

Chapter 29

MANAGEMENT OF ACUTE LARYNGOTRACHEAL TRAUMA

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INTRODUCTION

Wartime management of laryngeal trauma has a long history; the first known instructions for treating laryngeal trauma are in the Edwin Smith Papyrus, an ancient Egyptian writing from around 1,500 BCE. Unlike other contemporary Egyptian writings, which often contained magical concepts, historians note that this text methodically introduces readers to injuries they might encounter, provides a decision tree on whether and how to treat them, and describes techniques that would be considered reasonable today.¹

Although several other references to laryngeal trauma are found in the ancient literature—including an account of Alexander the Great saving a soldier by slicing open the man's trachea with the tip of his sword—it wasn't until after World War II that the

field began showing systematic development. The work of Lynch,² Looper,³ Holinger and Johnston,⁴ Gussack,⁵ and others provided the foundation for current laryngeal trauma guidelines. In 1983, Schaefer published his first series on external laryngeal trauma,⁶ following up in 1992 with additional cases.⁷ Bent⁸ and later Butler⁹ published results from the (then) Medical College of Georgia. As the body of clinical literature grew, some excellent cadaver and animal studies shed light on the type of fractures to expect, what materials can be used to stabilize fractures, and the impact of stents on mucosa and laryngeal framework. In 2013, Schaefer wrote a thorough review commentary on laryngeal trauma for the journal *Laryngoscope*.¹⁰

INCIDENCE OF LARYNGEAL TRAUMA IN THE IRAQ AND AFGHANISTAN WARS

In data from recent conflicts, laryngotracheal trauma is usually grouped within overall injuries to the head and neck. British data from early in the wars documented that 5% of all surgical procedures were for head and neck injuries,¹¹ while early US data showed that these injuries varied between 16% and 21%.^{12,13} Later, Owens et al documented that from 2001 to 2005, 30% of injuries were to the head and neck, with 3% of combat wounds isolated to the neck.¹⁴ Reviewing 10 years of war in both theaters, Chan et al showed that head and neck injuries accounted for 41% of wounds.¹⁵ There was a clear escalation of head and neck injuries as a percentage of overall injuries as the wars progressed, which paralleled the increased use of body armor by coalition forces and the progression of attacks from gunshot wounds early in the war (resulting from fighting with enemy combat troops) to multiple-fragment blast injuries later in the war (resulting from insurgents using improvised explosive devices).¹⁵

Combat-related injuries to the neck are frequently fatal. Breeze et al conducted a review of all penetrating cervical ballistic injuries in United Kingdom (UK) service members from 2004 to 2008. There were 75 cases in total, including personnel killed in action (KIA), and 63% of these were fatal.¹⁶ Teasing out a comparable figure from the Joint Facial and Invasive Neck Trauma (J-FAINT) study (a review by Feldt et al¹⁷ of 37,523 facial and penetrating neck injuries from 2003 to 2011) showed that 28% of the dead (not including KIA) had neck injuries. In both studies, many who died had polytrauma, and the deaths cannot be firmly attributed solely to the penetrating neck injuries.

Several studies reporting from the wars include data specifically concerning laryngotracheal trauma. Three of 28 survivors (10%) in the UK study of penetrating

neck injury had repairs to the larynx or trachea.¹⁶ Another study from Breeze included 13 laryngotracheal injuries among 251 injuries to the head and neck (5%).¹⁸ Brennan et al¹⁹ reviewed emergency airway interventions and penetrating neck trauma from the beginning of otolaryngologists' deployments in 2004 to near the end of the surge in 2007. The authors inspected their personal operative logs to mine the details during a time when systematic data collection was lacking. This period included the Fallujah offensive and the most violent parts of the civil war and the coalition surge. The data demonstrated that 28 of 112 patients who underwent neck exploration (25%) had injury to the laryngotracheal complex.¹⁹ In patients with penetrating neck injury that required a surgical airway, 25 of 59 (42%) had laryngotracheal trauma.²⁰ Lastly, a secondary review of the J-FAINT data revealed that there were 104 laryngeal cartilage injuries, 48 hyoid fractures, 32 tracheal injuries, 2 vocal cord injuries, 1 esophageal injury, and 6 pharyngeal injuries. Feldt and Salinas state that this review likely heavily underestimated the true incidence of laryngotracheal trauma in the wars because only data on US service members were reviewed and the quality of the data varied, depending on the surgeons' care in documentation and the evolution of data tracking as the war progressed (July 2013 email from Salinas and Feldt to Eller).

While battle-related penetrating injuries are more common than nonpenetrating injuries, battle-related blunt injuries occur and must be considered. Especially in the multiply injured blast victim, blunt laryngeal trauma may not be readily apparent, and identifying injuries requires a high index of suspicion. In improvised explosive device blasts and battle-related motor

vehicle accidents (MVAs), there is ample opportunity for blunt laryngeal trauma to be hidden among other injuries. Initially stable patients may have unobservable but progressive laryngeal swelling from edema or paraglottic space hematoma formation. Periodic reassessment is required.

Nonbattle injuries are also very common. Hauret et al showed that 35% of soldiers evacuated from Iraq and Afghanistan between 2001 and 2006 had nonbattle injuries. These were most commonly due to sports or training, falls or jumps, and MVAs. Of 257 injuries to the head and neck, only 12 were isolated to the neck (specific injuries were not delineated).²¹ Madson et al showed that of all patients evacuated to a regional combat support hospital for craniofacial injury, 24.3% were due to nonbattle injury, and 57% of these were due to MVAs and falls.²²

Most data on blunt laryngeal trauma comes from the civilian setting. In 2006, Verschueren et al pub-

lished the results of a 12-year review at a tertiary care center.²³ Of 16,465 patients who had head, neck, or facial injuries, 37 (0.2%) had laryngeal fractures. Of these injuries, 85% were caused by blunt trauma, and 96% of these patients also had maxillofacial trauma. Of the 27 patients with available records, 8 (29%) required open reduction and internal fixation of the laryngeal fracture and 2 (7%) required a stent. Attempting to determine if the mechanism of injury altered the pattern of injury, Stassen et al²⁴ analyzed 15 patients with a laryngeal injury in a civilian trauma center. Blunt trauma and low velocity penetrating trauma yielded similar injury patterns, though the detail of the discussion was limited. Of the 15 patients, 60% had blunt trauma, and 88% of these were due to MVAs. Blunt trauma was twice as likely to cause isolated laryngeal trauma without injury to the trachea, while penetrating trauma had more balanced effects.

BIOMECHANICS OF LARYNGEAL INJURY

The laryngotracheal complex is largely protected from external forces by the mandible superiorly, manubrium inferiorly, and vertebral column posteriorly. Its ability to move within the neck adds additional protection from external forces. As people age, the larynx descends from the level of the C4 vertebrae to C7 and undergoes progressive calcification (in men more so than in women). In early adulthood, calcification starts in the posterior-inferior thyroid cartilage and the posterior portion of the cricoid cartilage.²⁵⁻²⁷ The increased exposure to external forces and increased brittleness due to calcification correlate with increased risk of fracture as age increases.

Laryngeal injuries differ based on age and gender. Subglottic and cervical trachea injuries are more commonly observed in women secondary to their tendency toward long, thin necks. Elderly patients have a higher incidence of comminuted laryngeal fractures secondary to advanced calcification.²⁸ Pediatric patients typically have less severe laryngeal injuries and are less likely to experience laryngeal fractures. This is the result of the more elastic cartilage and the superior location of the larynx, which allows better protection by the mandible.²⁹ Unfortunately, soft tissue damage is more common in children, because there is less fibrous tissue support and mucous membranes have loose attachments.³⁰ For the same reason, injuries that do not cause much swelling in adults can cause significant swelling in children, and the threshold for preemptive intubation should be lower in children.

Blunt Injury

Regardless of the mechanism, blunt laryngeal trauma involves a distributed force across the larynx. Most of the time, injury happens when the head and neck are extended, lifting the mandible and exposing the larynx.³¹ Common events causing injury include:

- impact with vehicle parts (steering wheel, dashboard, or the rim of the hatch of an armored vehicle);
- impact with sporting equipment;
- martial arts; and
- falls.

Thyroid Cartilage Injuries

If the force is directed posteriorly, the larynx is driven against the vertebral column. The thyroid cartilage splays around the vertebrae, stressing the anterior hinge point and leading to a vertical midline fracture (in young children this portion is softer, allowing it to significantly flex without breaking³⁰). The distance between the thyroid cartilages and the arytenoids decreases, and then the larynx snaps back to its original position. The energy transfer through the soft tissues causes sheer stress, resulting in mucosal tearing and bleeding. If the inferior cornua of the thyroid cartilage are driven sufficiently posterior, disruption of the cricothyroid joints can occur.¹⁰ The recurrent laryngeal nerve courses immediately posterior to this joint and can be injured, causing a vocal fold immobility on that

side. Bilateral recurrent laryngeal nerve injury could lead to airway compromise without other structural damage.

