MAXILLOFACIAL AND NECK TRAUMA

Chapter 6

Contributing Authors
Robert G. Hale, DDS, COL, US Army
David K. Hayes, MD, COL, US Army
George Orloff, MD
Kyle Peterson, DO, CDR, US Navy
David B. Powers, DMD, MD, COL, US Air Force
Swaminatha Mahadevan, MD

Table of Contents

Introduction

This chapter will review maxillofacial and neck injuries combat casualty care (CCC) providers will likely encounter at Level II and III care facilities. The chapter is intended to convey lessons learned in Operation Enduring Freedom (OEF) and Operation Iraqi Freedom (OIF). Pertinent anatomy, injury patterns, treatment of battle injuries, and differences between civilian trauma management in the United States (US) versus CCC are presented. The generalist CCC provider will be presented with the information required to assess and stabilize maxillofacial and neck injuries. Special consideration is given to airway management since significant trauma to the maxillofacial and neck areas greatly influences airway management (Fig. 1). Evidence-based recommendations to prevent and manage infections of combat-related injuries of the head and neck are provided. Additionally, information is provided to prepare the specialist CCC provider, deployed for the first time, to both stabilize and definitively manage (typically in host nation patients) maxillofacial and neck battle injuries.

Figure 1. *The first consideration in this casualty with significant head and neck trauma is securing the airway. Image courtesy of Tamer Goksel, DDS, MD, COL, US Army.*

Overview

The combat theater will produce varying combinations of blunt and penetrating injuries to the head and neck. Blunt trauma can result from motor vehicle accidents, blast injury (tertiary effect), falls, heavy equipment injuries, sport injuries, and altercations. Many of these blunt trauma injury mechanisms are similar to those experienced in the US. The majority of these blunt trauma-related maxillofacial injuries are closed fractures and lacerations. Management of these injuries involves: (1) airway management, (2) prevention of disability from central nervous system injuries, and (3) systematic reconstruction of facial structures (Figs. 2 and 3).

Combat (gunshot wounds and blast injuries) often results in penetrating maxillofacial and neck injuries. Penetrating trauma results in a combination of complex lacerations, open fractures, and wounds complicated by tissue avulsions and burns (Fig. 4).[1] There is an increased frequency of maxillofacial injuries in OEF/OIF compared to previous American wars in the past century. The incidence of head and neck region injuries in World War II and the Korean War was 21 percent, in the Vietnam War it was 16 percent, and in OEF/OIF is 30 percent.[2] Recent advances in body armor and cranial vault protection have led to the increase in the percentage of head and neck casualties that survive initial injuries (Fig. 5).[3] The high incidence of blast injuries caused by improvised explosive devices (IEDs) is likely an additional factor contributing to the higher frequency of head and neck injuries in OEF/OIF.[4]

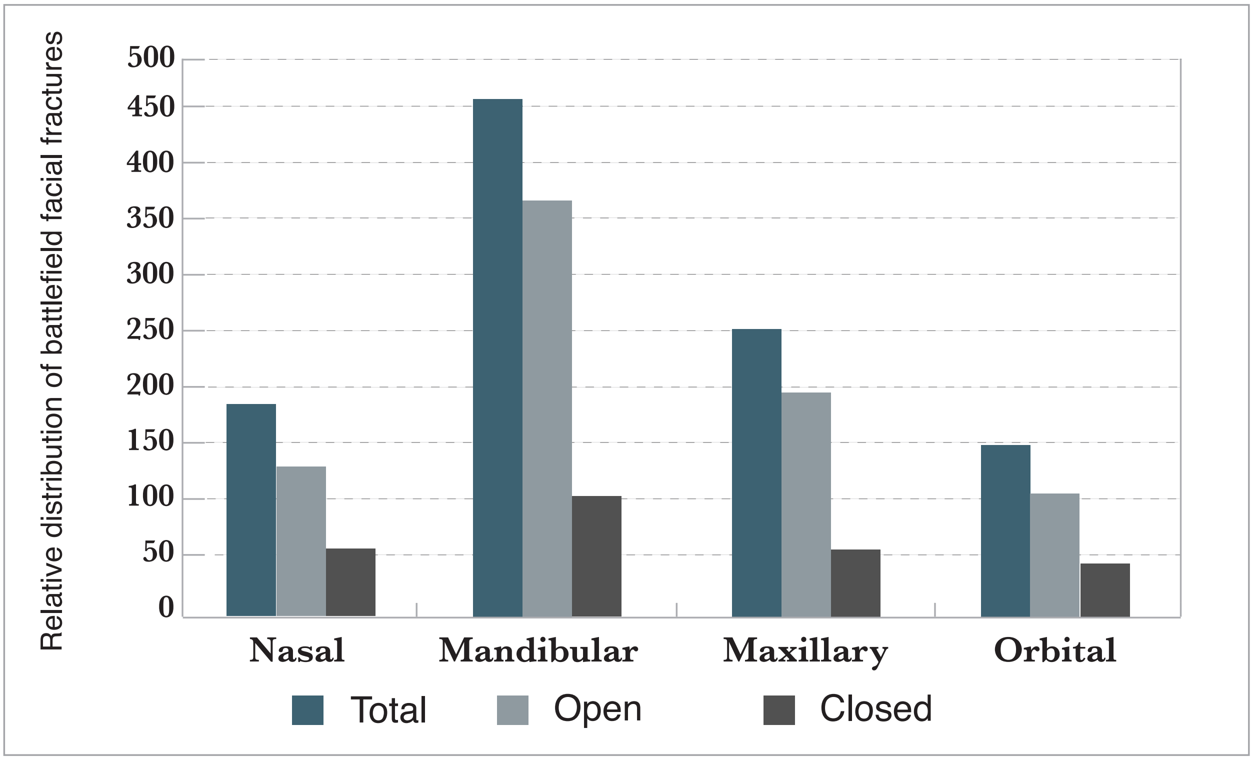


Figure 2. *Relative distribution of battlefield facial fractures. Most battlefield injury facial fractures are open. Data source: Joint Theater Trauma Registry (unpublished).*

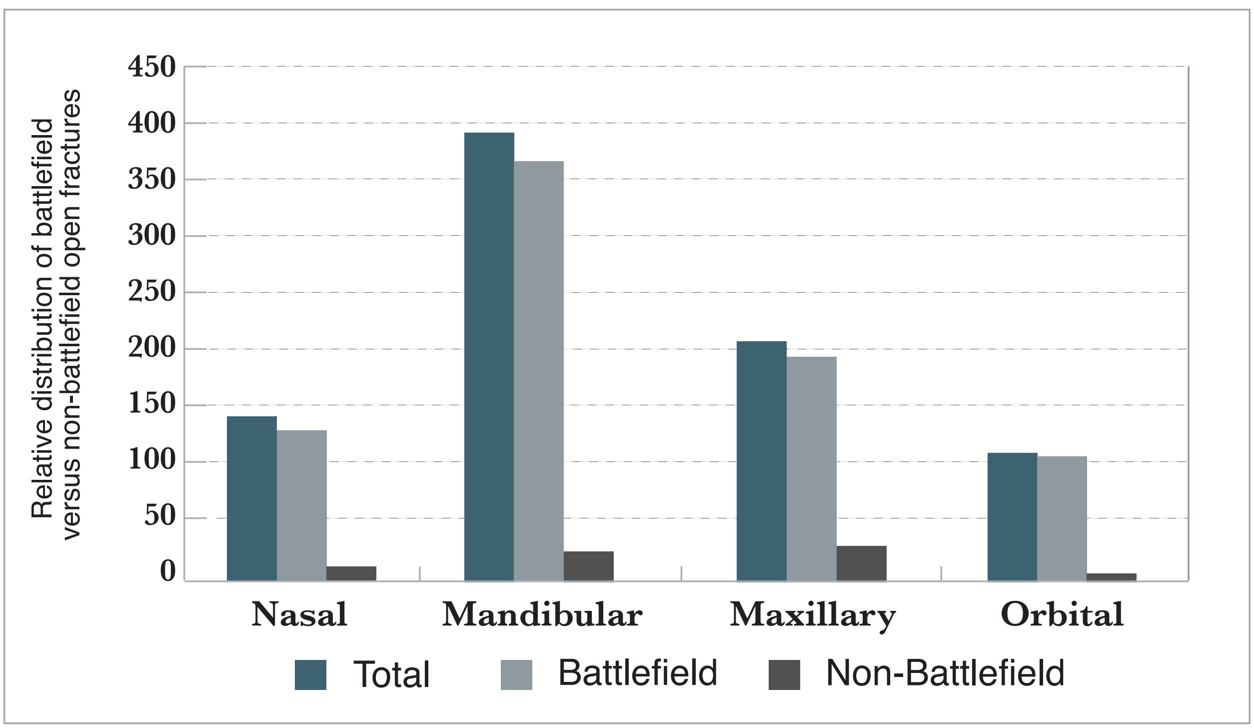


Figure 3. *Relative distribution of battlefield versus non-battlefield open fractures. Data source: Joint Theater Trauma Registry (unpublished).*

Figure 4. (Above) *Explosive blast trauma can result in a combination of complex facial lacerations, open fractures, tissue avulsion, and burns. Image courtesy of Tamer Goksel, DDS, MD, COL, US Army.*

Figure 5. (Right) *Recent advances in body armor and cranial vault protection have led to an increase in the percentage of head and neck casualties that survive initial injuries. Defense Imagery Management Operations Center (DIMOC).*

Combat injuries often cause complex penetrating maxillofacial and neck wounds, including lacerations, open fractures, tissue avulsions, and burns.

Lew et al. analyzed the Joint Theatre Trauma Registry (JTTR) database to describe the type, distribution, and mechanism of injury of maxillofacial injuries experienced by US service members in OEF/OIF (Tables 1, 2 and 3).[1] The JTTR is a military healthcare database, started at the beginning of military operations in Afghanistan (October 19, 2001), of all US military service members injured and treated at any medical facility throughout the evacuation system and spanning all military services at all levels of care.[5] During the six-year study period there were 7,770 injured service members entered into the JTTR. Approximately 26 percent of injured service members (2,014/7,770) had maxillofacial injuries.[1] There were 4,783 maxillofacial injuries among the 2,014 injured service members (average 2.4 injuries per service member with range of 1 to 8). The majority of patients were male (98 percent) and the average age was 26-years-old, with a range of 18 to 57 years of age. The relative distribution of maxillofacial injuries stratified by branch of military service was 72 percent (Army), 24 percent (Marines), 2 percent (Navy), and 1 percent (Air Force).

Body Region	Body Surface Area (Percent)	WWII	Korea	Vietnam	OEF/OIF
Head/Neck	12	21	21.4	16.0	30.0
Thorax	16	13	10	13.4	5.9
Abdomen	11	8	8.4	9.4	9.4
Extremities	61	58	60.2	61.1	54.5

Table 1. *Percent distribution of wounds by body region. Adapted from Lew, 2010.*[1]

Craniomaxillofacial Wound Types	Number	Percent
Total Soft-Tissue	2788	58
Complicated Penetrating Soft-Tissue	660	14
Simple Penetrating Soft-Tissue	2128	44
Fractures	1280	27
Abrasions	231	5
Dental	204	4
Contusions	111	2
Dislocations	6	<1
Skull	15	<1
Unknown	148	3

Table 2. *Characterization of craniofacial injuries sustained in battle by US service members in OEF and OIF. Adapted from Lew, 2010.*[1]

Mechanism of Injury	Number of Injuries	Percent
Explosive	4061	84
IED	3228	67
Grenade/Rocket-propelled grenade (RPG)	428	9
Mortar	263	5
Landmine	142	3
Bomb	26	<1
Gunshot Wound	400	8
Motor Vehicle Accident	77	2
Other / Not Documented	81	2
Fragment / Shrapnel	43	1
Helicopter / Plane Crash	40	1
Miscellaneous	55	1

Table 3. *Mechanism of injury of combat-related craniomaxillofacial injuries in OEF and OIF. Adapted from Lew, 2010.*[1]

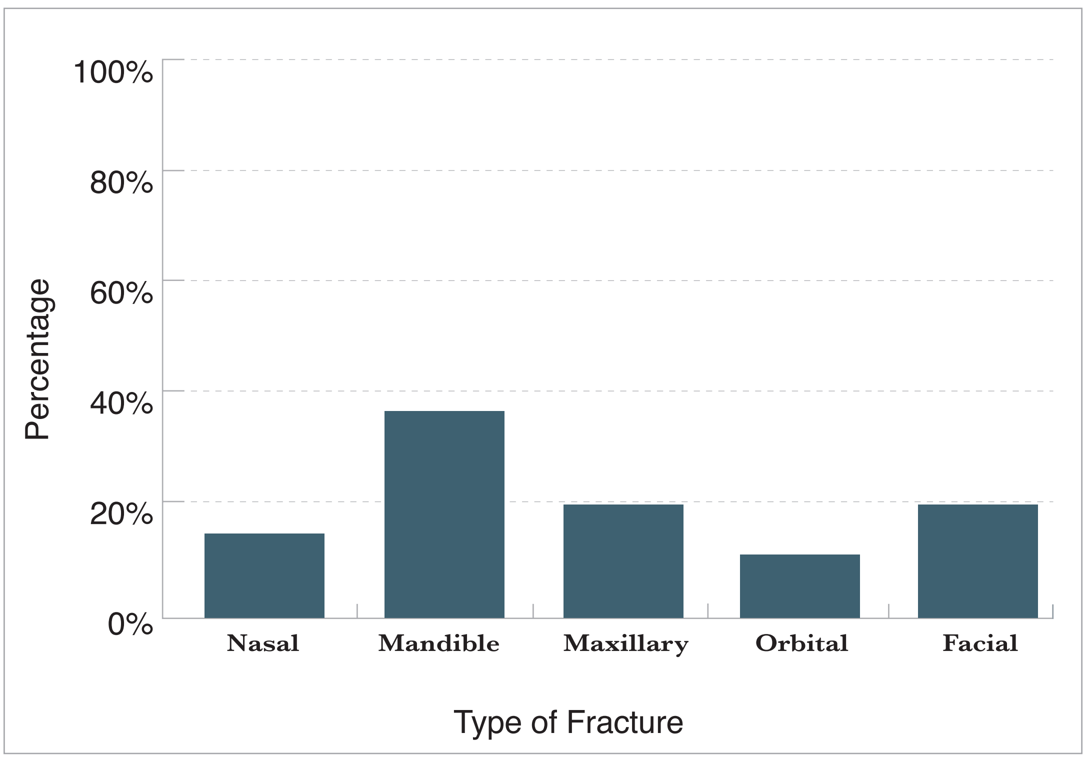


Figure 6. *Distribution of combat facial fractures in OEF and OIF. Adapted from Lew, 2010.*[1]

Based on analysis of the JTTR, the majority of maxillofacial combat injuries were penetrating soft-tissue injuries and fractures. A majority of the fractures were open. The primary mechanism of injury to the maxillofacial region was explosive devices.

The majority of maxillofacial combat injuries were penetrating soft-tissue injuries (58 percent) and fractures (27 percent). A majority of the fractures (76 percent) were open. Amongst the facial fractures, the mandible (36 percent) most frequently involved bone, followed by the maxilla and zygoma (19 percent), nasal bone (14 percent), and orbital wall (11 percent). The remaining fractures (20 percent) were not otherwise specified facial fractures (Fig. 6).[1] The primary mechanism of injury to the maxillofacial region was explosive devices (84 to 88 percent); this injury mechanism is much higher than previous wars.[1,2] Improvised explosive device wounds are the consequence of high-energy projectiles and are characterized by tissues grossly contaminated with dirt, rocks, plastic, glass, animal or human remains, and other materials.[6] Gunshot wounds (GSWs) accounted for just 8 percent of maxillofacial combat injuries. Burns traditionally account for 5 percent of all evacuated combat casualties. Explosions were the primary cause of combat burns (86 percent), which involved the face in 77 percent of cases.[7]

Lessons Learned - Maxillofacial Injuries

Maxillofacial battle injuries are present in 26 percent of casualties evacuated from Combat Support Hospitals (CSHs).[1] These highly visible injuries, although bloody, are rarely the sole cause of shock. Death resulting from airway loss following maxillofacial injury is the primary concern. Establishing a secure airway is paramount for casualties with severe head and neck injuries. Direct laryngoscopy with endotracheal intubation and surgical cricothyroidotomy are commonly used techniques to secure an airway in combat casualties.

Although they are often bloody, maxillofacial injuries are rarely the source of shock. The critical, immediate life-threat following maxillofacial injury is airway compromise due to oropharyngeal bleeding, swelling, and loss of mandibular structural integrity.

During direct laryngoscopy, exposure of the glottis is highly dependent on displacement of the tongue with a laryngoscope blade against an intact mandibular arch. Once mandibular body integrity is disrupted by fracture or avulsion, anterior displacement of the tongue is easier, but blood, soft-tissue swelling, and debris may continue to obscure the glottis. A maneuver to consider if the glottis is obscured despite aggressive suctioning is to push air through the glottis by compressing the chest; bubbles will localize the glottis for intubation. If this fails, and bag-valve-mask ventilation is not feasible, the CCC provider needs to perform an immediate cricothyroidotomy.

Once the casualty has a secured airway, in the authors' experience, direct pressure and aggressive packing of open bleeding wounds or bleeding nasal and oropharyngeal cavities will control all but the most catastrophic hemorrhages (Figs. 7 and 8). Flail mandible fractures may compromise a patient's airway and, if left untreated, cause considerable pain and morbidity. Early tracheotomy and external pin fixation to stabilize mandible fractures prior to air evacuation should be considered. An orthopedic pin fixator, such as the Hoffman® II device, works well to obtain gross alignment and fixation of the fractured mandible (Fig. 9).

Figure 7. (Left) *With the airway secure, a compression dressing has been applied to control bleeding in the oropharyngeal cavity.*

Figure 8. (Below) *A casualty with explosive blast-related penetrating fragmentation wounds to the torso and head. Note the secured airway and compression dressings applied to the head and face. Image courtesy of Kurt W. Grathwohl, MD, COL, MC, US Army.*

For uncontrolled hemorrhage from open wounds and nasal or oropharyngeal cavities, the airway should be secured and the wounds or cavities aggressively packed.

Head and neck wounds should be copiously irrigated, wound contaminants should be removed, and clearly nonviable tissue fragments should be debrided. Judicious initial debridement of facial wounds will provide the face surgeon with a subsequent opportunity to assess viability of critical structures. Facial

Figure 9. (Left) *An orthopedic pin fixator, such as the Hoffman® II device, works well to obtain gross alignment and fixation of a fractured mandible prior to transport. Image courtesy of Tamer Goksel, DDS, MD, COL, US Army.*

Figure 10. (Below) *The maxillofacial region corresponds to head structures not protected by a Kevlar® helmet. Image courtesy of Defense Imagery Management Operations Center (DIMOC).*

lacerations that can be explored and debrided effectively should be closed primarily unless underlying fractures are present.[8] Facial fractures are frequently accessed through existing lacerations. Packing the wound open (temporarily), rather than closing the wound, will prevent open facial fractures from being overlooked in later evacuation phases. Wound packing should be changed at least every 24 hours. Definitive facial fracture repair can be delayed up to two weeks without significantly affecting the outcome in most cases.[8]

With the exception of fractures that significantly alter normal dental occlusion or compromise the airway, definitive facial fracture repair can be delayed up to two weeks.

Information for the Generalist - Maxillofacial Injuries

Improvised explosive devices cause a majority of injuries in OEF/OIF.[2] The face of combat casualties is particularly vulnerable to explosive injuries. Explosions cause a high incidence of ocular injuries, facial fractures, and complex soft-tissue wounds and burns.[1,7] The critical, immediate problem following maxillofacial injury is airway compromise due to oropharyngeal bleeding, swelling, and loss of mandibular structural integrity. Initial treatment of oromaxillofacial injury involves securing the patient's airway and controlling bleeding, while simultaneously protecting the brain, cervical spine, and eyes from further injury. Once the airway is stabilized, efforts can be focused upon hemorrhage control and treatment of additional injuries identified in the secondary survey.

Maxillofacial anatomy comprises the bony and soft-tissue structures anterior and inferior to the base of the skull, from the ears forward and from the brow down to the chin. This region corresponds to head structures not protected by a Kevlar® helmet (Fig. 10). The tongue is attached to the forward projecting mandible, which supports the patency of the upper airway. Beneath the skin, critical structures at risk from penetrating trauma are the parotid glands, parotid ducts, and major facial nerve branches. Unrecognized injuries to these structures may result in high morbidity.[9]

The midface is the area between the eyebrows and base of the nose. The midface contains pneumatized (air-filled) paranasal sinuses. The bones encasing the sinus cavities are thin and lined by mucosa. Projectiles can easily perforate and traverse the midface and lead to subsequent infections. Globe injuries, vascular injuries, and intracranial penetration are critical associated injuries following penetrating trauma to the midface.[10,11]

The lower face is the area from the base of the nose to the chin, including the tooth-bearing parts of the maxilla and the entire mandible. The lower face skeleton is composed of thick cortical bone and dense dental structures. The tongue, surrounded by these hard structures, is at risk for severe injury leading to airway obstruction when high-speed projectiles fragment surrounding structures and produce secondary projectiles.

Airway Control and Breathing Support

Airway management is arguably the single most important skill taught to and possessed by emergency careproviders. Effective airway management in the combat casualty often makes the difference between life and death and takes initial precedence over most other clinical considerations.

