Review Article

Lower airway injuries and anaesthesia

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Purpose: The perioperative management of lower airway injuries is a difficult clinical problem. Since few reviews present the management of this injury from an anaesthetic perspective, we undertook a literature review of this topic.

Sources: A computerized search of the National Library of Medicine database using tracheal or bronchial injury as key words produced 140 English language citations. An eight-year chart review outlining our experience in an urban Canadian setting is also presented.

Findings: The most frequent findings in patients with injury to the lower airway are dyspnoea and surgical emphysema. Other findings include cough, haemoptysis, sucking neck or chest wounds, mediastinal emphysema or pneumothorax. Endoscopy with a fiberoptic scope is the technique of choice for diagnosis, airway management and as a preparatory step in planning of the surgical repair. An airway technique employing direct vision is preferable to blind attempts during tracheal intubation. The use of a double lumen endobronchial tube or selective endobronchial intubation may be needed to achieve adequate pulmonary ventilation. A number of prospective randomized clinical trials comparing conventional mechanical ventilation with high frequency jet ventilation in patients with acute lung injury have demonstrated no difference in effectiveness of ventilation or oxygenation.

Conclusions: Patients with lower airway injuries usually present when they are least expected and are a challenge to manage. The clinical presentation of a lower airway injury may be overt or subtle. Resuscitation and anaesthetic management are

directed towards control of the airway, maintenance of adequate pulmonary ventilation and management of blood loss.

Objectif: La gestion périopératoire des traumatismes des voies aériennes inférieures est complexe. Comme sa gestion anesthésique n'a jamais été explorée à fonds, les auteurs ont effectué un tour d'horizon de la littérature portant sur ce type de blessure.

Source: Une recherche informatisée des données de la National Library of Medicine utilisant les mots clés traumatisme (injury) trachéal et bronchique a révélé 140 références en langue anglaise. La révision des dossiers de huit années d'expérience dans un milieu urbain canadien est aussi présentée.

Résultats: La dyspnée et l'emphysème chirurgical sont les signes les plus fréquents des blessures aux voies aériennes inférieures. L'endoscopie fibroptique constitue la technique de choix pour le diagnostic, la gestion des voies aériennes et l'approche préparatoire à la chirurgie. Une technique de vision directe est préférable aux tentatives d'intubation à l'aveugle de la trachée. L'utilisation du tube endobronchique à double lumière ou l'intubation endobronchique sélective peuvent s'avérer nécessaires pour ventiler adéquatement. Plusieurs études cliniques randomisées et prospectives visant à comparer la ventilation mécanique conventionnelle avec la ventilation à jet à haute fréquence n'ont pas démontré de différences en ce qui concerne l'efficacité de la ventilation et de l'oxygénation.

Conclusions: Les lésions traumatiques des voies respiratoires inférieures sont ordinairement inattendues et représentent un défi de taille. La lésion traumatique des voies respiratoires inférieures peut se manifester cliniquement ou demeurer discrète. La réanimation et la gestion anesthésique visent à contrôler les voies aériennes, à maintenir une ventilation adéquate et à traiter l'hémorragie.

Key words

COMPLICATIONS: mortality, trauma, chest;
INTUBATION, TRACHEAL: technique;
SURGERY: trauma, thoracic.

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Contents

- Introduction
 - History and epidemiology
- Path-physiology
 - Mortality
- Clinical presentation and diagnosis
 - History and physical examination

- Radiology
- Endoscopy
- Resuscitation and airway management
- Extra-thoracic trachea
- Intra-thoracic trachea
- Intraoperative management
- Airway
- Ventilation
- Monitoring
- Anaesthesia
- Fluid management
- Surgical considerations
- Postoperative management
- Local experience
- Acknowledgements
- References

Injuries of the lower airway can be divided into two groups; extra thoracic tracheal injuries and intra-thoracic tracheobronchial injuries. Although injuries of the lower airway are relatively uncommon, the incidence in hospital based studies may be increasing due to greater urban violence and better pre-hospital care.

A search of the National Library of Medicine database combining the key words trachea, bronchi and tracheobronchial and cross-referencing these words with thoracic trauma and wounds and injuries and again with anaesthesia produced only three English language citations. Two of these citations were review articles. One of the reviews dealt with airway management in general while the second review dealt with the diagnosis and care of chest trauma as a general topic but included a section on tracheal and bronchial injuries.^{1,2} The third citation was a case report describing the anaesthetic management of an elective tracheal resection.³ A repeat search with tracheal or bronchial injury as the key words produced 140 citations, most being surgical case series. Unfortunately, surgical reports rarely concentrate on resuscitation or the anaesthetic management. This review outlines the patho-physiology, diagnosis, airway management as well as the intraoperative and postoperative management of patients with lower airway injuries. In addition, an eight-year review outlining our experience in an urban Canadian setting is presented.