When force is directed from the side, parasagittal displaced fractures of the thyroid cartilage tend to occur. The fractures usually occur anterior to the oblique line of the thyroid lamina because the insertion of the thyrohyoid and inferior constrictor muscles cushion and stabilize the cartilage posteriorly. Blunt forces that strike the anterior larynx at the level of the glottis often cause both an anterior vertical fracture and a horizontal fracture. The downward pull of the cricothyroid muscle along the posteroinferior border of the thyroid cartilage and the action of the sternothyroid muscle at the inferior tubercle can cause displacement of this fracture line. In 1992 Lee dropped a 5-kg weight from a 1-m height onto excised larynges of various-aged donors, and described four resulting fracture zones.³² Cohn and Larson reported that a cruciate fracture occurs when the trauma is at the level of the glottis, below the thyroid prominence. When it is superior to that, a horizontal fracture can be produced.³³

Cricoid Injuries

The signet ring-shaped cricoid cartilage usually fractures in two places.¹⁰ Because the cricoid has more significant mass posteriorly, the fractures usually occur laterally and anteriorly; however, posterior fractures occasionally do occur.

Arytenoid Injuries

Unfortunately, the literature contains little data on the biomechanics of arytenoid injury due to trauma. Miles et al experimentally created blunt anterior laryngeal injury in dogs in 1971.³⁴ They describe gross dislocation, fracture, and hemarthrosis in one dog, and frequently found vocal process fractures that were healing at the postmortem histological examination. Many authors report arytenoid dislocation or subluxation after intubation trauma,^{35,36} but none explain the mechanism of this injury in external blunt trauma. Although several studies have attempted to understand the cricoarytenoid joint^{37,38} or recreate the forces needed to anteriorly sublux the arytenoid,³⁹ their focus has been on trauma from intubation rather than anterior blunt trauma. Also, the forces applied have not been sudden, as would be expected in trauma.

This chapter proposes two theories to explain arytenoid subluxation as a result of anterior blunt trauma:

1. Energy transmission through the cricoid, or in a wave down the vocal fold, passes through

the cricoarytenoid joint and suddenly terminates at the posterior cricoarytenoid ligament with significant force. Bleeding into the joint can further stress the ligament.

2. When the larynx impacts the vertebral column, the sagittal convexity of the vertebral body can allow the cricoid to travel a few millimeters further posterior than the arytenoid, causing an anterior subluxation.

"Clothesline" and Hyoid Injuries

"Clothesline" injuries are severe traumas noted when people are moving and strike a static object such as a wire, fence, or tree at the level of their neck.^{40,41} This mechanism of injury translates a great force to a relatively small area, often resulting in cricotracheal separation and crushing the laryngeal cartilages. This pattern of injury often results in disruption or injury to both recurrent laryngeal nerves.

A force directed at the hyoid bone can fracture the hyoid and drive the thyroid cartilage inferiorly, tearing the thyroepiglottic ligament and causing bleeding into the paraglottic space.¹⁰ Some physicians find that hyoid fractures are more common in women, and that they usually occur in the hyoid body rather than the cornua.⁴²

Penetrating Trauma

Knives and other sharp objects lacerate or tear tissues in the path of the blade, and injuries of this type are predictable on physical examination. While sharp objects lacerate soft tissues and young cartilage, they often push firmer tissues out of the way. Projectile injuries are also predictable. Several factors come together to generate tissue damage: (a) projectile velocity; (b) projectile features such as mass, material, and shape; and (c) tissue features, such as density and elasticity. Tissue is injured in three ways:⁴³

1. *Laceration and crushing*: tissue damage caused directly by the projectile, its fragments, or fragments of bone it has broken.
2. *Cavitation*: a permanent cavity is caused by the path (track) of the bullet itself with crushing of tissue. A temporary cavity is formed by the "wake" of the projectile pushing the tissue away. Higher velocities and unstable projectiles create larger temporary cavities.
3. *Shock waves*: travel through the tissue and can damage structures not adjacent to the projectile trajectory. Shock waves can cause fluid-filled hollow organs to burst.

Low velocity projectiles tend to create a large permanent cavity, a small temporary cavity, and little shock wave effect. Nondeforming high velocity projectiles create a small permanent cavity, a larger temporary cavity, and a large shock wave. Deforming high velocity projectiles have a large permanent cavity, a large temporary cavity, and a tremendous shock wave. This is the most destructive type of penetrating injury because more of the kinetic energy of the pro-

jectile is passed to the tissue. Unlike solid organs, the density of the tissues in the neck varies (some are filled with air), and the forces are distributed in an unequal manner.⁴⁴ High velocity projectiles are significantly more damaging than low velocity projectiles, and at least one case exists in which a projectile traversed the pharynx without striking the larynx, yet laryngeal fractures still occurred (July 2013 email from Joseph Brennan to Eller).

DIAGNOSIS AND AIRWAY MANAGEMENT IN ACUTE LARYNGEAL TRAUMA

Signs and Symptoms

Figure 29-1 lists the most common symptoms of airway injury. Knowing the mechanism of injury assists greatly in forming a differential diagnosis. If the patient arrives intubated, it is important to find out from the crew delivering the patient whether any injury was previously identified on direct laryngoscopy. For the patient who arrives awake, listening to the voice and asking the patient if his or her voice is normal can be very helpful. What may sound good to the physician may sound terrible to the patient, and vice versa. A strong, full voice suggests reasonable lung function, mobile vocal folds, and cerebral perfusion.²⁰ Conversely, stridor, stertor (in the event of hyoid/epiglottic displacement), hoarseness, anxiety, unequal inspiration/expiration phases, or pain localized to the larynx suggest injury.

The most common signs of trauma are presented in Figure 29-2. During the primary survey, one should look for injury to the mandible, cervical contusions, subcutaneous emphysema, laryngeal crepitation, and hemoptysis or blood in the suction. The symptoms may progress over time, and

frequent reevaluation is necessary. There is a poor correlation between most symptoms and the severity of the injury.⁷

Imaging

Computed tomography (CT) is the current study of choice in the trauma workup. CT angiography (CTA) is now the standard of care in the evaluation of penetrating neck trauma.⁴⁵ Either CT or CTA can be useful in determining the extent of laryngeal framework injury and guiding diagnostic and reconstructive decisions, but they should only be undertaken in patients with a stable airway or those with a secured airway.^{6,46,47} CT can clearly delineate arytenoid malposition, laryngeal framework fractures, parapharyngeal space hematomas, and hyoid fractures, and may suggest disruption of the hyoepiglottic ligament. The role of contrast swallowing examinations is discussed in the section on Managing Pharyngoesophageal Injury.

Classifying Laryngeal Injuries

There have been many classifications of laryngeal trauma, some based more on the injury, some on the intervention. In Lynch's 1950 thesis to the American

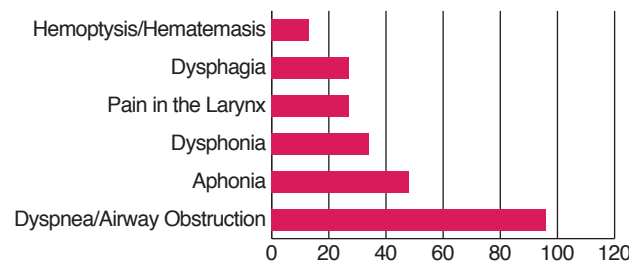


Figure 29-1. Comparative presence of laryngotracheal trauma symptoms. Amounts refer to numbers of patients with each symptom in various studies.

Data source: compiled from selected reports from 1942 to 2011 tabulated in a recent publication: Schaefer SD. Management of acute blunt and penetrating external laryngeal trauma. *Laryngoscope*. 2014;124(1):233–244. Epub 2013 Jun 26.

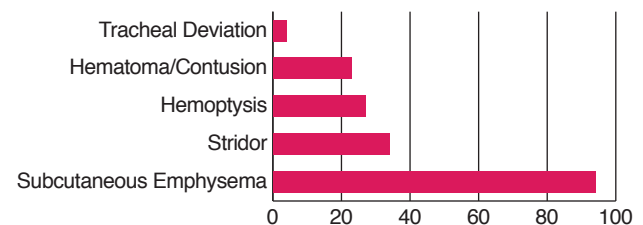


Figure 29-2. Signs of laryngotracheal trauma. Amounts refer to numbers of patients with each sign in various studies.

Data source: compiled from selected reports from 1942 to 2011 tabulated in a recent publication: Schaefer SD. Management of acute blunt and penetrating external laryngeal trauma. *Laryngoscope*. 2014;124(1):233–244. Epub 2013 Jun 26.

TABLE 29-1

FUHRMAN'S MODIFICATION OF THE SCHAEFER CLASSIFICATION

Group	Characteristic
I	Minimal or no compromise; minor endolaryngeal hematoma; no fractures
II	Endolaryngeal hematoma or edema associated with compromised airway; nondisplaced fracture on computed tomography scan; minor mucosal lacerations without cartilage exposure
III	Massive endolaryngeal edema with airway obstruction; mucosal tears and cartilage exposure; immobility of vocal folds
IV	Same as group III with more than three fracture lines on imaging; massive endolaryngeal derangement
V	Laryngotracheal separation

Data source: Fuhrman GM, Stieg FH 3rd, Buerk CA. Blunt laryngeal trauma: classification and management protocol. *J Trauma*. 1990;30:87-92.

