoid distance <3 fingers, and floor of the mouth to thyroid notch distance <2 fingers. One point is assigned for each abnormal findings yielding a maximum of three points.

M stands for **Mallampati score**, in which inability to visualize the uvula suggests a grade 3 or 4 view during laryngoscopy. One point is assigned for Mallampati Grade 3 and 4 view.

O stands for **Obstruction**. Airway obstruction from any cause, and the signs and symptoms described above are detected with this part of the assessment tool. One point is assigned to the presence of airway obstruction.

N stands for **Neck Mobility**. Apart from preexisting cervical diseases, the trauma patient with a cervical collar may have significant limitation of neck mobility causing reduction of the laryngeal view during direct laryngoscopy. One point is assigned to the presence of neck mobility caused by any reason.

Thus, by addition of points from each item of LEMON a maximum of 10 and a minimum score of 0 is obtained.

High LEMON scores have been shown to be associated with a greater likelihood of difficult intubation [12]. It should be emphasized that as in any airway evaluation method, this method as well provides information only about the likelihood of difficulty and is not a definite marker of difficult airway management.

Airway evaluation in patients requiring emergency tracheal intubation shortly after trauma is solely based on clinical examination. During the later stages of treatment, radiographic evaluation of the craniofacial region may additionally contribute to airway evaluation. Computed tomography (CT) examination and magnetic resonance (MR) imaging have largely replaced conventional radiographic evaluation for this purpose during the past decade. They will be discussed during the review of specific injuries below.

Ultrasound technology has recently emerged as a tool for airway management. It aids in both airway evaluation and intervention, and its potential benefit is especially relevant in the time of critical immediate phase after trauma. The airway can be evaluated with this method all the way from the mouth to the lung (Table 2.1), and airway structures such as the tongue, oropharynx, hypopharynx, hyoid bone, epiglottis, larynx, vocal cords, cricothyroid membrane, cricoid cartilage, trachea, esophagus, lung, and pleura can be imaged. It is also possible to identify the stomach and predict the volume of its contents after placing the patient in right lateral position [14]. Ultrasound imaging for upper airway evaluation is performed by using an 8–15 MHz linear array probe placed in the transverse axis in the submandibular area and moved downward to the level of the suprasternal notch. In this region the focus of evaluation is usually centered in four levels: (a) submandibular region where the muscles in the floor of the mouth (geniohyoid) and the tongue are imaged; (b) over the hyoid bone where the soft tissue thickness of the anterior neck, which appears to correlate with difficulty of laryngoscopy if it exceeds 2.8 cm, can be measured [15]; (c) the

Table 2.1 Possible uses of ultrasonography for airway management

Clinical application	Comment
Predicting difficult airway management [96]	Demonstrated to be useful in small series of obese patients
Diagnosis of head and neck pathology with potential of causing difficulty of airway management [97]	Both intrinsic and extrinsic head and neck pathology can be diagnosed
Measuring gastric content [98]	Best results are obtained if the patient is placed in right lateral decubitus position
Predicting appropriate diameter of endotracheal, endobronchial, and tracheostomy tubes [99]	
Differentiating between tracheal and endobronchial intubation	
Differentiating between tracheal and esophageal intubation [38]	Allows detection of esophageal intubation and it is especially helpful in the presence of no circulation (cardiac arrest)
Diagnosing pneumothorax [100]	Fastest way to rule out a suspicion of intraoperative pneumothorax
Identifying the cricothyroid membrane [101]	For preparation of emergency cricothyroidotomy, transtracheal O ₂ insufflation, translaryngeal (retrograde) intubation, administration of local anesthetics when palpation of the cricothyroid membrane is not possible
Identifying trachea and trachea and tracheal ring interspaces for tracheostomy and percutaneous dilatational tracheostomy [102]	Usually needed in the intensive care unit few days after trauma

Modified from Kristensen MS and Teoh WHL. Ultrasound probe in the hands of the anesthesiologist: a powerful new tool for airway management. *Anesthesiology News Supplement on Guide to Airway Management*. 2013; page 23-30

thyroid membrane between the hyoid bone and the thyroid cartilage where, in addition to measurement of the soft tissue thickness, the preepiglottic space and epiglottis can be identified. At this level, moving the transducer slightly caudad to the level of the thyroid cartilage allows imaging of the larynx at the level of the vocal cords with demonstration of the thyroid and cricoid cartilages, vocal ligaments, and the anterior commissure; and (d) at the level of the thyroid isthmus and suprasternal notch where the posterior air/mucosa interface can be identified (Fig. 2.5) [16]. It should be emphasized that the position of the probe as it is moved distally over the airway is gradually tilted from parallel to the axis of the body at the submandibular area to perpendicular to the axis of the body at the thyroid or cricoid cartilage level. Pneumothorax and endobronchial intubation can be diagnosed in B-mode ultrasound imaging by transverse placement of the ultrasound probe over two adjacent ribs and observing lung sliding [17, 18]. If M-mode imaging is used, the presence of a

succession of horizontal lines may be related to endobronchial intubation or pneumothorax. The “lung pulse” observed in M-mode normally results from movement of the visceral over the parietal pleura with every heartbeat and may give the false impression that pneumothorax or endobronchial intubation do not exist. Of course in patients with cardiac arrest the “lung pulse” is absent (Fig. 2.6) [19].

Indications for Emergency Tracheal Intubation

Absolute indications for emergency tracheal intubation for trauma and smoke inhalation victims are provided by the Eastern Association for the Surgery of Trauma (EAST) guidelines. Essentially, as mentioned above, the criteria for these indications are based on the presence of hypoxia, hypoventilation, and inability to protect the airway (Table 2.2) [20].

Several retrospective studies, however, have identified additional indications for emergency

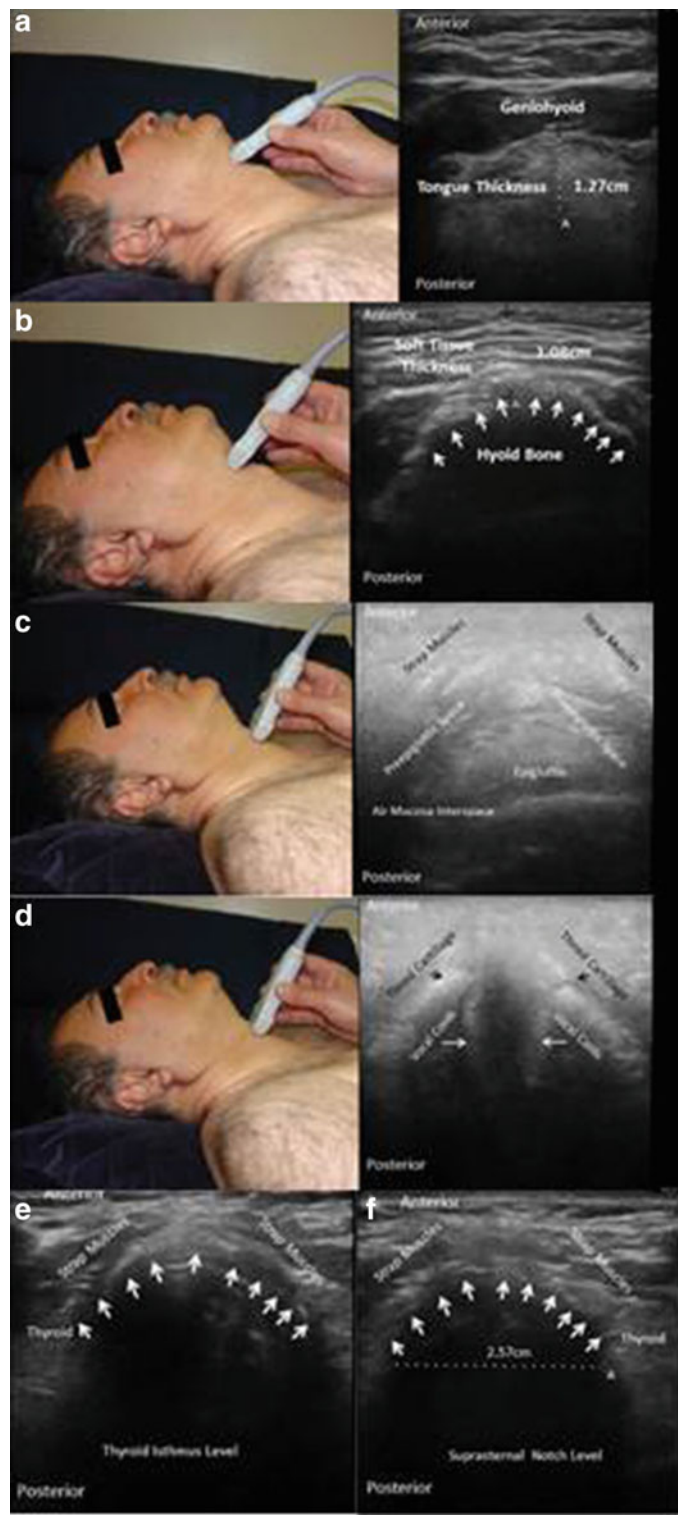


Fig. 2.5 Ultrasonographic evaluation of the upper airway. (a) In supine position of the patient the ultrasound probe is placed submentally to image the geniohyoid and

the tongue. (b) The probe is moved downward over the hyoid bone to measure the soft tissue thickness over the hyoid. Soft tissue thickness exceeding 2.5–3.0 cm may be