History and epidemiology

Lower airway injuries appear to be the product of a modern society. The description and treatment of a penetrating wound of the oesophagus and trachea was first described in Scotland in 1792.⁴ A traumatic bronchial injury was first reported in 1873 and in 1945 Sanger described the first successful repair of a bronchial lacer-

ation.⁴ This was followed by reports of the successful repair of a bronchial rupture in 1949 and with a successful repair of a ruptured trachea in 1957.⁵

The precise frequency of a lower airway injury is unknown although these injuries are generally considered to be rare. Bertelsen and Howitz, in a seven year series, documented 33 (2.8%) injuries to the tracheobronchial tree in autopsies for trauma.⁶ If both blunt and penetrating mechanisms are considered, injuries are more commonly found in the extra-thoracic trachea.⁷ However, in a review of blunt lower airway injuries, only 4% were located in the extra-thoracic trachea while 62% were located in the bronchial tree.⁸ Overall, penetrating injuries are more common than blunt injuries.^{7,9} An American study reported 65 patients with injuries to the cervical trachea in more than 700 patients presenting with neck trauma over a 27-year period. Eighty-three percent were the result of a penetrating injury.⁹ The incidence of intra-thoracic tracheal and tracheobronchial injuries is more difficult to quantitate. Many patients sustaining this injury die before reaching hospital and blunt injuries of the tracheobronchial tree may be missed on initial presentation.^{10,11} The incidence of penetrating intra-thoracic tracheal trauma has not been clearly defined although gun shot or stab wounds are more common (64–77%) than blunt injuries in the bronchi or intra-thoracic trachea.^{12–14} In a study from Baltimore, Maryland two patients (0.4%) had tracheobronchial injuries in a review of 515 patients admitted with blunt thoracic trauma.¹⁵

Patho-physiology

Because of its exposed position, the extra-thoracic trachea is particularly prone to trauma.^{16,17} Blunt injuries to the cervical trachea are most likely due to a direct blow or trauma. Injuries to the extra-thoracic trachea have been referred to as “clothesline injuries” or “the padded dash syndrome.” The manner of injury is similar in both instances. In the clothesline injury the victim with his or her neck in extension collides with a hidden wire or cable.¹⁸ The “padded dash syndrome” usually occurs in an unbelted front seat passenger in which the head and torso are thrown forward during deceleration with a frontal impact and the forehead or mid-face strike the windshield. This results in hyperextension of the neck and the exposed trachea strikes the narrow edge of the padded dash board.¹⁹ On occasion, violent hyperextension of the head and neck can lead to transverse rupture of the trachea.^{6,20}

Blunt injuries to the intra-thoracic tracheobronchial tree are due to deceleration or chest compression. As reported by Alyono *et al.*, high speed motor vehicle and motorcycle crashes are the main cause of blunt

intra-thoracic tracheal injuries.²¹ Three mechanisms of blunt injury to the intra-thoracic trachea and bronchi have been postulated. In the first, antero-posterior compression of the thorax leads to transverse widening of the chest wall. Both lungs are pulled in a lateral direction by the increasing transverse diameter, if the pleural space remains intact and intra-pleural pressure remains normal. As a result, traction is produced at the carina in a situation similar to a wishbone. If the lateral motion of both main stem bronchi overcomes the elasticity of the tracheobronchial tree, rupture occurs. This mechanism may account for the high proportion of blunt injuries to the tracheobronchial that are found within 2 cm of the carina.^{5,7,21-23} In the second, antero-posterior compression of the tracheobronchial tree increases the intra-tracheal and intra-bronchial pressures if the glottis is closed at the moment of impact. The increased pressure of the air in the tracheobronchial tree exceeds the ability of the trachea to contain it and results in a tracheal tear. As described by Laplace's law, tracheal wall tension will be largest where the airway is of greatest diameter leading to rupture of the trachea near the carina. This mechanism of injury may account for linear tears of the membranous trachea.^{5,7,12,21-23} In the third mechanism, the trachea is fixed at the carina and cricoid cartilages. A blow to the chest or sudden deceleration results in movement of the trachea around its fixed points of attachment. This movement may lead to shearing forces that may cause disruption.^{5,7,21-23} One of the authors (BRB) has managed a patient in whom it was postulated that disruption of the right main stem bronchus was due to penetrating injury from fractured ribs after a fall.