There are fundamental differences in the management of casualties arriving to treatment facilities with blunt trauma to the face versus penetrating injury. Patients with isolated blunt force trauma to the face and neck typically undergo standard spinal immobilization measures (e.g., in-line traction) during initial airway management (when the tactical setting allows). Combat casualties with penetrating injuries to the face and neck often pose significant airway visualization challenges (Fig. 11). The primary priority in such patients (at immediate risk for airway obstruction) is securing a stable airway. This often results in more liberal initial manipulation of the head and neck to enable lifesaving airway interventions. Fortunately, studies performed in civilian and combat settings suggest that most patients with normal neurological motor exams following isolated penetrating trauma to the neck will not have a mechanically destabilized spinal column.[12,13] Of note, blast injury management is complicated by the fact that combined blunt force and penetrating injuries to the face and neck often occur.

Studies performed in civilian and combat settings suggest that following isolated penetrating trauma to the neck, most patients with normal neurological motor exams will not have a mechanically destabilized spinal column.

Airway and Breathing Assessment

The initial casualty assessment determines whether the airway is open and protected and if breathing is present and adequate. This is achieved through inspection, auscultation, and palpation (look, listen, and feel). Start by observing the patient for objective signs of airway compromise. Note the presence

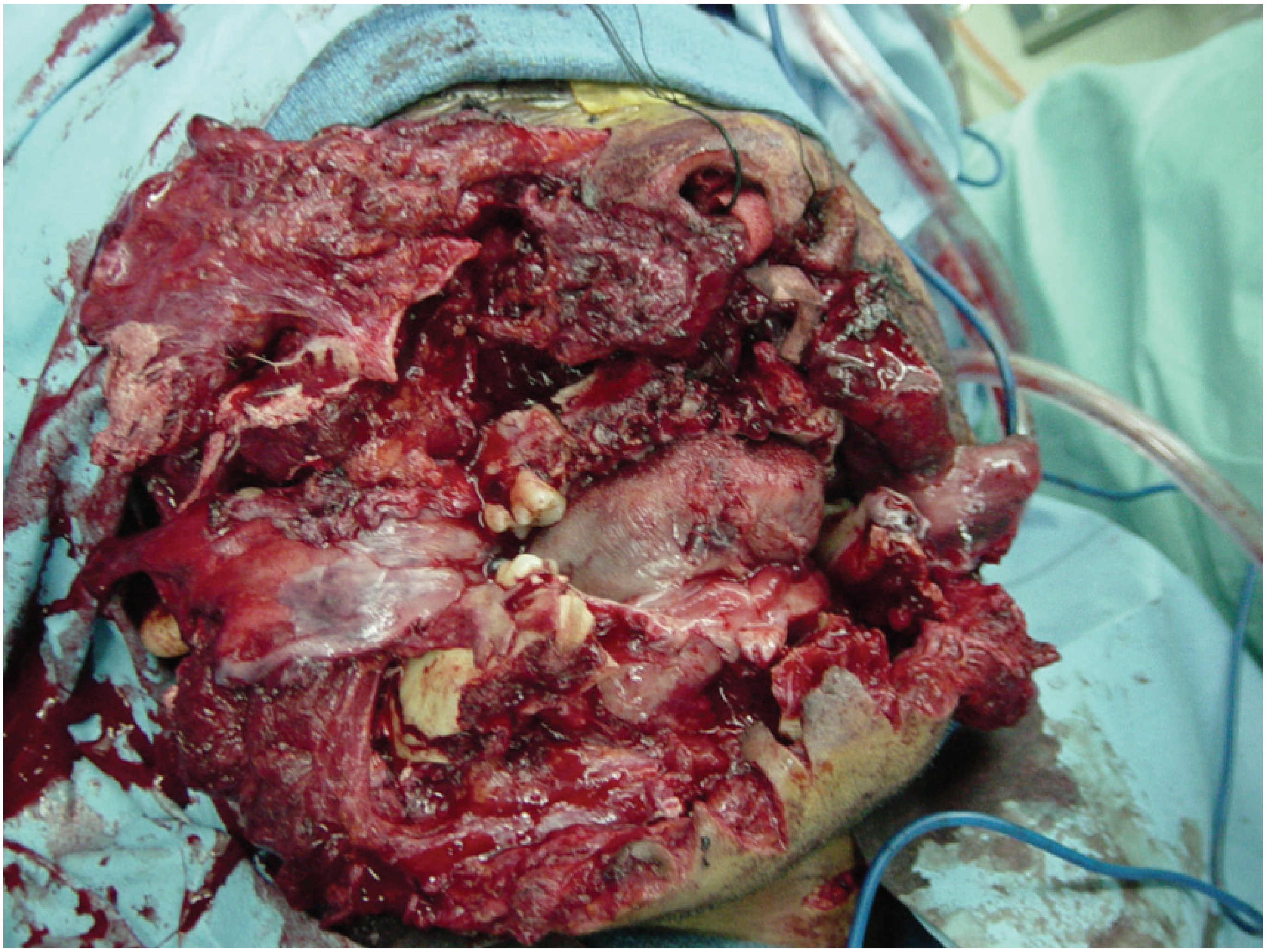


Figure 11. *Penetrating trauma to the maxillofacial region can make visualization of the airway extremely challenging. Image courtesy of Tamer Goksel, DDS, MD, COL, US Army.*

or absence and quality of speech. A normal voice suggests that the airway is adequate for the moment. Gurgling is a consequence of obstruction of the upper airway by liquids, such as blood or vomit, pooling in the oral cavity or hypopharynx. Snoring usually indicates partial airway obstruction at the pharyngeal level, while hoarseness suggests a laryngeal process. Snoring is classically due to obstruction of the upper airway by the tongue. This can occur due to loss of muscle tone secondary to loss of consciousness or as a result of loss of structural integrity of the mandible, as is seen in explosive or ballistic trauma. Stridor, a high-pitched sound, may be associated with partial airway obstruction at the level of the larynx (inspiratory stridor) or at the level of the trachea (expiratory stridor). Wheezing is usually secondary to narrowing of the lower airways. This can result from exacerbation of preexisting disease (e.g., reactive airway disease) or due to compression of the airway by soft-tissue edema, a foreign object, or an expanding hematoma. Aphonia in the conscious patient is an extremely worrisome sign. A patient who is too short of breath to speak is in grave danger of impending respiratory compromise.

Feel for air movement at the mouth and nose. Open the mouth and inspect the upper airway, taking care not to extend or rotate the neck. Look for and remove any vomitus, blood, or other foreign bodies. Identify swelling of the tongue or uvula, any sites of bleeding, or any other visible abnormalities of the oropharynx. The gentle use of a tongue blade may facilitate this task. The patient's ability to spontaneously swallow and handle secretions indicates airway protective mechanisms are intact. In the unconscious patient, the absence of a gag reflex has traditionally been equated to a loss of protective airway reflexes.

The midface and mandible should be inspected and palpated for structural integrity. Injuries to these structures may lead to distortion and loss of airway patency. Mandible fractures can lead to a loss of structural support and subsequent airway obstruction. Patients with these injuries may refuse to lie down in an attempt to maintain airway patency. The anterior neck should be carefully inspected for penetrating wounds. Asymmetry or swelling (i.e., from a vascular injury) of the neck may herald impending airway compromise. The detection of crepitus upon palpation of the neck suggests injury to the airway or a communicating pneumomediastinum. Auscultation should demonstrate clear and equal breath sounds. Diminished breath sounds may result from respiratory splinting causing atelectasis, pneumothorax, hemothorax, or pleural effusion. Wheezing and dyspnea imply lower airway obstruction. Patient agitation may represent hypoxia. Obtundation suggests hypercarbia. Cyanosis indicates hypoxemia. Hypoxia represents low oxygen at the cellular level, whereas hypoxemia is low oxygen solely with reference to arterial blood. In essence, each relates to low oxygen levels. Note the patient's respiratory rate and pattern.

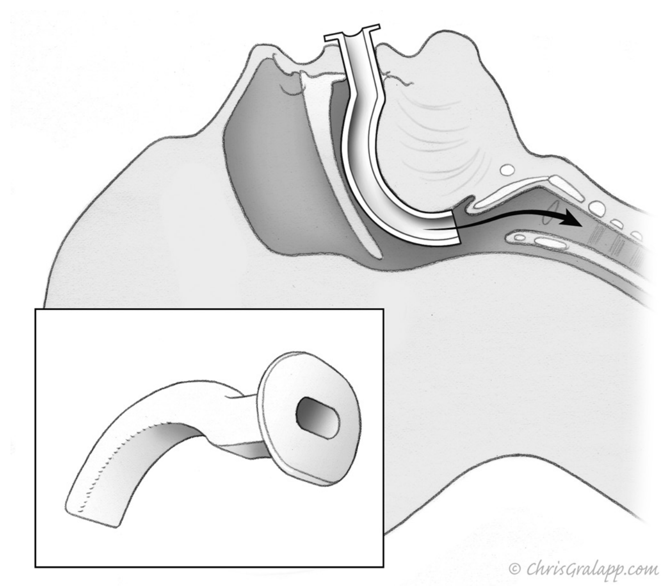
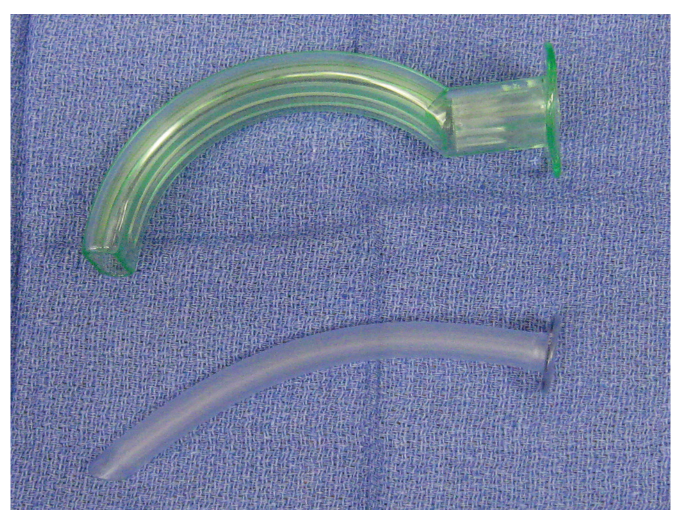


Figure 12. (Top Left) *A jaw-thrust maneuver is an effective way to open the airway in a patient with potential cervical spine injury. Illustrator: Chris Gralapp.*

Figure 13. (Top Right) *The oropharyngeal airway is a C-shaped device designed to hold the tongue off the posterior pharyngeal wall while providing an air channel through the mouth. Illustrator: Chris Gralapp.*

Figure 14. (Bottom Right) *Example of oropharyngeal airway (top) and nasopharyngeal airway (below).*



Bradypnea or tachypnea may be a sign of respiratory compromise. Respiratory muscle fatigue may result in the recruitment of accessory muscles of respiration. This is clinically manifested as suprasternal, supraclavicular, or intercostal muscle retractions. Look for a symmetrical rise and fall of the chest. Significant chest trauma may result in paradoxical or discordant chest wall movement (e.g., flail chest).

Initial Airway Control

Ensuring airway patency is essential for adequate oxygenation and ventilation and is the first priority in airway control. The conscious patient uses the musculature of his/her upper airway and protective reflexes to maintain a patent airway and protect against aspiration of foreign substances (e.g., vomitus). In the severely ill or unconscious trauma patient, protective airway mechanisms may be impaired or lost, predisposing the patient to aspiration of secretions, blood, and gastric contents.

Opening the airway is the first step in airway management. Upper airway obstruction in the unconscious

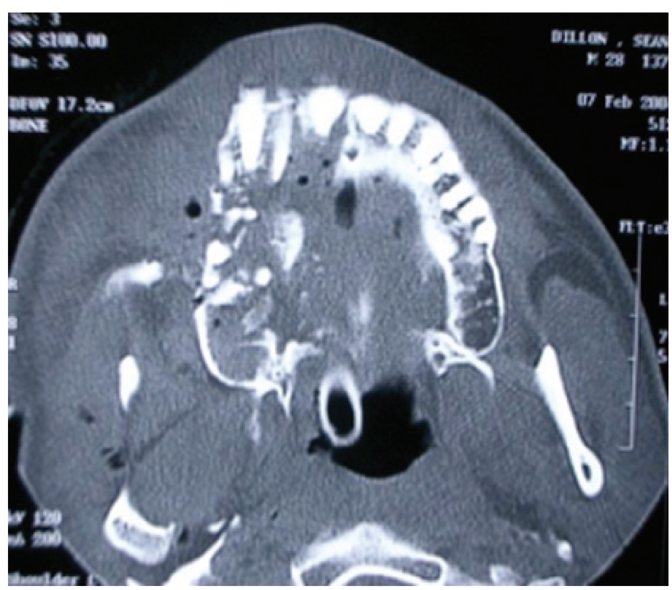


Figure 15. (Top Left) *Nasopharyngeal airways inserted in a combat casualty. A nasopharyngeal airway can establish a temporary, nonsurgical airway in a spontaneously breathing patient.* (Top Right, Bottom Right) *Though it does not provide definitive airway protection, these CT images clearly demonstrate the effectiveness of the nasopharyngeal airway as an adjunct in maintaining airway patency.*

patient is most commonly the result of posterior displacement of the tongue and epiglottis. Simple bedside maneuvers can remove this occlusion and reestablish airway patency and airflow. Carefully remove a casualty's helmet or any headgear while maintaining manual in-line stabilization of the cervical spine. The chin-lift with head-tilt maneuver is a simple, effective technique for opening the airway but should be avoided in any patient with a potentially unstable cervical spine. The jaw thrust without head-tilt maneuver can be performed while maintaining cervical spine alignment (Fig. 12). Between 2 to 4 percent of patients with facial fractures from blunt trauma (in civilian studies) have concomitant cervical spinal fractures, and approximately 10 to 12 percent have cervical ligamentous injury.[14,15] Although these techniques work well, they require the continuous involvement of several careproviders to maintain airway patency and cervical spine alignment.

Although effective in opening the airway, the chin-lift with head-tilt maneuver should be avoided in any patient with a potential cervical spine injury.

Oral and Nasal Airways

Oral and nasal adjunctive airway aids can establish a nonsurgical airway in a spontaneously breathing patient (Fig. 13). Though an oropharyngeal or nasopharyngeal airway may help establish a temporary airway, they do not provide definitive airway protection (e.g., protect against aspiration of vomitus).

Nasal airways should not be placed in the setting of midface craniofacial injuries, as they can inadvertently be introduced into the cranial vault in cases of concomitant midface and skull base fractures.

The oropharyngeal airway is a C-shaped device designed to hold the tongue off the posterior pharyngeal wall while providing an air channel and suction conduit through the mouth (Fig. 14). An oropharyngeal airway is most effective in patients who are spontaneously breathing and lack a gag or cough reflex. The use of an oropharyngeal airway in a patient with a gag or cough reflex is contraindicated as it may stimulate vomiting or laryngospasm. Oral airways can cause complications; when used in conscious or semiconscious casualties, they may stimulate vomiting, laryngospasm, or patient agitation. Hence, inappropriate use of oral airways may worsen airway problems (e.g., potentially exacerbate cervical spinal injuries). They are also useful in assisting bag-valve-mask ventilation efforts in patients with respiratory failure. The oropharyngeal airway comes in various sizes to accommodate children to large adults. Proper oropharyngeal airway size is estimated by placing the oropharyngeal airway flange at the corner of the mouth. The distal tip of the airway should then reach the angle of the jaw.

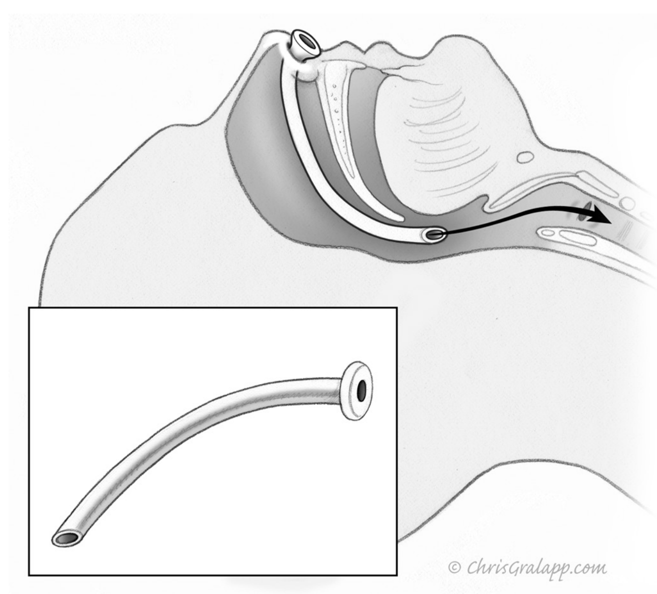


Figure 16. *The nasopharyngeal airway is an uncuffed curved tube made of soft rubber or plastic that provides a conduit for airflow between the nares and pharynx. Nasal airways should not be used in the setting of midface craniofacial injuries. Illustrator: Chris Gralapp.*

The nasopharyngeal airway is an uncuffed, curved tube made of soft rubber or plastic that provides a conduit for airflow between the nares and pharynx (Fig. 15). Nasopharyngeal airways are commonly used in intoxicated or semiconscious patients who do not tolerate an oropharyngeal airway. They are also effective when trauma, trismus (i.e., clenched teeth), or another obstacle (i.e., wiring of the teeth) preclude the placement of an oropharyngeal airway. Proper nasopharyngeal airway length is determined by measuring the distance from the tip of the nose to the tragus of the ear. Nasal airways may induce bleeding from the nose. Nasal airways should not be placed in the setting of midface craniofacial injuries, as they potentially can be introduced into the cranial vault in cases of concomitant midface and skull base fractures (Fig. 16).[16]

Cervical Spine Protection and Control

All patients with significant blunt trauma to the head or face are at risk for cervical spine injury. The amount of force required to fracture the facial bones ranges from 275 to 1800 pounds per square inch, and careful consideration for unstable cervical spinal injury must be maintained throughout the process of securing the airway.[17] Inadvertent movement of the neck of a patient with an unstable cervical spine injury can lead to permanent neurologic disability or death. Accordingly, many combat casualties are transported to the CSH with spinal immobilization.

An effective approach to airway management in patients with possible cervical spine injuries is rapid sequence intubation with in-line spinal immobilization. Pharmacologically paralyzing the patient reduces the risk of the patient moving during intubation attempts, improves airway visualization, and facilitates subsequent endotracheal intubation. A second individual maintaining immobilization of the head and neck in the neutral position throughout the procedure prevents inadvertent movement of the cervical spine by the laryngoscopist (Fig. 17). Careproviders need to ensure the patient can be effectively bag-valve-mask ventilated or that an alternative rescue airway intervention is planned (e.g., surgical airway) prior to pharmacologically paralyzing the patient, in the event endotracheal intubation is not possible.

As previously noted, combat casualties with penetrating injuries to the face and neck often pose significant

Figure 17. *In-line cervical spine immobilization in a casualty with penetrating maxillofacial injury.*

Figure 18. *A combat casualty with a definitive airway. A secured endotracheal tube is positioned in the trachea with its cuff inflated, attached to an oxygen-rich ventilation device.*

airway visualization challenges, which often result in more liberal manipulation of the head and neck to enable lifesaving airway interventions. Studies suggest that most patients with normal neurological motor exams following penetrating trauma to the neck will not have a mechanically destabilized spinal column.[12,13]

Definitive Airway Control and Breathing Support

A definitive airway ensures airway patency and protection. It requires an endotracheal tube (ETT) or tracheostomy tube in the trachea with the cuff inflated, secured in place, and attached to an oxygen-rich ventilation device (Fig. 18). Failure to secure a definitive airway in a timely manner can have adverse consequences for the combat casualty. The decision to intubate a combat casualty is often complicated and may depend on a variety of clinical factors. There are several fundamental reasons for securing a definitive airway in such patients. These include: (1) failure of ventilation or oxygenation; (2) inability to maintain or protect an airway; (3) potential for deterioration based on the patient's clinical presentation; and (4) facilitation of patient management (e.g., combative head injury patient who needs a neuroimaging or aeromedical evacuation). At this stage, intubation should be attempted with one of the following modalities:

- Standard oral or nasal endotracheal intubation
  - Adjuncts include the GlideScope®, Light Wand® or fiberoptic scope
  - Extreme caution should be used with nasal endotracheal intubation in patients with known midface fractures due to potential violation of the anterior cranial vault.
- Laryngeal mask airway (LMA™)
- Esophageal tracheal Combitube®

The benefit of endotracheal intubation or a Combitube® is that the casualty can be transported with either of these devices after they are properly secured. Should an LMA™ be used and patient transport remains an issue, the patient should be considered to only have a temporary airway since the LMA™ does not actually enter the trachea and dislodgement or movement is a potential complication. In addition, the LMA™ has limitations associated with decreased ability to ventilate at increased airway pressures, contraindications in penetrating upper airway trauma or central airway obstruction with foreign body, and potential aspiration risks.[18] In a Level III or higher care facility where immediate patient movement is not a tactical concern, the LMA™ serves as an appropriate adjunct to facilitate ventilation prior to performing endotracheal intubation or a surgical airway.

Extreme caution should be used with nasal endotracheal intubation in patients with known midface fractures due to potential violation of the anterior cranial vault.