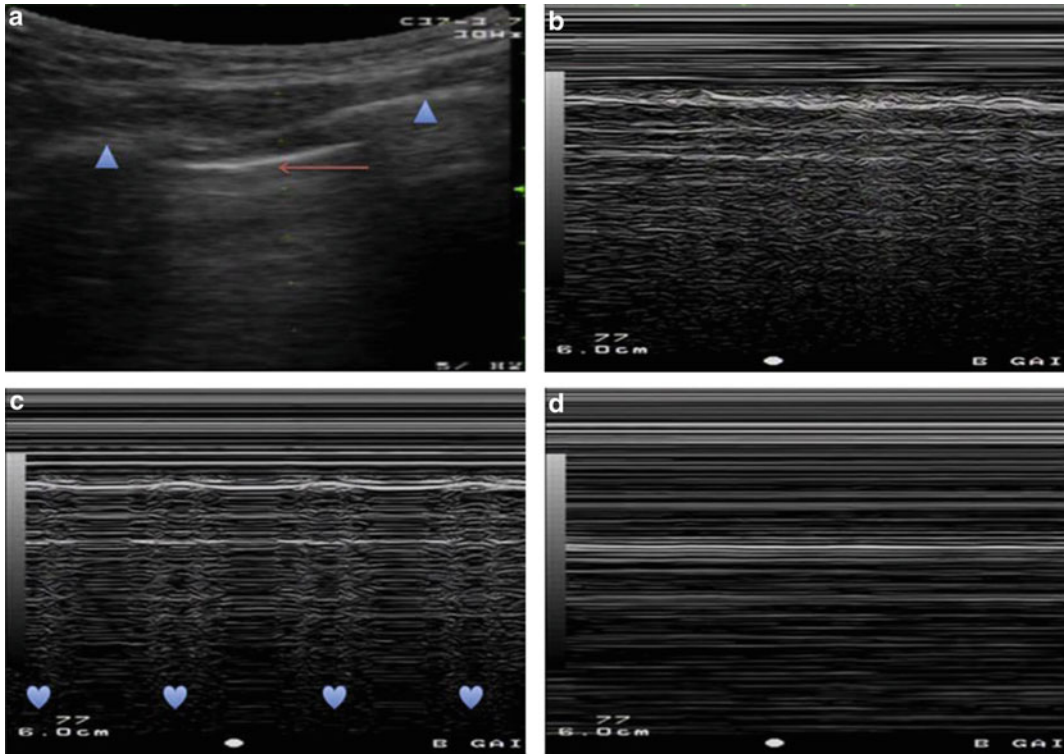


Fig. 2.6 Ultrasonographic views of lung sliding (**a, b**) and absence of lung sliding (**c, d**). (**a**) Ultrasound probe placed longitudinally over the chest showing 2D image of pleural lines (*arrow*) and successive ribs (*arrowheads*). On a dynamic image sliding of the visceral over parietal pleura suggests absence of pneumothorax. (**b**) With M-mode image lung sliding generated a sandy pattern which is often described as a seashore sign. (**c**) M-mode image obtained in the absence of lung sliding. Succession of *horizontal lines* is interrupted by intermittent fluctuations

at points marked by *heart shapes*. These fluctuations are caused by heart beats and are called lung pulse. (**d**) Absence of lung sliding in the absence of heart beat effect is reflected over the M-mode image as uninterrupted horizontal lines termed as the stratosphere sign. Reproduced with permission from Sim S-S, Lien WC, Chou HC et al.: Ultrasonographic lung sliding sign in confirming proper endotracheal intubation during emergency intubation. *Resuscitation* 2012; 83:307-312

tracheal intubation in other trauma patients [21–24]. These include moderate cognitive impairment (GCS score 9–12), persistent combativeness unresponsive to mild to moderate sedation, respiratory distress without hypoxia or hypoventilation, cervical spinal cord injury (CSCI) with evidence of respiratory insufficiency (complete or incomplete SCI at C5 or above) [20]. Interestingly, these studies show that one

of the three patients intubated with these criteria had a head injury.

Techniques of Airway Management

The objective in airway management of trauma patients is to achieve a safe tracheal intubation in the shortest possible time without causing a

Fig. 2.5 (continued) associated with difficult tracheal intubation. (**c**) Ultrasound image at the thyrohyoid membrane demonstrates strap muscles, preepiglottic space, epiglottis, and the air–mucosa interspace. (**d**) Ultrasound probe placed over the thyroid cartilage showing the image

of thyroid cartilage and vocal cords. (**e**) Ultrasound image at the level of the thyroid isthmus showing the image of thyroid and the subglottic airway. (**f**) Ultrasound image at the suprasternal notch showing the airway. The diameter of the airway can be measured at each level of the airway

Table 2.2 Absolute indications for emergency tracheal intubations in trauma and smoke inhalation victims

<i>Trauma victims</i>
Airway obstruction
Hypoventilation
Persistent hypoxemia ($\text{SaO}_2 < 90\%$) despite supplemental oxygen
Severe cognitive impairment (Glasgow Coma Scale [GCS] score < 8)
Severe hemorrhagic shock
Cardiac arrest
<i>Smoke inhalation victims</i>
Airway obstruction
Severe cognitive impairment (GCS score < 8)
Major cutaneous burn (body surface area $> 10\%$)
Major burns and/or smoke inhalation with an anticipated prolonged transport time to definitive care
Impending airway obstruction as follows:
Moderate-to-severe facial burn
Moderate-to-severe oropharyngeal burn
Moderate-to-severe airway injury observed during endoscopy

decrease in blood pressure or blood O_2 saturation, or an increase in CO_2 tension. This is especially important in head-injured patients in whom even short periods of hypoxia and/or hypotension are likely to increase the size of secondary injury, worsening the outcome. Based on the EAST airway management guidelines, orotracheal intubation guided by direct laryngoscopy is the technique of choice for emergency tracheal intubation of trauma patients [20].

There are, however, other alternatives which may be used as rescue devices when difficulty arises with classical mask ventilation and tracheal intubation using direct laryngoscopy with conventional blades. Supraglottic airway devices, by bypassing the oropharynx, offer the benefits of rapid blind placement as well as a high success rate in situations of combined difficult mask ventilation, laryngoscopy, and cricothyroidotomy that may be experienced in patients with obesity, obstructive sleep apnea, short neck, limited neck movement, previous radiotherapy to the cervicofacial region, beard, etc. Although extensive information exists about the use of supraglottic devices in the nontrauma in-hospital setting, data for trauma patients in this area are limited mainly to prehospital airway management by nonphysician personnel. The success rate of these devices as a rescue

technique after failed tracheal intubation in prehospital trauma varies between 87 % and 100 %. Since there are more than ten supraglottic devices available on the market, it is difficult to recommend a specific one for this purpose; familiarity of the operator with a specific device appears to be the most important factor.

Videolaryngoscopes provide an indirect view of the larynx. Unless there is intrinsic distortion of the airway, these devices enable the operator to visualize the larynx almost every time. However, depending on the oropharyngeal anatomy, direction of the tracheal tube into the larynx may not always be successful. Videolaryngoscopes can be divided into two groups: those guiding the tube toward the laryngeal inlet (Airtraq, Pentax AWS) and those requiring the operator to direct the tube into the larynx (GlideScope, Storz, etc.). Some devices in the second category such as the GlideScope have stylets designed to facilitate manipulation of the tube. Besides improving the Cormack and Lehane grade, videolaryngoscopes may decrease cervical spine motion and the force and pressure applied to the posterior pharynx, features that may be advantageous during management of cervical spine injury [25–28].