The trachea, at all levels, is intimately associated with the oesophagus. Oesophageal injuries frequently accompany tracheal injuries whether or not the mechanism of injury is blunt or penetrating in nature. In addition, the heart and major vessels are close to the trachea. As a result these structures are frequently injured along with the trachea particularly during penetrating trauma.⁵

Gunshot wounds are associated with more complications than are stab injuries. The greater kinetic energy of the bullet results in a temporary cavity which produces tissue damage beyond the missile tract (permanent cavity). As a result, there is greater tracheal damage as well as a greater frequency of injury to adjacent structures such as blood vessels or the oesophagus when the penetrating injury is due to a gunshot wound.²⁴

Mortality

Mortality data is difficult to interpret as patients frequently die from their injuries before reaching hospital.^{10,11} Ecker *et al.* reviewed all patients with a diagnosis of injury to the tracheobronchial tree admitted to

TABLE I Mortality from lower airway injuries in adults

Injury location and mechanism		Study	Subjects	Death
Extrathoracic penetrating	Sheely <i>et al.</i> (1974) ⁹	54	2	
	Symbas <i>et al.</i> (1976) ¹⁶	15	3	
	Grover <i>et al.</i> (1978) ¹⁴	7	0	
	Symbas <i>et al.</i> (1982) ¹⁷	13	1	
	Shama <i>et al.</i> (1984) ²³	11	0	
	Edwards <i>et al.</i> (1987) ²⁵	9	0	
	Flynn <i>et al.</i> (1989) ¹	14	0	
Total		123	6	(4.9%)
Intrathoracic penetrating	Symbas <i>et al.</i> (1976) ¹⁶	5	0	
	Symbas <i>et al.</i> (1982) ¹⁷	5	0	
	Flynn <i>et al.</i> (1989) ¹²	3	3	
Total		13	3	(23.1%)
Extrathoracic blunt	Sheely <i>et al.</i> (1974) ⁹	11	2	
	Jones <i>et al.</i> (1984) ²⁶	4	0	
Total		15	2	(13.3%)
Intrathoracic blunt	Deslauriers <i>et al.</i> (1982) ²⁷	13	1	
	Jones <i>et al.</i> (1984) ²⁶	9	4	
	De La Rocha <i>et al.</i> (1985) ²⁸	7	2	
	Ramzy <i>et al.</i> (1988) ²⁹	8	2	
	Baumgartner <i>et al.</i> (1990) ³⁰	9	2	
Total		46	11	(23.9%)

Parkland Memorial Hospital and all medico-legal autopsies done by the Dallas County Medical Examiner's Office over nine years. Of 105 patients with injuries to the lower airway, 77% were dead on arrival at hospital.¹¹ Mortality depends on the location and mechanism of injury (Table I).

Acute mortality appears to be associated primarily with concomitant cardiac and vascular injuries with early death the result of haemorrhage or airway obstruction.^{7,10-12} Other less common causes of early death include delay in recognizing the injury and massive aspiration of blood.⁷ Late mortality has been attributed to infection, adult respiratory distress syndrome, multiple organ dysfunction syndrome and cerebral infarction from associated vascular injuries.^{16,17,24,30}

Clinical presentation and diagnosis

Signs and symptoms of injury to the lower airway can be relatively non-specific and subtle, particularly in a trauma patient with multiple injuries.^{7,31} Consequently, a high index of suspicion is needed in order to make the diagnosis and institute appropriate early management.¹⁹ While imaging techniques may be useful in confirming the diagnosis, endoscopy with a fiberoptic scope is the technique of choice for diagnosis, airway management

TABLE II Frequency of physical findings with lower airway injury

Study	Location	n	Subcutaneous emphysema	Respiratory distress	Hissing wound	Haemoptysis	Shock
Ecker <i>et al.</i> ¹¹	I & E	24	70.8%	87.5%	—	54.2%	16.7%
Sheely <i>et al.</i> ⁹	E	65	63.1%	20%	18.5%	16.9%	12.3%
Symbas <i>et al.</i> ¹⁶	I & E	20	85%	55%	15%	33.3%	—
Grover <i>et al.</i> ¹⁴	I & E	14	92.9%	57.1%	—	—	14.3%
Symbas <i>et al.</i> ¹⁷	I & E	18	77.8%	72.2%	33.3%	44.4%	—
Deslauriers <i>et al.</i> ²⁷	I	13	69.2%	69.2%	—	30.8%	—
Jones <i>et al.</i> ²⁶	I & E	13	84.6%	76.9%	—	46.2%	30.8%
Kelly <i>et al.</i> ⁷	I & E	106	36.8%	87.7%	—	26.4%	—
De La Rocha <i>et al.</i> ²⁸	I	7	71.4%	42.9%	0	14.2%	14.2%
Edwards <i>et al.</i> ²⁵	I & E	12	83.3%	58.3%	—	33.3%	—
Flynn <i>et al.</i> ¹³	I & E	22	59.1%	40.9%	36.3%	13.6%	13.6%
Baumgartner <i>et al.</i> ³⁰	I	9	100%	66.7%	—	44.4%	—
Sunnybrook	I & E	13	53.8%	53.8%	30.8%	7.7%	7.7%
Average		336	60%	64%	23%	28%	15%

'I' represents an intra-thoracic tracheal injury location.