Preparation for Endotracheal Intubation

Careful preparation prior to attempting endotracheal intubation is essential to achieving success. This point cannot be emphasized enough. Careproviders need to ensure adequate suction, oxygen flow, airway equipment, pharmacologic agents, and monitoring equipment are present. This includes airway adjuncts and alternative airway devices, including a cricothyroidotomy tray in case initial methods are unsuccessful. Suction systems should be tested and readily available at the bedside for removal of blood, vomitus, and foreign bodies. A high-flow oxygen mask and bag-valve-mask ventilation device should be ready for use. Ideally, patients should be preoxygenated with 100 percent high-flow oxygen to enable several attempts at intubation without the need for bag-valve-mask ventilation (which causes gastric distention and increases the risk of passive regurgitation of gastric contents). At least two functioning laryngoscope handles and appropriately sized and shaped laryngoscope blades should be obtained. The anticipated blade of choice should be clicked into position to ensure that the light functions properly. An ETT should be chosen based on the patient's anatomy and one smaller size should be prepared as well. The average adult male will require a 7.5- or 8.0-millimeter (internal diameter) ETT, the average adult female requires a 7.0- or 7.5-millimeter ETT. In children, the ETT size may be estimated by the formula: ETT size = 4 + (age in years /4). The ETT cuff should be inflated to test for an air leak. A stylet should be inserted within the ETT to shape it into a configuration that will facilitate insertion into the airway. Care must be taken to ensure that the tip of the stylet does not protrude from the end of the ETT or through the small distal side port (Murphy's eye). The patient should have at least one intravenous (IV) catheter inserted, and patency of the line should be verified and ensured. The specific rapid sequence intubation medications, proper dosing, and sequence of administration should be determined. These pharmacological agents should be drawn up and syringes labeled. Cardiac monitoring, blood pressure monitoring, and pulse oximetry are mandatory for all patients. If available, an end-tidal CO_2 monitor should be readied as well.

In children, the ETT size may be estimated by the formula: ETT size = 4 + (age in years /4).

Endotracheal Intubation Technique

With the laryngoscope in the left hand (assuming a right-hand-dominant laryngoscopist), the mouth is gently opened with the right hand. The laryngoscope is gently inserted into the right side of the patient's mouth, and the tongue is displaced to the left (Fig. 19). The curved (Macintosh) blade is slid into the vallecula and the straight (Miller) blade is positioned below the epiglottis (Fig. 20). The handle is pushed along the axis of the handle at a 45-degree angle to the patient's body. Avoid the tendency to leverage (i.e., crowbar) the laryngoscope blade against the teeth, as this may fracture the teeth.

Figure 19. *Insertion of laryngoscope and application of cricoid pressure during intubation. Illustrator: Chris Gralapp.*

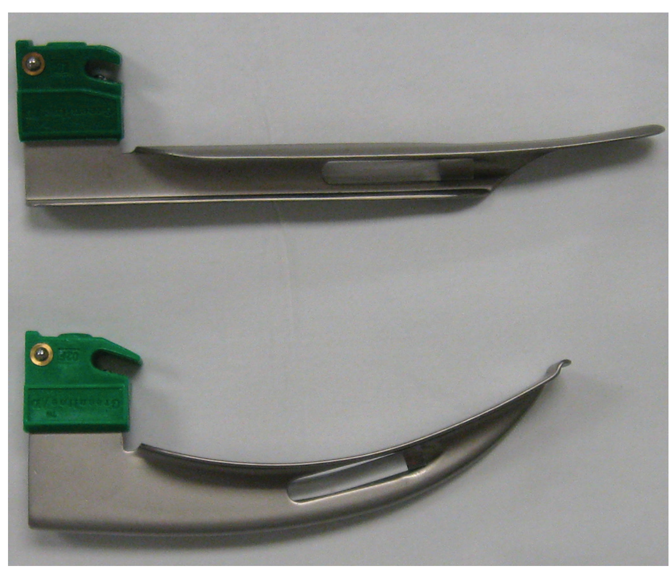


Figure 20. *The straight (Miller) blade is positioned below the epiglottis whereas the curved (Macintosh) blade is placed in the vallecula during endotracheal intubation.*

With a clear view of the glottis, the right hand gently inserts the ETT until the cuff is about two to three centimeters past the vocal cords. Blind intubation (i.e., passing the ETT without visualization of the vocal cords) increases the likelihood of esophageal intubation. In the average-size adult male, the 23-centimeter mark of the ETT will be located at the corner of the mouth (21 centimeters in women). Once the ETT is in place, the stylet should be removed and the cuff inflated until there is no audible air leak with bag ventilation. The ETT cuff pressure should be kept below 25 cm H_2O pressure. This will minimize the risk of tracheal mucosal injury attributable to excessive cuff pressures.[19] Adequate preoxygenation should allow the laryngoscopist multiple attempts at intubation before arterial oxygen desaturation occurs. A dedicated team member should be focused on the patient's cardiac rhythm, blood pressure, and oxygen saturation during laryngoscopy and should alert the endoscopist to any abnormalities.

Endotracheal tube cuff pressure should be kept below 25 cm H_2O to minimize the risk of tracheal mucosal injury.

After any unsuccessful attempt, always recheck the patient's position, and make the necessary adjustments. It is important to attempt to improve your chance of successfully intubating the patient with each successive attempt. This is often done by changing the size or type of laryngoscope blade, repositioning the patient, or by utilizing additional techniques (e.g., fiberoptic intubation).

Rapid Sequence Intubation

Rapid sequence intubation is a series of defined steps intended to allow for rapid endotracheal intubation of a patient with minimal bag-valve-mask ventilation. Given that most patients requiring emergent intubation have not fasted and may have full stomachs, bag-valve-mask ventilation may inadvertently lead to gastric distention and passive regurgitation and increase the risk of aspiration. To perform rapid sequence intubation and avoid this complication, the patient is first preoxygenated to provide adequate blood oxygentation despite a period of apnea without interposed assisted ventilation. This is followed by the sequential administration of an induction agent and a rapidly acting neuromuscular blocking agent to induce a state of unconsciousness and paralysis, respectively. An assistant should apply Sellick's maneuver (cricoid pressure), just as the patient is noted to lose consciousness (Fig. 19). This application of firm pressure to the cricoid cartilage is intended to compress the esophagus (although recent studies suggest the postcricoid hypopharynx is the site of compression) and prevent passive regurgitation of gastric contents.[20] Sellick's maneuver should be maintained until the ETT has been placed, its position verified, and the cuff inflated. Cricoid pressure can occasionally hinder airway visualization; hence, pressure should be reduced to facilitate vocal cord visualization as indicated.[21] Sellick's maneuver should be discontinued in patients who are actively vomiting (versus passive regurgitation). Esophageal compression in a patient who is actively vomiting risks esophageal rupture.

Awake Endotracheal Intubation

Performing oral intubation on a patient who is awake is an intervention that will require liberal topical airway anesthesia and patient sedation prior to inspection or intubation of the patient's airway. This approach allows for the preservation of the patient's airway reflexes and spontaneous breathing while the laryngoscopist takes a quick look at the glottis, vocal cords, and internal airway anatomy. The classic scenario for employing such a technique is the patient with distorted upper airway anatomy (Fig. 16). Under these circumstances, intubation by rapid sequence intubation is often unsuccessful. Subsequent bag-valve-mask ventilation may be ineffective due to loss of normal architecture and inability to create an adequate mask-to-mouth seal (e.g., displaced mandible fractures and soft-tissue loss) or can cause air to dissect into the tissue planes of the neck (e.g., following penetrating oropharyngeal injuries), further distorting airway anatomy. Disadvantages of oral intubation of a patient who is awake include oversedation, discomfort and stress, deleterious effects in patients with cardiac disorders, or increased intracranial pressure. Fiberoptic laryngoscopy assessment of the airway (when available) and subsequent ETT placement are alternatives and very valuable methods of performing an awake oral intubation.

Crash Endotracheal Intubation

A crash intubation is the immediate endotracheal intubation of a patient without the use of any medications. It is indicated in patients with respiratory arrest, agonal respirations, or deep unresponsiveness. The advantages of this approach often include technical ease and rapidity. Disadvantages include the potential for increased intracranial pressure from the stress of intubation as well as emesis and aspiration.

Confirmation of Endotracheal Tube Placement

As inadvertent intubation of the esophagus can occur during airway management, proper positioning of the ETT within the trachea needs to be confirmed after every intubation. Failure to recognize an esophageal intubation can result in patient death. Methods used to detect ETT placement include clinical assessment, pulse oximetry, end-tidal carbon dioxide ($ETCO_2$) detection, suction bulb or syringe aspiration techniques, and ultrasonography.[22] Chest radiography can be used to assess ETT position but does not confirm ETT placement within the trachea. Since the esophagus lies directly behind the trachea, an ETT placed incorrectly in the esophagus may appear to be within the trachea on an anterior-posterior chest radiograph.

> Failure to recognize an esophageal intubation can result in patient death. Clinical observations, end-tidal CO_2 colorimetry, and continuous noninvasive pulse oximetry can be used to help confirm appropriate positioning of the ETT within the trachea.

Classically, a combination of clinical observations has been used to confirm correct ETT placement. These include (1) direct visualization of the ETT passing through the vocal cords during intubation; (2) auscultation of clear and equal breath sounds over both lung fields; (3) absence of breath sounds when auscultating over the epigastrium; (4) observation of symmetrical chest rise during ventilation; and (5) observation of condensation (fogging) of the ETT during ventilation. Though these clinical findings should be assessed in every intubated patient, they are subject to failure as the sole means for confirming ETT placement.

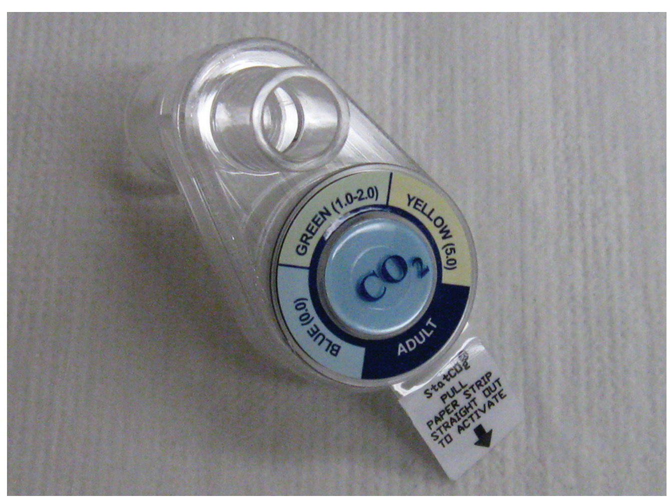


Figure 21. *A colorimetric end-tidal CO_2 detector can be placed between the ETT and bag following intubation, with a (depending on brand) blue- or purple-to-yellow color change indicating a correctly placed ETT.*

Continuous noninvasive pulse oximetry should be standard for every patient being intubated. A drop in oxygen saturation following intubation is suggestive of an esophageal intubation. However, this drop may be delayed for several minutes if the patient was adequately preoxygenated. In certain patients (i.e., hypotensive), oxygen saturation measurements may be unreliable or difficult to detect. Detection and measurement of exhaled carbon dioxide is a highly reliable method for detecting proper placement of the ETT within the trachea.[23] A colorimetric end-tidal CO_2 detector is a small disposable device that connects between the bag and the ETT. When the device detects end-tidal volume CO_2, its colorimetric indicator (depending on brand) changes from blue or purple to yellow (Fig. 21). The absence of this color change usually indicates the tube is incorrectly placed in the esophagus. An important exception is that the colorimetric indicator will remain purple even with correct ETT placement within the trachea in patients with prolonged cardiac arrest. These patients are not circulating carbon dioxide to their pulmonary circulation and into their airways. The recovery prognosis for such patients is dismal.[23]

Aspiration devices may also be used for confirmation of ETT placement and work based on the principle that the trachea is a rigid air-filled structure, whereas the esophagus is soft-walled.[22] Attempts to draw air through an ETT placed in the esophagus will meet resistance from collapse of the esophageal wall around the distal ETT, whereas air will freely flow when drawn through an ETT in the trachea. Two commonly used aspiration appliances are a bulb suction device and a large-volume syringe.

Surgical Airway Management

Despite active bleeding and gaping facial wounds, the fastest and most direct technique to establish a definitive airway is often direct laryngoscopy and oral endotracheal intubation. If direct laryngoscopy fails, a cricothyroidotomy is an expedient technique to establish a definitive airway. Even in the hands of experienced careproviders, alternative surgical airways (e.g., tracheotomy) require a formal surgical setting, proper patient positioning, surgical assistance, and good lighting. The degree of skill required to surgically create such alternative airways coupled with the required resources conspire to make such surgical interventions challenging for generalists providing CCC.

> If attempts at direct laryngoscopy and endotracheal intubation fail, a cricothyroidotomy is an expedient technique to establish a definitive airway.

Cricothyroidotomy

Surgical airway management entails the creation of an opening into the trachea to provide oxygenation and ventilation. Proficiency with surgical airway techniques can mean the difference between life and death. Should difficulty arise in obtaining a secure airway via endotracheal intubation (and bag-valve-mask ventilation is not feasible), there should be no hesitation to proceed directly to a surgical cricothyroidotomy. In an emergency, a surgical cricothyroidotomy is preferred to a tracheotomy, as the distance from the skin to the cricothyroid membrane in most adults is approximately 10 millimeters (mm), compared to the average distance from the skin to the trachea being approximately 20 to 30 mm.[24] In addition, at the level of the second and third tracheal rings, the potential exists for violating the highly vascular thyroid isthmus. The resultant hemorrhage can complicate visualization of the trachea.

> A cricothyroidotomy is preferred to a tracheotomy as an emergency surgical airway.

A cricothyroidotomy creates an immediate surgical opening through the cricothyroid membrane to allow the placement of an ETT or cuffed tracheostomy tube. The primary indication for a cricothyroidotomy is the immediate need for an airway when oral endotracheal intubation is not achievable and bag-valve-

Figure 22. *A cricothyroidotomy creates an immediate surgical opening through the cricothyroid membrane to allow the placement of an ETT or cuffed tracheostomy tube. It requires decisive action and a coordinated team effort.*

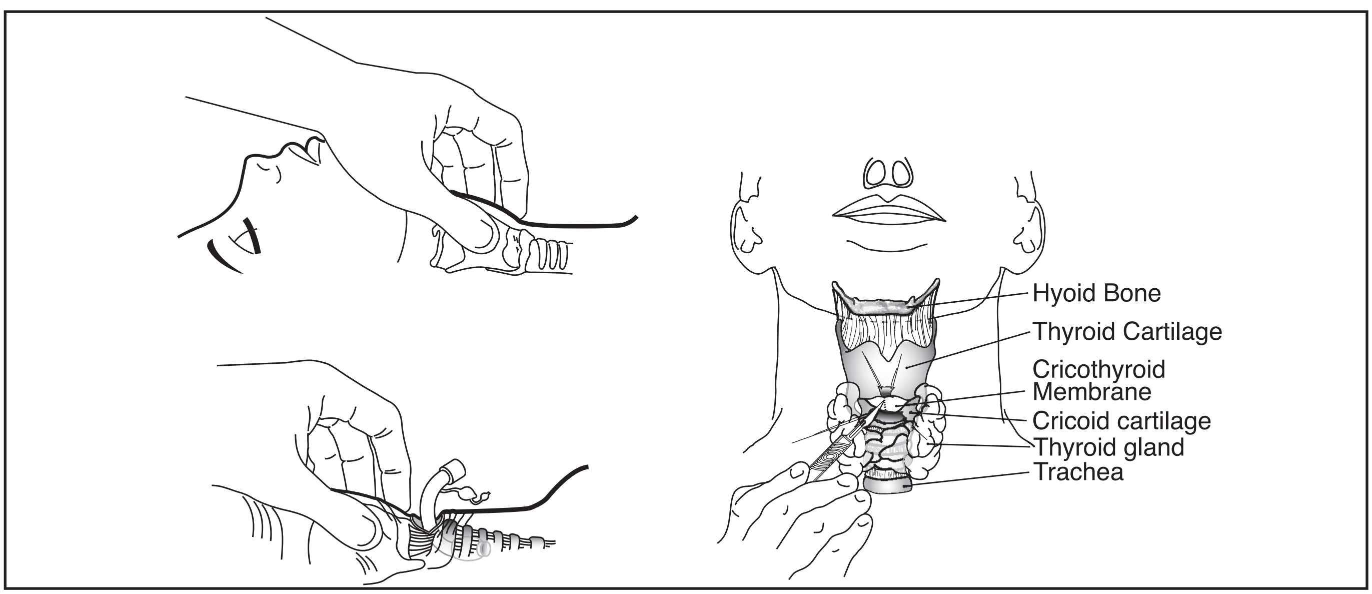


Figure 23. *Landmarks for cricothyroidotomy. Image courtesy of the Borden Institute, Office of The Surgeon General, Washington, DC. Illustrator: Bruce Maston.*

Steps of Surgical Cricothyroidotomy
1. Identify the cricothyroid membrane, which is positioned between the cricoid ring and thyroid cartilage
2. Prepare and sterilize the skin widely to allow for increased visualization of the operative field
3. Anesthetize the site if time or circumstances allow
4. Grasp and secure the thyroid cartilage with your nondominant hand, placing digits one and three along the outer contour of the thyroid cartilage, and use your second digit to identify the cricothyroid membrane
5. Make a one- to two-centimeter vertical skin incision* placed just inferior to the thyroid cartilage past the level of cricothyroid membrane through the following structures: a. Skin b. Subcutaneous tissues c. Cervical fascia * The author prefers vertical incisions, as the potential is decreased for injuring the anterior jugular veins or superior thyroid arteries that lay lateral to the cricothyroid membrane[25]
6. Bluntly dissect the tissues to expose the cricothyroid membrane
7. Make a horizontal incision through the lower half of the cricothyroid membrane and pass a tracheal hook under the inferior surface of the thyroid cartilage and retract upward with the tracheal hook
8. Open the membrane with dilator forceps or the back of a scalpel handle
9. Insert a lubricated, small-cuffed endotracheal tube (6.0 to 7.0 mm internal diameter tube works well in adults) until you see the balloon of the tube disappear below the level of the membrane
10. Confirm tracheal intubation: a. End-tidal CO_2 colorimetry b. Chest rise c. Bilateral breath sounds
11. Secure the endotracheal tube with sutures to the skin

Table 4. *Steps of surgical cricothyroidotomy.*

mask ventilation is not feasible (Figs. 22 and 23). A classic example is the patient with severe facial trauma in whom conventional airway management might be extremely complicated or impossible (Fig. 11). The steps of surgical cricothyroidotomy are outlined in Table 4.

A CCC provider inexperienced in performing cricothyroidotomy should not attempt a smaller stab incision of only the cricothyroid membrane in an emergency situation unless the patient has a thin soft-tissue profile with readily apparent thyroid and cricoid cartilages. The characteristic thick, muscular neck of many US service members makes correct performance of an isolated stab incision into the cricothyroid membrane extremely difficult.

Contraindications to cricothyroidotomy include: (1) the ability to secure an orotracheal intubation; and (2) complete tracheal transection with retraction of distal trachea into the mediastinum. Relative contraindications include the presence of injuries or infections of the larynx and children under the age of 12 years. In children of this age, poorly defined anatomic landmarks and an extremely small cricothyroid membrane make the procedure difficult, if not impossible to perform. These age-based guidelines are variable. If a younger child is large for his or her age and has well-developed anatomy, the procedure may be successful. A surgical tracheotomy is the preferred method for airway stabilization in children under the age of 12, if conditions allow. Complications of cricothyroidotomy include incorrect location of tube placement, hemorrhage (and tube obstruction), tracheal or laryngeal injury, infection, pneumomediastinum, subglottic stenosis, and voice change.[26,27]

Percutaneous Transtracheal Ventilation (Needle Cricothyroidotomy)

An important (particularly in young children) surgical airway procedure is needle cricothyroidotomy with percutaneous transtracheal ventilation (PTTV) (Fig. 24). Percutaneous transtracheal ventilation involves inserting a 14-gauge transtracheal catheter into the cricothyroid membrane with the catheter connected to a ventilation system; lungs are insufflated with 15 liters per minute oxygen flow, one second on and four seconds off.[28,29] Advantages of this technique include its simplicity, safety, and speed. There is typically less bleeding when compared with cricothyroidotomy, and age is not a contraindication, making it a valuable airway management adjunct in children younger than age 12. During PTTV, the upper airway must be free of obstruction to allow for complete exhalation; otherwise, the patient is at risk for barotrauma from air stacking. All patients receiving PTTV should have oral and nasal airways placed. Unlike cricothyroidotomy, PTTV does not provide airway protection. Therefore, it should be thought of as a temporizing measure until a definitive airway can be established.

Figure 24. *Percutaneous transtracheal ventilation (PTTV). Illustrator: Chris Gralapp.*

The Difficult Airway

A recurring difficult-to-manage scenario in OEF/OIF is a casualty with avulsion of the lower face. Despite injury severity, such casualties often present conscious, sitting up in an air-hungry position, and drooling a combination of saliva and blood. Attempts to place these patients in a supine position is resisted by the patient because the airway becomes immediately impaired. In addition, such patients are not easy to bag-valve-mask ventilate, as creating a tight mask seal is impeded by missing anatomy and active bleeding. The inability to bag-valve-mask ventilate a patient is a contraindication to administering a muscle paralytic medication (rapid sequence induction).

There are several approaches to such a scenario. One approach involves the use of a nonparalytic medication such as ketamine (1 to 2 milligrams [mg] per kilogram intravenous bolus infusion) and an antisialogogue like atropine (0.01 mg per kilogram) to facilitate direct laryngoscopy. This often provides the endoscopist with the ability to visualize the vocal cords and perform intubation or gain confidence that intubation is achievable if a paralytic medication is subsequently administered. A surgical cricothyroidotomy is another airway intervention that can be performed under ketamine anesthesia (1 to 2 mg per kilogram intravenous bolus infusion), which preserves a patient's ability to maintain airway tonicity and respiratory drive. Alternatively, if equipment and trained careproviders are available, fiberoptic laryngoscopy can be attempted. However, fiberoptic laryngoscopy efforts are often unsuccessful due to active bleeding obscuring airway visualization or the unavailability of instruments and trained personnel.