Although experience with videolaryngoscopes in nontrauma patients is extensive,

Table 2.3 Performance characteristics of GlideScope in 2,004 patients

Performance criteria tested	Number (%)
Overall success rate	1,944 of 2,004 (97 %)
Success in predicted difficult intubation	1,377 of 1,428 (96 %)
Success after failed conventional laryngoscopy	224 of 239 (94 %)
Complications	21 of 2,004 (1 %)
Major complications ^a	6 of 2,004 (0.3 %)
Predictors of GlideScope failure	Altered neck anatomy ^b

^aDental, pharyngeal, tracheal, and laryngeal injury

^bSurgical scar, radiation changes, neck mass

Reproduced with permission from Aziz MF, Healy D, Kheterpal S et al.: Routine clinical practice effectiveness of the Glidescope in difficult airway management: an analysis of 2004 Glidescope intubations, complications, and failures from two institutions. *Anesthesiology* 2011; 114:34-41

few studies have evaluated these devices in the trauma setting. In one study, the laryngeal view with the GlideScope was superior to that obtained with the Macintosh blade [29]. In another study involving 822 emergency room patients, of whom more than 60 % had sustained trauma, the first attempt success rate with the GlideScope was higher than that with conventional laryngoscopes; nevertheless the overall success rate was similar between the two techniques [30]. The overall success rate was also found to be similar in another study of trauma patients, although intubation times were longer with the GlideScope [31]. A recent prospective randomized study comparing the Macintosh blade and videolaryngoscope (GlideScope) for intubation of a group of trauma patients ($n = 623$) demonstrated no difference in mortality. Intubation with the GlideScope took longer (median 56 s vs. 40 s). Although the difference in duration of intubation, while statistically significant, may appear relatively small, it was associated with a longer duration of decreased O₂ saturation. In fact, the severe head injury patients in the study, who are expected to be most vulnerable to hypoxia in the early post-trauma phase because of the likelihood of development or expansion of secondary injury, had a higher incidence of hypoxia (O₂ saturation <80 %) during intubation with the videolaryngoscope than with the Macintosh blade (50 % vs. 24 %). The authors suspected that this may have been one of the reasons for a statistically significant higher mortality rate in the head-injured patients intubated with the

GlideScope (30 % vs. 14 %) [32]. Inability to demonstrate a difference in success of intubation between direct laryngoscopy and videolaryngoscopy may be related to the use of an unselected population in whom direct laryngoscopy has a high success rate. It is now clear that in the nontrauma population many, but not all, patients in whom tracheal intubation with direct laryngoscopy failed, video laryngoscopic intubation was successful. Likewise in patients known to be difficult, video laryngoscopy was more successful in tracheal intubation than direct laryngoscopy (Tables 2.3, 2.4, and 2.5) [33–37].

Ultrasound can be useful for airway intervention. Apart from identifying esophageal intubation, especially in patients with cardiac arrest or low flow states when the end tidal CO₂ measurement is unreliable [38], and helping to recognize endobronchial intubation, its most valuable use for airway intervention is in identification of the cricoid cartilage and cricothyroid membrane for emergency cricothyrotomy when these structures cannot be identified by palpation [39, 40].

Airway Management in Specific Injuries

Head, Open Eye, and Contained Major Vessel Injuries

In addition to adequate oxygenation and ventilation, patients with these injuries require deep anesthesia and profound muscle relaxation before airway manipulation. This helps prevent

Table 2.4 Comparison of performance characteristics of Macintosh and C-MAC laryngoscopes in 300 patients having at least one predictor of difficult intubation

	Macintosh	C-MAC	
	Number (%)	Number (%)	<i>p</i>
First attempt intubation	124 of 147 (84 %)	138 of 149 (93 %)	0.026
Grade 1 or 2 view	119 of 147 (81 %)	139 of 149 (93 %)	<0.01
Laryngoscopy time	33 s (95 %) (CI 29–36)	46 s (95 %) (CI 40–51)	<0.001
Facilitatory manipulation needed ^a	46 of 124 (37 %)	33 of 138 (24 %)	<0.020
Complications	16 of 124 (13 %)	27 of 138 (20 %)	

^aExternal laryngeal pressure or gum elastic bougie
Reproduced with permission from Aziz MF, Healy D, Kheterpal S et al.: Routine clinical practice effectiveness of the Glidescope in difficult airway management: an analysis of 2004 Glidescope intubations, complications, and failures from two institutions. *Anesthesiology* 2011; 114:34-41

Table 2.5 Comparative intubating characteristics of airway scope (Pentax), C-MAC (Storz), and GlideScope

	Airway scope (Pentax)	C-MAC (Storz)	GlideScope
Intubation time (s)	20.6 ± 11.5	31.9 ± 17.6	31.2 ± 15
Grade 1 view (%)	97	87	78
First attempt intubation rate (%)	95	93	91

Reproduced with permission from Teoh WH, Saxena S, Shah MK, Sia AT: Comparison of three videolaryngoscopes: Pentax airway scope, C-MAC, Glidescope vs Macintosh laryngoscope for tracheal intubation. *Anaesthesia* 2010; 65:1126-32

hypertension, coughing, and bucking, and thereby minimizes intracranial, intraocular, or intravascular pressure elevation, which can result in herniation of the brain, extrusion of eye contents, or dislodgment of a hemostatic clot from an injured vessel, respectively.

Anesthetic agents selected for management of brain injury should produce the least increase in intracranial pressure (ICP), the least decrease in mean arterial pressure, and the greatest reduction in cerebral metabolic rate (CMRO₂). One of the most important factors in the etiology of cerebral ischemia is increased ICP from intracranial hematoma and/or cerebral edema. Prompt decompression of the cranial contents is the most crucial means of ensuring cerebral well-being. Hypotension caused by anesthetics or other factors contributes to the development or

progression of cerebral ischemia. Utmost attention should be paid during anesthesia to avoid hypotension and hypoxia. A minimal mean arterial pressure of 60 mmHg is generally accepted as the threshold for brain ischemia or as the lower limit of autoregulation, but depending on the patient, the duration of hypotension, the anesthetic technique, and the state of the cerebral vasculature, this threshold may be as high as 70–80 mmHg. The preferred anesthetic sequence to achieve optimal brain oxygenation includes preoxygenation and opioid loading, followed by an intravenous anesthetic and muscle relaxant. Systemic hypotension, ICP elevation, and decreased cerebral perfusion pressure (CPP = mean arterial pressure – ICP) should be avoided. Intravenous anesthetics are the most common causes of hypotension during induction. This problem can be ameliorated by administering pretreatment doses of opioids (fentanyl, 2–3 µg/kg), which permit reduction of the intravenous anesthetic dose. This may also prevent the myoclonic movements associated with etomidate and occasionally with propofol, and thus reduce the risks of ICP and IOP increase. Nevertheless, myoclonus is best prevented by careful timing of the dose of muscle relaxants. Another measure to preserve CPP during anesthesia is to administer vasopressors, being aware that hypovolemia may be masked by their use. Alpha-1 agonist agents, although considered cerebral vasoconstrictors and thus contraindicated, do not actually produce this effect in the usual doses [41].

Opioid loading, however, may also be responsible for hypotension, as it inhibits the overactive sympathetic activity that is likely to be present in trauma patients with or without head injury. In head-injured patients this may occur whether cerebral autoregulation is present or absent, and if untreated can produce secondary ischemic insults. Thus, hemodynamic responses to the opioid should be carefully monitored and promptly corrected [42].

For many years ketamine was considered to be contraindicated in patients with head and vascular injuries because it may increase both intracranial and systemic vascular pressures; it does not increase intraocular pressure (IOP). Its effect on ICP when used as an induction agent has recently been questioned, and actually some studies have demonstrated decreases in ICP when it is used for sedation [43–46].

Any muscle relaxant, including succinylcholine, may be used as long as the fasciculation produced by this agent is inhibited by prior administration of an adequate dose of a nondepolarizing muscle relaxant. More recently, however, the use of defasciculating doses of nondepolarizing muscle relaxants for head-injured patients has also been questioned, as the evidence that succinylcholine-induced fasciculations produce significant elevation of ICP in this setting is lacking [47]. However, fasciculations do increase IOP, necessitating the use of intravenous anesthetics and defasciculating doses of nondepolarizing agents [48]. Avoiding succinylcholine usually does not alleviate the problem because laryngoscopy and tracheal intubation produce a greater and longer-lasting increase in IOP [49]. Alternatively, rocuronium can provide intubating conditions within 60 s following a dose of 1.6–2.0 mg/kg, although the neuromuscular blockade produced by this dose lasts approximately 2 h [50]. Intravenous lidocaine has an attenuating effect on the pressor response to airway instrumentation, but it is mild and unpredictable. Of course, neither muscle relaxants nor intravenous anesthetics are indicated when initial assessment suggests a difficult airway. Airway management with mild sedation and gentle topical anesthesia of the

airway to prevent bucking and coughing may be needed in these patients. As in any other trauma patient, hypotension dictates either reduced or no intravenous anesthetic administration. None of the nondepolarizing muscle relaxants causes elevation of ICP or IOP in the absence of associated tracheal intubation.