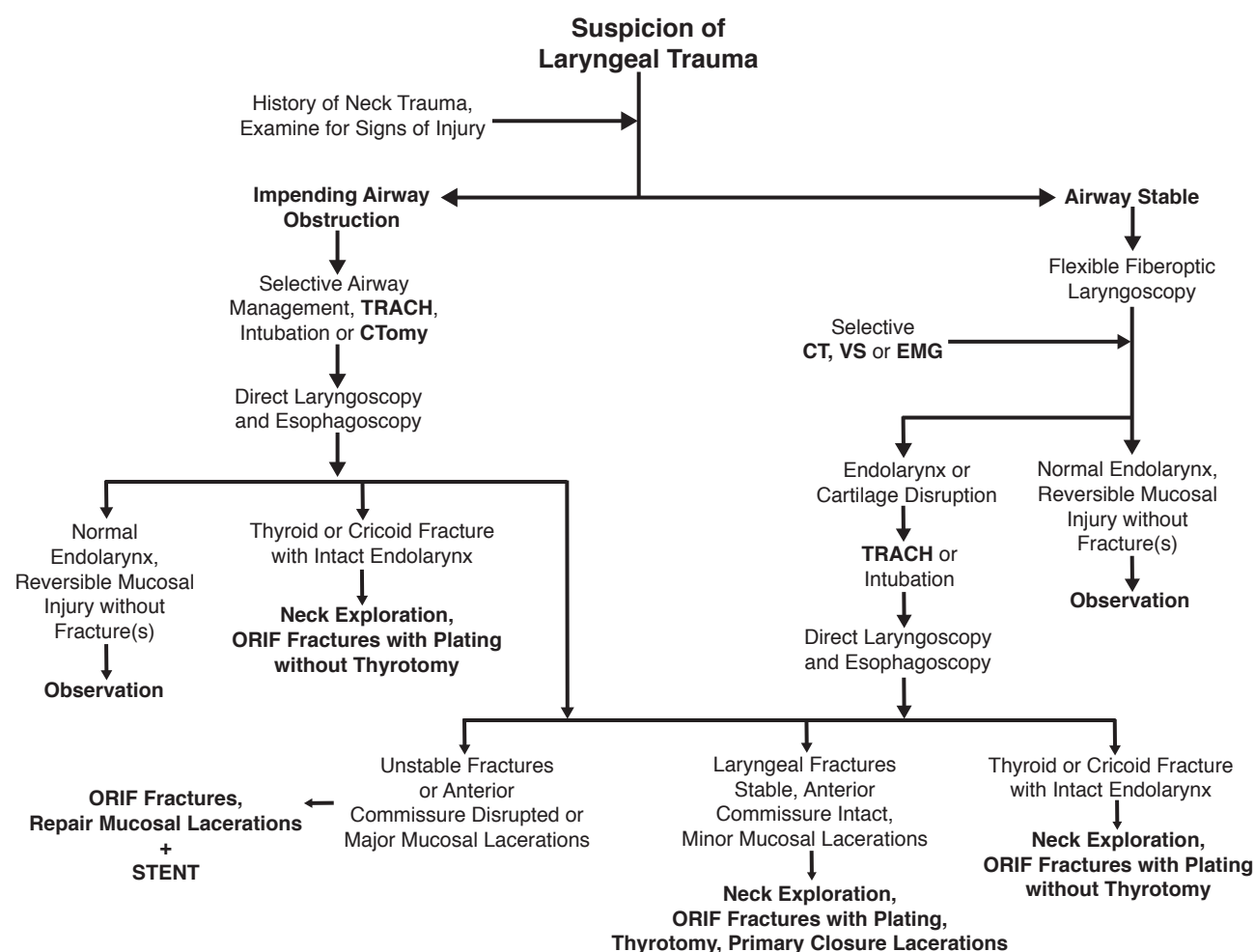


Figure 29-3. Schaefer's algorithm for management of acute laryngeal trauma.

CT: computed tomography; Ctomy: cricothyrotomy; EMG: electromyography; ORIF: open reduction and internal fixation; TRACH: tracheotomy; VS: videostroboscopy

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Laryngological, Rhinological and Otological Society, he presented one of the first classification schemes of laryngeal trauma injuries, dividing the trauma into four groups: (1) external wounds involving laryngeal cartilage or the hyoid without intrinsic laceration or injury; (2) wounds producing laceration or injury to the interior surface of the larynx; (3) wounds without external injury but causing displacement and laceration of interior structures; and (4) a combination of the three types.² Many of these principles are car-

ried forward in more recent laryngeal classification paradigms.⁴⁸

The most commonly used laryngeal trauma classification today is the Schaefer-Fuhrman system (Table 29-1),^{7,10,48} which separates laryngeal trauma into five categories based on physical exam and radiographic findings. Most current laryngeal trauma treatment algorithms are based on this classification. Schaefer updated his thorough laryngeal fracture treatment algorithm in 2013 (Figure 29-3).

IMMEDIATE AIRWAY MANAGEMENT

Acute Airway Obstruction Present

If the primary survey suggests there is laryngeal trauma and the patient is experiencing airway obstruction, a surgical airway is immediately indicated. If palpation of the larynx suggests there is continuity of the cricoid and trachea and the cricoid is not fractured, a cricothyroidotomy is the most expeditious way to establish the airway. Otherwise, a formal tracheotomy is preferred. Tracheotomy is very safe but should be performed under as much control as possible. A recent multiinstitutional review of 1,175 tracheotomies (for all reasons) found a 1.4% intraoperative complication rate.⁴⁹

The frequency of urgent tracheotomy is subject to individual preference and difficult to determine from the literature. In two papers for example, the incidence of patients who underwent tracheostomy during the management of laryngeal trauma varied from 18% to 69%, but limitations in the data prevented the authors from stating how many of these were urgent.

Acute Airway Obstruction Not Present

If the primary survey suggests a laryngeal injury, and the patient is ventilating but will need

to be intubated soon (eg, for airway protection or treatment of other injuries), flexible laryngoscopy should be employed if it is available. Most anesthesiology departments have a flexible bronchoscope if a flexible laryngoscope is not available. Schaefer¹⁰ offers three principles to follow when performing a translaryngeal intubation: (1) the larynx and trachea must be intact and fully connected, without partial separation; (2) the larynx must be visible with flexible endoscopy to determine what further damage may be caused by the intubation; and (3) the most experienced person available should perform the intubation. If there are concerns after considering these three points, or if the patient is not stable, cricothyroidotomy or tracheotomy should be performed under the most controlled circumstances possible. The success of translaryngeal intubation varies widely, with Gussak reporting a 70% success rate without complication, and others reporting a 70% failure rate.^{5,50}

Risks of oral intubation include further disruption of damaged or fractured endolaryngeal structures, intubation into false passageways in the neck from lacerations and altered anatomy, and complete laryngotracheal disruption in partially avulsed settings.

DEFINITIVE MANAGEMENT OF LARYNGEAL INJURIES

Once the extent of laryngeal injuries is known, plans should be made for repair. If the airway is not yet secured, it is imperative that a plan for airway management be discussed with the anesthesiologist and that the entire team be briefed before the case begins on what will be done in the event the airway is lost. The four operative goals are to:

1. provide a safe airway;
2. ensure that related injuries are identified and treated,
3. restore anatomical relationships, and
4. repair mucosal injury.

The optimal timing of definitive repair has been the subject of several reports,^{9,51,52} and there is consensus that laryngeal trauma should be repaired as soon as the patient is medically stable to proceed. Exhibit 29-1 lists laryngology and airway instruments and equipment for definitive care that should be included in a deployment package. Exhibit 29-2 includes items that may be used in place of the manufactured products.

Rigid Endoscopy

It is almost universally accepted that rigid endoscopy, if permitted by the patient's condition,

EXHIBIT 29-1

LARYNGOLOGY EQUIPMENT FOR DEFINITIVE CARE

Laryngoscopes

- wide-mouth laryngoscope (eg, Lindholm, Slotted Parsons Adult (Karl Storz, Tuttlingen, Germany))
- glottoscope: (eg, adult Dedo, Sataloff [Medtronic, Minneapolis, MN] medium female; these will accept a 6.0 ETT transluminally)
- anterior commissure laryngoscope (eg, Hollinger, Ossoff-Pilling [Teleflex Medical, NC])
- Werda (Karl Storz, Tuttlingen, Germany) distending laryngopharyngoscope
- appropriate light carriers for each; cord adapters should be standardized

Suspension Laryngoscopy Tools

- tooth guards
- suspension arms (2)
- cross-table stand connected to the operating table (eg, Mustard table) to allow mobility of the table's height without altering laryngeal suspension (do not use a floor stand)
- Y-shaped light cables (2 or 3), with appropriate connectors and adaptors for the telescopes and laryngoscopes you have
- 4-mm, 30-cm telescopes in 0° and 30°
- heavy (>30 cm) graspers to allow transfer of ETT through laryngoscope
- laser-safe ETTs
- It is unlikely that ENT would warrant a laser in a deployment equipment package, but urology may take a laser for urolithiasis. This could be used for treating subglottic stenosis or ablating granulation tissue, etc.
- cautery: monopolar, suction monopolar, and endoscopic bipolar

Bronchoesophagoscopy Tools

- rigid esophagoscopes with light carriers (two adult sizes and one pediatric size)
- ventilating bronchoscopes (pediatric through adult sizes)
- circuit adaptors
- telescope bridges
- standard foreign body forceps

Suction Devices

- laryngeal
- whistle tip and flat tip in a large bore for removing mucous and blood
- thumb control sizes 7 and 5 for more delicate work
- esophageal and bronchial

Basic Set of Micro Instruments

- probes, straight and angled
- vocal cord spreaders
- straight, right, and left alligator graspers
- right and left large triangle graspers
- scissors: straight with a 90° up bend to cut along the vocal fold; left and right curved