An additional approach involves preoxygenating such patients with 100 percent high-flow oxygen for several minutes and then initiating rapid sequence induction while the patient is still sitting upright. Once the patient is unconscious and supine, direct laryngoscopy is immediately attempted. Exposure of the glottis is highly dependent on displacement of the tongue with a laryngoscope blade against an intact mandibular arch. Once mandibular body integrity is disrupted by fracture or avulsion, anterior displacement of the tongue is easier; but blood, soft-tissue swelling, and debris may continue to obscure the glottis. To aid exposure of the glottis in these situations, traction on a suture passed through the tip of the tongue can assist in opening the airway for intubation. If the glottis is still obscured despite aggressive suctioning, pressing on the chest to push air through the glottis may produce bubbles that will help localize the glottis for intubation. If this fails, a surgical cricothyroidotomy is rapidly performed.

> When mandibular body integrity is disrupted, traction on a suture passed through the tip of the tongue can assist in exposure of the glottis and in opening the airway for intubation.

Initial Management Considerations

Once a definitive airway is established, active bleeding is controlled with nasal packs, oropharyngeal packs, and pressure dressings that are applied by wrapping the head with Kerlix™ gauze. The goal is to at least slow blood loss to a level that can be replaced by blood products and allow the patient to be fully assessed and stabilized before transfer to the operating room. Patients with suspected ocular globe injuries should not have compression dressings applied, pending exclusion of globe rupture. After primary survey and stabilization of other injuries, secondary survey of severely injured maxillofacial structures is performed along with appropriate imaging.

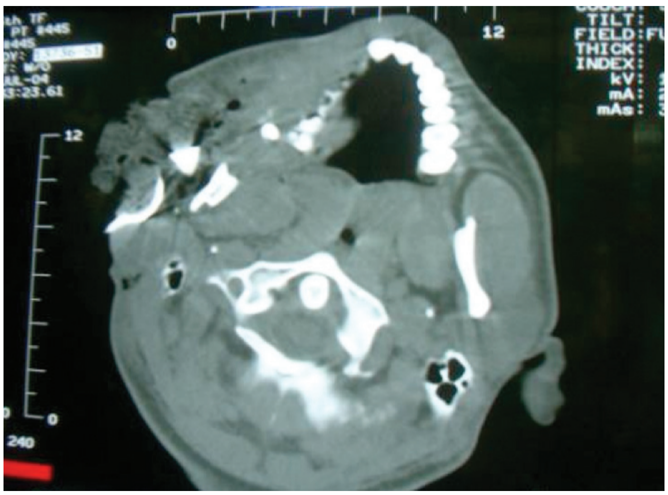
Computed tomography (CT) imaging of the maxillofacial region and cervical spine (to screen for spinal injury) is often required prior to maxillofacial reconstruction. The sequence of treatment steps includes fracture management and soft-tissue repair. In the combat theater, time and resource-consuming maxillofacial reconstruction is avoided in casualties eligible for evacuation. The administration of an initial course of broad-spectrum prophylactic antibiotics should be considered following head and neck combat-related injuries (especially open fractures). A comprehensive review of the literature fails to support prophylactic antibiotic coverage beyond 24 hours of initial surgical intervention.[8] Hence, perioperative antibiotics should be terminated 24 hours after primary repair of maxillofacial wounds.

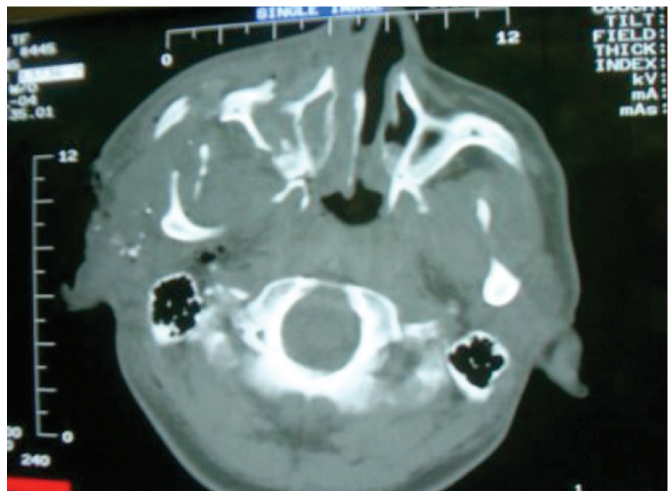
Mandible Fractures

Definitive management of maxillofacial fractures is best deferred to face specialists. A Barton bandage is an effective measure a generalist may use to stabilize a flail mandible fracture. This temporizing measure incorporates an extension of the head wrap bandage under the chin to stabilize the mandible against the

Figure 25. *Casualty arrives at a Field Hospital with a pressure dressing in place. An AK-47 bullet entrance wound is adjacent to the nose (anatomical left side of patient).*

Figure 26. *Rapid sequence induction is immediately performed with oral endotracheal intubation. Note exit wound on anatomical right side of face.*





Figures 27 and 28. *Two axial CT images demonstrating the bullet's path from the base of the nose (anatomical left side of face) traversing the face and causing fragmented dentition and extensive soft-tissue injury to the anatomical right side of the face.*

Figures 29 and 30. *Definitive care on this nontransferable host nation casualty occurred in one step. This included tracheotomy, debridement of hopelessly comminuted fragments and debris, fracture repair with open reduction and internal fixation, and parotidectomy and facial nerve repair with greater auricular nerve graft to the upper division, followed by oral and skin flaps for closure.*

maxilla to control pain. This intervention should be delayed until the airway is secured or deemed safe and uncompromised (Figs. 25 to 30). Application of dental wires and arch bar techniques requires dental expertise; these techniques can effectively stabilize fractures and control pain (Fig. 31). Wiring the teeth together, however, compromises the airway and should be avoided in most cases of severe maxillofacial trauma treated in-theater. Elastic intermaxillary fixation with lightly applied rubber band ligatures is an excellent substitute to wire fixation for the ambulatory patient.

Wiring the teeth together compromises the airway and should be avoided in most cases of severe maxillofacial trauma treated in-theater.

Dental Injury

Teeth avulsed on the battlefield should be discarded. Even under the most ideal conditions of immediate root canal therapy and dental fixation, reimplanted teeth activate a chronic inflammatory response that causes irreversible root resorption. An exception is if the avulsion time for an anterior maxillary root is less than 30 minutes, and dental expertise is readily available for reimplantation as a temporizing measure to preserve alveolar bone until a dental implant is placed.[30] Likewise, dentoalveolar fragments suspended in the airway from a scant soft-tissue pedicle should be removed to prevent aspiration of loose dentition. Lost dentoalveolar structures can be replaced by tissue grafting techniques and dental implants once the casualty is evacuated to the US.

Figure 31. *Intermaxillary fixation is used judiciously in the combat theater and only on ambulatory patients with no airway compromise. Elastic bands between the dental arches instead of wire ligatures are highly recommended for transport. Image courtesy of the Borden Institute, Office of The Surgeon General, Washington, DC.*

Figure 32. *Near complete avulsion of the ear.* (Left) *Prior to surgical intervention, note small soft-tissue pedicle.* (Right) *Following repair, venous congestion threatens tissue survival. Medical leeches can be beneficial in such cases.*

Teeth avulsed on the battlefield should be discarded. The primary exception is an anterior maxillary tooth with an avulsion time of less than 30 minutes.

Facial Injury

Facial features such as the ears, nose, and lips are at risk for avulsion on the battlefield. Following complete avulsion, very little can be done to reattach the body part without immediate microvascular surgical resources. Partially avulsed structures should be assessed by a face specialist before debridement. Even a small soft-tissue pedicle can perfuse an ear or nose, and the consequence of failure is no worse than not trying at all. Venous congestion of reattached tissue can be treated with leeches (Fig. 32).[31,32,33] Access to leeches for such interventions is limited in OEF/OIF. In the authors' experience, the resourcefulness of host nationals (e.g., obtaining leeches from a nearby riverbank) should be not be underestimated.

Even a small soft-tissue pedicle can perfuse a partially avulsed ear or nose, and the consequence of failure is no worse than not trying at all.

Parotid and Facial Nerve Injuries

Penetrating injuries to the face can disrupt the parotid capsule, sever parotid ducts, and injure major branches of the facial nerve. Careful evaluation and inspection are necessary to rule out these injuries prior to wound closure because significant morbidity occurs when these injuries go unrecognized.[34] A reference line dropped vertically from the lateral canthus helps identify the parotid duct as posterior to the line, just below the nasal base, and lying over the masseter (Figs. 33 and 34). If there is any doubt regarding parotid duct integrity, the laceration should be cleaned, packed open, dressed wet-to-dry, and referred for treatment by a specialist. The same reference line is used to establish reparability of

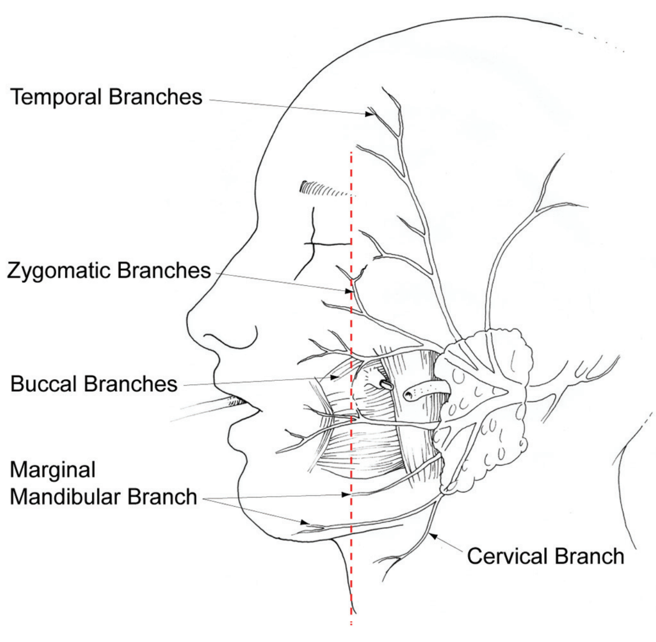


Figure 33. *Branches of the facial nerve and a parotid duct injury. Parotid duct injuries and severed facial nerve branches posterior to a vertical line drawn down from the lateral canthus of the eye should be cleaned, packed open, and referred for treatment by a specialist. Image courtesy of the Borden Institute, Office of The Surgeon General, Washington, DC.*

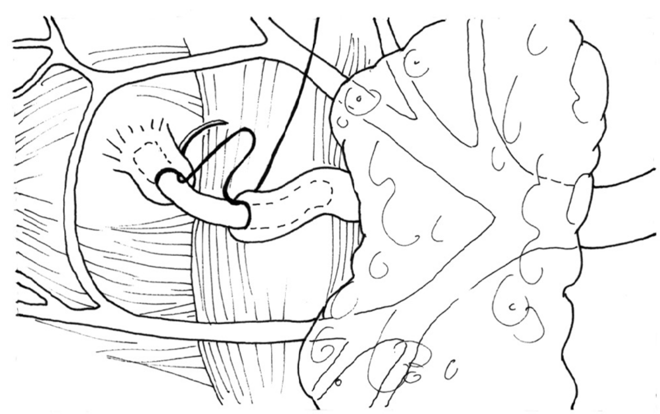


Figure 34. *Repair of the parotid duct should be completed by a face specialist. Image courtesy of the Borden Institute, Office of The Surgeon General, Washington, DC.*

Figure 35. *Through-and-through cheek laceration.* (Top Left) *Penetrating injuries to the face can disrupt the parotid capsule, sever parotid ducts, and injure major branches of the facial nerve.* (Top Right) *Parotid duct and branches of marginal mandibular nerve were identified and repaired, followed by watertight closure of the mucosa and* (Bottom Right) *repair of deep layers and dermis.*

facial nerve branches. Wounds posterior to this reference line are packed open for specialist care if nerve dysfunction is clinically evident. Parotid capsule disruption requires special closure, pressure bandages, and possibly botulinum (toxin) injections (Fig. 35). These injections minimize saliva secretion as the wound heals and are intended to prevent cutaneous fistula formation.

Parotid duct injuries and severed facial nerve branches posterior to a vertical line drawn down from the lateral canthus of the eye should be cleaned, packed open, and referred for treatment by a specialist.

Facial Lacerations

Facial lacerations are anesthetized by subcutaneous injection of 1 percent lidocaine with epinephrine through the wound edges (the addition of 0.25 percent bupivacaine will add hours of postoperative pain relief), followed by careful cleansing and inspection of the wound. After hemostasis is achieved, deep lacerations are closed in layers with absorbable 4-0 polyglycolic interrupted sutures starting with the deep subcutaneous layer, then the dermis to approximate the wound edges. Finally, 4-0 to 6-0 (depending on exact location) nylon skin sutures are used to create a tension-free closure of the skin. Petroleum gel coverage of the wound maintains a physiologic environment for favorable healing. Facial sutures should be removed within three to five days to prevent track scars, and adhesive skin closure interventions (e.g., Steri-Strips™ or cyanoacrylate tissue glue) are applied for an additional two weeks.

Facial lacerations that can be explored and debrided effectively should be closed primarily unless underlying fractures are present.[8] In the authors' experience, simple lacerations can be packed open and closed in a delayed fashion (up to four days later) without significant cosmetic compromise, whereas complex lacerations should be definitively treated within two days to achieve the best possible repair. Macerated or abraded facial soft-tissue should be cleaned and covered with petroleum gel (ophthalmic petroleum gel if wounds are near eyes). Closing facial wounds with advanced flaps should be deferred (when possible) until arrival at Level IV and V facilities.

Facial lacerations that can be explored and debrided effectively should be closed primarily unless underlying fractures are present.

Information for the Specialist - Maxillofacial Injuries

Overview

According to a study of a six-year period of battle injuries recorded in the JTTR, penetrating trauma is the mechanism of injury in 92 percent of US service members evacuated from theater with maxillofacial injuries.[1] Face burns occur in 77 percent of service members evacuated from theater with combat-related burns.[7] Maxillofacial blast injury is characterized in the JTTR database as a combination of complex lacerations and open comminuted fractures, complicated by avulsions and burns.[1] This is in sharp contrast to maxillofacial injuries encountered in the civilian setting, which are predominately caused by blunt trauma. While most injured US service members are stabilized for evacuation to a Level IV or V medical facility for definitive care, the deployed surgeon will be expected to provide definitive care to injured host

Figure 36. *Casualties with complex facial wounds that can be transferred to higher levels of care should have their wounds cleaned, stabilized, and packed wet-to-dry.*

nation patients, security forces, and detainees. This is especially true in Afghanistan, where transfer to local surgical facilities is rarely possible. Since severe blast injury is uncommon in the US, the nature of injuries the deployed face surgeon will likely encounter will be outside his/her usual scope of practice. This section will help bridge this experience gap for the newly deployed face surgeon by addressing penetrating maxillofacial battle injuries.

> As severe blast injury is uncommon in the US, the nature of injuries the deployed face surgeon will encounter will likely be outside his/her usual scope of practice.

Initial Management

The high incidence of airway compromise following severe maxillofacial trauma requires immediate interventions to stabilize and secure a patient's airway. Endotracheal intubation (when feasible) and surgical cricothyroidotomy are well established first-line interventions for securing a casualty's airway. Face specialists may also need to reduce fractured and displaced facial bones that are encroaching on a patient's airway. Severe hemorrhage from fractured bony segments may necessitate immediate surgery to ligate injured vessels or reduce fragments to control hemorrhage (covered later in this chapter).

Once the airway is secured and active bleeding controlled with application of pressure bandages, damage control resuscitation and, when indicated, damage control surgery are immediate priorities. Initial maxillofacial fracture stabilization and soft-tissue repair can be delayed for several days until the casualty is deemed stable from the trauma surgeon's perspective (Fig. 36).

Maxillofacial Wound Care

"The maxillofacial region is anatomically complex with skin and mucosa lining structures that support the upper airway, deglutition apparatus, and specialized sensory organs of sight, smell, hearing, taste, and touch."[8] Although the integrity of the mucosal lining is often disrupted by penetrating maxillofacial battle injuries, the rich blood supply allows for early primary closure after appropriate debridement.[8] The risk of cavitation necrosis to the head and neck following gunshot wounds is low. This is because the head and neck lack large muscle masses, the investing tissues are highly vascular, and the potential space for disruption is limited in depth prior to encountering the hard tissues of the mandible.[8]

> Primary closure of penetrating maxillofacial injuries may be performed following judicious wound debridement.

Maxillofacial wounds suffered in combat will often require serial debridement and irrigation to remove gross debris and foreign bodies. Such interventions can be scheduled in coordination with the multiple trips to the operating room casualties undergo during damage control surgery for concurrent injuries. The surgeon should consider early lateral canthotomies for maxillofacial wounds complicated by burns involving the periorbita to prevent orbital compartment syndrome and loss of vision (Fig. 37). Tracheotomy should also be considered at this early phase. Frost sutures (intermarginal sutures placed between the eyelids to protect the cornea) and bolster dressings will help protect against corneal injury and ectropion formation (Fig. 38).

Application of arch bars and external pin fixation (Hoffman® II orthopedic devices) are expedient

Figure 37. *Second-degree face burns involving the periorbita. Lateral canthotomies are performed to prevent orbital compartment syndrome. Using tape or Velcro® straps to secure the endotracheal tube interferes with wound healing and risks accidental extubation. A better technique is to wire the tube to the lower teeth.*

Figure 38. *Bolster dressings and Frost sutures will help prevent ectropion in the acute phase of burn recovery. Likewise, a plastic lip retractor will help prevent microstomia.*

techniques to stabilize flail mandible fractures (Fig. 39). Nasal packs should be removed at three days. Facial pressure dressings should be removed and replaced, wet-to-dry, daily. Standard ear-nose-throat (ENT) textbooks routinely recommend prophylactic antibiotic administration while the nose is packed to prevent complications associated with *Staphylococcus aureus* dissemination.[35]

Infection Prevention and Management

Infection prevention and management are integral components of all phases of CCC. In 2007, the US Army Surgeon General commissioned a group of researchers to review the literature and publish evidence-based recommendations for the prevention and treatment of combat-related infections.[36] A team consisting of an infectious disease specialist, a head and neck surgeon, an ophthalmologist, and an oral and maxillofacial surgeon focused on infections of maxillofacial and neck combat-related injuries.[8]

War Wounds

War wounds are traditionally considered contaminated. Animal studies have demonstrated that animals become rapidly colonized with bacteria found in the immediate environment in which projectile-related wounding occurs.[37] The integrity of the mucosal lining (especially the oral cavity) is an important factor

Figure 39. *Flail mandible.* (Above) *Avulsed dentate mandible was stabilized with a wrist external pin fixator and the lower lip wound temporarily closed.* (Right) *Once sutures were released at a Level V facility, the preexisting two-thirds avulsion of the lower lip, chin, and oral vestibule become apparent.*

following injuries to the maxillofacial region. Wounds characterized by disruption of the integrity of the mucosal lining within the oral cavity are prone to infection by bacteria found within saliva. Despite these characteristics, the rich vascular supply of the face (among other factors) does allow for early primary wound closure of face wounds following wound irrigation and debridement.[8]

Early definitive treatment with debridement, irrigation, early repair of soft- and hard-tissues, and early administration of broad-spectrum prophylactic antibiotics are interventions that decrease war infections.[8,38,39,40] All war wounds to the head and neck should be treated with 24 hours of prophylactic antibiotic therapy. There is no evidence to indicate that longer courses of antibiotics are of any benefit, provided war wounds are repaired in less than 12 hours, and prophylactic antibiotics are administered within six hours of initial head and neck injury.[41,42,43] Third-generation cephalosporin antibiotics provide adequate perioperative prophylaxis for maxillofacial, head, and neck injury surgical interventions.[44] Current US Army recommendations are that maxillofacial war injuries not repaired in less than or equal to 12 hours, or without prophylactic antibiotics greater than or equal to six hours following injury, have a high risk of infection and require a treatment course of 10 to 14 days of antibiotics.[15] Combat casualty care data supporting these recommendations are limited. However, similar recommendations are widely published in civilian oral and maxillofacial textbooks.[39,40] High-risk maxillofacial wound characteristics include those with comminuted fractures or avulsed mandible defects, wounds with compromised blood supply, wounds closed under tension, and tissue flap or skin graft closures. Such wounds may benefit from a more prolonged course of prophylactic antibiotic therapy.[8]

> Early definitive treatment with debridement, irrigation, repair of soft- and hard-tissues, administration of broad-spectrum prophylactic antibiotics, minimal introduction of foreign surgical material during initial surgery, and coverage of bone with tension-free closure are all interventions that decrease war infections.

Epidemiology of Wound Infection

Infection rates following war-related maxillofacial injuries are outlined in Table 5. The actual pathogens that cause infections following war-related maxillofacial injury are poorly characterized.[45,46] Civilian studies in non-trauma patient populations have found that the cause of infection was polymicrobial in 88 to 96 percent of patients who develop infections following head and neck surgery.[47,48] Aerobic organisms were found in 54 to 91 percent of infections and anaerobic organisms were found in 54 to 74 percent of infections.[47,48] The specific pathogens cultured in the aforementioned studies were highly variable and included *Staphylococcus aureus, Pseudomonas aeruginosa, Klebsiella* species, *Escherichia coli, Proteus mirabilis, Bacteroides fragilis, Peptococcus, Fusobacterium* species, *Peptostreptococcus*, and fungi (among others). Osteomyelitis is a notable infectious complication in several civilian gunshot wound injury studies.[49,50,51] Inadequate wound exploration, debridement, foreign body removal, and closure of pharyngoesophageal injuries were cited as reasons for developing osteomyelitis.