Cervical Spine Injury

Overall incidence of cervical spine injury after blunt trauma is estimated to be 2 % [51]. Concomitant craniofacial injury and Glasgow coma scale of 8 or less triples this risk [51]. As in brain injury, secondary injury by factors such as hypoxia and hypotension is also likely in spinal cord injuries; estimated rate of this complication varies between 10 % and 30 % [51], indicating the importance of appropriate airway management. In the cervical spine (C-spine)-injured patient as well, airway management consists of two components: evaluation and intervention. In this instance evaluation includes not only the airway but also the spine itself, as the presence of a C-spine injury greatly affects the strategy for intervention. The definitive method of diagnosis of C-spine injury in the early phase after injury is thin slice (2 or 3 mm) computed tomography (CT). Subjecting every patient with suspected C-spine injury to CT, however, would result in many unnecessary radiographic studies, radiation exposure, high costs, and delays in patient care. In the beginning of the millennium, a prospective observational study performed in 34,000 patients in 21 centers across the United States produced a simple decision instrument, in which a clinical evaluation showing absence of posterior cervical pain and tenderness, no focal neurological deficit, normal alertness, no evidence of intoxication, and no obvious distracting injury indicated a low probability of a C-spine injury and justified ruling it out without the need for radiographic evaluation [52]. This decision rule, the National Emergency X-radiography (NEXUS) criteria, has been embraced by the EAST and is used throughout

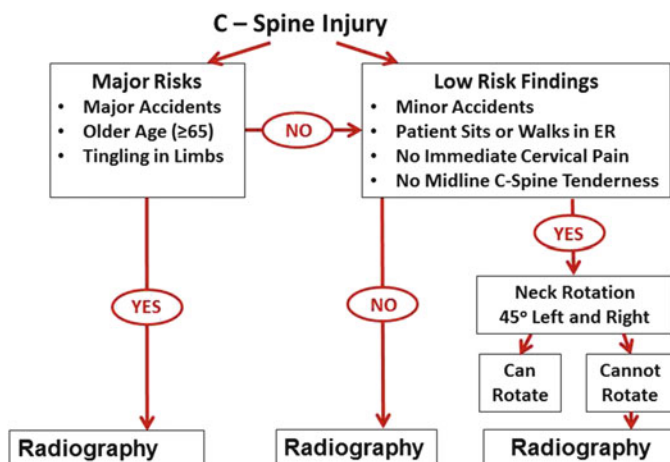


Fig. 2.7 Management algorithm followed by the Canadian C-spine rule for the initial care of cervical spine injuries

the US. There is, however, no definition of a distracting injury, and the decision about its presence and its impact on evaluation is left to the perception and judgment of the clinician. Recently there has been increasing doubt about the effect of a distracting injury on the recognition of a C-spine injury. At least one study demonstrated a similar rate of C-spine injury diagnosis whether there was a presumed distracting injury or not [53]. On the other hand, some trauma surgeons believe that in the major trauma setting, ruling out C-spine injury with the NEXUS criteria alone may be fraught with the danger of missing some clinically important unstable injuries. Thus, they believe that CT evaluation in addition to clinical examination is indicated in all major trauma patients [54].

The relative weakness of the NEXUS criteria compared to the Canadian C-spine rule has also been demonstrated [55, 56]. The latter instrument is based on three high risk and five low risk criteria plus the patient's ability to actively rotate the neck: Age greater than 65 years; dangerous mechanisms of injury such as a fall from an elevation greater than 3 ft or 5 stairs; an axial load to the head, as in diving or in an MVA at a speed greater than 100 km/h with rollover or ejection, bicycle collision, or being hit by a high-speed vehicle; or if the patient reports the development of paresthesias in his extremities,

Table 2.6 Diagnostic performance of NEXUS and Canadian C-spine rule

Assessment	Canadian C-spine rule		NEXUS	
	Injury	No injury	Injury	No injury
Positive	161	3,995	147	3,599
Negative	1	3,281	15	2,677

Data from Stiell JG, Clement CM, McKnight RD et al.: Canadian C-spine rule versus the NEXUS low-risk criteria in patients with trauma. *New England Journal of Medicine* 2003; 349:2510-8

are high risk factors that mandate radiographic studies. Low risk criteria such as a simple rear-end motor vehicle collision, ability to sit or ambulate in the ER, absence of immediate but not delayed neck pain, or absence of midline C-spine tenderness permit safe assessment of range of motion as the next evaluation step. Finally, the patient's ability to rotate the neck actively 45° in each direction allows clearing the C-spine without radiographic evaluation (Fig. 2.7) [55]. As compared to the NEXUS criteria, the Canadian C-spine rule, which is not used as widely as the NEXUS in the USA, appears to be a safer instrument for evaluating the possibility of a C-spine injury (Table 2.6) [55].

These findings have important implications for the anesthesiologist in that C-spine injury can be ruled out reliably by clinical criteria. However, though with a very small likelihood,

patients cleared clinically, especially with NEXUS criteria, may still harbor an unstable injury and could potentially develop neurologic damage during airway management, thus active evaluation and C-spine protection during intubation are generally necessary in all cases.

For those who cannot be cleared clinically and thus require radiographic evaluation, it is now clear that the diagnostic capability of three-view plain films (the previous standard) is inferior to helical (spiral) CT scans with sagittal and coronal reconstruction. Thus, in modern trauma centers radiographic evaluation of the C-spine is now done with thin slice CT, except in pediatric patients who are sensitive to the excessive radiation of the CT scan (six times greater than conventional radiograms), potentially increasing the risk of thyroid cancer later in life [57].

There is, however, a subset of patients who have normal CT results but are either obtunded or have neck pain. Given the fact that CT is not sensitive in diagnosis of soft tissue and ligamentous injury, how can these be ruled out in these patients? The conventional approach used to be to obtain flexion/extension series. However, the efficacy of dynamic fluoroscopy is very limited because of the need for repeated examinations, the difficulty in identifying specific ligamentous injuries, inadequate visualization of lower C-spine, and extremely low yield, combined with the relatively dangerous and cost-ineffective nature of these studies. In the first few days following the injury, active flexion/extension movement of the patient is limited because of pain. Also during this period, the study is fraught with the danger of spinal cord injury and must be done with the participation of a neurosurgeon. Data from two clinical studies demonstrates the low yield of flexion/extension series. In one study only 2 % of the 837 patients with unstable injuries [58], and in another, only 0.7 % of 301 patients were diagnosed [59]. In other patients, the studies were negative, inadequate, or falsely positive or negative [58, 59]. For these reasons many trauma centers no longer perform flexion/extension films.

MRI is currently performed as an adjuvant assessment in cognitively dysfunctional patients

with negative CT results. MRI is a reliable tool; when it is normal it can conclusively exclude C-spine injury and is thus established as the gold standard for clearing the C-spine in a clinically suspicious blunt trauma patient [60]. However, it is expensive, requires patient transport and medical supervision during a relatively long study period, and is so sensitive that it can detect subtle stable injuries which are clinically insignificant. Additionally, in the comatose patient with a normal CT and no abnormal neurologic signs, it does not add any information to change clinical management [61]. Also, for several reasons it cannot be done in the first few days of the injury, the time when airway management is most frequently required.

Another possibility is to keep the rigid cervical collar in place until the patient regains cognitive function and can be evaluated. This is the situation encountered in most instances when airway management is needed for the critically injured patient. Immobilization in a rigid cervical collar for more than 48–72 h has its own price, including an increased incidence of pressure sores, intracranial hypertension in the setting of a simultaneous head injury, airway management challenges, compromised central venous access, infection from suboptimal central venous catheter care, and difficult oral hygiene. Thus, every effort must be made to remove the collar as soon as possible.

A more recently proposed approach, practiced by trauma surgeons in Europe, Australia, New Zealand, and Canada, and in many but not all trauma centers in the US, is to rely on the CT study using a modern multidetector device with less than 3 mm cuts. The demonstrated diagnostic ability of this method is excellent, with a 99.99 % sensitivity and specificity and 100 % negative predictive value [62]. In practical terms, this method can miss one unstable C-Spine injury in about 5,000 patients who are not cleared by clinical examination, which in a typical level I trauma center translates into one patient every 10–15 years.

As in any other diagnostic study, there are certain conditions that C-Spine injury theoretically could be missed by CT examination. For

example, acute rupture of a transverse atlantal ligament produces significant instability despite the absence of a neurological deficit and normal alignment while the patient is lying supine on a CT scanner. Likewise in a head-injured patient, a mild to moderate central cord syndrome that may occur in situations of spinal cord injury without radiologic findings (SCIWORA) may be difficult to discern with CT scan. Finally, human error is always possible, and misread CT scans by inexperienced clinicians can be a reason for a missed injury.

Although anesthesiologists are not responsible for clearing the C-spine, knowing the process and pitfalls of C-spine clearance may help airway management planning and intervention. Nevertheless, it should be emphasized that many patients present to anesthesiologists for airway management with a C-spine that is not cleared and a hard collar restricting neck flexion and extension; the emergent nature of the injury precludes the use of time-consuming diagnostic measures prior to airway management. The goal is to secure the airway without causing or worsening spinal cord damage. Several studies have reviewed the possibility of new or increasing spinal cord injury resulting from airway management. In 1987, Marshall and colleagues [63] studied the frequency and causes of neurologic deterioration in 154 spinal cord-injured patients after admission to the hospital. The deficits increased in nine patients. None were related to airway management; these complications were caused by placement and adjustment of neck-stabilizing devices. Indeed, although small, some anteroposterior translation and angulation of the unstable spine occurs during application and removal of any one- or two-piece cervical collar [64].