'E' represents an extra-thoracic injury location.

and as a preparatory step in planning of the surgical repair.^{14,27,29,30,32}

History and physical examination

Injuries to the extra-thoracic trachea tend to have a more obvious and dramatic presentation than do intra-thoracic tracheal injuries.⁵ Patients presenting with extra-thoracic tracheal injury, if conscious, complain of dyspnoea and may have associated complaints of pain, cough and haemoptysis. Acute respiratory distress is one of the key signs of extra-thoracic trachea injury. Respiratory difficulty may present as hoarseness but may range to complete airway obstruction. Other findings include surgical emphysema of the neck and/or the anterior chest. Neck or chest wounds may suck in air. Air may track into the mediastinum resulting in pneumomediastinum or air may be seen bubbling through neck wounds.^{8,18,19,33} Bleeding from associated vascular injuries may present as shock or death due to asphyxiation from blood in the airway (Table II). The severity of clinical signs correlates with the extent of airway injury.⁵ Many extra-thoracic tracheal injuries are discovered or confirmed at surgical exploration of sub-platysmal neck wounds.⁹

Injuries to the intra-thoracic trachea present with two patterns.³⁴ First, if the tracheal or bronchial rupture communicates directly with a pleural space, a large pneumothorax, perhaps under tension, will result. Tube thoracostomy will not completely evacuate this pneumothorax and there will be a persistent large air leak through the chest tube. Dyspnoea may worsen if suction is applied to the chest tube.^{5,8,10,27} Second, if there is no communication with the pleural space and the lower air-

way rupture is contained within the mediastinum then the presenting findings will be isolated mediastinal and subcutaneous emphysema.^{5,10} Mediastinal emphysema can worsen dramatically if positive pressure ventilation is commenced.

Although non-specific, dyspnoea is perhaps the most common complaint of conscious patients with intra-thoracic tracheal injuries.²⁷ Surgical emphysema and respiratory distress are the most common findings at admission. Other signs suggestive of tracheal injury include haemoptysis, hypovolaemic shock from associated vascular injuries and cyanosis.^{7,11,26,30} Massive haemoptysis is the sign of an associated vascular injury and not of an isolated tracheobronchial injury. The frequency of physical findings are outlined in Table II. Stridor does not seem to be an important finding in intra-thoracic tracheal injuries. Air escaping from wounds during respiratory appears to be confined to penetrating trauma of the intra-thoracic trachea.^{9,12,19,20}

Not all injuries to the lower airway are obvious on presentation to the emergency department. Bronchial injuries secondary to blunt trauma often present late with physical signs of airway stenosis. Bronchiectasis or persistent atelectasis may be indicative of a previously unrecognized and untreated bronchial injury.^{5,10,21}

Radiology

Imaging techniques are not diagnostic of lower airway injuries.^{5,10,21} Extra-thoracic trachea injuries are clinically obvious or are discovered during surgical exploration of a neck wound.^{9,21} As a result few studies of extra-thoracic tracheal injuries describe radiographic investiga-

TABLE III Frequency of radiographic with lower airway injury

Study	Location	n	Subcutaneous emphysema	Mediastinal emphysema	Haemoptysis	Pneumothorax	Atelectasis
Ecker <i>et al.</i> ¹¹	I & E	24	41.7%	33.3%	33.3%	41.7%	12.5%
Grover <i>et al.</i> ¹⁴	I & E	14	92.9%	57.1%	—	50.0%	—
Symbas <i>et al.</i> ¹⁷	I & E	18	55.6%	22.2%	16.7%	22.2%	—
Jones <i>et al.</i> ²⁶	I & E	13	69.2%	46.2%	15.4%	38.5%	—
Flynn <i>et al.</i> ¹²	I & E	22	40.9%	36.4%	22.7%	31.8%	—
Baumgartner <i>et al.</i> ³⁰	I	9	100%	33.3%	11.1%	66.7%	—
Sunnybrook	I & E	13	69.2%	23.1%	0	30.1%	0
Average		113	61%	35%	19%	38%	8%

'I' represents an intra-thoracic tracheal injury location.