Stent and Keel Materials

- larynx: Gore-Tex (Gore and Associates, Elkton, MD) and Montgomery (Boston Scientific, Boston MA) stents
- tracheal: Dumon (Novatech, Cedex, France) and Silastic (Dow Corning, Midland, MI) removable

Suture

- 2-0 PROLENE (Ethicon, Somerville, NJ), to stabilize stents, keels, and fractures
- 4-0 PROLENE, to secure anterior commissure position in laryngofissure
- 5-0 Monocryl (Ethicon) on P-3 needle, for endoscopic suturing (do this rarely)
- 6-0 chromic, for mucosal suturing via laryngofissure
- barbed suture (V-Loc [Covidien, Dublin, Ireland] or other), which holds tension when tension is difficult to maintain and eliminates knot tying

Flexible Endoscopes

- with battery pack and light cord; these will be needed in the clinic as well as the operating room
- flexible bronchoscope with a port for suctioning
- flexible endoscopes with a port might also be used with urology's laser, if available

ENT: ear-nose-throat; ETT: endotracheal tube

EXHIBIT 29-2**ITEMS THAT CAN BE ADAPTED FOR USE IN THE LARYNX****Stents and Keels**

- Doyle splints (useful for external buttons and keels if Gore-Tex [Gore and Associates, Elkton, MD] is not available)
- silicone sheeting
- endotracheal tubes (can be modified to make a stent, especially small tubes with low pressure/high volume cuffs)
- dental molding material (stent material)
- Wound VAC (vacuum-assisted closure) sponge (stent material)
- vascular grafts (source of Gore-Tex for keels or thyroplasty)
- urology catheters and stone baskets (useful for passing suture in and out of the larynx quickly to secure stents and keels)

Visualization

- glide scope (when straight laryngoscopes are inadequate)
- flexible esophagoscope or bronchoscope with graspers (for foreign body retrieval)
- cystoscopes
- arthroscopes

Other

- laparoscopy equipment (clip appliers, etc)
- any other items available

should be accomplished prior to embarking on laryngeal repair.^{10,23,52} Factors to consider include the following:

- Injured patients cannot always cooperate well enough to allow the same thorough flexible examination that can be obtained in routine office visits.
- Tissue swelling, blood in the pharynx, and other pitfalls frequently occur.
- Some lacerations may not be evident initially.
- Swallowing can sweep blood away from an injury.
- Telltale signs of wound healing are not apparent in the acute stage.
- The postcricoid area and esophagus are best examined with a rigid endoscope.

Because the laryngoscope spreads apart the tissues for a complete evaluation of all of the folds and membranes of the larynx, a thorough rigid examination is paramount to understanding the injury. However, rigid laryngoscopy can exacerbate an injury, for instance, displacing a nondisplaced fracture or enlarging a tear. For this reason the operator should proceed with deliberate caution.

Endoscopic Interventions**Endoscopic Suturing**

Closing endolaryngeal mucosal injuries primarily without performing an external laryngotomy, if possible, is desirable. Also, microsuturing vocal fold defects has been shown to speed return of mucosal wave in a randomized controlled trial and others studies.^{53,54} Unfortunately, placing sutures through a laryngoscope is one of the most challenging and frustrating aspects of laryngeal surgery, and will continue to be until robotics have advanced to allow human wrist and hand movements to be replicated at the level of the endolarynx. RealHand high dexterity instruments (Novare Surgical Systems, Cupertino, CA) are an intermediate solution.⁵⁵ If these are unavailable, the following techniques may be useful:

- **Knots.** Tie as few knots as possible: Use an endoknot technique (Figure 29-4) or a triple surgeon's knot for the first throw.
- **Clips.** A hemoclip via an endoscopic clip applier may be used to clip the suture ends together. Clip aspiration, although a valid

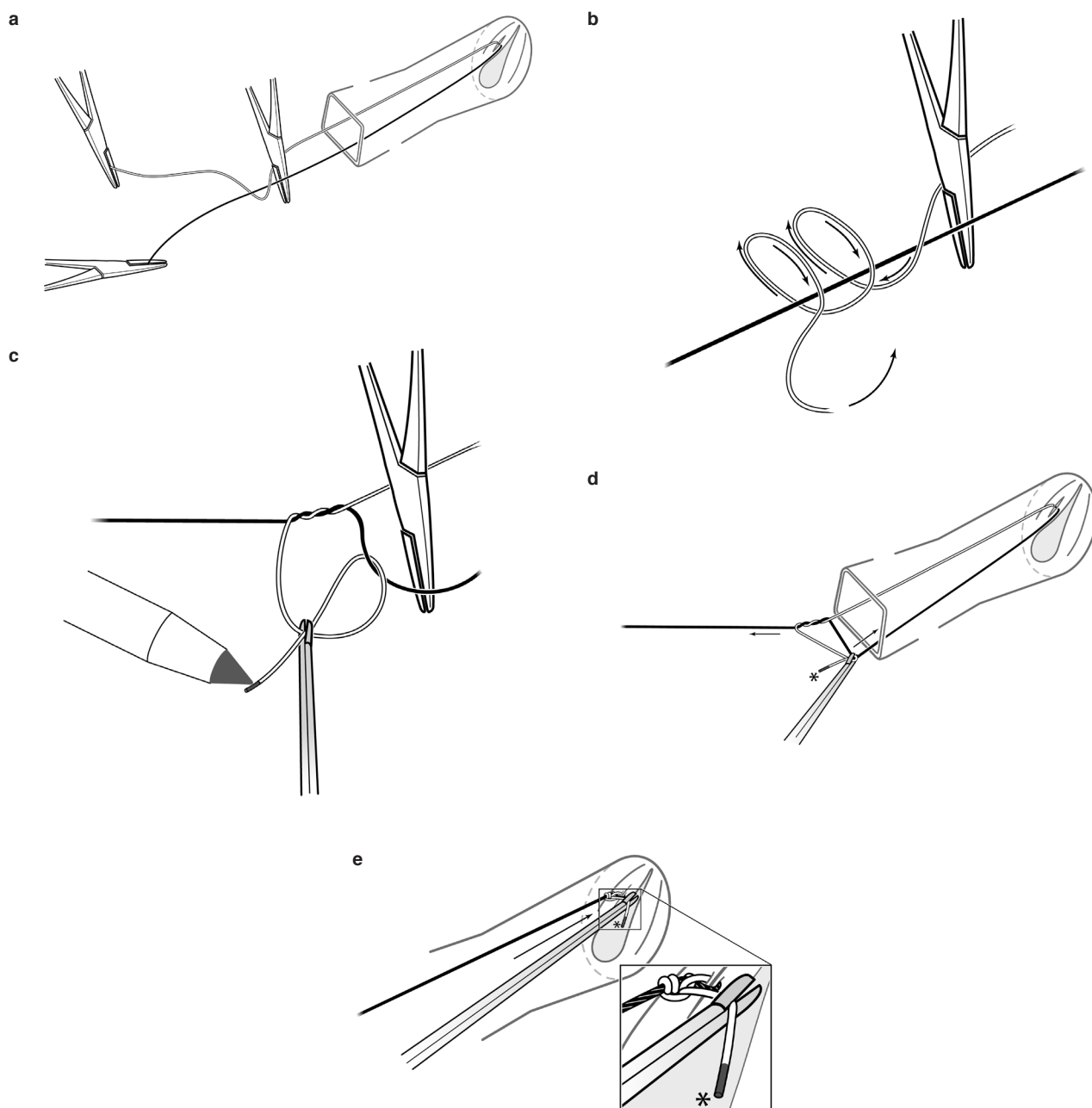


Figure 29-4. Endoknot technique.

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concern, has not been problematic for those who use the technique frequently (Paul Castellanos, MD, personal communication, June 2013).

- **Barbed suture.** Recently developed barbed suture such as V-Loc (Covidien, Dublin, Ireland) and Stratafix (Ethicon, Somerville, NJ)

may allow knotless suturing. Stratafix is available in a 4-0 Monocryl (Ethicon) suture but only comes on larger needles. While the body of research is still growing, a single report suggests this suture may be associated with more wound complications than conventional suture in skin closure.⁵⁶ Some surgeons are

using it in tracheal resection and reanastomosis (Paul Castellanos, MD, personal communication, June 2013).

Tissue Glues

In an effort to obviate the need to suture through a laryngoscope, tissue glues have been used in several centers. Tissue glues such as fibrin sealants or cyanoacrylate are used extensively across surgical disciplines to reduce surgical time and eliminate suturing. Fibrin sealants mix fibrinogen with thrombin and calcium chloride, which initiates a clotting reaction. Precise application is challenging through a laryngoscope, and although long applicators can be used, they are often imprecise. An alternative is to apply each element sequentially using a fine needle or a Cottonoid (Codman, Buenos Aires, Argentina) sponge, allowing the inter-elemental reaction to occur on the tissue. If too much of the first element is applied, it can be cleaned off before applying the second. If too much of the second is applied, the excess, which has not reacted due to the limited availability of the first element, can be removed after the reaction as occurred.