Hindman and colleagues [65] reviewed the closed claims for perioperative cervical cord, root, and spine injury in 48 patients. Interestingly, most cervical cord injuries occurred in the absence of traumatic spine injury, instability, or airway difficulties. Overall, airway management-related neurologic damage represented 11 % (five patients) of the total of 48 claims. Three of these patients had no trauma

but ankylosing spondylitis in two and severe cervical spondylosis with cord compression on the third patient. Cervical spine instability before airway management was present in nine patients. Of these, seven patients had traumatic spinal instability, of whom six underwent cervical cord surgery; neurologic damage was related to the surgery and not to the airway management in these patients. Spinal cord injury attributed to airway management occurred in two of the seven claims with prior trauma-induced unstable C-spines following difficult laryngoscopy and intubation without precautions. McLeod and Calder [66] reviewed nine allegedly intubation-related postoperative spinal cord injuries. Of the nine patients only three in two reports had traumatic C-spine injuries. It is possible that at least two of these cases are the same patients described by Hindman and colleagues [65]. In any case two of the injuries in McLeod and Calder's [66] series were not recognized and laryngoscopy and intubation were performed without precautions. The third patient had an airway obstruction secondary to cervical hematoma. Intubation failed and cricothyroidotomy was performed. Thus, airway management-related spinal cord injury may occur in C-spine-injured patients, but if it does, it is rare. This does not imply, however, that protection of the neck is unnecessary during airway management.

Direct laryngoscopy with manual inline stabilization (MILS) is the standard of care for these patients in the acute stage. In the presence of MILS the glottic view on direct laryngoscopy is restricted because of limitation of neck extension; thus tracheal intubation may be facilitated by the use of adjunctive measures such as bougie, stylet, or external laryngeal pressure. MILS also may require greater anterior pressure on the tongue by the laryngoscope blade. This pressure is transmitted to the spine and can increase the movement of the unstable segment. This has been elegantly demonstrated by Santoni and colleagues [67] who placed multiple pressure transducers on the anterior surface of the Macintosh blade to measure pressures exerted on the tongue (and indirectly to the spine), during various phases of direct

Pressures Applied during Laryngoscopy with MAC Blade

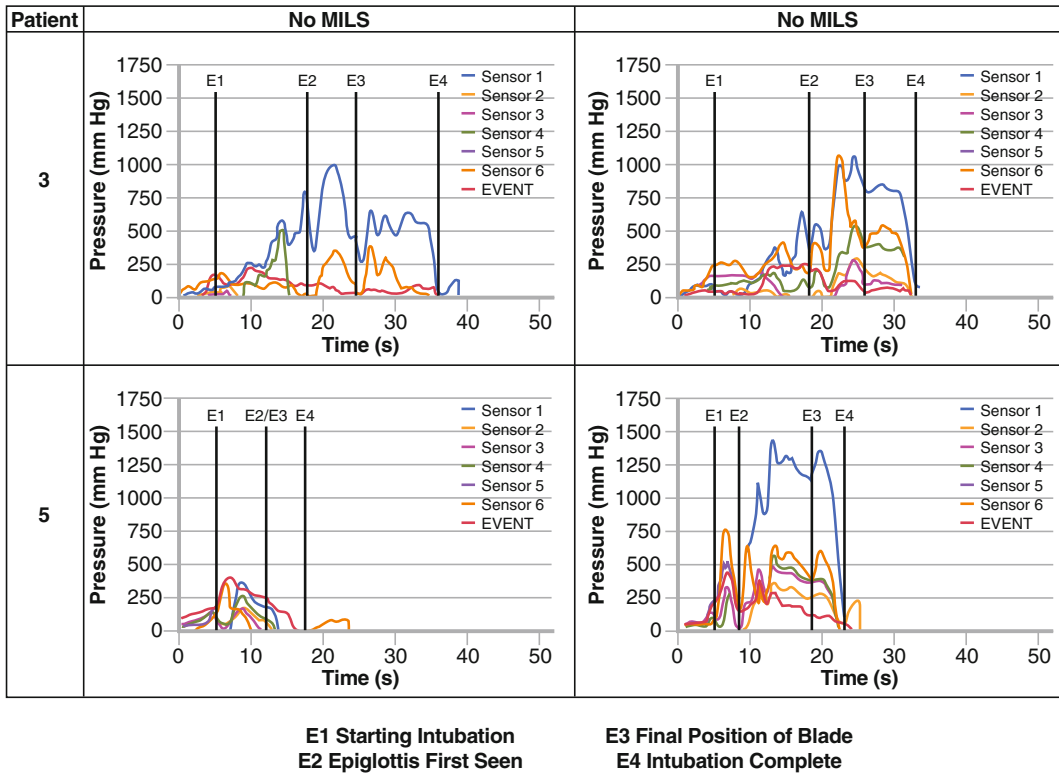


Fig. 2.8 Pressures applied by the MacIntosh laryngoscope blade on the tongue and indirectly on the C-Spine during various phases of direct laryngoscopy and intubation in two patients. Note that applied pressure is greatest from the time of final position of the blade to the completion of intubation, especially with application of manual

inline stabilization (MILS) of the head and neck. Reproduced with permission from Santoni BG, Hindman BJ, Puttlitz CM et al.: Manual in-line stabilization increases pressures applied by the laryngoscope blade during direct laryngoscopy and orotracheal intubation. *Anesthesiology* 2009; 110:24-31

laryngoscopy and intubation. Exerted pressures during the best laryngoscopic view were twice as large with MILS than without (Fig. 2.8). These findings confirm the results of a video fluoroscopic study conducted by Lennarson and colleagues [68] in C4–5 cervical spine destabilized fresh cadavers. They looked at the angular rotation and the anterior/posterior (AP) and axial displacements (change in vertical intervertebral space height) during laryngoscopy with and without MILS. There was no change in angular rotation and axial distraction when the laryngoscopy was done in the presence of MILS. There was, however, significant anteroposterior displacement of as much as 1.9 mm, compared to 1 mm without MILS (Fig. 2.9). The maximum

physiologic AP displacement of the C-spine is about 3–3.5 mm [69]. Thus, with or without MILS, movement of the unstable segment during laryngoscopy is still within the physiologic range. However, this change occurred in an experimental C-spine preparation. Under clinical conditions when the extent of injury is unknown, it is difficult to predict the extent of damage even when C-spine movement is within the physiologic range. There are additional reasons for maintaining the practice of applying MILS during airway management of a suspected C-spine-injured patient [70]. First, there is no randomized clinical trial to show conclusively that outcome during airway management is not different with or without MILS. Second,

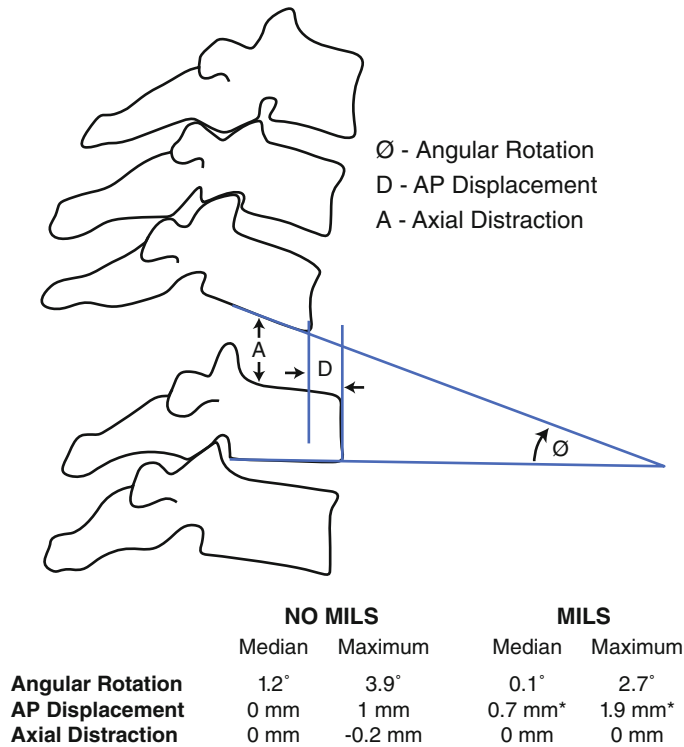


Fig. 2.9 Effect of manual inline stabilization (MILS) on the cervical spine angular rotation, and the anterior–posterior and axial displacements during laryngoscopy and intubation in C4–C5 destabilized fresh cadavers. *Upper panel* depicts the definitions of angular rotation, and anterior-posterior and axial displacements of the spine. *Lower panel* shows the extent of movement in each of these directions during laryngoscopy and intubation with and without MILS (*Upper panel*, reproduced

with permission from Gerling MC, Davis DP, Hamilton RS, Morris GF, Vilke GF, Garfin SR, Hayden SR. Effects of cervical spine immobilization technique and laryngoscope blade selection on an unstable cervical spine in cadaver model of intubation. *Lower panel*, data obtained from Lennarson PJ, Smith DW, Sawin PD et al.: Cervical spinal motion during intubation: efficacy of stabilization maneuvers in the setting of complete segmental instability. *Journal of Neurosurgery* 2001; 94:265-70)

development or worsening of spinal cord injury after institution of MILS during initial management has been less than that encountered during the prestabilization era, suggesting a protective effect of neck stabilization during airway management. Third, MILS can serve to warn physicians about the possibility of an underlying C-spine injury. It is reasonable, however, to allow some cervical movement by relaxing the MILS to optimize visualization of the larynx when the glottic view is restricted during laryngoscopy. As mentioned above, bougies, stylets, or cricoid pressure in this situation may further facilitate laryngeal view and intubation.