'E' represents an extra-thoracic injury location.

tions.^{9,16} Typical findings on radiographs of the chest or cervical region include subcutaneous and mediastinal emphysema.¹⁷ Occasionally patients with extra-thoracic tracheal injuries may present with a small pneumothorax.^{5,9,14}

Diagnostic imaging is more important in patients with intra-thoracic tracheobronchial injuries and radiographic findings on the plain antero-posterior chest radiograph should warn of the possibility of an intra-thoracic airway injury. Subcutaneous and mediastinal emphysema appear to be the most frequent radiographic markers of lower airway rupture.^{5,8,10} Other radiological findings include pneumothorax, haemothorax, emphysema of the deep cervical fascia and fractured ribs (Table III).^{5,8,10} If there is no communication of the airway injury with the pleural space then radiological findings will be limited to mediastinal and subcutaneous emphysema. A small pneumothorax may be present but this will disappear with tube thoracostomy. If the airway injury communicates with the pleural space, as in a bronchial rupture, then a large ipsilateral pneumothorax will be present in addition to the pneumomediastinum and subcutaneous emphysema. Tube thoracostomy will often have little effect on the size of the pneumothorax on subsequent radiographs.^{5,8,10,27} Transection of a main stem bronchus may present with the affected lung having dropped down in the chest cavity.^{8,10}

Computed tomography is not useful as it provides only indirect evidence of the injury.^{5,35} Magnetic resonance imaging may be more successful in identifying lower airway injuries but more experience is needed.³⁵ Contrast bronchography is contraindicated in patients with suspected lower airway injuries because the contrast agent may worsen any acute lung injury.¹⁰

Endoscopy

Bronchoscopy remains the most useful diagnostic pro-

cedure and should be performed whenever a lower airway injury is suspected to confirm the diagnosis, evaluate its extent and location, confirm the placement of the tracheal tube and to plan of the surgical repair and airway management.^{5,8,10,14,23,27,29,30,33} Fiberoptic bronchoscopy is particularly useful in patients with lower airway injuries following blunt trauma.¹⁴ Associated injuries to the face, head and cervical spine may contraindicate the use of the rigid bronchoscope.³⁶ Ideally endoscopic evaluation should occur in the operating room where a surgical team is prepared to intervene immediately to secure the airway or repair the injury if required.^{5,8,10,26,31,37} Indications for bronchoscopy in patients with blunt thoracic trauma include pneumomediastinum, pneumothorax refractory to tube thoracostomy, persistent atelectasis, haemoptysis and surgical emphysema.¹² Endoscopic techniques should not delay definitive airway management in the setting of impending airway obstruction. Baumgartner *et al.* cautions that bronchoscopy should be performed by an individual experienced in the endoscopic findings of trauma.³⁰ Tracheobronchial injuries may be subtle when viewed endoscopically and can be missed by the inexperienced or hasty.³⁸

Resuscitation and airway management

As with any other form of trauma, airway management remains the first priority of resuscitation. Airway control beyond the injury is usually needed.³⁶ Patients arriving with or developing airway obstruction require rapid establishment of the airway. Other indications for tracheal intubation include respiratory failure from other injuries, prevention of aspiration of blood, control of haemoptysis, airway protection in the unconscious or head injured patient, and persistent haemodynamic instability.^{7,16,17,39} Ventilation of the lungs may present a further challenge.

FIGURE 1 Airway management of extra-thoracic tracheal injuries.^{25,39}

Extra-thoracic trachea

Airway management in patients with extra-thoracic tracheal injuries is similar to that of external laryngeal trauma (Figure 1). Because of the nature of the injury these patients may have associated damage of the cervical spine.^{25,39} Patients presenting with complete or impending airway obstruction require urgent tracheostomy under local anaesthesia. If the airway is not severely compromised but control is necessary then tracheal intubation may be performed after the extent and location of the injury have been ascertained by bronchoscopy.^{9,39,40} Tracheal intubation under direct vision is preferable because repeated attempts at blind tracheal intubation may induce partial or complete airway obstruction.^{8,10,25,33,41} Bronchoscopy may determine cuff position and, in the presence of tracheal transection, the bronchoscope can traverse the site of injury acting as a guide on which the tracheal tube may be passed to ensure that the cuff is in the distal segment.^{5,10,14,41} However if endoscopic securing of the airway is unsuccessful, it should be abandoned in favour of a surgical approach.⁴² Although the rigid bronchoscope could be of assistance in the airway management of these patients, the equipment and expertise may not be available. Occasionally because of complete transection of the cervical trachea, the trachea may retract into the thorax. The distal end of the trachea can be retrieved and intubated with a sterile endotracheal tube.^{10,43} In some

FIGURE 2 Airway management of intra-thoracic tracheal injuries.

instances the quickest and easiest way to secure the airway in patients with open cervical wounds is to intubate the distal end of the trachea through the wound itself.^{14,44}

Once the airway has been managed other possible injuries such as tension pneumothorax and haemothorax should be pursued and managed. Since there is a high incidence of associated vascular injuries, hypovolaemia should be managed with volume replacement and external haemorrhage control in the presence of active bleeding.^{9,39}