Unfortunately, tissue glues are not a panacea for laryngeal repair. Fibrin sealants have been shown to induce collagen deposition on the vocal folds of pigs⁵⁷ and rabbits,⁵⁸ perhaps limiting their long-term usefulness in this anatomic subsite. Cyanoacrylate is infrequently used in the larynx due to its inability to bind to tissue when moisture is present. Only one paper addresses its use for fracture fixation in guinea pigs, where it was found to be inferior to fibrin products.⁵⁹

Laser Welding

Another tool to alleviate endolaryngeal suturing is laser welding. First introduced in the mid-1990s by Wang's group,⁶⁰ this concept continues to evolve for use in the larynx and elsewhere. Laser welding with the carbon dioxide laser is essentially a thermal seal and is not appropriate in all circumstances. Recent work by Franco et al has yielded good prospects for future applications using an Nd:YAG (neodymium-doped yttrium aluminum garnet) laser and rose bengal solution.⁶¹

Transcutaneous Laryngeal Suture Placement

Keel placement and vocal fold lateralization can frequently be done endoscopically via a variety of methods. The endo-extralaryngeal suture passage technique described by Lichtenberger is useful in procedures of these kinds, but it is nearly impossible without his proprietary equipment,⁶² which is not always available. As reported in other publications,^{63,64} 16-gauge

angiography catheters and a urology stone basket can be used to quickly pass suture in an external-internal direction. The basket catches the suture end to pull it out through the angiography catheter and has reduced the operative time by more than 50% (Eller, unpublished data, 2013).

External Interventions

The injured larynx often requires open intervention. The primary goal is to restore anatomic relationships to enable return of function and to prevent scarring. It is clear that early restoration of form and closure of lacerations prevents many of the late complications.^{9,51,52}

Access

Penetrating injuries may lend themselves to good access (see case presentations, below). In blunt injury, a transverse incision over the larynx provides excellent exposure. Similarly, fractures may be extended to gain access to the endolarynx. An anterior laryngofissure also provides a very safe way to approach the endolarynx, but an imprecise laryngofissure will permanently damage the vocal fold and the voice. Simpson and Rosen describe a simple method of identifying the anterior commissure: slow incision of the anterior cartilage is carried out with lateral traction using hooks to put the cartilage under tension. Once the cartilage separates, a no. 12 scalpel is used to complete the division of Broyle's ligament under direct visualization from above or below.⁶⁵ An alternative combined approach is to observe the division of the anterior commissure via flexible laryngoscopy, much like observing the glottis during thyroplasty. Once the larynx is open, use 6-0 fast-absorbing gut suture to repair lacerations on the vocal folds and 5-0 VICRYL (Ethicon) for other repairs.

When the endolaryngeal repair is complete, or when the anterior commissure has been avulsed, it should be reattached to the external perichondrium of the thyroid cartilage using permanent suture; otherwise insufficient tension will result in an anterior glottic gap postoperatively.¹⁰ Looking at pediatric airway reconstruction as a guide to the consequences of imprecise anterior commissure division and reconstruction, MacArthur's group showed that 78% of patients had altered anatomy, 100% had decreases in voice quality and volume, and 50% had decreased intelligibility.⁶⁶

Framework Stabilization

After the endolarynx has been repaired, reconstitution of the laryngeal framework is critical. Luminal stenting is not useful for stabilizing thyroid cartilage

fractures, and extraluminal fixation of the cricoid avoids complexity and stent-related complications (see below). Historically, suture or wire was used to reduce and fixate fractures. Since Woo first described miniplate framework reconstruction in 1990,⁶⁷ good animal⁶⁸ and laboratory^{69,70} studies have been conducted demonstrating that multipoint fixation with miniplates enables a more stable, stronger, and faster-healing repair than can be accomplished with wire alone, wire with a tube batten, or suture. Bioabsorbable plates have also been useful in thyroid cartilage repair⁷¹ and laryngotracheal reconstruction.⁷² A larger screw size, such as an emergency screw, allows better purchase in the cartilage. Lewis et al showed that a 0.8- to 1.5-mm drill bit with a 2.0-mm screw had the strongest hold.⁶⁹

Addressing Tissue Loss

Occasionally, especially with high velocity penetrating trauma, there is loss of tissue that needs to be replaced. Techniques to accomplish this have evolved primarily for patients who have had sections of their airway resected for cancer or as a part of airway reconstruction due to stenosis. The sternomastoid periosteal flap described by Friedman and Mayer is a single-stage tracheal or cricoid reconstruction that does not require a separate donor site and provides a stiff wall that is resistant to physiologic aerodynamic forces.⁷³ Other techniques borrowed from laryngotracheal reconstruction include costal and thyroid ala cartilage as donor materials,⁷⁴ sternohyoid muscle flaps,⁷⁵ nickel-titanium mesh,⁷⁶ prefabricated costal cartilage radial forearm free-tissue transfer,⁷⁷ and composite nasal septal cartilage free grafts.⁷⁸

Managing Hyoid Fractures

Hyoid fractures are frequently found in association with other laryngeal injuries. They are most common in hanging and strangulation, but also occur in sport injuries and MVAs. In a 2012 literature review by Ramchand et al, operative repair was done in only 10.9% of cases.⁴² Most of the literature regarding hyoid bone fracture is related to forensic pathology. Considering that the hyoid bone is partially resected in the Sistrunk procedure, and that review of related literature showed the Sistrunk procedure has only a 6% to 7% complication rate (mostly recurrence or wound-related problems),^{79,80} conservative management for hyoid fractures is considered safe.

Managing Pharyngoesophageal Injury

Injuries to the pharynx and esophagus are rare. In the J-FAINT study, only 35 esophageal injuries were documented in 25,834 facial and neck injuries.¹⁷ Soliman et al found only 1 esophageal injury out of 144 cases of penetrating neck trauma.⁸¹ Diagnosing esophageal injury is critical, however; Vallböhmer et al reported a 16% mortality for cases that took longer than 24 hours to discover.⁸² Soliman et al⁸¹ also reported that esophagoscopy was positive only when contrast esophagram suggested abnormality. They recommended CT of the neck, followed by contrast esophagography in patients who do not meet criteria for urgent neck exploration.⁸¹ Gonzalez et al demonstrated that CT esophagram is equivalent to standard contrast esophagoscopy, and can be quickly obtained by having the patient ingest low osmolar contrast (commonly used intravenously) just prior to the study.⁸³ Management is tailored to the injury, and ranges from observation with nasogastric drainage to endoscopic or open repair.⁸⁴

Keels and Stents

A keel or stent is useful when the anterior commissure has been disrupted, when there is risk of contact between the vocal folds during the healing process, or when there is significant mucosal loss. Keels should be secured anteriorly, should be easy to remove, and should not damage the vocal folds. There are several commercial keels available. The Montgomery keel (Boston Scientific, Boston MA) is intended to be inserted through a laryngofissure and explanted later. Some authors have used Silastic (Dow Corning, Midland, MI),⁸⁵ but it can be too stiff and the endolarynx can become ulcerated where it contacts the stent during coughing, breathing, or swallowing. Preferable is using Gore-Tex (Gore and Associates, Elkton, MD) held in place with 0 or 2-0 PROLENE (Ethicon), tied in the anterior commissure over buttons on the skin. The PROLENE pulls the Gore-Tex firmly against the soft tissue anteriorly, separating the tissue effectively, and the soft Gore-Tex is very gentle on the tissues (Figure 29-5). Furthermore, a Gore-Tex keel can be fashioned from any Gore-Tex item kept in stock: vascular grafts and patches, thyroplasty implants, etc. As previously mentioned, the 16-gauge intravenous catheter and urology stone basket technique can be used to quickly secure the keel. Lastly, in what could be considered a chemical keel, Abraham et al utilized botulinum toxin to prevent laryngeal closure and scar formation.⁸⁶

Stents are used to maintain the lumen of the airway during the initial phases of wound healing. Stents do

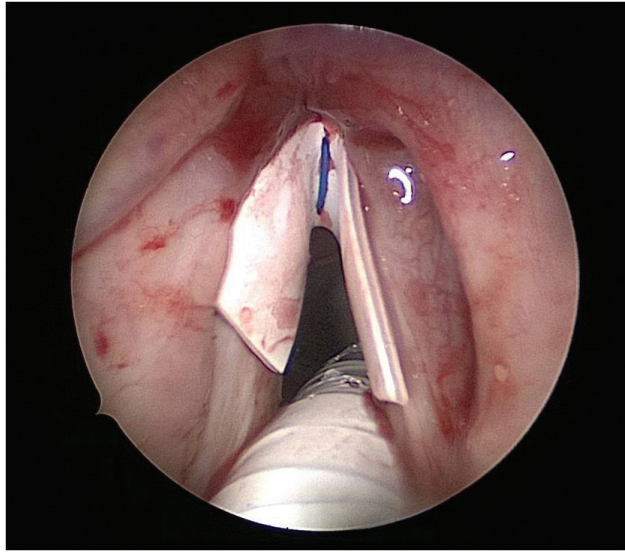


Figure 29-5. Gore-Tex (Gore and Associates, Elkton, MD) used as a keel for the anterior commissure, secured with a 2-0 PROLENE (Ethicon, Somerville, NJ) using external-internal suture technique facilitated with urologic snare.

not have an effect on the configuration of the thyroid cartilage but are useful in supporting the injured cricoid if sufficient external fixation is not possible. Stents can be commercially produced or custom made at the time of surgery. Examples include a finger cot, modified endotracheal tube (ETT), dental modeling material, and even hearing aid molding material.^{87,88} Most data on stents comes from the stenosis literature, which shows that stents can promote mucociliary clearance in areas of denuded lining by providing a scaffold for capillary action between the wall of the lumen and the stent.⁸⁹ Jewett et al showed that stents promote graft mucosalization and vascularization.⁹⁰ Stents can also act as a soft pressure bandage on the circumferential larynx, hold the arytenoids apart to prevent posterior adhesion, or serve as a bolster for mucosal or skin grafting support.