Almost any of the available airway devices cause some C-spine movement [68, 71, 72]. Face

mask ventilation with chin lift and jaw thrust results in significant posterior displacement. Supraglottic intubating airways, with or without FOB guidance, can also cause neck motion not much different than that caused by direct laryngoscopy. A wide variety of video laryngoscopes are available and they are evaluated in various conditions that imitate C-spine injury such as simulators, cadavers with destabilized necks, and patients with intact necks. Without doubt video laryngoscopes improve the laryngeal view even in the most difficult airways. They probably reduce neck movement as well, but they do not eliminate it (Table 2.7) [51, 73–75]. As mentioned above video laryngoscopes can be divided into two

Table 2.7 Performance characteristics of four tracheal intubation devices tested in lightly embalmed cadaver model with global ligamentous instability at C5–C6

	Macintosh	ILMA	Lightwand	Airtraq
Time to intubate (s)	22	42	34	27
Failure rate (%)	0	23	0	0
Flexion/extension (°)	4.7	3	2.4	2.9
Lateral bending (°)	2.7	1.9	1.5	1.9
Axial rotation (°)	4.3	2.9	2.3	2.8
M/L translation (mm)	2.0	1.1	1.1	1.3
AP translation (mm)	5.7	3.6	2.7	3.3
Axial distraction (mm)	2.8	1.9	1.6	2.1

M/L medial/lateral, *AP* anterior/posterior, *ILMA* intubating laryngeal mask airway

Adapted from Prasarn ML, Conrad B, Rubery PT et al.: Comparison of 4 airway devices on cervical spine alignment in a cadaver model with global ligamentous instability at C5–C6. *Spine* 2012;37: 476–81

categories: those that permit a view of the larynx with a rigid video-furnished blade by which the ET tube can be directed into the larynx by the operator (GlideScope, Storz), and those which direct the tube into the laryngeal inlet in addition to optimizing the view (Airtraq, Pentax Airway scope, King Vision). Of all these airway techniques FOB-guided nasotracheal intubation causes the least displacement [71, 76], although it may be associated with other problems such as prolonged intubation time, nose bleed, etc. Thus, during the initial phase after trauma when cervical spine injury is suspected, orotracheal intubation by applying MILS and using either a conventional blade or a videolaryngoscope after anesthetic induction is the most appropriate technique of intubation. In the later phases after trauma (24 h or longer), FOB-guided oro- or naso-tracheal intubation after sedation and topicalization of the airway is preferred. This approach allows neurologic testing immediately after securing the airway.

Management of Direct Airway Injuries

Trauma-induced direct damage to the airway or the surrounding tissue can occur anywhere between the nasopharynx and the bronchi. Occasionally injury may involve more than one level of the airway, resulting in persistent dysfunction after one of the problems is corrected.

Maxillofacial Injuries

Both penetrating and blunt mechanisms may be responsible for maxillofacial trauma. The face, head, and neck are vulnerable to missile and explosion injuries. Of the penetrating injuries, high velocity missiles produce severe and unpredictable disfiguring wounds. Battle injuries, which are mostly caused by explosives and ballistics, are more likely to be associated with multiple open and comminuted facial fractures [77]. In the blunt trauma category, injuries caused by altercations are usually less severe than those produced by motor vehicle accidents or falls.

Panfacial fractures involving the lower, middle, and upper face are likely to develop with high impact blunt injuries. This type of trauma is likely to involve more than one of the five regions of the facial skeleton: mandible, maxilla, zygomatic complex, naso-orbito-ethmoid region, and frontal bone [78]. The resistance of individual facial bones to blunt impact varies; the thin nasal bones are least and the thick supraorbital bone is the most resistant. Associated head and/or cervical spine injury should be suspected, especially in the presence of fractures of the more resistant facial bones. Facial fractures may not involve only the anterior bones. The fracture line may extend posteriorly and involve the pterygoid process of the sphenoid bone, the posterior buttress of the facial skeleton, which can cause posterior displacement of the face and obstruction of the nasopharynx. In a LeFort 1 fracture the pterygoid process is damaged at its inferior tip with minimal

displacement. LeFort 2 and 3 fractures involve the pterygoid process close to its base, where it is connected to the sphenoid bone, causing significant posterior displacement and giving the face a “dishpan” or “baby face” appearance. These fractures may also involve the cribriform plate causing cerebrospinal fluid leakage with the risk of infection.

Difficulty in airway management may arise from mechanical or functional limitation of mouth opening, soft-tissue edema of the pharynx, peripharyngeal hematoma, and blood or debris in the oropharynx. The result of these is partial or complete airway obstruction which may lead to difficulty in visualizing the larynx in the acute stage of these injuries. Occasionally, teeth or foreign bodies in the pharynx may be aspirated into the airway. If not recognized, these foreign bodies may cause some degree of obstruction in distal airways with subsequent pneumonia. Injured maxillofacial soft tissues are dynamic. Serious airway compromise may develop within a few hours in up to 50 % of patients with major penetrating facial injuries or multiple trauma as a result of an expanding hematoma or progressive inflammation or edema resulting from the trauma itself and/or liberal administration of fluids. Although rare, massive hemorrhage, most frequently from the internal maxillary artery or its branches, may be life threatening, requiring angioembolization. Prophylactic intubation of the trachea may avert airway compromise in these circumstances [79].

As mentioned fracture-induced encroachment on the airway or limitation of mandibular movement, pain, and trismus may limit mouth opening. Fentanyl in titrated doses of up to 2–4 µg/kg over a period of 10–20 min may produce an improvement in the patient’s ability to open the mouth if mechanical limitation is not present.

Unless severe airway compromise or bleeding is complicating the clinical picture in panfacial fractures, surgery may be delayed for as long as a week without adverse effect on the repair. Panfacial fractures, most of which are managed after stabilizing hemodynamic and oxygenation status and repair of vital injuries, are usually repaired with the principle of “bottom up and

outside in” in the same session of a prolonged procedure. Thus, the mandible is repaired before the maxilla, and zygomatic fractures before naso-orbito-ethmoid fractures. Some of the reasons for this approach are to maintain the vertical length of the face, repairing the simple mandibular fracture before a complex maxillary fracture, and preventing facial asymmetry [78]. Surgery during the early phase may be limited to intermaxillary fixation, which may be done under local or general anesthesia depending on the type of fracture, patient tolerance, and hemodynamic and respiratory status. Some of these patients may require tracheostomy using either an open or percutaneous technique, preferably over an endotracheal tube [80, 81]. Patients operated for definitive repair a few days after injury will present with a CT scan delineating the skeletal injury. Both two-dimensional spiral CT scanning with axial, coronal, and sagittal projections and three-dimensional CT scans provide adequate evaluation of maxillofacial fractures, aiding in planning of airway management [82].

The selection of an airway management technique in the presence of a maxillofacial fracture is based on the patient’s presenting condition. Most patients with isolated facial injuries do not require emergency tracheal intubation. Patients who present with airway compromise may be intubated using direct laryngoscopy; the decision about the use of anesthetics and muscle relaxants is based on the results of airway evaluation. Bleeding into the oropharynx precludes the use of a flexible FOB, and often of a videolaryngoscope, because of obstruction of the view by blood and secretions. A retrograde technique, using a wire or epidural catheter passed through a 14-gauge catheter introduced into the trachea through the cricothyroid membrane, may be used if the patient can open his or her mouth. A surgical airway with either open or percutaneous technique is indicated when there is airway compromise, direct laryngoscopy has failed or is considered impossible, the jaws will be wired, or when a tracheostomy will be performed anyway after definitive repair of the fracture [80,