War-Related Maxillofacial Injury Infection Rates
Vietnam: 7 percent rate of infection[52]
Iran-Iraq War: 11 percent rate of infection[53]
Balkan conflict: 19 percent rate of infection[54]

Table 5. *War-related maxillofacial injury infection rates.*

Prevention of Infection: Surgical Management

Early repair of soft- and hard-tissues following irrigation, conservative wound debridement, early administration of broad-spectrum prophylactic antibiotics, minimal introduction of foreign surgical material during initial surgery, and coverage of bone with tension-free closure have been cited as interventions that decrease war infections.[39,40,55,56,57] The inner mucosal lining of maxillofacial structures should be maximally preserved during debridement efforts. Avulsion defects of the mandible are best treated by early stabilization of existing bone fragments, primary soft-tissue closure, wound drainage, repeated debridements, and delayed bone reconstruction (e.g., eight weeks following injury).[8] Bone grafting of mandibular injuries is best deferred to Level IV and V care facilities and performed in a delayed fashion. Bone grafting of mandibular defects is best performed on infection-free and well-perfused wound beds.[58,59] Further studies are required to determine whether rigid internal fixation of maxillofacial war wounds (as is often practiced in the course of host national care in OEF/OIF) has favorable outcomes (e.g., decreasing wound infection rates).

Avulsion defects of the mandible are best treated by early stabilization of existing bone fragments, primary soft-tissue closure, wound drainage, repeated debridements, and delayed bone reconstruction.

Diagnosis of Infection

Signs of a head and neck infection include erythema, edema, warmth, lymphadenopathy, drainage, or fluctuance at the wound site. Patients may complain of fever, increased pain at the site of injury, malaise, fevers, or difficulty tolerating oral intake. Laboratory testing may reveal evidence of inflammation (e.g., elevated white blood cell count). Radiographic imaging such as ultrasonography and CT or magnetic resonance imaging (MRI) can be used to help define the infection. Radionuclide scanning and MRI can be used to screen for evidence of early osteomyelitis. Of note, the ferromagnetic characteristics of embedded projectiles need to be assessed prior to MRI. Plain radiograph findings of osteomyelitis occur late in the disease course, following significant destruction of cortical bone.[60]

Management of Infection

The following interventions are helpful in treating wound infections: (1) incision and drainage of accumulated purulent collections; (2) debridement of foreign bodies or necrotic material; (3) stabilization of fracture fragments; and (4) broad-spectrum antibiotic therapy.[45,54] There are no definitive studies in war settings to determine optimal choice or duration of antibiotic therapy for established infections. Standard expert-based recommendations include a 10 to 14 day course (or two to three days following wound closure and no evidence of infection) of broad-spectrum antibiotic therapy.[36] Osteomyelitis typically requires a minimum of six weeks of antibiotic therapy.[8] Ampicillin/sulbactam, clindamycin and a quinolone, and piperacillin/tazobactam have all been described as reasonable first-line agents for treatment of established infections of the head and neck in war settings.[8] Complications of wound infections of the head and neck include delayed healing, scarring/deformity, sinus tracts, nonunion of bone fragments, ocular infections, osteomyelitis, venous and cerebral sinus thrombosis, and necrotizing fasciitis.[40,45,50,51]

Although no definitive studies exist, standard recommendations for treatment of established combat wound infections include 10 to 14 days of broad-spectrum antibiotic therapy.[36]

Definitive Management

Over the past 25 years, the development of modern craniomaxillofacial surgical principles and techniques has resulted in dramatic improvements in facial fracture surgery. However, these principles and techniques are primarily based on the experience of civilian patients with blunt trauma. The preponderance of penetrating maxillofacial battle injuries (complicated by tissue avulsions and burns) caused by explosive devices in OEF/OIF has increased treatment requirements, including the application of microvascular composite tissue transfer, a technology driven by oncologic surgery. Even the combination of these technologies falls short of reconstructing the face to a natural form and function, because transferred tissues lack both the delicate contours and features of the face and neuromuscular integration.

Research in regenerative medicine and composite tissue allotransplantation over the next five to 10 years holds promise to improve reconstruction results for severely wounded service members. For now, the deployed face surgeon needs to stabilize US casualties with severe maxillofacial wounds for transfer to Level IV and V facilities for definitive care. Face specialists need to apply time-honored techniques to close severe facial wounds on casualties not eligible for evacuation, which, in the experience of the authors, make up the largest surgical patient load. Basic principles are reviewed in this section with emphasis placed on management of unique wounds the face specialist will most likely encounter in the combat zone versus within the US. Unless otherwise noted, the following recommendations are based on the training and experience of the authors.

Severe maxillofacial wounds in US casualties should be stabilized and transferred to Level IV and V facilities for definitive care.

Evaluation and Treatment Planning

Beyond the primary and secondary surveys and initial resuscitation of a combat casualty, maxillofacial examination begins with an overall inspection of the face for asymmetry, contusions, swellings, and lacerations. Palpate the entire facial skeleton for areas of irregularity or instability. The canthal attachments should be tested for stability, especially in cases of midface trauma. The nose should be palpated and inspected for signs of fracture. Mandibular range of motion should be assessed and jaw joints palpated. Evaluate for malocclusion, signs of dental trauma, intraoral lacerations, through-and-through lacerations, embedded debris, disruption of salivary ducts, and cranial nerve dysfunction. Evaluation of visual acuity, inspection of the anterior and posterior chambers, pupillary reflexes, and extraocular movements may be difficult to perform on the traumatized patient, and ophthalmology consultation is desirable. A detailed discussion of the ocular exam is provided in the Ocular Trauma chapter.

Radiographic Imaging

Three-dimensional reconstruction of CT scans is the imaging procedure of choice for facial injuries. Computed tomography scans can be extended to the cervical spine and cranium to define trauma to these areas. Panoramic tomography (Panorex) provides additional information on the dentition of an ambulatory patient should this modality be available in the deployed setting. Preinjury photographs and identification cards are also helpful during the evaluation phase.

Fracture Stabilization

After thorough maxillofacial evaluation and specialty consultations, a list of injuries is developed in order to plan definitive treatment. Clinical judgment is a critical factor in determining the indication, scope, and timing of surgery. As noted earlier, if the severely injured casualty can be evacuated to a higher level of care, the focus should then be on stabilizing the maxillofacial wounds for transfer. Often two to three days of damage control surgery in-theater will allow the face specialist the opportunity to secure a definitive surgical airway, serially debride and irrigate wounds and remove foreign material and necrotic tissue, address grossly unstable fractures, and apply wound dressings.

A small bone (Hoffman® II) or specific craniomaxillofacial external pin fixation device is an expedient technique to temporarily stabilize flail mandible fractures. Arch bars and bridle wires for intra-arch stabilization are also helpful, but wire intermaxillary fixation should be avoided (Figs. 40 and 41). Wiring the teeth together compromises the airway and should be avoided in most cases of severe maxillofacial trauma treated in-theater. Elastic intermaxillary fixation with lightly applied rubber band ligatures is an excellent substitute to wire fixation for the ambulatory patient.

Figure 40. *Bridle wires may be used for intra-arch stabilization.*

Figure 41. *Bridle wire placement (red line denotes fracture line).*

For transferable patients, a small bone (Hoffman® II) or specific craniomaxillofacial external pin fixation device is an expedient technique to temporarily stabilize flail mandible fractures. Wiring the teeth together compromises the airway and should be avoided in most all cases of severe maxillofacial trauma treated in-theater.

Definitive Repair

Definitive treatment of the nontransferable casualty requires preoperative analysis of incisions to expose the skeleton for fracture mobilization and reduction, methods of bony fixation, need for primary bone grafting, and repair of soft-tissues. The presence of tissue avulsions and burns obviously complicates planning. In those situations, wound closure may require local and regional flaps or, in the case of burns, stabilization of fractures through external pin fixation and interdental fixation techniques. Incisions may involve the use of existing lacerations, scalp incisions, periorbital incisions, cervical incisions, and incisions in the oral cavity (Fig. 42). Rigid internal fixation is desirable, but if the soft-tissue envelope is compromised, external pin and/or dental fixation may be required. Airway management, both during and after the operation, should be collaboratively performed with input from the anesthesiologist and trauma surgeon. Oral or nasal intubations are airway options, but if access to the surgical field or associated injuries (e.g., unstable cervical spine or basilar skull fractures) prevents their use, an elective tracheotomy should be considered.

Informed Consent

Even in the combat theater, informed consent for an elective operation is a feature of comprehensive care. If the patient is not able to make an informed consent, review the potential risks with the patient's family. The concerned parties should be aware that despite your best efforts, preinjury appearance will unlikely be achieved. The possibility of revision or staged surgeries to achieve the best results cannot be realistically determined or promised in the combat theater. The consent process with the potential for loss of vision, intracranial injury, and even death, although rare, needs to be accepted and documented.

Timing of Surgery

It is prudent to delay surgery on unstable patients with intracranial injuries. Once intracranial injuries

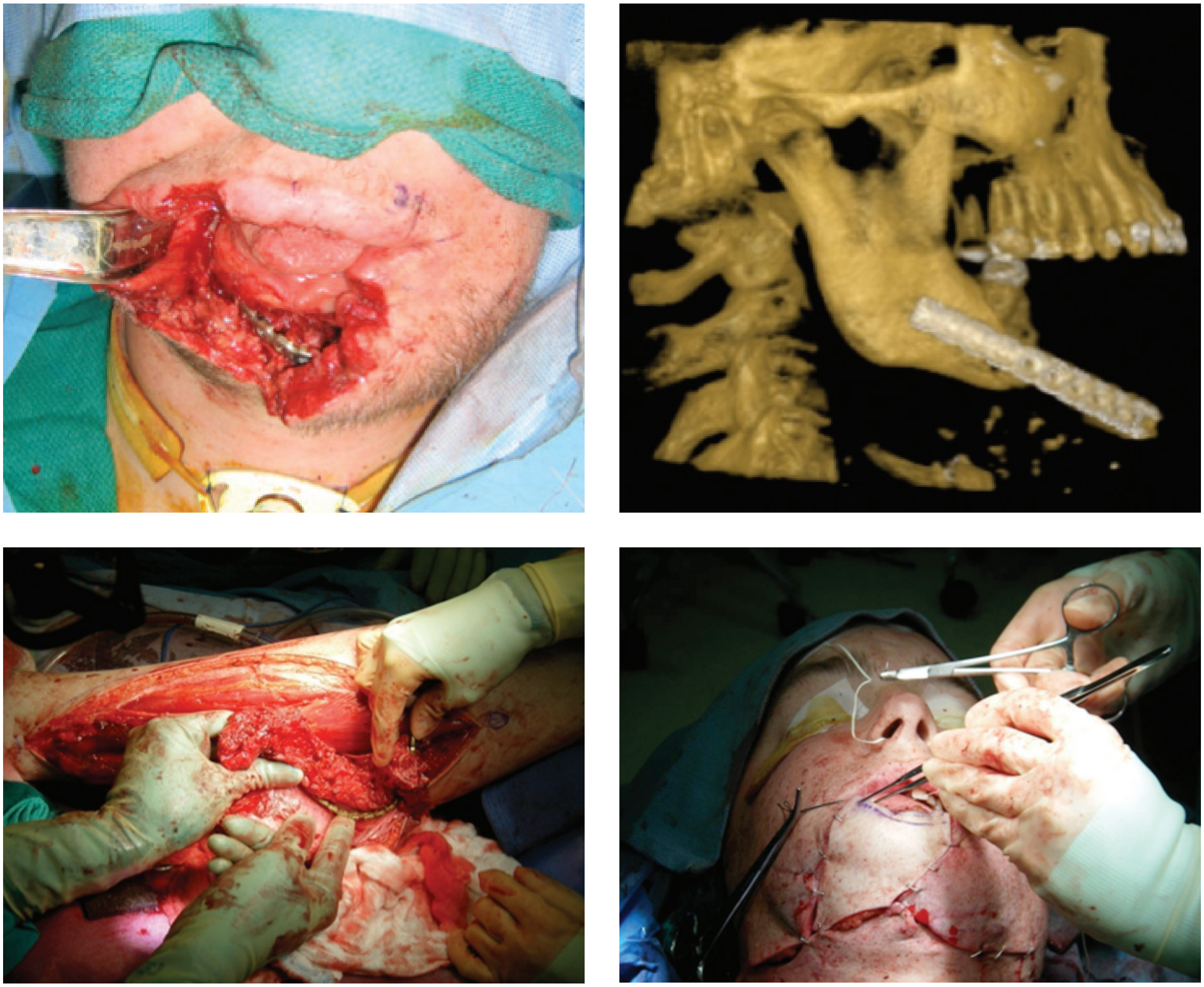


Figure 42. (Top Left) *Improvised explosive device injury to lower face resulting in lower lip and chin avulsion and avulsion of entire dentate mandible.* (Top Right) *Three-dimensional CT imaging is the modality of choice for facial injuries.* (Bottom Left) *A fibular microvascular flap is grafted and restores soft-tissue and bone continuity.* (Bottom Right) *The flap will remain insensate, adynamic, different in color and texture, and hairless.*

stabilize, early repair of facial fractures in these patients should be considered with input from neurosurgical consultants. It is difficult to predict when an unconscious patient will neurologically improve. If maxillofacial surgery is delayed beyond two to three weeks, subsequent attempts at repair are exceedingly difficult, if not impossible, because of soft-tissue envelope contracture and fibrous unions.[61]

It is prudent to delay facial reconstruction in unstable patients with intracranial injuries. However, delayed maxillofacial repair is more difficult after two to three weeks due to soft-tissue envelope contracture and fibrous unions.

Surgical Principles

The overall plan to treat hard- and soft-tissue injuries to the maxillofacial region is to reconstruct facial fractures before definitively closing the soft-tissue wounds. The goal of fracture repair is to reconstruct preinjury facial projection, proportions, and form and function, and to support subsequent soft-tissue

Figure 43. (Top Left and Top Right) *An explosive device caused third- and fourth-degree burns and comminuted fractures to the midface. The mandible fracture was reconstructed primarily through cervical incisions. Burn closure took precedence over midface bony reconstruction.* (Bottom Left) *After one to two weeks, the burns on the face will demarcate tissue requiring debridement. The resultant soft-tissue bed is dressed until healthy enough to receive split-thickness skin grafts.* (Bottom Right) *Multiple secondary procedures are expected in cases of burns and soft-tissue avulsion.*

reconstruction. The soft-tissue wounds can then be redraped over a rigid and correct facial framework. In cases of severe facial burns and avulsions, soft-tissue care often precedes definitive fracture care, and extensive revisions are expected (Fig. 43).

The goal of facial fracture repair is to restore preinjury facial projection, proportions, and form and function, and to support subsequent soft-tissue reconstruction.

Facial Soft-Tissue Injuries

Penetrating trauma on the battlefield tends to injure both hard- and soft-tissues. This section will initially address soft-tissue injuries, but composite tissue injuries are discussed later by region (upper face, midface, and lower face) because penetrating battle injuries are manifested differently in those regions. Blunt trauma injury patterns and treatment to the maxillofacial area will not be discussed in detail since it is expected that the deployed face specialist is competent in this injury pattern (commonly seen in the US civilian setting). The deployed face surgeon should ensure access to reference sources that cover maxillofacial trauma, orbital trauma, soft-tissue management, and pedicle and rotational flap management. Beyond book references, the deployed face surgeon should develop online communication with rear echelon experts in their respective fields. This online connection, more than any collection of books, will give the face specialist access to expert consultation and provide a forum to discuss difficult management decisions.

Penetrating trauma to the face causes a variety of soft-tissue defects. This section will outline facial wound closure and surgery to reconstruct the lips and nose, features that remain extremely challenging to reconstruct. Ear avulsions are seen with combat injuries. The face surgeon may have the opportunity to salvage avulsed ear cartilage in a postauricular skin pouch. The avulsed ear is prepared by removing or dermabrading the skin but leaving perichondrium intact over the cartilage. In general, cheek defects from penetrating trauma are closed by wide undermining of wound edges, or development of a rhomboid or cervicofacial flap. Buccal, tongue, or floor of mouth flaps will close the mucosal lining of most full-thickness cheek defects. Severed parotid ducts should be cannulated and repaired primarily. Repair of at least the severed temporal nerve or upper division of the facial nerve is critical to restore the protective function of the eyelid.

As a general rule, lip defects with less than 33 percent vermillion-lip-length loss can be closed primarily by modifying the defect to a "V" or "M" and advancing the skin-muscle flaps.[62] The blood supply to even macerated facial skin and mucosa is surprisingly robust, and no tissue should be discarded until defect closure is carefully planned. Defects measuring 33 to 67 percent of vermillion-lip-length can be closed with staged lip switch flaps, such as Abbe-Estlander flaps.[62,63] Larger lip defects can be treated by dissection of perioral skin-muscle flaps and advancing flaps circumferentially to provide orbicularis oris function using classic procedures of Karapandzic and Giles.[63] All of these flaps cause microstomia, but lip function is preserved. Loss of over 67 percent of vermillion-lip-length will require lateral sliding cheek flaps or nasolabial flaps to close the wound, along with buccal mucosa advancement or pedicle ventral tongue flaps to replace the vermillion.[62] Total lip avulsion in a nontransferable patient will require multiple staged tissue transfers (i.e., temporoparietal or cervicofacial flaps). Staged flap reconstruction is necessary to reconstruct commissure defects. Patients, families, and command need to make the commitment for host nation patients to return for staged procedures.

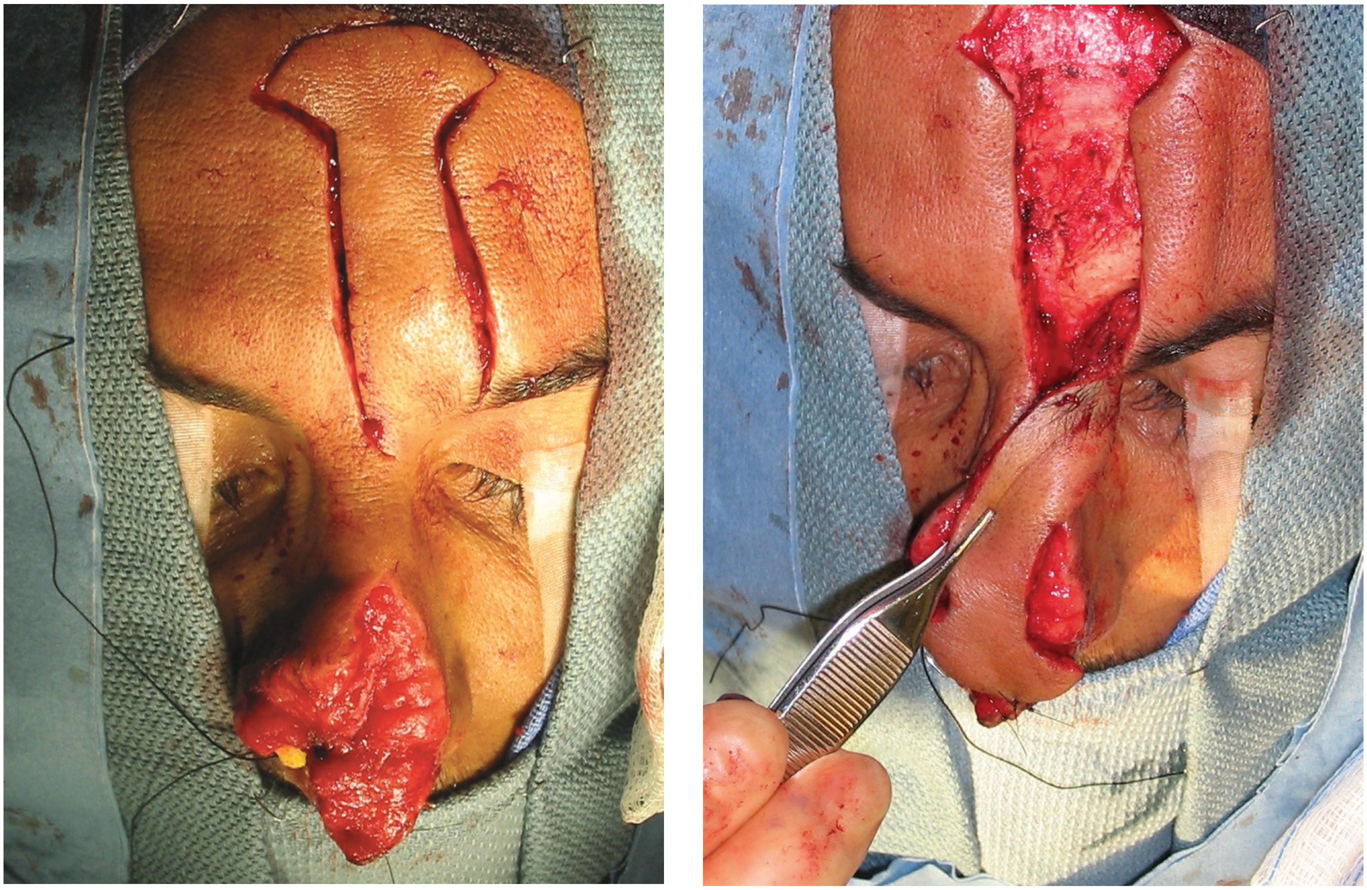


Figure 44. *Gunshot wound to the nose in a host nation male.* (Left) *A median forehead flap was fashioned.* (Right) *Rotation of the flap onto the defect. Image courtesy of the Borden Institute, Office of The Surgeon General, Washington, DC.*

As a general rule, lip defects with less than 33 percent vermillion-lip-length loss can be closed primarily by modifying the defect to a "V" or "M" and advancing the skin-muscle flaps.

Staged forehead flaps based on supraorbital, supratrochlear, infratrochlear, and superficial temporal vessels are robust flaps useful for immediate reconstruction of the avulsed nose (Fig. 44). Full-thickness nasal avulsion with loss of mucosal lining can lead to synechiae and chronic nasal airway obstruction unless the lining is replaced. The author (RGH) prefers a separate broad-based pericranial flap to replace intranasal lining.[64] Loss of septal support is reconstructed with a cantilever cranial bone graft. Melolabial flaps are useful to reconstruct alar defects.