Intra-thoracic trachea

Tracheal intubation in patients with intra-thoracic tracheobronchial injuries is best achieved with the aid of fibreoptic bronchoscopy to ensure that the tracheal tube does not leave the trachea at the site of rupture or increase the damage at the site of injury (Figure 2).^{14,21,25,41} As with extra-thoracic lesions endoscopy allows characterization of the injury and aids in the correct placement of the endotracheal tube.¹⁴ The cuff of the endotracheal tube should be placed, if possible, beyond the level of tracheal injury. In the presence of a bronchial injury it may be necessary to place the tip of the endotracheal tube into the contralateral bronchus (Figure 3).^{5,10,14} When tracheobronchial injury is sus-

FIGURE 3 Role of the fiberoptic bronchoscope: The fiberoptic bronchoscope has a major role in diagnosis and airway management. Evaluation of the injury, tracheal and selective bronchial intubation can be performed endoscopically. Modified with the permission of the publisher.⁵

pected an uncut endotracheal tube should be used for deliberate bronchial intubation.¹⁰ If immediate airway control is not required and a tracheobronchial injury is suspected, endoscopic examination of the trachea and bronchi should take place in an operating room equipped to proceed with surgical repair.⁸

Pulmonary ventilation may be extremely difficult in patients with intra-thoracic tracheal or bronchial rupture. During positive pressure ventilation, in patients with communication to the pleural space, much of the delivered breath may be vented into the pleural space resulting in inadequate alveolar ventilation. Up to 25% of the minute ventilation has been measured leaving the chest tube of patients with the adult respiratory distress syndrome and bronchopleural fistula during conventional mechanical ventilation.⁴⁵ Use of a double lumen endobronchial tube or selective bronchial intubation may be required to achieve adequate pulmonary ventilation.

Although high frequency ventilation has been recommended by some based on anecdotal reports other studies suggest that oxygenation and ventilation may be more difficult in the presence of a lung injury.^{47,48} In animals with artificially created bronchopleural fistula and absent lung pathology, high frequency jet ventilation (HFJV) has been successfully used in maintaining arterial blood gases.^{49,50} Studies in humans with normal lungs also demonstrated improved pulmonary ventila-

tion using a HFJV technique.⁵³ In patients suffering from the adult respiratory distress syndrome and a bronchopleural fistula, HFJV carried out at the same mean airway pressure as conventional ventilation resulted in deterioration of ventilation as measured by arterial blood gasses or leakage of gas through the fistula.^{52,53} It is uncertain whether the experience from adult respiratory distress syndrome patients with bronchopleural fistula can be applied to patients with lower airway lacerations and pulmonary contusions and therefore HFJV should be used with caution.

Intraoperative management

The intraoperative management of tracheobronchial injuries offers unique challenges to both the anaesthetist and surgeon. Close cooperation between them is mandatory during surgical repair of lower airway injuries.^{8,10,21,31} Before the induction of anaesthesia for surgical repair to lower airway injuries, the chest tubes must be free and connected to an underwater seal apparatus to prevent the redevelopment of a pneumothorax.¹⁰

Airway

Most patients with lower airway injuries will arrive at the operating room with their tracheas intubated as part of their resuscitation. The airway should be secured as described previously before the induction of anaesthesia. It may also be necessary to perform tracheal toilet for aspirated blood or gastric contents.³⁷ One surgical review admonishes against the use of muscle relaxants and general anaesthesia before establishment of an airway, but no evidence is cited to support the position offered.⁴⁴

Manipulation of the endotracheal tube may be required intraoperatively. It is frequently necessary to pass a tube beyond the injury for ventilation. Ideally this should be done under fiberoptic bronchoscopic guidance or under direct vision of the surgeon after the airway injury has been exposed at thoracotomy. Endobronchial intubation of the contralateral mainstem bronchus may be necessary and can be achieved by either pushing an endotracheal tube into a bronchus or with the use of a double lumen endobronchial tube. Both techniques may be used to reduce air leaks and assist in surgical exposure by allowing collapse of the lung in the surgical field.^{8,10,14,21,29,47} Rarely, it may be necessary to provide ventilation through the operative field using a sterile endobronchial tube placed into the distal tracheal or one or both bronchi.^{10,18,29,54,55} Extubation of the trachea should be performed as soon as indicated postoperatively.⁸

An evaluation of the oesophagus is mandatory in patients with both blunt and penetrating tracheal

injuries.⁵⁶ The oesophagus can be evaluated pre-operatively and/or during repair of the tracheal injury.

Ventilation

While most patients with lower airway injuries require positive pressure ventilation as part of their ongoing resuscitation some recommend, where possible, spontaneous ventilation to reduce airway pressure until the pleural cavity has been incised.^{30,54} Positive pressure ventilation may either be vented to the pleural space in those patients with direct communication or cause massive surgical emphysema in patients without communication to the pleural space.¹⁰ In such patients, the anaesthesia ventilator may not be able to deliver an adequate minute ventilation and it may be necessary to use a free standing volume ventilator intraoperatively. Hypovolaemia, pulmonary oedema and pulmonary contusion may be correlated with the need for a free standing volume ventilator.⁵⁷ Bronchoscopic positioning of the tracheal tube cuff beyond a tracheal laceration or into a contralateral bronchus will minimize this ventilatory compromise.^{5,8}

Cardiopulmonary bypass has been used to provide adequate ventilatory and circulatory support in the presence of complex airway and vascular injuries. Anti-coagulation required for cardiopulmonary bypass may cause bleeding in other injured organs such as the lungs and the brain.^{8,9} As a result, cardiopulmonary bypass likely has a role in localized injuries due to penetrating trauma but its disadvantages outweigh its advantages in the blunt polytraumatized patient.