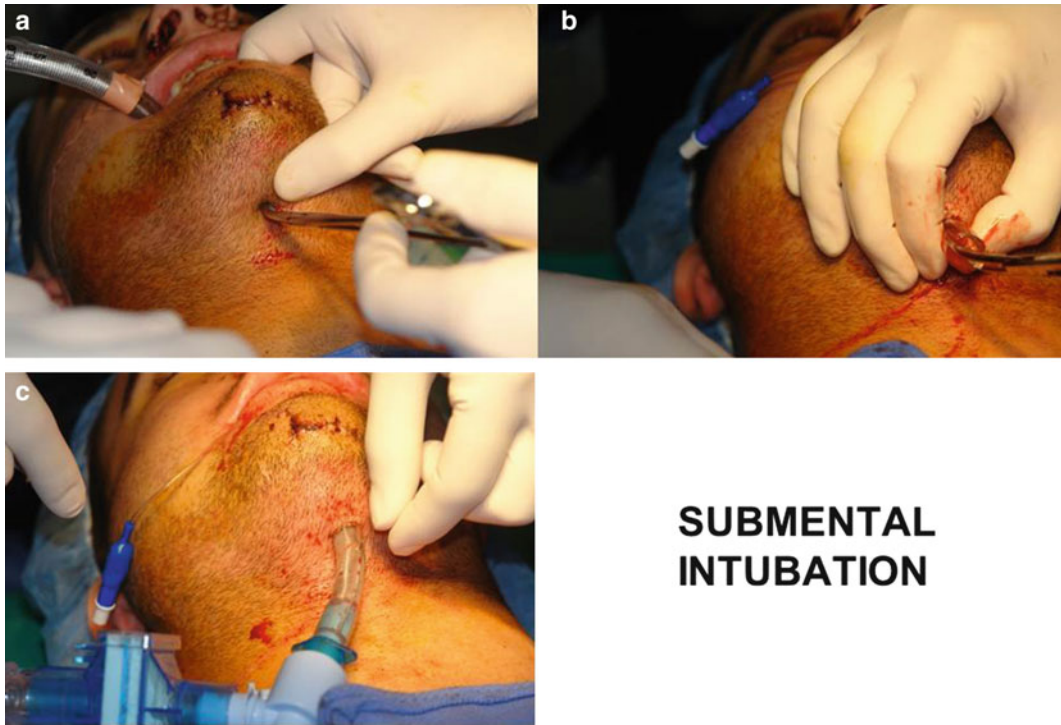


Fig. 2.10 Submental intubation. (a) Small submental incision is made and the floor of the mouth is pierced with a clamp introduced through the incision in the patient intubated with a flexible armored tube, (b) Proximal end

of the endotracheal tube is grabbed with the clamp introduced into the floor of the mouth and pulled through the submental incision, (c) The tube is connected to the breathing circuit

81]. Tracheostomy may often be avoided with the use of submental intubation in patients operated electively for definitive repair of injuries [83, 84]. This technique involves making a small submental incision after intubation of the trachea with a flexible armored tube, introducing a clamp through the incision, piercing the floor of the mouth, grabbing the proximal end of the endotracheal tube, and pulling it through the incision (Fig. 2.10). Thus, the oral cavity is free and the tracheal wall remains intact. Postoperatively the tube can be removed or redirected to its original position. Nasogastric or blind nasotracheal intubation should be avoided in the early stage after trauma when a basilar skull or maxillary fracture is suspected: the tube may enter the cranium or the orbital fossa, damaging the brain or the eye. Hemorrhagic shock and life-threatening cranial, cervical, laryngotracheal, thoracic, and cervical spine injuries may accompany major facial fractures; airway management

must be tailored accordingly (Fig. 2.11). The likelihood of cranial injury increases in midface fractures involving the frontal sinus, as well as the orbitozygomatic and orbitoethmoid complexes.

Cervical Injuries

Both blunt and penetrating trauma can cause direct laryngotracheal injury. These injuries are relatively rare compared to maxillofacial injuries partly because of protection of the anterior aspect of the neck by the mandible. The incidence of blunt and penetrating laryngotracheal injuries admitted to major trauma centers is 0.34 % and 4 %, respectively [85]. As in maxillofacial injuries, wartime laryngotracheal injuries are more severe and occur more frequently (5 % in United States and 11 % in United Kingdom forces) [86] than peacetime injuries (0.91 %).

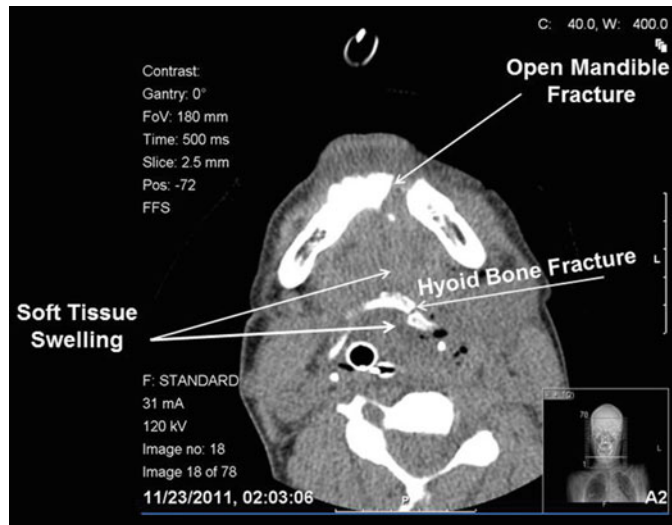


Fig. 2.11 Computed tomography scan of a patient sustaining hyoid bone and open mandibular fracture. Note

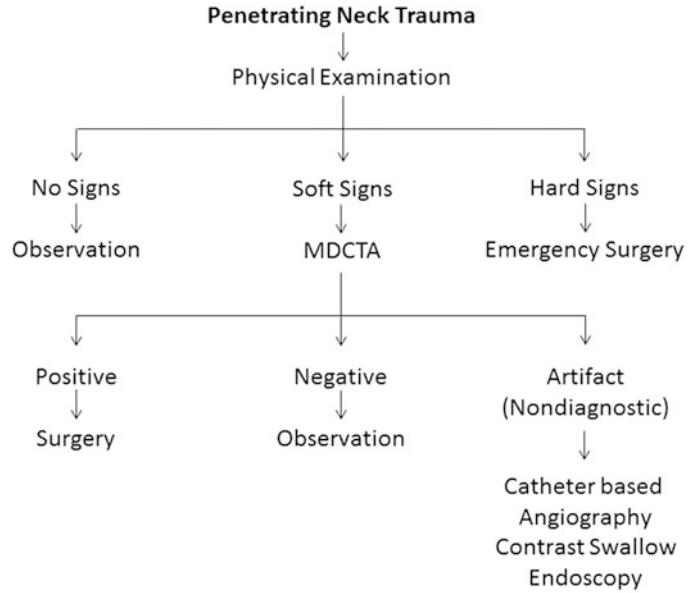
submandibular edema. Airway obstruction after induction of anesthesia necessitated emergency surgical airway

Interestingly, involvement of the pharynx and esophagus, which are in proximity to the cervical airway, is less likely than airway injuries in peacetime trauma (0.08 % after blunt and 0.9 % after penetrating trauma); [85] they may be more frequent in combat injuries. Although direct injury to the airway is relatively rare, the tightly organized anatomic structures within the neck may result in airway compromise when other cervical structures are injured. For example, vascular injury in this region can cause airway obstruction because of laryngeal edema resulting from shift of the larynx and compression of the veins by the hematoma. Likewise, a retropharyngeal abscess after an unrecognized esophageal injury may result in partial or total airway obstruction. Thus, cervical airway injuries should be considered in conjunction with any neck injury rather than as isolated entities.

Anatomically, the neck is divided into anterior and posterior triangles, and in its anteroposterior direction into three zones (1, 2 and 3, from caudad to cephalad). The boundaries of the anterior triangle are the midline, the lower border of the mandible, and the anterior border of the sternocleidomastoid muscle. A prominent area in this region is the “laryngeal trapezium”

which is bounded superiorly by the hyoid bone, inferiorly by the sternal notch, and laterally by the anterior borders of both sternocleidomastoid muscles. The posterior triangle is bounded by the middle third of the clavicle inferiorly, the posterior border of the sternocleidomastoid muscle medially, and the anterior border of the trapezius muscle posteriorly. Wounds in the anterior region compromise the airway more often than posterior injuries because of their proximity to the larynx, trachea, laryngeal nerves, and the important cervical vessels. Zone 1, also called the root of the neck or the thyrocervical region, is the narrow area below the clavicles. Injuries to this area are not only life threatening, but are also difficult to control surgically. On the other hand, this area is protected by the osseous upper anterior chest wall and is injured less often than zone 2. Zone 2 is the region between the clavicle or the cricoid cartilage inferiorly and the angle of the mandible superiorly. It is most likely to be injured by both penetrating and blunt trauma with resulting injuries to the arterial, venous, aerodigestive, and neural structures. Mortality from injuries to this region is relatively low, probably because they are easy to evaluate and treat. Zone 3 comprises the area between the angle of the mandible and the base of the skull.

Fig. 2.12 Management strategy of patients with penetrating neck trauma. Adapted by permission from Inaba K, Branco BC, Menaker J et al.: Evaluation of multidetector computed tomography for penetrating neck injury: a prospective multicenter study. *Journal of Trauma* 2012; 72:576-84



Surgical access is difficult to this area because it is obscured by the ramus of the mandible.

There are several causes of penetrating neck injuries: stab, gunshot, or shotgun wounds, explosions, or occupational hazards. Although explosions can cause injury by several mechanisms, damage is most commonly produced by the energized fragments overlying buried devices [86]. Of the other mechanisms, gunshot wounds usually are the most severe and unpredictable. Penetrating neck wounds are classified not only by their causes, but also by the location of the entry point of the object, the physiologic stability of the patient, and the organs injured. It should be emphasized that entry point may not always correspond to the location of interior damage, especially after high-velocity gunshot wounds [87].

Blunt neck injuries are caused by motor vehicle accidents, falls, and sudden collision with an object at the level of the neck. For example, a chain set between two sides of a dirt road represents a threat of neck injury for a person on a bicycle or motorcycle.