Facial Burns

The immediate concern for significant facial burns (second- and third-degree) is to evaluate the patient for airway burns and secure the airway accordingly. After irrigating the wounds, sterile dry dressings should be applied to wounds. The choice of topical burn dressings and when to apply them are often based on provider preference, available supplies, and transport times between successive medical facilities. Providers in the field should simply cover burns with a clean, dry dressing and avoid applying any topical ointments, including burn creams, to the wounds.[65]

This approach eliminates the need for careproviders to later have to remove creams when patients present at the next facility in the evacuation chain. The use of silver-impregnated dressing such as Silverlon®, Acticoat®, or SilverSeal® as the initial dressing is an alternative option. These materials are easy to apply, provide topical antimicrobial protection, and do not impede the subsequent wound evaluation and care. A more detailed discussion of burn management is found in the Acute Burn Care chapter.

Oral ETTs are best secured by keeping tape and straps off the face and affixing the tube to several lower anterior teeth. Significant burn involvement of the periorbita puts the patient at risk for orbital compartment syndrome, which is prophylactically treated by lateral canthotomies (discussed in detail in the Ocular Trauma chapter). Corneal protection and ectropion prevention are achieved by bolstering eyelids together or performing a Frost suture. Intercommissure lip distance is maintained by a plastic oral prosthesis for perioral burns. Sepsis is not risked by delaying face debridement until burn margins fully demarcate, typically by seven to 10 days. Debridement of deep second- and third-degree burns is followed by dressing changes until the wound bed is ready for closure with skin grafts. Split-thickness skin grafts are used in areas where contracture will minimally harm function (i.e., contracture can be tolerated). Full-thickness skin grafts are preferred in areas such as the perioral region and lower eyelid. Use sutures, Xeroform™ bolsters, and face dressings to secure grafts on the face.

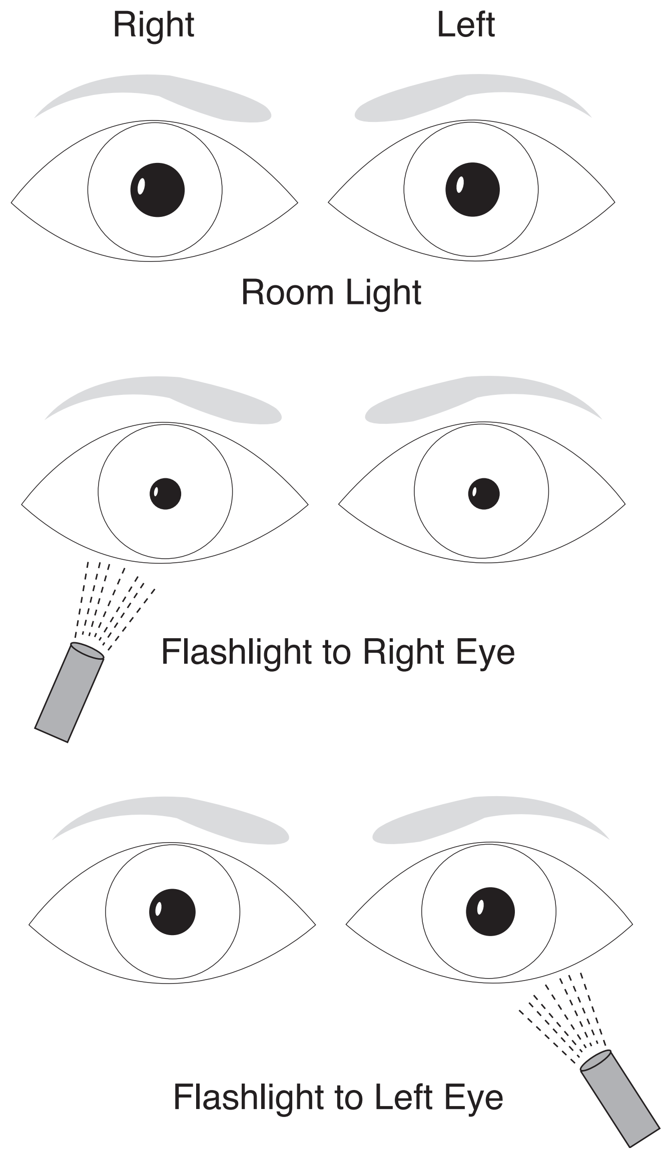


Figure 45. *Swinging flashlight test reveals an afferent pupillary defect in the left eye (anatomical left).*

Upper and Midface Injuries

Ocular Assessment

Management of maxillofacial blast injuries requires the face surgeon to diagnose and treat conditions that threaten vision following trauma or surgery. This is a difficult but important task, especially when treating foreign-speaking, uncooperative, sedated, or obtunded patients. In these situations, an objective clinical method to assess for an afferent pupillary defect (Marcus Gunn pupil) indicates optic nerve dysfunction is helpful (Fig. 45). A field expedient test is the swinging flashlight test. The test is performed in a dark room by methodically swinging a flashlight from one eye to the other. An abnormal exam that indicates optic nerve dysfunction-related vision loss will demonstrate that both pupils will dilate symmetrically when

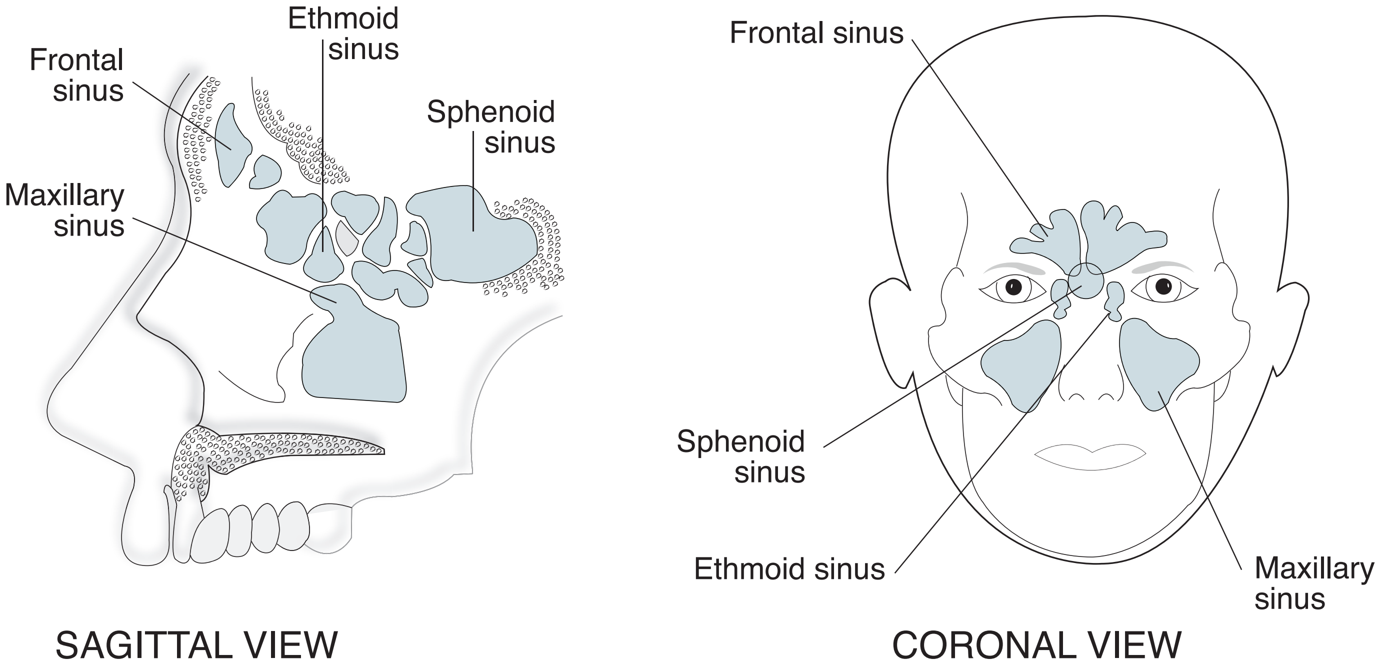


Figure 46. *Schematic of facial sinuses.*

the light is directed into the affected eye, and both pupils will constrict symmetrically when the light is directed into the normal eye.

Frontal Sinus Fractures

The frontal sinus is a paranasal cavity lined by mucosa located between the anterior cranial fossa and the naso-orbito-ethmoidal (NOE) region of the frontal bone. Sinus drainage is through ducts located in the anterosuperior part of the anterior ethmoid complex into the middle meatus. Thin bone separates this sinus from the cranium, which puts the brain at risk from penetrating trauma. Additionally, injury to the frontonasal ducts prevents drainage of mucosal secretions, which can lead to intracranial complications (Fig. 46).[66] Frontal sinus and NOE fractures that extend intracranially can cause a cerebrospinal fluid leak manifested as rhinorrhea (Fig. 47). Significantly displaced posterior wall fractures are usually associated with torn dura.[67] An indication for surgery is the presence of a foreign body in the frontal sinus. Bloody nasal drainage can be field tested at bedside for cerebrospinal fluid by placing the fluid on a linen sheet. Cerebrospinal fluid diffuses faster than blood and creates a clear halo around a bloodstain.[68] Of note, this test is not very accurate and maintaining a high index of suspicion for these injuries is prudent irrespective of test results. The definitive laboratory diagnosis for the presence of cerebrospinal fluid is beta-2 transferrin, which is not routinely available in the combat theater.[69,70,71]

Frontal sinus and NOE fractures that extend intracranially can cause a cerebrospinal fluid leak manifested as rhinorrhea.

The frontal sinus can be approached through an existing skin laceration, but a coronal incision provides the best exposure. The sinus should be explored, irrigated, and all foreign bodies and devitalized tissue removed. If a nasofrontal outflow tract (frontonasal duct) injury is absent, the anterior sinus wall is anatomically reduced and fixated. If significant bone loss is present or if the fragments are comminuted beyond repair, fixated cranial bone grafts are useful to fill the defects. Fractures involving the nasofrontal outflow tract (frontonasal duct) may produce obstruction and infection. Treatment designed to prevent infection involves sinus membrane ablation and frontonasal duct obliteration.[72] This is performed through a frontal bone flap with removal of all mucosa from the sinus with a rotary diamond burr. A pericranial flap elevated from the coronal flap and placed over bone grafts to plug the duct system is useful to isolate the nasal cavity from the cranium.[73] Obliteration of the sinus with fat or muscle-free grafts is frequently recommended in the literature, but the operated sinus can also be left empty for spontaneous osteogenesis.[74,75,76,77]

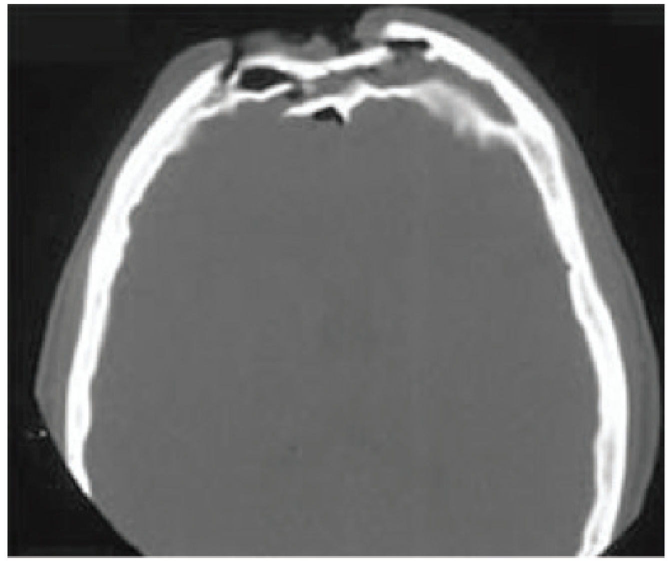


Figure 47. *An axial CT image of a posteriorly displaced frontal sinus fracture. Fracture displacement of the posterior wall of the frontal sinus with cerebrospinal fluid leakage or a foreign body lodged in the frontal sinus is an indication for surgery.*

Significantly displaced frontal bone fractures associated with a cerebrospinal fluid leak require a cranialization procedure in consultation with neurosurgery, if available (Figs. 48 to 55). Cranialization is the removal of the posterior wall of the frontal sinus to repair torn dura and allow anterior displacement of the brain into the prepared sinus cavity. Care must be taken to avoid injury to the dura and superior sagittal sinus during the flap osteotomy. The author (RGH) uses a powered perforator to develop burr holes in the frontotemporal areas, followed by a craniotome with a guarded side-cutting burr to cut and remove two parasagittal frontal bone flaps, leaving a two-centimeter wide bone strut in the midline. The dura over the superior sagittal sinus can then be elevated from the frontal crest and protected during removal of the midline bone strut. This technique adds several minutes to the cranialization procedure but helps avoid tremendous blood loss from violation of the superior sagittal sinus; avoiding neurosurgical complications in a CSH is important because consultation may only be available by Internet. After the posterior wall of the frontal sinus is removed, the dura injury can be repaired. Complete mucosal ablation of the remaining sinus walls is followed by obliteration of the frontonasal ducts. A pericranial flap dissected from the coronal flap can be advanced over the ducts to provide a vascularized brain–nose barrier. It is important to note that performing a cranialization procedure on US service members in a deployed setting without neurosurgical support is not advised. Ideally, such an intervention should be deferred until service members are evacuated to Level IV or V care facilities due to the potential for a catastrophic bleed from the superior sagittal sinus. The face specialist may be forced to perform such an intervention on host nationals, as they typically do not have access to higher levels of care.

Naso-Orbito-Ethmoid (NOE) Region Fractures

The NOE region is beneath the frontal bone and is located below the floor of the anterior cranial fossa and between the medial orbital walls. Besides involving issues relating to nasofrontal outflow tract drainage described above, fractures and penetrating trauma can also cause displacement of the medial canthal ligaments. Instability of the medial canthal ligaments can be assessed by palpating the medial canthus while applying traction on the lateral canthus (bowstring test). A bimanual exam is performed by inserting an instrument intranasally into the area of the medial canthus while placing the index finger externally on the medial canthus. All displaced or unstable NOE fractures require surgery to reconstruct intercanthal distance and nasal projection.

Figure 48. *A 16-year-old Afghan male with an avulsed nose and penetrating injury to the frontal sinus and anterior cranial fossa and left eye from an explosive device. Cranialization of frontal sinus and repair of dura were indicated.*

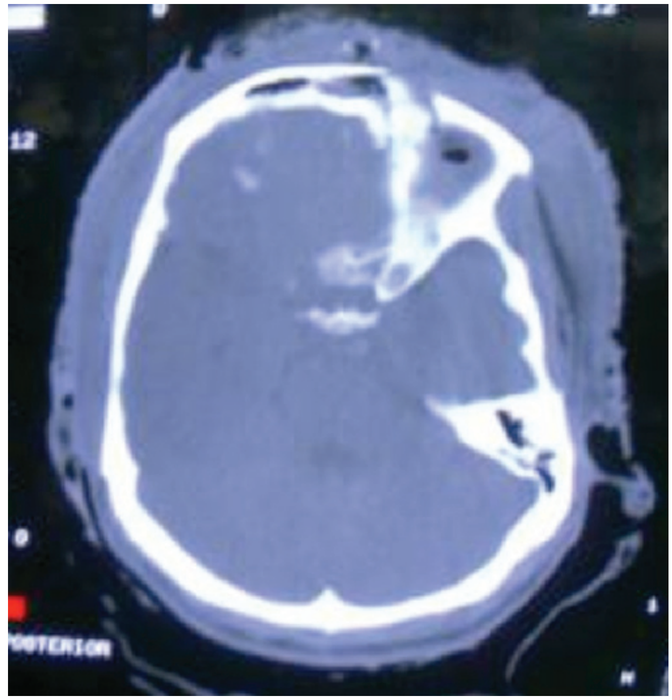


Figure 49. *CT image demonstrating frontal sinus and anterior cranial fossa injury.*

Figure 50. *A guarded craniotome connected the burr holes and the bone flap was carefully elevated to avoid damaging the superior sagittal sinus.*

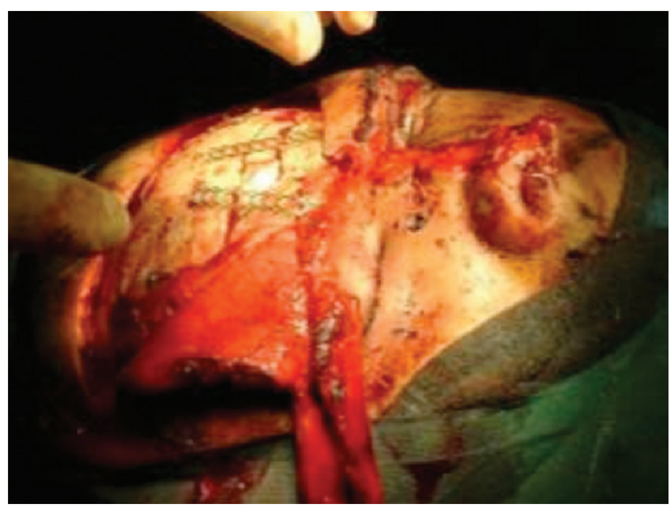


Figure 51. *The frontal flap and fragments are replaced and fixated rigidly.*

Figure 52. *Skin flap reapproximation.*

Figure 53. *Occipital view of scalp wound closure.*

Figure 54. *Patient at one week following injury.*

Figure 55. *Patient at three months following injury after flap division and minor revision.*

Type I NOE fractures involve a large bone fragment with the medial canthi attached. This fracture can be reduced and managed by rigidly fixating the fragment to stable bones superiorly and inferiorly. Type II is a comminuted fracture with the medial canthi attached to operable central bone fragments.[78] Type III NOE fractures involve avulsion of the medial canthus from bone. Type II and III fractures are difficult to treat and require wide exposure through multiple incisions or reflection of a coronal flap beyond the level of the nasofrontal junction with placement of transnasal wires to restore intercanthal distance. Reconstruction of comminuted NOE fractures may require a cantilever cranial bone graft to support nasal projection. The cantilever bone graft engages the area between the upper lateral cartilages and fixates superiorly with miniplates and screws.

Battle injuries to the maxilla, zygomas, orbits, and nose make up at least 44 percent of the injuries to the maxillofacial area.[1] The maxilla occupies the mid-aspect of the face between the cranial base and dentition. Three bony struts support the maxilla: the nasomaxillary, the zygomaticomaxillary, and the pterygomaxillary buttresses. The zygoma articulates with the frontal bone, maxilla, temporal bone, and greater wing of the sphenoid bone. The orbital floor extends back 35 to 40 mm from the rim to the posterior wall of the maxillary sinus. Exploding debris easily penetrates the thin walls of the orbits and paranasal sinuses. The fracture pattern from penetrating trauma varies from typical LeFort to comminuted fractures with avulsed bony fragments. Fractures with no displacement require only observation. Blast debris in the sinuses and airway should be removed. If the fracture is displaced, exploration with anatomic reduction and fixation is indicated. The experience and clinical judgment of the surgeon will dictate the exposure and methods of fixation.

Naso-orbito-ethmoid fractures without displacement require observation only, whereas displaced fractures necessitate exploration with anatomic reduction and fixation.

Zygoma Fractures

Reconstruction of a significantly displaced zygoma fracture requires multiple exposure sites in areas of fracture: the zygomaticofrontal suture, the infraorbital rim, the zygomaticomaxillary buttress, and occasionally the zygomatic arch. The zygomatic arch is an important consideration in aligning significantly displaced or comminuted zygoma fractures because the arch defines midface width and projection. The zygomatic arch should be reduced and fixated as a relatively straight structure. A maxillary vestibule incision provides exposure of the zygomaticomaxillary buttress and infraorbital area. The choice of lower eyelid incision depends on the surgeon's training and experience, but the transconjunctival incision, with or without a canthotomy, has the least risk for lower lid retraction. The zygomaticofrontal suture is exposed by a separate incision in the lateral aspect of the supratarsal fold of the upper eyelid.

For comminuted or severely displaced zygoma fractures, a coronal incision is performed to reconstruct the facial width and projection by exposing the zygomatic arch. In front of the ear and above the arch, the superficial layer of the deep temporal fascia is identified and then incised to the fatty space (superficial temporal fat pad); dissection is carried out in this layer to the arch to avoid injury to the frontal branch of the facial nerve. The zygomatic arch is reduced and fixated, followed by figure-of-eight wire ligature to the zygomaticofrontal fracture and a microplate to the rim. The fractured zygoma can then be rotated into proper position and fixated at the zygomaticomaxillary buttress after confirming intraorbitally that the zygomaticosphenoid (greater wing) articulation is aligned. Cranial bone grafts should be used in areas of avulsion or severe comminution.