Unfortunately, the tendency for stents to induce granulation is also well known. Nouraei et al showed that local inflammation is usually a result of *Staphylococcus aureus* or *Pseudomonas aeruginosa* colonization, which can cause local tissue sepsis and actually impair mucosal healing.^{91,92} Thus, according to the literature, stents should be removed 7 to 14 days after placement. The literature is also clear that permanent expandable stenting in its current form should be avoided in benign stenosis.⁹³ Nearly all laryngeal stents require a tracheostomy, and hollow stents that extend above the ventricle almost universally are complicated by aspiration.

Medical Interventions

Corticosteroids

Corticosteroid use in laryngeal trauma is common but not well studied. In some early studies on laryngeal trauma, steroids were not used and patients requiring even significant operative repair had good outcomes.⁷ Some evidence does support the use steroids in laryngeal trauma. A small 1971 canine experiment by Miles, Olson, and Rodriguez on laryngeal fracture repair found that those animals taking steroids had better outcomes when controlled for repair type and time than those not on steroids.³⁴

Steroids are proven to be valuable therapy in other laryngeal pathologies.⁹⁴ Steroids are commonly used in microflap surgery, where they have been shown to delay inflammatory and neovascular responses and reduce acute collagen deposition.⁹⁵ However, a canine study did not show steroids to have a perceptible effect on eventual vibratory characteristics.⁹⁶ Steroids are the standard of care in croup and are very effective in reducing edema in autoimmune laryngeal inflammatory conditions.⁹⁷ Translating this knowledge to the care of the injured larynx, steroids may be used to facilitate extubation, stave off intubation or tracheotomy, and limit synechia formation caused by the swelling-enabled contact of lacerated mucosa.⁹⁸

Antireflux Medications

The use of a proton pump inhibitors (PPIs) has not been widely studied in the setting of external laryngeal trauma, although it is commonly recommended.⁹⁹ A 2009 study by Kantas et al found better surgical outcomes and lower mean Reflux Finding Scores and Reflux Symptom Index scores in subjects treated with PPIs among patients with surgically induced endolaryngeal trauma compared to control cases.¹⁰⁰ Reflux also plays a direct role in the perpetuation of vocal process granulomas.¹⁰¹ Therefore, PPI use in laryngeal trauma is recommended.

Antibiotics

Several studies have demonstrated that *P aeruginosa* and *S aureus* are the main pathogens that lead to catastrophic infections, but infections are frequently polymicrobial.^{90,102} In the acute setting, broad-spectrum coverage including anaerobic pathogens is recommended, especially if there are large internal tears, if hardware is used and there is a communication between the lumen and the repair, if a stent is used, or if repair is delayed.

PEDIATRIC LARYNGEAL TRAUMA

Pediatric laryngeal trauma is much less common than adult laryngeal trauma. There were no reported cases in the war-related literature (although one author [RLE] cared for a boy with a laryngeal gunshot wound). A 2011 review of the National Trauma Data Bank found only 69 cases of pediatric laryngeal trauma among 1.9 million trauma cases (0.0036%, approximately 1 / 27,000). In comparison, the overall incidence was 1 out of 5,000 cases for a similar period.^{29,51} The study found that 82% of laryngeal injuries in the pediatric population were blunt force injuries. Falls, clothesline injuries, and sports-related injuries are more common in children than MVA-related trauma due to mandatory safety seat and rear seat riding requirements for small children.^{103,104}

Differences exist in both the anatomy and physiology of pediatric laryngeal trauma. The larynx sits higher in the neck in children and is protected by the mandible. Uncalcified pediatric cartilages are more pliable and rarely fracture. Conversely, a lack of firm

attachment of the mucosa puts children at risk for substantial airway swelling.³⁰ In the setting of the smaller airways found in children, significant airflow impairment may occur from the same edema an adult would tolerate without complication.

Furthermore, emergency airway management protocols differ in the pediatric patient. Awake tracheostomy is not generally possible. Some providers advocate that the airway be gained with rigid bronchoscopy, but this is a procedure most surgeons do not perform frequently. Urgent pediatric airways should be treated in the way the team feels will be most successful considering the immediacy, equipment, and expertise available. Transtracheal oxygen infusion via a large intravenous catheter can buy precious minutes in an emergency (even if jet ventilation is not available). Tracheotomy via a vertical incision to avoid medially located great vessels is preferred over cricothyrotomy due to the lack of space in the cricothyroid membrane and the narrow cricoid cartilage in children.

LARYNGEAL BURNS

Inhalational burns should be considered whenever burns are discovered on the face or upper torso, when there is a large percentage of burned surface area, or when the mechanism of injury suggests inhalation injury. In both inhalation burns and caustic exposures, the more proximal airway is usually at greater risk because these tissues are the first to absorb the heat or toxin, and the laryngeal adductor reflex closes the glottis to prevent tracheal and lung injury. Patients with inhalational burns may not be symptomatic early on, but significant swelling can occur and early intubation is recommended. The combination of burn-induced mucosal sloughing, the secondary inflammatory response, and continued irritation from the endotracheal tube puts these patients at high risk for glottic

or supraglottic stenosis.

Endoscopy within the first 24 hours is recommended, with repeated exams as necessary to document and monitor the stable airway.^{16,17} Patients with suspected burn injuries are more likely to have iatrogenic injury secondary to ETT or tracheostomy. Studies of noninvasive ventilation such as bilevel positive airway pressure have shown reduced episodes of pneumonia and fewer secondary effects of iatrogenic injury with its use. Contraindications for noninvasive ventilation include massive facial trauma (inability to wear a face mask), unconscious patients or those with compromised cough or clearance of secretions, extreme pressure requirements, or worsening pulmonary exam.¹⁸

SUMMARY

Acute laryngeal trauma is simultaneously simple and complex. While putting the larynx back together is a matter of plating the framework and sewing up the lacerations, careful attention to the three-dimensional anatomic relationships is required to

enable an airway that is not fraught with recurrent stenosis and a voice that meets the personal and vocational needs of the patient. This chapter has presented methods to successfully manage acute wartime laryngeal trauma.

CASE PRESENTATIONS

Case Study 29-1: Low Velocity Penetrating Injury to the Larynx*History and Initial Management*

A 16-year-old male presented after being shot in the neck by a handgun. He was intubated by the medics at the scene and had no other injuries. CT scan of the neck demonstrated a comminuted thyroid cartilage fracture with free air within the neck. The trajectory of the projectile was clearly visible and there was no vascular injury. After complete evaluation, he was transported to the operating room for direct laryngoscopy and management.

Discussion of the Injury and Operative Management

- Although the specific gun that caused this injury is unknown, an average handgun has an estimated muzzle velocity of 350 m/s and projectile mass of 7.45 g, which produces a kinetic energy ($k = 1/2 mv^2$) of 453 J.
- There was a right-sided entrance wound and a left-sided exit wound slightly more anterior than the entrance, indicating that the bullet had traveled from a right posterior lateral to a left anterior lateral direction or had been deflected by the thyroid cartilage.
- Direct laryngoscopy demonstrated that the

anterior commissure was intact, but showed some minor mucosal lacerations without tissue loss (Figure 29-6). The arytenoids were not involved, and the cricoid cartilage was uninjured. Cricoarytenoid joint mobility was normal by palpation.

- A low tracheotomy was performed.
- Transcervical exposure of the larynx suggested that the bullet impacted and traveled along the right thyroid lamina just above the level of the vocal folds. There was some loss of cartilage anteriorly. Both the framework and the mucosa were in need of repair.
- Completion of the soft tissue portion of the midline traumatic supraglottic laryngofissure allowed exposure of the superior vocal fold surface without disruption of the anterior commissure. The transverse fractures aided greatly in this exposure, preventing the need to transect Broyle's ligament.
- A 7-0 chromic suture on a Castro Viejo needle driver was used for superficial repair through this exposure. Care was taken to not disrupt Broyle's ligament.
- The framework was repaired with 2-0 PROLENE suture (Figure 29-7).
- Routine wound closure with drains was performed; and antibiotics were prescribed for a week.
- The patient was decannulated on day 3 and reported a normal voice at 3 weeks. Laryngoscopy revealed good glottic closure and complete healing of the internal lacerations.

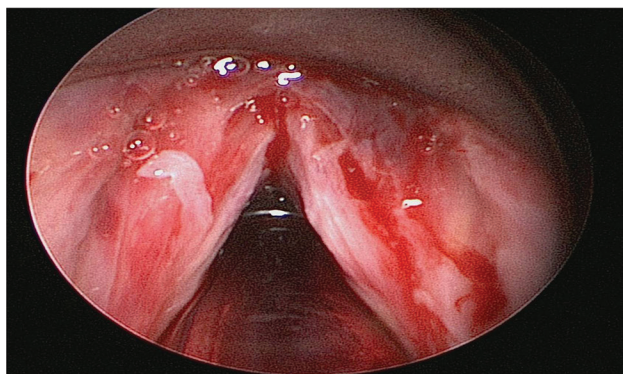


Figure 29-6. View of glottis of gunshot victim on direct laryngoscopy. The anterior commissure is intact and there are minor tears on the vocal folds. These are due to the transmission of energy through the soft tissues, with tearing at the point of attachment at the end of the vocal fold. The bullet struck the right side of the larynx first, so there is more damage to that side.