Clinical signs such as air escape, hemoptysis, and coughing spells are present in almost all patients with penetrating injuries, facilitating

the diagnosis. In contrast, major blunt laryngotracheal damage may easily be missed, because many patients have mild or no symptoms, which may be missed during the initial evaluation. Hoarseness, muffled voice, dyspnea, stridor, dysphagia, odynophagia, cervical pain and tenderness, ecchymosis, subcutaneous emphysema, and flattening of the thyroid cartilage protuberance (Adam's apple) are the classical signs and symptoms of blunt laryngotracheal injuries. Almost never are all of these symptoms seen in a single patient.

The approach to management of penetrating neck injuries has gone through multiple changes during the last two decades. The current management strategy for penetrating neck injuries is summarized in Fig. 2.12 [88]. It is now clear that physical examination of the neck reliably reveals unstable patients, those with hard signs and soft signs (Table 2.8) and asymptomatic patients. Unstable patients and those with obvious signs (hard signs) (Table 2.8) are candidates for emergency surgical exploration without additional workup. Asymptomatic patients can be observed for 24 h without any radiologic examination. Patients with soft signs and probably those who are asymptomatic but whose injury is

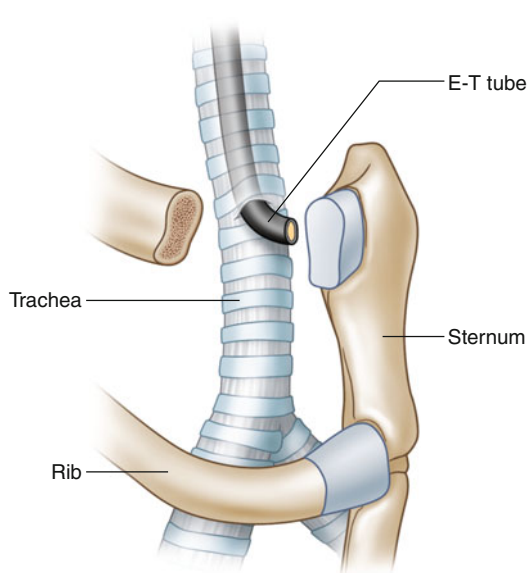
Table 2.8 The list of hard signs that indicate surgery without work-up, and soft signs that indicate evaluation with multidetector computed tomographic angiography (MDCTA) in penetrating cervical injuries

Hard clinical signs after penetrating neck injury	Soft clinical signs after penetrating neck injury
Shock unresponsive to initial fluid resuscitation	Nonexpanding or nonpulsatile hematoma
Active hemorrhage from the neck	Venous oozing
Expanding or pulsatile hematoma	Subcutaneous emphysema
Bruit or thrill in the area of injury	Dysphonia
Massive hemoptysis or hematemesis	Minor hemoptysis
Air bubbling from the injury site	Dysphagia
Neurological signs of cerebral ischemia	Injury proximity to vital organs

Adapted by permission from Inaba K, Branco BC, Menaker J et al.: Evaluation of multidetector computed tomography for penetrating neck injury: a prospective multicenter study. *Journal of Trauma* 2012; 72:576-84

near vital organs should undergo multidetector computed tomography angiography (MDCTA) scanning with image reconstruction. Surgery may be indicated in those with positive MDCTA findings. Soft signs include non-expanding or non-pulsatile hematoma, venous oozing, subcutaneous emphysema, dysphonia, minor hemoptysis, and dysphagia (Table 2.8). The presence of retained missiles may interfere with the accuracy of the MDCTA image and mask clinically significant injury. These patients may require angiography for the diagnosis of vascular damage, or esophagram or bronchoscopy for diagnosis of esophageal or airway injuries [88]. The insidious and often silent nature of blunt cervical airway injuries requires a high degree of suspicion and often evaluation by computed tomography (CT) and preferably MDCTA, unless the patient is unstable.

Whether the airway injury is blunt or penetrating, attempts at blind tracheal intubation may produce further trauma to the larynx and complete airway obstruction if the endotracheal tube enters a false passage or disrupts the continuity of an already tenuous airway (Fig. 2.13) [89]. Thus, whenever possible, intubation of the trachea should be performed under direct vision using an FOB, or the airway should be secured surgically. The two-man technique, one operator performing laryngoscopy with a conventional blade or a video laryngoscope and directing the second exploring the airway with an FOB, is the preferable technique. A CT scan of the neck provides valuable information and should be viewed, if

**Fig. 2.13** Schematic representation of an endotracheal tube entry into a false passage through the tracheal wall defect caused by the injury

available, before any airway intervention in all stable patients with neck injury and without respiratory and hemodynamic compromise.

Although development of edema and subsequent airway obstruction necessitates securing the airway at the earliest possible time after most cervical airway injuries, the approach to airway management depends on the clinical presentation [89]. Some airway injuries observed on CT scan may be mild with minimal symptoms and without progression. These patients can be managed conservatively without intubation [90]. The tracheas of some patients with penetrating

airway injuries may be amenable to intubation through the airway defect in the neck without the need for anesthetics or laryngoscopy. The presence of cartilaginous fractures or mucosal abnormalities necessitates intubation with preservation of spontaneous breathing using an FOB or awake tracheostomy. Laryngeal damage precludes cricothyroidotomy. Tracheostomy should be performed with extreme caution because up to 70 % of patients with blunt laryngeal injuries may have an associated cervical spine injury and neck extension to optimize surgical exposure may jeopardize the integrity of the spinal cord [89]. Uncooperative or confused patients may not tolerate awake airway manipulation. It may be best to transport these patients to the OR, induce anesthesia with inhalational agents, and intubate the trachea without muscle relaxants [89]. Episodes of airway obstruction during spontaneous breathing under an inhalational anesthetic can be managed by positioning the patient upright in addition to the usual maneuvers.

Complete transection of the trachea is rare, but when it occurs it is life-threatening; the distal segment of the trachea retracts into the chest, causing airway obstruction either spontaneously or during airway manipulation. Surgery involves pulling up the distal end and performing an end-to-end anastomosis to the proximal segment or suturing it to the skin as a permanent tracheostomy [91]. In extreme situations, such as complete or near-complete transection of the larynx and trachea, femorofemoral bypass or percutaneous cardiopulmonary support may be considered if time permits [92]. Vascular injuries causing hemorrhagic shock are also an indication for airway management. Bleeding in these patients can be controlled temporarily by the index finger covered with a sterile glove introduced through the cervical wound and compressing the bleeding site. Alternatively, the inflation of the balloon of a Foley catheter introduced through the wound tract can control the bleeding [93]. However, airway management in these patients and in those with cervical hematoma may be challenging because of the shift of the trachea to the contralateral side.

Thoracic Airway Injuries

Although penetrating trauma can cause damage to any segment of the intrathoracic airway, blunt injury usually involves the posterior membranous portion of the trachea and the mainstem bronchi, usually within approximately 3 cm of the carina. A significant number of these injuries results from iatrogenic causes such as tracheal intubation [94]. The usual signs and symptoms include those produced by pneumothorax, pneumomediastinum, pneumopericardium, subcutaneous emphysema, and a continuous air leak from the chest tube; they occur frequently but are not specific for thoracic airway damage. Radiographically, a radiolucent line along the prevertebral fascia due to air tracking up from the mediastinum, peribronchial air or sudden obstruction along an air-filled bronchus, and the “dropped lung” sign that occurs when there is complete intrapleural bronchial transection causing the apex of the collapsed lung to descend to the level of the hilum are important indications of intrathoracic airway injury. Additionally in patients intubated without the suspicion of a tracheal injury, difficulty in obtaining a seal around the endotracheal tube, or the presence on a chest radiograph of a large radiolucent area in the trachea corresponding to the cuff suggests a perforated airway. Airway management is similar to that of cervical airway injury. All airway manipulations must be done under direct vision using an FOB to prevent entry into a false passage. Anesthetics, and especially muscle relaxants, may produce irreversible obstruction, presumably because of relaxation of structures that maintain patency of the airway in the awake patient; however, airway loss may also occur during attempts at awake intubation, often as a result of further distortion of the airway by the endotracheal tube, patient agitation, or bleeding into the airway [95]. After intubation of the trachea, the adequacy of airway intervention is evaluated mainly by auscultation and capnography. Nevertheless, pulmonary contusion, atelectasis, diaphragmatic rupture with thoracic migration of the abdominal contents,

and pneumothorax may complicate the interpretation of chest auscultation. Likewise, CO₂ elimination may be decreased or absent in shock and cardiac arrest.

Because the outcome after surgical repair of these injuries is often suboptimal and complicated by stump leak and empyema, suture line stenosis, or the need for tracheostomy or pneumonectomy, many surgeons choose selective conservative management. Patients with lesions larger than 4 cm, cartilaginous rather than membranous injuries, concomitant esophageal trauma, progressive subcutaneous emphysema, severe dyspnea requiring intubation and ventilation, difficulty with mechanical ventilation, pneumothorax with an air leak through the chest drains, and/or mediastinitis are still managed surgically. Those without these problems may be treated nonoperatively with a reasonable outcome [94].

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