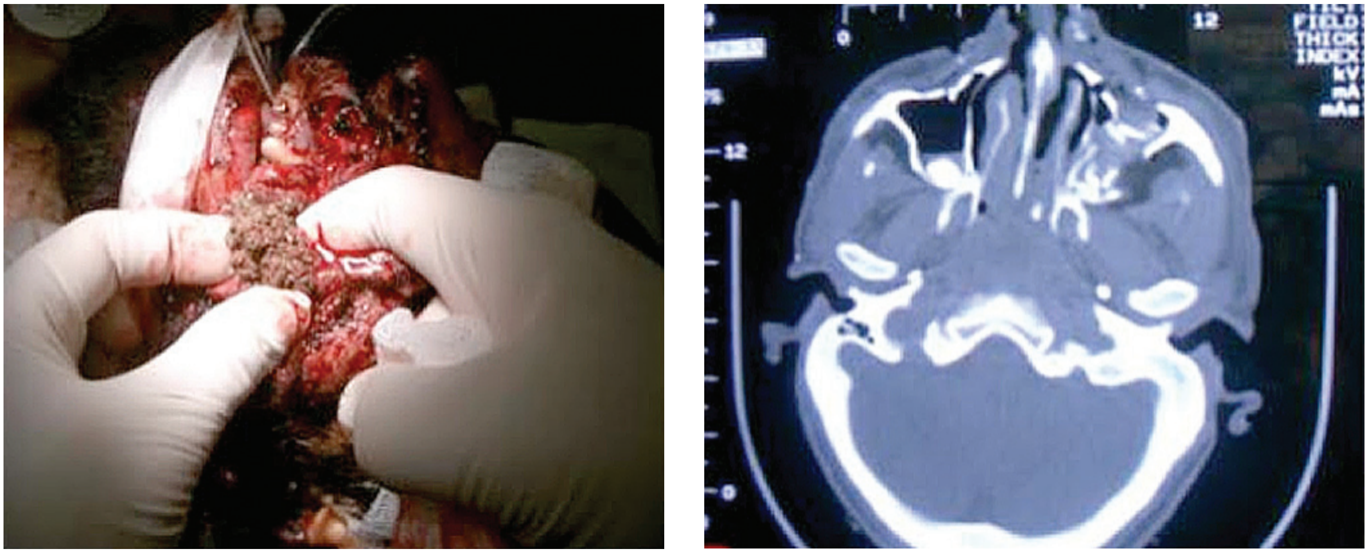


Figure 56. (Left) *A piece of shrapnel removed from a combat casualty suffering penetrating fragmentation injuries to the face.* (Right) *Axial CT image revealing shrapnel that has perforated and comminuted the thin bones of the midface.*

Orbit Fractures

Orbital floor fractures are reconstructed in the usual fashion by identifying the residual floor ledge of the posterior orbit through a lid incision with dissection beneath periorbita. If available, an endoscope inserted into the maxillary sinus can visualize the posterior ledge and confirm adequacy of reduction and reconstruction. Large floor defects are reconstructed with a variety of materials, but in the combat theater choices are limited. To avoid late complications of infection and extrusion, the author (RGH) prefers cranial bone graft shavings harvested from the temporoparietal area with the pericranium attached. These grafts are harvested using a wide, short, and sharp osteotome angled at a low profile and engaged by a heavy mallet. The resultant bone shaving, slightly curled and attached to pericranium, is placed over floor defects. Several stacked shavings may be necessary to correct orbital volume defects; fixation is not necessary.

LeFort Fractures

LeFort fractures present with malocclusion, midface instability, nasal bleeding, and periorbital edema. Penetrating trauma of the maxilla above the dentition can cause a LeFort fracture or penetrate the thin bony walls and lodge debris into paranasal sinuses (Fig. 56). Caldwell Luc access may be necessary to remove debris from the sinus followed by nasal antrostomy (endoscopic equipment is not necessarily available in Level III care facilities). LeFort fractures are manipulated through vestibule incisions and reduction performed to reconstruct facial height, projection, and occlusion. Typically, 1.5 to 2.0 mm bone plates are used to fixate the fracture at the nasomaxillary and zygomaticomaxillary buttresses, and bone grafts are placed in defect areas.

Lower Face Injuries

Penetrating trauma to the lower face by explosive debris can fragment and avulse the thick cortical bones of the mandible and dentoalveolar structures. Fragmentation of the mandible and dentoalveolar structures places the tongue and surrounding areas at risk of laceration with subsequent airway compromise (Fig. 57). Securing a definitive airway is an important consideration for penetrating trauma to the lower face.

The U-shaped mandible has a dentate portion and an articular portion. The dentate portion has a thick, compact, inferior border and a dense dentoalveolar process superiorly. The ascending ramus ends as the condylar process that articulates with the cranium to form the temporomandibular joint. Blood supply to the mandible varies with anatomical area: the ramus, condyles, and symphysis have large muscular attachments to nourish the bone; however the mandibular body receives the majority of blood supply centrally from the inferior alveolar vessels.[79]

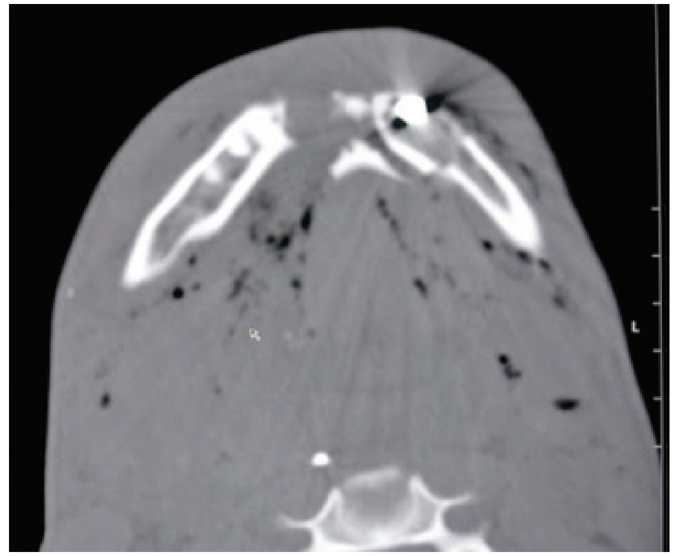


Figure 57. *An axial CT image demonstrating a comminuted mandibular fracture. Fragmentation of the lower face can result in loss of mandibular tongue support and supraglottic edema leading to airway compromise.*

Evaluation

Evaluation of the lower face begins with inspection and palpation of the face along the inferior border and joints to reveal point tenderness, instability, or step-off deformities. Orally, evaluate for malocclusion and disruptions of the soft-tissue envelope, teeth, and dental arch. Anterior traction on the mandible by grasping the mandibular incisors and chin will often cause pain at the fracture sites. Likewise, pushing inward at the angles of the mandible will also reveal fracture sites. Radiographic evaluation of the mandible is best done with a CT scan.

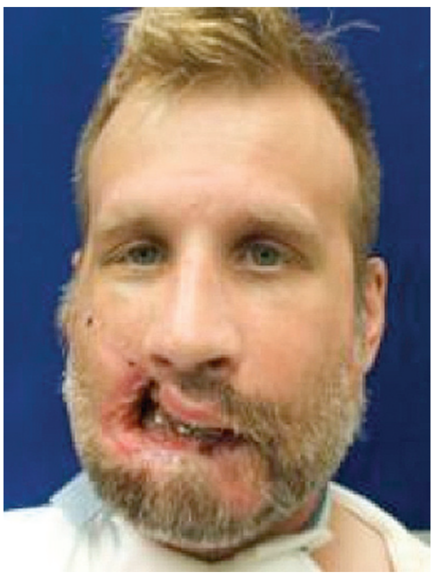
Treatment

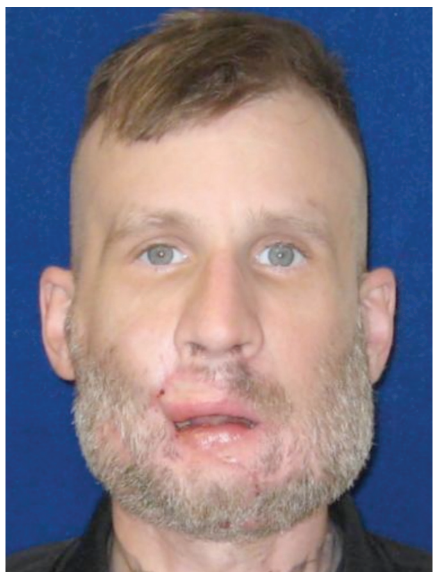
The goal of mandibular reconstruction is restoration of the lower facial height, chin projection, arch form, and occlusion. The location and condition of the fracture dictates the surgical approach. Nondisplaced fractures without occlusal disturbances are treated with a soft diet. Closed reduction is used when a fracture is displaced with minimal occlusal disturbances. Grossly displaced fractures usually require open reduction with internal or external fixation.

> The goal of mandibular reconstruction is restoration of lower facial height, chin projection, arch form, and occlusion.

Uncorrectable or irreparably comminuted open mandibular fractures should be debrided of small, devitalized fragments. Larger, viable fragments should be reduced and fixated as soon as possible to minimize pain, soft-tissue injury, and risk of infection. Reduction of the fractured mandible is aided by dental knowledge and intraoperative intermaxillary fixation to align major dentoalveolar fragments (Fig. 58). The decision to debride or retain a fragment rests with the surgeon's clinical judgment and experience. Any retained fragment needs to be large enough to be fixated and yet remain attached or covered with an adequate soft-tissue envelope for healing. Keep in mind, the soft-tissue envelope of a severely comminuted mandibular body fracture is not only torn and compromised, but also contaminated by bacteria-laden saliva in a nondependent wound bed. The prudent face surgeon chooses the least risky course of action for the situation. An overly limited debridement puts the polytrauma casualty at risk for complications of mandibular infection, while an overly aggressive debridement adds multiple major future interventions to an already complicated treatment course. Of the two extremes, mandibular

Figure 58. (Top Left) *An explosion caused avulsions of 40 percent of the upper lip and 80 percent of the lower lip in this casualty. Shrapnel perforated through the posterior face to cause a LeFort fracture and comminuted bilateral mandible fractures.* (Bottom Left) *Six weeks after bone reconstruction, a series of soft-tissue procedures attempt lip reconstruction (rhomboid, lateral sliding cheek, buccal mucosa flaps, bilateral cervicofacial flap, and ventral tongue flap) with limited success.* (Bottom Center and Bottom Right) *Reconstruction replaced facial features, but microstomia and lip incompetence persisted. This soldier chose to redeploy to Iraq after lip reconstruction.*





infection will likely delay other surgical services from performing critical and timely procedures, whereas complex mandibular reconstruction for a continuity defect can be electively delayed for months until the casualty is sufficiently recovered from multiple other wounds. Likewise, overly limited debridement of a complicated mandible fracture on host nation patients risks infection with the possibility of not having access to timely or sufficient care. Overly aggressive treatment may leave a mandibular continuity defect unrepaired. The treatment decision in a combat zone is difficult; but, in the case of the US service member, the decision can be deferred to a higher level of care. In the case of the injured host nation patient in the combat zone, decision making should involve the patient, family, and command.

Immediate bone grafting of mandibular body defects is not recommended because the wound bed is compromised by injury, contaminated by saliva, and is essentially a nondependent wound of the floor of the mouth.[80] Late grafting of bone defects requires adequate soft-tissue bed and in cases of avulsion, regional soft-tissue flaps (pectoralis) are often needed to prepare the recipient site. Mandibular body continuity defects greater than six centimeters, especially central, are problematic to reconstruct without the advantage of microvascular surgery to perform osseous free flaps.[81,82,83] Consultation with the host nation patient and family, along with command input, will lessen the burden of decision-making since long-term follow-up by the same face surgeon is unlikely.

Immediate bone grafting of mandibular body defects is not recommended because the wound bed is compromised by injury, contaminated by saliva, and is a nondependent wound of the floor of mouth.

Panfacial Fractures

The two basic approaches to panfacial fractures have traditionally been from bottom-to-top or from top-to-bottom.[84,85] The bottom-to-top approach is based on the premise that the mandible can be anatomically reconstructed to provide an intact relationship for positioning of the maxilla. Facial width reconstruction in this technique is based on correct anatomical reduction of the mandibular body, ramus, and condyles. Positioning of the fractured maxilla to the cranium is then based on seating the condyles into the glenoid fossae, as dictated by intermaxillary fixation, followed by zygoma and frontonasal reconstruction. The bottom-to-top approach is preferred in cases of blunt trauma when mandibular continuity can be assured through anatomic alignment and fixation of large fragments.

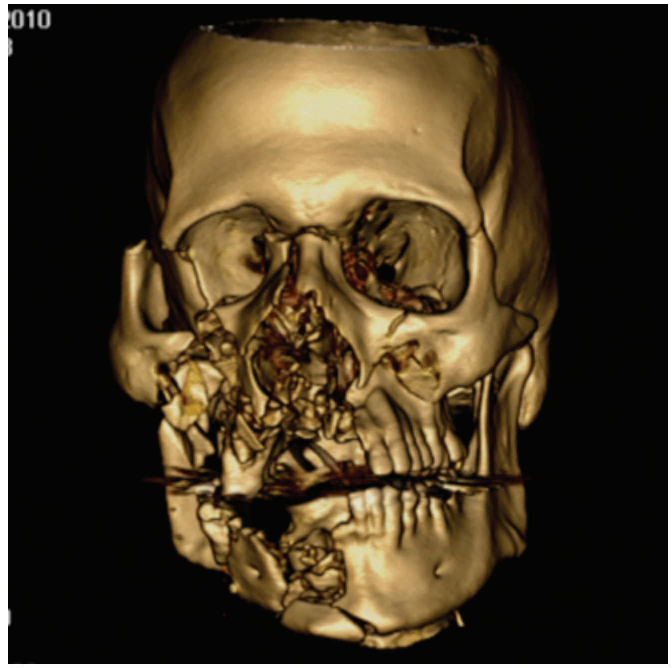


Figure 59. *Complex right orbit, zygoma, maxilla, and mandible fractures due to an IED. Partial avulsion of the maxilla and mandible will challenge the surgeon's ability to symmetrically reconstruct facial width and height. Computer reconstruction of image from a live patient. Stereolithographic resin models and computer imaging are useful reconstruction tools (used at Level V care facilities) when avulsion of key anatomical parts occurs.*

In cases of severe mandibular comminution from a maxillofacial blast injury, anatomical reduction of the mandible may be impossible (Fig. 59). In the top-to-bottom approach, midface projection is defined initially by reconstructing the outer facial frame to include the zygomatic arch, zygoma, and frontal areas. Second, the inner facial frame – including the nasoethmoid complex and infraorbital rims – is reconstructed. Third, the maxilla is repositioned and reconstructed by plating the zygomaticomaxillary and nasomaxillary buttresses. Lastly, temporary intermaxillary fixation followed by open reduction and fixation of the mandible is performed using interdental relationships to dictate mandibular projection. Mandibular continuity defects are reconstructed with reconstruction plates and bone grafted secondarily.

Summary

Management of maxillofacial battle injuries ranges from the simple to the highly complex. Penetrating trauma on the battlefield is the predominant mechanism of maxillofacial injuries. Injuries include multiple complex soft-tissue wounds and open fractures, occasionally complicated by tissue avulsions and burns. Infection of combat-related wounds remains a problem. Broad-spectrum prophylactic antibiotic therapy, administered one hour prior to surgical intervention and continued for a 24-hour period, is recommended. An important consideration to prevent infections is early wound care, early stabilization, preservation of soft-tissue, and early evacuation.

Following patient stabilization, including securing a definitive airway, US service members with severe maxillofacial wounds should undergo conservative wound debridement and be transported to higher levels of care. Difficulty arises in the appropriate planning and execution of definitive repair in host nation civilians, local forces, and detained personnel. In such cases, complex battle injuries are best approached with interventions that have the least risk of postoperative complications but are consistent with predictable and favorable outcomes. Before surgery, it is critical to communicate the operative plan and the possibility of deviation depending on operative findings or postoperative complications. The patient, family, and military command need to be aware of the severity of the injury and the high likelihood that further future reconstructive surgeries and treatment will be needed.

Penetrating Neck Wounds

Introduction

Three percent of wounds sustained in OEF and OIF from October 2001 through January 2005 were neck wounds. Seventy-eight percent of wounds were sustained from explosions.[2] The patterns of injury created by high-energy explosive devices (e.g., IEDs), the weapon of choice of insurgents in Iraq and Afghanistan, are more variable, less predictable, and not as well understood as those seen in previous conflicts or at civilian US trauma centers. Several studies are in the data collection phase, but comprehensive data on battle injuries to the neck and outcomes of treatment have not yet been compiled and published. With that understood, historical studies of trauma management remain a useful starting point for making clinical decisions. In particular, the Advanced Trauma Life Support (ATLS) protocols developed by the American College of Surgeons are largely based on civilian trauma experience, but are the basis of a logical approach to trauma casualties that has stood the test of time.[86]

> The patterns of injury created by high-energy explosive devices are more variable, less predictable, and not as well understood as those seen in previous conflicts or at civilian US trauma centers.

During the 50 years prior to the widespread use of IEDs, injury patterns and treatment outcomes following penetrating neck wounds were fairly consistent. In 1963, Stone et al. reported that vascular injuries in the neck accounted for 50 percent of deaths following penetrating neck trauma.[87] Thirty years later, in a multi-institutional review of penetrating neck injuries from 16 US medical centers, McConnell et al. also reported the number one leading cause of death from penetrating neck trauma was exsanguinating hemorrhage.[88] In that study, the following incidence of injury to structures of the neck was reported: larynx and trachea (10 percent), internal jugular vein (9 percent), common and internal carotid arteries (7 percent), subclavian artery (2 percent), external carotid artery (2 percent), and vertebral artery (1 percent). Other relevant observations in the study include: (1) that one-third of initially asymptomatic patients with Zone I neck trauma were ultimately diagnosed with significant Zone I neck injuries; and (2) 25 percent of initially asymptomatic patients with neck Zone III trauma were diagnosed with an arterial injury. Penetrating trauma to Zone II managed by mandatory neck exploration was negative 30 to 50 percent of the time. A major cause of late mortality was missed esophageal injuries because esophageal and pharyngeal injuries were often asymptomatic on presentation. When surgical repair or drainage was performed less than 24 hours after the injury, the survival rate was greater than 90 percent; when performed more than 24 hours after the injury, survival dropped to 65 percent.[88,89]

Anatomy

It is useful to divide structures of the neck into five major functional groups to ensure a comprehensive assessment is performed and as a map for focusing a secondary survey and surgical approaches (Table 6). Two muscles of the neck serve as key landmarks and their importance must be understood. The platysma defines superficial from deep structures of the neck. If a wound does not penetrate deep to the level of the platysma, it is not classified as a penetrating neck wound. Although the transverse cervical veins, running superficial to the platysma, may be large and can bleed profusely when severed, they are easily controlled with direct pressure and can be managed with simple ligature. The sternocleidomastoid muscle further divides the neck into the anterior triangle and posterior triangle (Fig. 60). Generally speaking, the posterior triangle contains the spine and muscles, whereas the anterior triangle contains the vasculature, nerves, airway, esophagus, and glands.

> If a wound does not penetrate the platysma, it is not classified as a significant penetrating neck wound.

Neck Anatomy
• Airway (pharynx, larynx, trachea, lung) • Major Vessels (carotid arteries, innominate artery, aortic arch vessels, jugular veins, subclavian veins) • Gastrointestinal Tract (pharynx, esophagus) • Nerves (spinal cord, brachial plexus, peripheral nerves, cranial nerves) • Bones (mandibular angles, styloid processes, spine)

Table 6. *Neck anatomy.*

Neck Zones

When evaluating penetrating injuries, the neck is commonly divided into three anatomic zones for purposes of initial assessment and management planning (Fig. 61). The utility of this division is based upon two concepts: injury patterns and surgical management approaches. As discussed above, injury patterns from high-energy explosives are variable, lowering the predictive value of observing a penetrating wound in a particular zone. However, the limitations associated with surgical exploration and control of hemorrhage in each zone still make the concept useful. The boundaries and major contents of each zone are reviewed here. The impact of injuries on management planning is discussed by zone in a later section.

Zone I is the horizontal area between the clavicle/suprasternal notch and the cricoid cartilage (including the thoracic inlet). Surgical access to this zone may require thoracotomy or sternotomy, management of vascular injuries here is challenging, and injury mortality is high.[90] The proximal common carotid, vertebral and subclavian arteries, subclavian, innominate and jugular veins, proximal trachea, recurrent laryngeal nerves, esophagus, thoracic duct, lower thyroid and parathyroid glands, and thymus are located in this zone. Zone II is the area between horizontal lines drawn at the level of the cricoid cartilage and the angle of the mandible. Surgical access to this zone is straightforward, via a standard neck exploration incision. Zone II contains the internal and external carotid arteries, jugular veins, pharynx, larynx, esophagus, recurrent laryngeal nerves, spinal cord, trachea, upper thyroid, and parathyroid glands. Zone III lies between the angle of the mandible and the base of the skull. Surgical access to this zone often requires mandibulotomy or maneuvers to anteriorly displace the mandible, and may require craniotomy. Management of vascular injuries here is difficult, and injury mortality is high.[91,92] Zone III contains the extracranial carotid and vertebral arteries, the jugular veins, cranial nerves IX through XII, and the sympathetic nerve trunk.