Monitoring

Standard monitoring such as ECG, blood pressure by cuff, temperature, airway pressure, peripheral nerve stimulator, pulse oximetry and end-tidal carbon dioxide measurement is essential. Monitoring of arterial pressure and urinary output is vital in these critically ill patients. An indwelling arterial catheter allows for continuous blood pressure measurement, blood gas, haematological and chemistry analysis freeing the anaesthetist's hands for other aspects of the patient's care. Central venous pressure or pulmonary artery catheters are less useful and should not delay resuscitation or definitive surgical repair.⁵⁷

Anaesthesia

Use of an inhalational agent during spontaneous ventilation has been advocated. Nitrous oxide may expand closed air containing spaces such as pneumothorax and therefore should be avoided.^{57,58} Another disadvantage of nitrous oxide use is the inability to deliver high inspired oxygen concentrations.⁵⁷

Fluid management

Because of the close anatomical association of the trachea with major thoracic and cervical structures, haemorrhage and hypovolaemic shock frequently occur with lower airway injuries.¹⁹ Adequate volume replacement of blood loss before induction of anaesthesia is mandatory. Previous knowledge of the location of any vascular injuries will guide placement of vascular catheters.⁵⁸ Multiple large bore intravenous catheters should be inserted and many patients require massive blood transfusions.^{38,58} However, in the presence of ongoing haemorrhage, definitive surgery should not be delayed for a prolonged preoperative period of transfusion therapy.

Surgical considerations

It is uncertain whether all tracheobronchial injuries require surgical repair. No centre has sufficient experience with this injury and firm treatment guidelines are lacking. Nonetheless, many authors comment that some tracheobronchial injuries have and can be managed expectantly. Non-operative management should be considered in the patient without a large air leak, without other indications for surgery (e.g., oesophageal injury), in which the injury is diagnosed at bronchoscopy and is "small" with edges that appear to be healthy and well-approximated and in which prolonged ventilatory support is not required.^{13,17,41} Acute surgical repair is aimed at preventing not only acute morbidity and death but also the delayed sequelae of tracheobronchial injuries, such as strictures. Thus, although there are reports of the non-operative management of tracheobronchial injuries, the mainstay of treatment remains early diagnosis and acute surgical repair.^{7,13}

There are only a few surgical approaches to tracheobronchial injuries. The collar incision appears to be the optimal for injuries to the cervical trachea. A sternotomy can be added to a collar incision for injuries to the proximal intra-thoracic trachea.⁸ In general, injuries to the intra-thoracic trachea, right bronchial tree and the proximal 2 cm. of the left main stem bronchus are approached by a right posterolateral thoracotomy. Injuries more distally in the left bronchial tree are exposed with a left posterolateral thoracotomy. It is conceivable that a sternotomy could be employed for bilateral bronchial injuries, most likely due to penetrating injury.

The options for the surgical management of injuries to the extra-thoracic trachea are primary repair, resection and primary anastomosis and tracheostomy. The insertion of tracheal grafts may be necessary but should be deferred for delayed repairs. The anterior aspect of the cervical trachea is most commonly involved and it is often possible to fashion a tracheostomy from the tra-

cheal defect. In such cases, the tracheostomy is the definitive treatment and can usually be removed in a short time. Alternatively, lacerations of the cervical trachea can be primarily repaired. Acute resection and primary anastomosis may be necessary for defects with considerable tissue destruction, although these patients rarely survive to reach the operating room.⁵⁹ Injuries of the intra-thoracic trachea and bronchi are treated with primary repair, tracheo-bronchoplastic resection or resection (pneumonectomy or lobectomy). Before closure of the surgical wounds the endotracheal tube is positioned as desired, generally below a tracheal repair if possible.

Postoperative management

Postoperative issues include effective pulmonary ventilation and adequate tracheal toilet. Ideally, this can be achieved with early tracheal extubation and adequate analgesia. Frequent therapeutic bronchoscopy may be required for tracheal toilet but the endoscopist should be wary of disrupting the repaired airway.^{5,18}

A large proportion of patients with lower airway injuries will require postoperative tracheal intubation for toilet and ventilation. Several authors recommend avoidance of high airway pressures during positive pressure ventilation as it has been postulated that elevated airway pressures will place the tracheal repair under tension leading to dehiscence.^{56,58} This may require the use of bronchodilators, sedation and, when necessary, neuromuscular blockade. Pressure limited ventilation including permissive hypercapnia may be necessary in patients with decreased lung compliance. Placement of the endotracheal tube cuff below the tracheal repair may be another effective strategy.