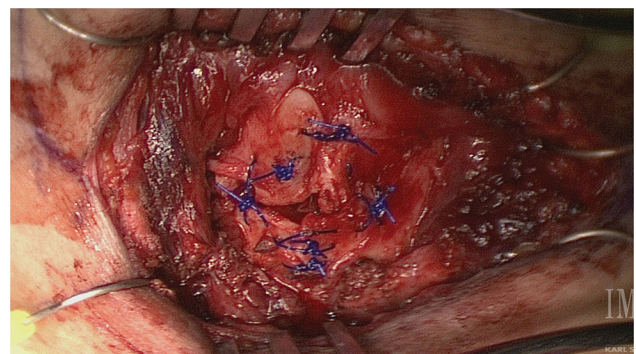


Figure 29-7. Anterior view after suture reconstruction of the thyroid cartilage. The sutures were placed in horizontal mattress and figure eight patterns to aid stability.

Important Points

- Multiple fracture lines make this a Schaefer IV fracture, although the fractures were minimally displaced and there was limited mucosal injury.
- Although the bullet did not actually traverse the endolarynx, the transfer of kinetic energy resulted in several thyroid cartilage fractures and mucosal injury, even though the patient was a young man without thyroid cartilage ossification. The same injury would likely have been more significant in an older individual.
- Importantly, the cricothyroid joints and the lower portions of each side of the thyroid cartilage were intact. This preserved the length of the vocal folds, and this area acted as the rigid base to reconstruct the upper portions of the thyroid cartilage, which helped make the suture repair viable.
- Suture repair of the cartilage was chosen, and the repair was suitable. However, suture will not rigidly fix the larynx. The short-term follow up of this patient precludes definitive understanding, but the lack of rigid fixation could have resulted in splaying of the thyroid cartilage and poor glottic closure (as in expansion laryngoplasty). Rigid fixation has been demonstrated in the lab to be superior to suture and would have been a better choice.^{68–70}
- Iatrogenic injury to the anterior commissure should be avoided if possible.
- No keel or stent was necessary because the cricoid cartilage was intact, the anterior commissure was intact, and primary repair of the mucosa was accomplished.



Figure 29-8. View of anterior neck of injured patient after damage control surgery at the initial point of care.

Case 29-2: High Velocity Penetrating Injury to the Larynx

History and Initial Management

An Iraqi civilian was struck in the neck by an AK-47 round. He was initially stabilized by medics and transported to a Role 2 facility, where the surgeon performed a tracheotomy, placed a drain, and loosely closed the anterior neck skin prior to transfer to Role 3 care (Figure 29-8). CT scan on arrival demonstrated massive disruption of the laryngeal framework (Figure 29-9). Other injuries were excluded and the patient was scheduled for repair.

Discussion of the Injury and Operative Management

- This is a much more significant injury than Case 29-1, owing completely to the velocity of the projectile involved. The AK-47 muzzle velocity is 715 m/s, with a projectile weight of 7.9 g, producing a kinetic energy of 2,019 J. Comparing the cases, the kinetic energy associated with the AK-47 is 4 times that of the handgun.
- The patient had significant disruption of laryngeal soft tissue and cartilages.
- Direct laryngoscopy and esophagoscopy ruled out esophageal and pharyngeal injury and allowed mapping of internal structures (Figure 29-10).

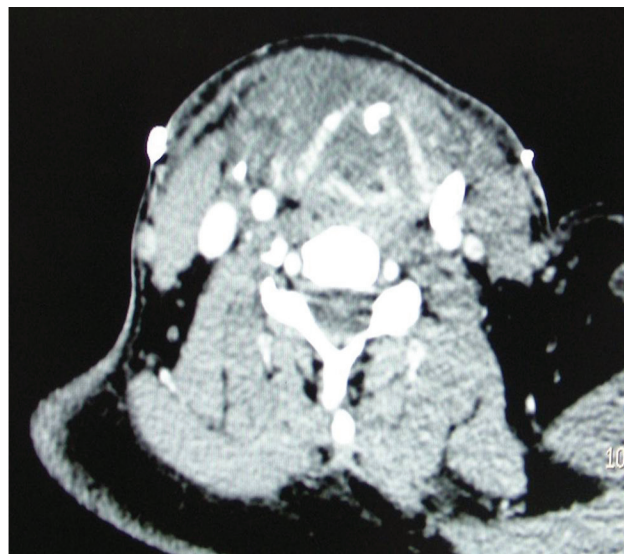


Figure 29-9. Computed tomography scan showing significant disruption of the thyroid cartilage with an anterior foreign body.

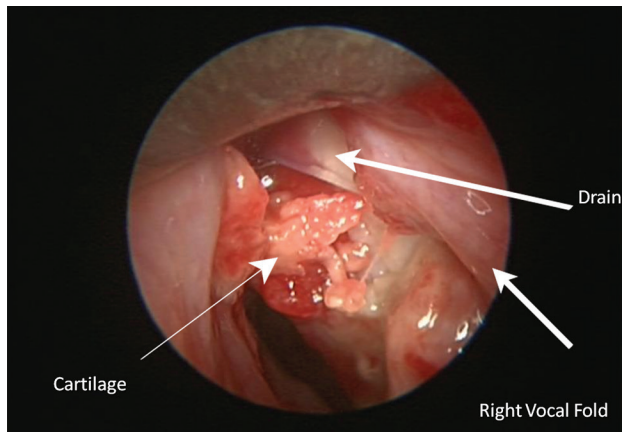


Figure 29-10. View on direct laryngoscopy.

- The wound was explored.
- The left vocal fold avulsion was repaired by suturing the remaining vocal ligament to the external thyroid cartilage perichondrium with 5-0 PROLENE. The right contribution to Broyle's ligament was secured similarly (Figure 29-11).
- A keel constructed from a Doyle splint (Summit Medical Inc, St Paul, MN) was fashioned and secured (Figure 29-12).
- Rigid plate fixation was performed using emergency screws from the beginning (drilling should be avoided if possible; see Figure 29-12).

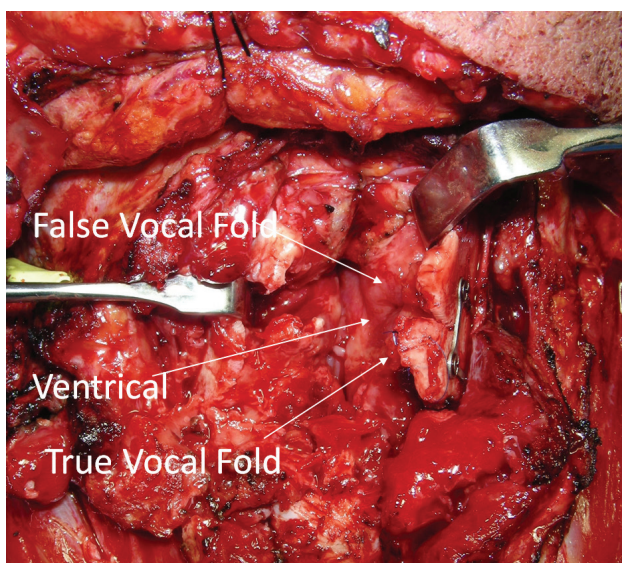


Figure 29-11. Initial stages of repair.

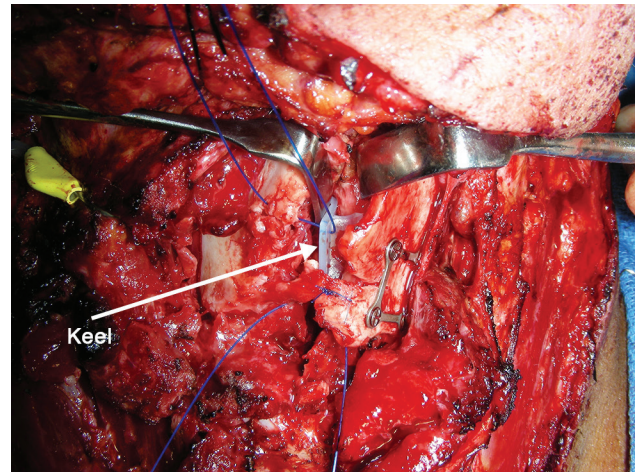


Figure 29-12. Framework repair complete with addition of modified Doyle splint keel.

- The laryngeal lumen was stented with an over-sewn ETT through the glottis, and a soft cuff was inflated in the cricoid (Figure 29-13).
- The stent and keel were removed at 2 weeks.
- Subsequent awake examination revealed right vocal fold paralysis.
- Late glottic stenosis required subsequent laser incision and dilation. Only a holmium laser was available in this situation (Figure 29-14).
- The patient had a poor voice outcome.
- The tracheotomy was likely permanent, but long-term follow-up was unavailable.

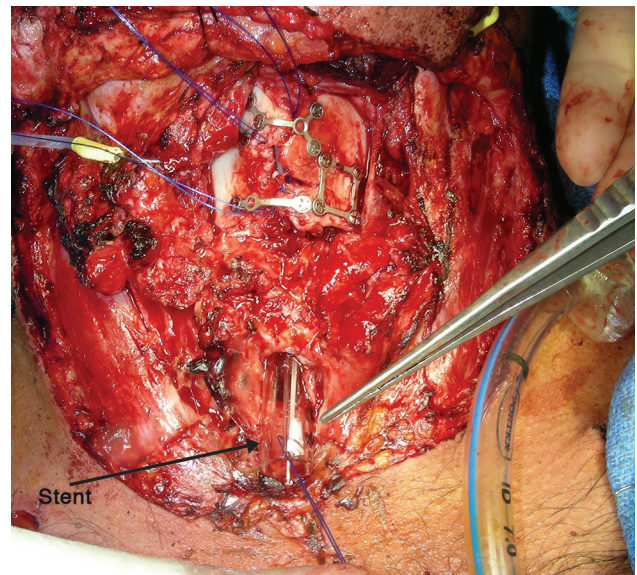


Figure 29-13. Addition of endotracheal tube stent.