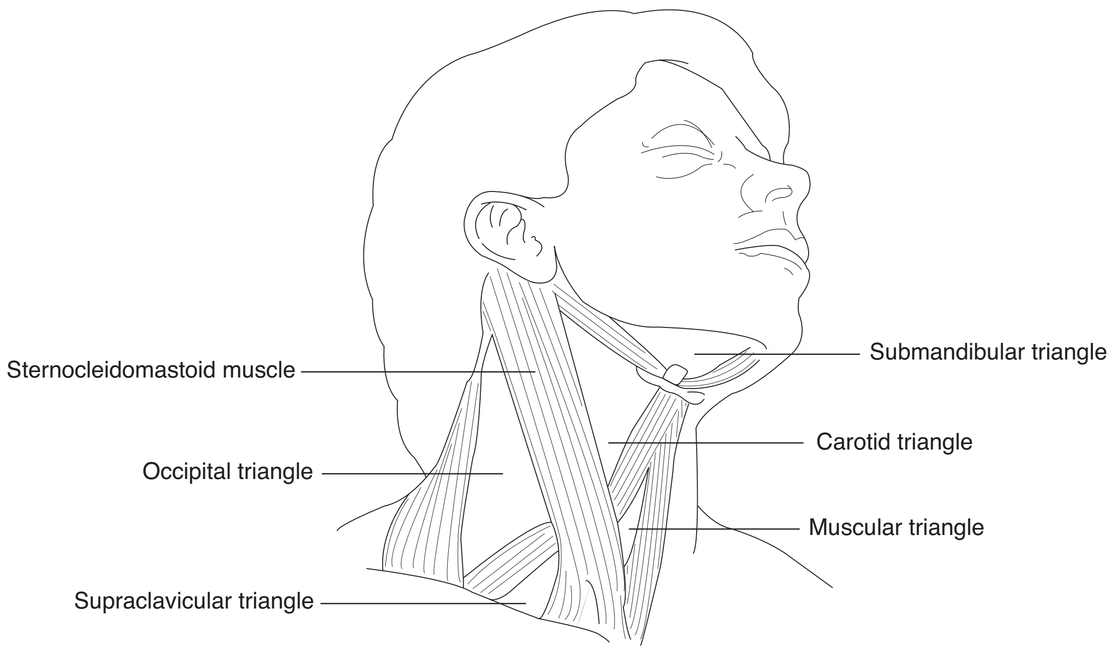


Figure 60. *Triangles of the neck. The sternocleidomastoid muscle divides the neck into the anterior triangle and posterior triangle.*

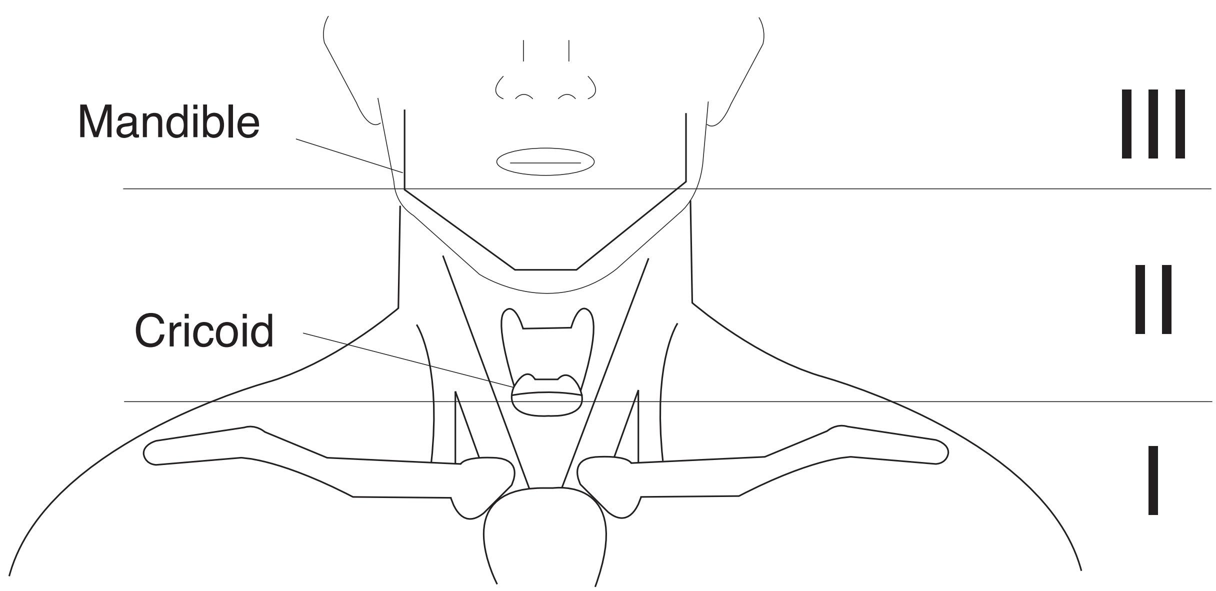


Figure 61. *The neck is commonly divided into three anatomic zones for purposes of initial assessment and management.*

Information for the Generalist - Neck Wounds

Initial Assessment and Management

Casualties with signs of significant neck injury, including active pulsatile hemorrhage, expanding hematoma, bruit, pulse deficit, subcutaneous emphysema, hoarseness, stridor, respiratory distress, or hemiparesis, have indications for immediate operative management and require urgent surgical consultation.[93]

Airway

The first priority in penetrating neck trauma is to assess and secure the airway, keeping in mind the potential for concomitant cervical spine injury. It may be difficult to fully assess the cervical spine until the airway is controlled, and rigorous spinal precautions should not be maintained at the expense of managing life-threatening airway or vascular injuries. Orotracheal intubation is the initial method of choice for securing the airway under most circumstances in Level III care facilities. Nasal intubation and fiberoptic intubation techniques are technically more difficult, require special equipment, and should be reserved for elective airway management. Use of a LMA™ to ventilate a casualty may serve as a bridge to buy time but is not a secure airway. A pharynx filled with blood or distortion of laryngeal landmarks can make endotracheal intubation difficult, and repeated blind intubation attempts risk enlarging a penetrating injury of the pharynx.

As discussed earlier in the chapter, cricothyroidotomy is the preferred method for establishing an immediate airway if rapid endotracheal intubation is not possible or is contraindicated. In casualties with large penetrating anterior neck wounds that require an urgent airway, consider extending the wound as necessary and intubating through the wound by isolating the trachea between two fingers and completing an incision into the anterior trachea. An emergency tracheotomy is the preferred method of establishing a definitive airway in cases of suspected tracheal disruption. Attempts at endotracheal intubation could convert a partial tracheal disruption into a complete transection, while attempts at a cricothyroidotomy would be futile, as the injured segment lies distal to the incision site.

The airway should be considered at-risk in any casualty that presents with a penetrating neck wound. An unremarkable physical exam in a soldier with well-developed cervical musculature who presents with a small penetrating wound(s) to the neck can be deceiving (Fig. 62). Casualties who appear to have a minor neck wound may still have a significant injury. Stridor, hoarseness or dysphonia, hemoptysis, and subcutaneous air should be specifically looked for and indicate potentially significant injury to deeper structures. Fiberoptic laryngoscopy (when available) is a helpful adjunct for identifying airway injuries.

In difficult to intubate casualties with large penetrating anterior neck wounds that require an urgent airway, consider extending the wound as necessary and intubating through the wound by isolating the trachea between two fingers and completing an incision into the anterior trachea.

Bleeding

Do not blindly clamp bleeding vessels in the neck. Most survivable hemorrhage from neck wounds can

Figure 62. (Top Left and Top Right) *These images illustrate a gunshot wound to the neck with an expanding hematoma. Casualties who appear to have a minor neck wound may still have a significant injury.* (Bottom Left) *Proximal and distal ligature control.* (Bottom Right) *Primary repair of a common carotid injury with saphenous vein graft. Images courtesy of Joel Nichols, MD.*

be controlled with directed pressure above and/or below the wound (compressing a bleeding vessel against the vertebrae), application of pressure directly over the wound, or by packing the wound with gauze. Vaginal tampons inserted into wounds (one- to two-centimeter size bleeding lacerations) caused by shrapnel can be effective at controlling hemorrhage. Pharyngeal packing after an airway has been secured is effective at controlling severe oral bleeding but must be under pressure and may require a full Kerlix™ roll or more to tamponade bleeding. Do not probe open neck wounds. This may lead to clot dislodgement and vigorous bleeding can occur. Injuries that do not penetrate the platysma do not cause significant injuries.[94] If violation of the platysma is uncertain, gently spread wound edges without probing. Stop as soon as platysma violation is recognized and call a surgeon. Suspect subclavian artery or vein injury in casualties with Zone I penetrating neck injuries. Intravenous access should be attained on the side of the body opposite the site of injury or in the lower torso/extremities to avoid potential extravasation of fluids.

Do not blindly clamp bleeding vessels in the neck. Most survivable hemorrhage from neck wounds can be controlled through application of pressure directly over the wound or by packing the wound with gauze.

Considerations for the Specialist

Operative Indications

It is useful to triage patients with penetrating neck injuries as either symptomatic or asymptomatic. Symptomatic injuries require immediate surgical exploration. Evidence of significant injury includes active pulsatile hemorrhage, expanding hematoma, bruit, pulse deficit, hoarseness, stridor, respiratory distress, or hemiparesis. Asymptomatic patients may be observed pending completion of appropriate studies. Choice of studies is guided by the location of the wound and often dictated by availability of resources.

Role of Imaging

Improvements in imaging technology, particularly computed tomographic angiography (CTA), are changing the management of patients with penetrating injuries of the neck in combat zones. In many Level III CSHs, CTA for examination of the vasculature has become the preferred method of evaluation due to the possibility of retained projectiles and occult injuries to the great vessels of the neck.[95] This reflects civilian trauma center experience. In a five-year retrospective study from 2000 to 2005 evaluating the role of CTA in clinical decision-making in the management of penetrating injuries to the neck, Osborn et al. reported that the use of CTA eliminated the performance of negative neck explorations without increasing adjunctive studies (esophagography, angiography, and various endoscopic procedures). No difference in morbidity or mortality was reported between their two study groups.[96]

Immediate Hemorrhage Control

In the authors' experience, external carotid artery injuries are easily managed by suture ligation. All veins in the neck can be safely ligated to control hemorrhage. Casualties with large venous injuries should have their wounds covered with tightly adherent dressing (e.g., Vaseline® gauze dressing) and should be placed in the Trendelenburg position if there is any concern about internal jugular vein injury and possible air embolus. If both internal jugular veins are interrupted by the injury, an attempt to repair one is appropriate. Exsanguinating oropharyngeal hemorrhage should be controlled by obtaining an immediate surgical airway (cricothyroidotomy or tracheotomy) followed by packing the pharynx. The casualty is then taken to the operating room, where a wide apron-incision is made from the mastoid tip to the midline of the neck at the cricoid level for definitive exploration. Although studies have shown that it is safe to close uncontaminated penetrating neck wounds primarily within six hours of injury, there is insufficient evidence to make a recommendation regarding primary closure of neck wounds caused by IEDs.[97]

Exsanguinating oropharyngeal hemorrhage should be controlled by obtaining an immediate surgical airway followed by packing the pharynx.

Penetrating Neck Injury Management

Zone I

Zone I injuries are reported to have a mortality rate as high as 12 percent.[90] The bony thorax and clavicle make surgical exploration of the root of the neck challenging. Stable casualties with Zone I injuries should be further evaluated by arteriography, laryngoscopy, and esophagoscopy. Unstable casualties with Zone I injuries require a median sternotomy or left anterior thoracotomy to control hemorrhage. Surgical repair is preferred unless the patient has already developed neurological changes consistent with coma and arteriogram confirms absence of antegrade flow. The decision to explore a Zone I injury should be reserved for surgeons with experience with these approaches.

> Unstable casualties with Zone I injuries require a median sternotomy or left anterior thoracotomy to control hemorrhage.

Zone II

Management of Zone II injuries continues to be debated. Multiple civilian studies have documented the safety of selective exploration of neck wounds that penetrate the platysma, and the management of casualties without significant symptoms is changing as technology advances. The most recent thorough review published on this subject was performed by Tisherman et al. in 2008.[98] These authors evaluated 112 articles examining the issue of mandatory exploration of all patients with penetrating neck wounds versus selective exploration based on physical examination with or without use of current imaging technologies and summarized their conclusions as clinical practice guidelines. They found strong evidence that selective operative management and mandatory exploration of penetrating injuries to Zone II of the neck have equivalent diagnostic accuracy and recommended selective exploration to minimize unnecessary surgery. They identified multiple studies that showed selective operative management of these injuries by experienced surgeons was safe in both community hospital and trauma center settings, with no difference in morbidity or mortality.[99,100,101] Tisherman et al. cited studies demonstrating CTA can safely reduce the number of negative neck explorations and that CTA or duplex ultrasound can be used in lieu of arteriography to rule out Zone II arterial injury following penetrating trauma to Zone II of the neck.[102,103,104,105] Based on the strength of evidence cited, the authors recommended high-resolution CTA as the initial diagnostic study of choice for Zone II penetrating injury to the neck. They also found evidence that careful serial physical examination, including auscultation of the carotid artery, is greater than 95 percent sensitive for detecting arterial or aerodigestive tract injuries requiring repair, but cautioned that clinicians should have a low threshold for obtaining imaging studies.[106,107]

The review by Tisherman et al. is thorough and timely, but caution must be exercised in extrapolating conclusions drawn from civilian experience to current combat environments.[98] In the authors' experience, the following management practices have been successfully employed in OEF and OIF. Symptomatic casualties (e.g., active pulsatile hemorrhage, audible bruit, rapidly expanding hematoma, airway or neurovascular compromise) with penetrating Zone II neck wounds undergo neck exploration. Asymptomatic casualties with penetrating Zone II neck wounds may be observed with frequent monitoring while being further evaluated for injury to the great vessels, trachea, or aerodigestive tract. Computed tomographic angiography or conventional arteriography, laryngoscopy and esophagoscopy are performed if the wounds are not surgically explored. If CTA or conventional arteriography, laryngoscopy, and esophagoscopy are not available, asymptomatic casualties with penetrating Zone II neck wounds are monitored continuously until transfer to a facility with advanced capabilities, or the wounds are surgically explored.

Although there is strong evidence that selective operative management and mandatory exploration of penetrating injuries to Zone II of the neck have equivalent diagnostic accuracy, caution must be exercised in extrapolating conclusions drawn from civilian experience to current combat environments.

A low threshold for proceeding to surgical exploration is suggested for casualties with multiple penetrating Zone II neck wounds such as shrapnel injuries from a high-energy explosive device. Further studies of high-energy blast wounds are necessary to determine whether CTA is sufficiently sensitive for detecting injuries that require surgical intervention and whether CTA may be relied upon to guide patient management. Based on the authors' experience, strict observation of casualties with penetrating Zone II neck wounds from blast injuries without concurrent radiographic evaluation of the great vessels, trachea, and esophagus (observation alone) is not recommended (Fig. 63).

Zone III

Zone III injuries are also associated with a high mortality rate.[91,92] The skull base, styloid process, and

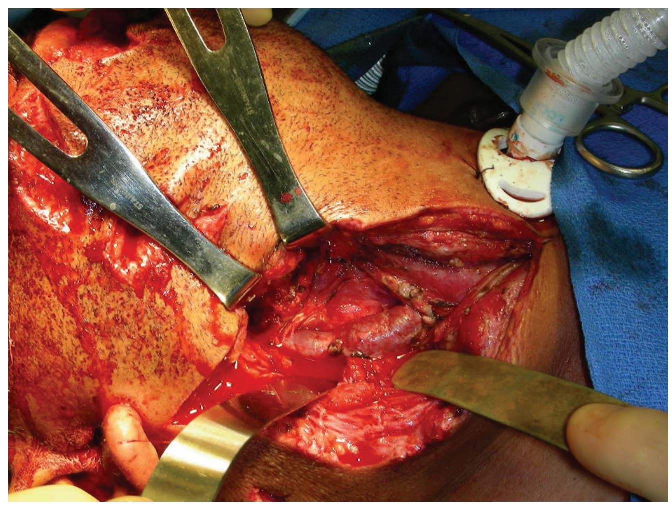


Figure 63. (Top Left) *Shrapnel injuries to the face and neck. This image demonstrates a patient with a secure surgical airway.* (Top Right) *Exposure of the great vessels of the neck during surgical exploration of Zone II neck injury.* (Bottom Right) *Closure of the wound.*

mandible make surgical exposure in this area difficult. The mandible may need to be divided or displaced anteriorly by dividing the stylomandibular ligament. Craniotomy may be required to control a high-carotid injury in this location. Stable casualties with Zone III should be further evaluated by arteriography to exclude carotid/vertebral artery injuries and a Gastrografin® contrast swallow imaging study should be considered if there is any suspicion of esophageal injury.[89, 93,108] When arteriography is not available, frequent intraoral examination should be performed to observe for edema or expanding hematoma within the parapharyngeal or retropharyngeal spaces. Nerves exiting the skull base are in close proximity to the great vessels, thus neurological deficits in a casualty with a Zone III injury are suggestive of injury to the great vessels.[91]

The decision to explore a Zone III injury should be reserved for surgeons with experience performing these approaches.

Bleeding from the internal carotid artery in Zone III may be controlled by passing a small-diameter (e.g., 4 French size) Fogarty catheter proximal to the injury and inflating the balloon to occlude the lumen. Alternatively, the internal carotid artery may be ligated through an incision parallel to the anterior border of the sternocleidomastoid muscle. If the internal carotid artery is ligated, the distal injury may continue to bleed from collateral circulation through the Circle of Willis and require packing as the artery enters the skull base. Achieving hemorrhage control of penetrating vertebral artery injuries can be very challenging and is associated with high morbidity and mortality rates.[92] The decision to explore a Zone III injury should be reserved for surgeons with experience performing these approaches.

Esophageal Injury

Esophageal injuries may be clinically silent initially. Signs of esophageal injury include subcutaneous air, crepitus, dysphagia, odynophagia, drooling, and hematemesis. Missed esophageal injuries are the cause of the majority of delayed complications seen with penetrating neck injuries.[89,108] When an esophageal leak progresses to mediastinitis, morbidity and mortality are significant.[89,107,109] Either contrast esophagography or esophagoscopy should be used to rule out an esophageal perforation that requires operative repair. Diagnostic workup should be expeditious as management delayed by more than 24 hours increases morbidity and mortality.[89,108] Early diagnosis may allow primary repair to be performed and generally results in superior outcomes.[109]

If esophageal injury is suspected, either contrast esophagography or esophagoscopy should be used to rule out an esophageal perforation that requires operative repair. Diagnostic workup should be expeditious as management delayed by more than 24 hours increases morbidity and mortality.

The accuracy of the evaluation for esophageal injury is dependent on the skills of the careproviders and the availability of diagnostic equipment. The sensitivity of esophagography to detect an esophageal injury is 62 percent to 100 percent, and the sensitivity of esophagoscopy is 43 percent to 100 percent.[110,111] In cases in which the cervical spine has not been cleared, flexible endoscopy is helpful in evaluating injuries of the pharynx and esophagus.[112,113] There have been reports of missed perforations near the cricopharyngeus muscle or in the hypopharynx, where flexible endoscopy is less effective because of mucosal redundancy.[114,115,116] Studies utilizing a combination of flexible endoscopy and rigid esophagoscopy to examine the entire cervical and upper thoracic esophagus generally demonstrate the best results. No perforations were missed in those series that used both techniques to evaluate all patients.[117] Gastrografin®

is recommended as a first-line contrast study agent for evaluation of esophageal injury.[118] Barium is used as a second-line agent because barium extravasation radiographically distorts soft-tissue planes for future studies, and it is more toxic to the peritoneal cavity. Care must be exercised to ensure patients do not aspirate Gastrografin®, which can cause significant pulmonary toxicity.[119]

If suspicion of a pharyngeal perforation remains despite an initial negative examination or exploration, the casualty should be kept nil per os (NPO), observed for seven days, and a swallow study should be repeated prior to advancing the diet to clear liquids. Fever, tachycardia, or widening of the mediastinum on serial chest radiographs or CT indicates the need for repeat endoscopy or neck exploration. When an esophageal injury is found early, surgical management should include copious wound irrigation, cautious debridement, a two-layer closure, and adequate drainage.[116] After repair of the mucosal perforation, a muscle flap should be placed over the esophageal suture line for further protection. If an extensive esophageal injury is present, a lateral cervical esophagostomy should be created and definitive repair performed later.[116]

> If an extensive esophageal injury is present, a lateral cervical esophagostomy should be created and definitive repair performed later.

Laryngotracheal Injury

When a wound involves the larynx or upper trachea, a tracheotomy should be established below the level of the injury. After a definitive airway is established, laryngotracheal injuries are not life-threatening, and definitive management may be delayed while treating more acute injuries. Laryngeal injuries may be evaluated with flexible endoscopy to differentiate between wounds that need only observation (small or shallow lacerations, nondisplaced fractures) and those that require a thyrotomy for open fracture reduction and mucosal approximation. If rigid endoscopy is performed, care must be taken to avoid extending lacerations.

> When a wound involves the larynx or upper trachea, a tracheotomy should be established below the level of the injury. Definitive tracheal repair may be delayed while treating more acute injuries.

Multiple authors recommend repair of laryngeal mucosal lacerations from a penetrating injury as soon as possible and have found an increase in debilitating long-term sequelae, including airway stenosis and poor voice quality associated with delayed repair. [51,120] Danic reported that even extensive laryngotracheal injuries may be safely repaired early.[97] When the inner laryngeal mucosa in an adult patient is badly macerated, a soft laryngeal stent fashioned from a six-centimeter segment of a 7.0 mm ETT, which has been permanently crimped in the middle by clamping it while heated, should be inserted. The crimp should be at the level of the vocal cords and fixed in place with through-and-through 1-0 Prolene® suture secured to the skin of the neck. An appropriately sized ETT should be selected and fashioned accordingly in smaller adults and children. In the authors' experience, tracheal lacerations extending less than 50 percent of the tracheal circumference do not require repair or tracheotomy. Longer lacerations without significant disruption of the tracheal mucosa may be reapproximated with interrupted 5-0 Prolene® sutures spaced two to three millimeters apart, without the need for a tracheotomy. More severe disruptions are initially treated by placing a tracheotomy either below or through the injury.

Summary

As with all trauma patients, initial management priorities include airway protection, breathing, and circulatory support. Casualties who present with signs and symptoms of shock and continuous hemorrhage from a neck wound should undergo immediate surgical exploration. After life-threatening injuries are stabilized, a more focused evaluation of the penetrating neck wound is undertaken. Upon wound exploration, if the platysma is not violated, surgical exploration is not indicated. Symptomatic casualties (e.g., active pulsatile hemorrhage, audible bruit, rapidly expanding hematoma, airway, or neurovascular compromise) with penetrating Zone II neck wounds should undergo neck exploration. Asymptomatic casualties with Zone II injuries that penetrate the platysma should be evaluated to rule out significant injury to the great vessels, trachea, or esophagus. The evaluation of stable casualties may be delayed if they are carefully monitored at frequent intervals. Casualties with Zone I and III penetrating injuries and penetrating esophageal and laryngotracheal injuries should be transferred to a Level IV or V facility for definitive management as soon as possible.

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