A number of prospective randomized clinical trials have compared conventional mechanical ventilation with high frequency jet ventilation in patients with acute lung injury. All showed no difference in effectiveness of ventilation between the two techniques with respect to ventilation and oxygenation. In addition neither technique demonstrated any clear differences in haemodynamic compromise or barotrauma.^{52,53,60}

Pain control is essential in order to provide adequate pulmonary ventilation and secretion clearance. Mackersie *et al.* reviewed their experience with continuous epidural (thoracic and lumbar) fentanyl infusion in the management of pain due to chest wall trauma. Tests of ventilatory function and arterial blood gases were measured before and after epidural infusion of fentanyl. Epidural fentanyl infusion was associated with improved ventilatory function and no change in PaCO₂.⁶¹ Cicala compared the effect of lumbar epidural morphine with that of thoracic epidural bupivacaine in patients with blunt

thoracic injuries. Both interventions decreased pain. However, while thoracic epidural bupivacaine resulted in improved pulmonary function as measured by vital capacity, forced expiratory volume and respiratory rate, lumbar epidural morphine had no effect on pulmonary function.⁶²

Lumbar epidural morphine was superior to intravenous opioid analgesia with respect to postoperative pain scores and pulmonary function after thoracotomy. Kavanagh *et al.* in a review of the management of postoperative thoracotomy pain concluded that continuous intercostal or intrapleural local anaesthetics, epidural infusions of local anaesthetic and opioids and epidural morphine (lumbar or thoracic) were effective means of pain control.⁶³ Whether this data can be generalized to patients with blunt chest trauma is unknown.

Physicians should be on the alert for evidence of disruption of a repaired airway. A new air leak, haemoptysis or worsening mediastinal or subcutaneous emphysema warrant bronchoscopy to assess the suture line. If dehiscence of a repaired tracheobronchial injury is discovered, immediate surgical consultation is required.

Postoperatively, patients with lower airway injuries will require broad spectrum antibiotics for both wound prophylaxis and to treat contamination of the pleural space and mediastinum. In addition, adequate early nutritional support should be instituted.

Finally, the diagnosis of a lower airway or associated oesophageal injury may have been missed during the initial assessment and only become evident in the days following the traumatic event. A high index of suspicion is required in patients with a persistent air leak, atelectasis or pneumonia, unexplained haemoptysis or pneumomediastinum. Although a rare injury, a missed tracheo-oesophageal fistula can lead to fatal pulmonary sepsis due to aspiration.

Local experience

Among the 3948 trauma victims admitted to Sunnybrook Health Science Centre between January 1, 1986 and December 31, 1993, 13 (0.03%) had lower airway injuries. Nine injuries were due to penetrating trauma while four were due to blunt trauma. Injury location and frequency are shown in Figure 4. Four patients with lower airway injuries died for an overall mortality rate of 31%. History and physical findings on presentation are presented in Table II and radiological findings are presented in Table III.

One patient after evaluation in the trauma room was treated non-operatively. Our experience suggests that 8 of the 12 patients presenting to the operating room had their tracheas intubated in the emergency room as part of their ongoing resuscitation. Tracheal intubation was

TABLE IV Method of tracheal intubation by technique

Location	Blind nasal	Oral laryngoscopic	Fibre-optic bronchoscope	Surgical
Trauma room		4	2	2
Operating room	1		2	1

Tracheal intubation was performed in the trauma room as part of the ongoing resuscitation. Tracheal intubation was carried out in the operating room prior to the induction of anaesthesia.

FIGURE 4 Frequency of lower airway injuries at Sunnybrook trauma unit by location and mechanism.

accomplished without the aid of induction agents or neuromuscular blocking drugs on all patients. Airway management by technique of procedure is outlined in Table IV.

Intra-operatively, spontaneous ventilation was attempted in one only patient. A double lumen endobronchial tube was used intra-operatively in two patients. Conventional mechanical ventilation was used in all patients in the operating room. Anaesthesia was achieved with opioids and neuromuscular blocking agents in all patients. Six patients received isoflurane and three patients were given nitrous oxide. Of those receiving nitrous oxide two patients had injuries to the cervical trachea and one had nitrous oxide added in after the pleural space was opened.

Postoperative mechanical ventilation was required in nine patients. Pulmonary ventilation was achieved by conventional means in seven patients and with the aid of high frequency jet ventilation in two patients. The

remaining three patients were able to breath spontaneously through a tracheostomy tube in the postoperative period.

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