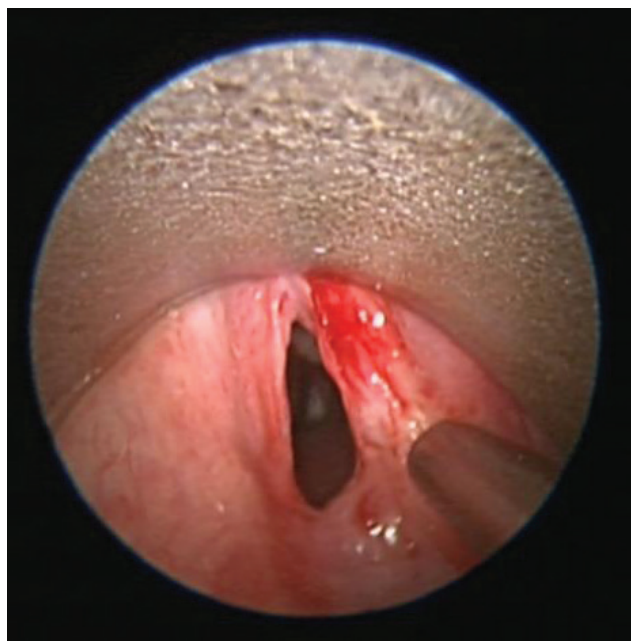


Figure 29-14. Endoscopic appearance at 6 weeks showing significant glottic stenosis.

Lessons Learned

- This was a difficult case. The primary poor outcome in this case was the glottic stenosis. The secondary attempt at correcting this problem was difficult with the equipment available. A better option would be using a split thickness skin graft on the stent so that exposed sections of the endolarynx would be primarily grafted. This may have prevented scarring. Another option would have been a finger-cot stent, which may avoid pressure points compared with the firmer ETT.
- Doyle splints are too stiff and can be associated with mucosal damage. Gore-Tex is a better option for keels (see Figure 29-5). The soft Gore-Tex prevents mucosal damage, and the strong anterior suture puts pressure in the anterior commissure to preserve the angle. With significant anterior injury, some blunting should be expected even in the best of cases.

Case 29-3: Time May Bring Clarity to Wounds

History and Initial Management

A male Iraqi was multiply wounded by an improvised explosive device, with fragment injury to the neck. He arrived transorally intubated. A CT demonstrated

free air in the neck with a suggestion of vascular injury and several pieces of embedded fragments near the airway. The patient was taken directly to the operating room for neck exploration, tracheotomy, and management of his airway and facial wounds. The neck exploration was negative for vascular injury, but several pieces of fragments were removed. A cricoid cartilage fracture was found during the tracheotomy, but the lumen appeared to be preserved when the transoral ETT was removed. Direct laryngoscopy was carried out after the tracheotomy and demonstrated tremendous transglottic edema, precluding a good inspection of the larynx. The patient was not stable enough to allow further intervention at that time.

Discussion of the Injury and Operative Management

This case is typical of multiply injured patients in a combat zone and can be used to highlight three important issues. (1) At this point in his care, the patient had a safe and secure airway (tracheostomy). (2) If this patient had been American or coalition, he could easily have been transferred to a higher level of care prior to definitive management of the laryngeal injury. Because the tracheotomy tube bypassed the injury, the injury might be easily forgotten, and avoidable stenosis might ensue. (3) With the amount of swelling in the endolarynx seen on initial direct laryngoscopy, delaying further treatment is appropriate. In this case, the patient's systemic condition dictated when a second look could be performed.

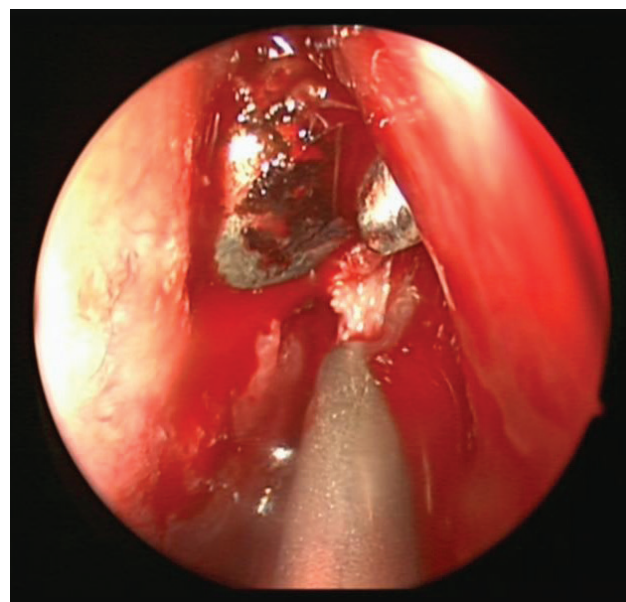


Figure 29-15. Endoscopic view of subglottic fragment.

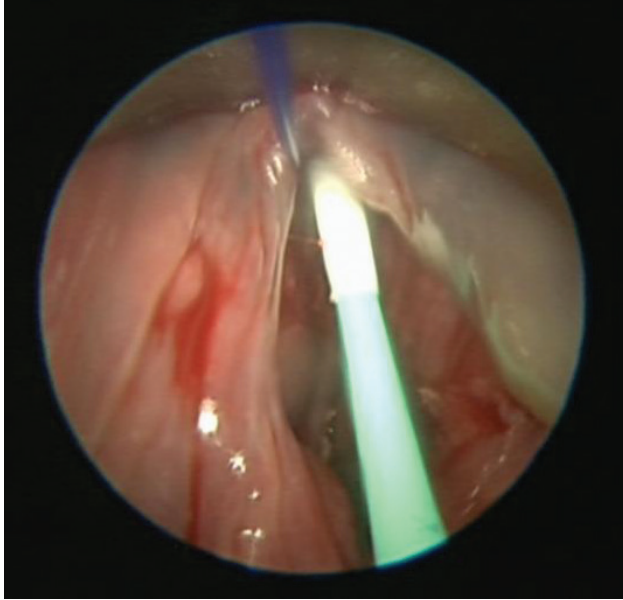


Figure 29-16. Intravenous canula is in place, ready to receive the free end of PROLENE (Ethicon, Somerville, NJ) suture used to secure the endotracheal tube stent.

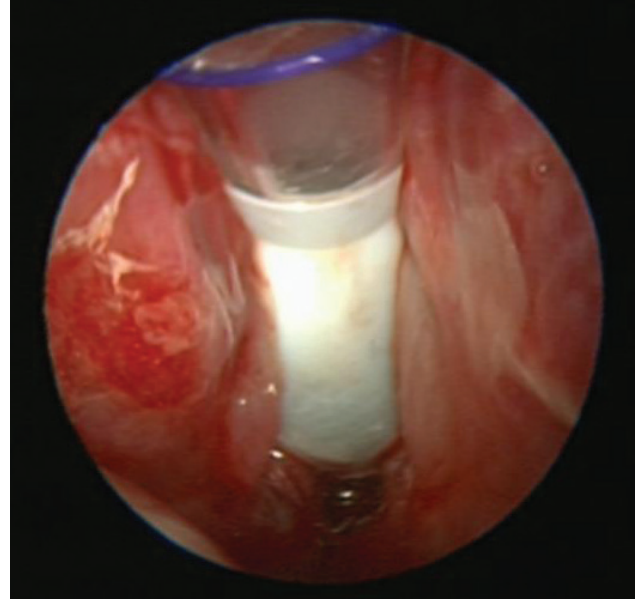


Figure 29-17. Stent made from a modified endotracheal tube, placed with the soft cuff in the cricoid lumen. The patient has a tracheostomy as his airway below the stent.

- After 48 hours, a second direct laryngoscopy revealed that several large pieces of subglottic shrapnel remained (Figure 29-15). These were removed transorally, resulting in good subglottic contours, but the raw edges, unstable cricoid structure, and persistent edema predisposed the patient to stenosis.
- The inflated cuff of a 4-0 pediatric ETT was used as soft balloon stent for the glottis and cricoid for 5 days. It was secured using an external-internal suture technique with a urology stone basket (Figures 29-16 and 29-17).
- The stent was removed in the operating room one week later. Direct laryngoscopy on return to the operating room for revision surgery of other injuries at 2 weeks demonstrated an excellent result.
- At 6 weeks, the patient stated that his voice was normal and he had no airway complaints.

Office examination showed normal vocal folds and a normal cricoid and cervical trachea.

Lessons Learned

- Definitive management of all injuries is not possible for all patients on the initial surgery.
- Because outside influences often dictate when a patient will be transferred (even local civilians may be transferred if an influx of casualties is expected), initial providers should clearly document each injury and communicate to receiving physicians directly if possible.
- Some injuries are difficult to fully understand during the acute phase. If possible, patients should be returned to the operating room for reassessment within 48 hours.

Acknowledgments

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