

# Chapter 10

## PATHOPHYSIOLOGY OF HEAD AND NECK INJURIES

JOSEPH A. BRENNAN, MD, FACS\*

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*\*Colonel, Medical Corps, US Air Force; Chief, Department of Surgery, San Antonio Military Medical Center, 3551 Roger Brooke Drive, Joint Base San Antonio, Fort Sam Houston, Texas 78234; Professor of Surgery, Uniformed Services University of the Health Sciences*

## INTRODUCTION

Over the past 150 years, military personnel wounded in action have had a survival rate of approximately 80%.<sup>1</sup> During the Vietnam War, service members wounded in action had survival rates ranging between 76% and 86.5%.<sup>2,3</sup> During the current conflicts in Iraq and Afghanistan, the survival rate is 90.4%.<sup>2,3</sup> This significant increase in the survival of those wounded in Iraq and Afghanistan has occurred despite the increased lethality of weapons used in both conflicts. Improvised explosive devices (IEDs) are now the most common mechanism of injury, accounting for as high as 76% of combat injuries in Iraq and Afghanistan.<sup>4</sup> In previous conflicts, blast injuries accounted for less than 10% of the wounded.<sup>1</sup>

During the past 10 years in Iraq and Afghanistan,

thousands of head and neck trauma patients have been treated at American medical facilities in both war zones.<sup>5,6</sup> The multispecialty head and neck surgical teams treating these patients include neurosurgeons, otolaryngologist/head and neck surgeons, oral maxillofacial surgeons, and ophthalmologists.<sup>7</sup> Valuable head and neck trauma lessons applicable to military and civilian practice were learned in Iraq and Afghanistan. These unique insights could be used in the civilian practice of trauma, especially in those situations where mass casualty events overwhelm the resources of local civilian medical facilities. Furthermore, these unique lessons learned can be used to guide head and neck trauma education and preparation for military and civilian surgeons.<sup>8,9</sup>

## PATHOPHYSIOLOGY OF HEAD AND NECK INJURIES

The most common mechanism of injury, the IED, typically occurs at close range and results in multisystem high-velocity injuries that can be devastating to the head and neck.<sup>10,11</sup> Even though the head, face, and neck comprise only 12% of the total body surface area, the incidence of head, face, and neck injuries in Operation Iraqi Freedom (OIF) and Operation Enduring Freedom (OEF) ranges between 25% and 40% of American wounded.<sup>5,6,12-16</sup> The higher incidence of head and neck injuries noted in OIF/OEF was discussed in detail in the "Sites of Injury" section in Chapter 6.

### Impact of Body Armor

Body armor consists of a vest with ceramic plates that can stop high-velocity bullets and fragments. Body armor can prevent torso, abdominal, and pelvic wounds, but with the exception of ballistic goggles and a helmet protecting the eyes and skull, the face and neck are unprotected.<sup>7,12</sup> The success of body armor in preventing torso wounds was demonstrated when only 10% of US Marines wearing body armor sustained torso wounds, while 24% of Iraqis without body armor sustained torso wounds.<sup>17,18</sup> However, body armor has

a negligible impact on the incidence of head and neck wounds. Investigations by forward surgical teams showed that US service members wearing body armor had a 19% incidence of head and neck wounds, while those without body armor had a 17% incidence of head and neck wounds.<sup>19</sup>

Due to the success of body armor in preventing potentially lethal torso injuries, the head and neck surgical teams are able to treat more patients with isolated and potentially survivable head and neck wounds. In previous conflicts, many soldiers with head and neck wounds who presented with potentially fatal chest and abdominal injuries were declared expectant.<sup>7</sup>

### Pretreatment by Forward Surgical Teams

Surgeons must be well trained and prepared to treat both acute "bleeding" trauma and complex craniofacial reconstructive trauma.<sup>20</sup> The belief that "by the time I get there" the patient will be stabilized may be false. The experience of the deployed head and neck surgeons in Iraq and Afghanistan differed greatly. In the "Pretreatment" section of Chapter 6, these different experiences are discussed in detail.

## BALLISTICS OF HEAD AND NECK TRAUMA

### Weapons

The mechanisms of head and neck injury seen in OIF and OEF included IED, gunshot, mortar/rocket, grenade (rocket propelled and hand grenade), mine, closed head trauma, and non-combat injuries (as-

sault and motor vehicle accident). Clearly the most devastating injuries are caused by IEDs, which have become the most commonly used weapon, causing more than 70% of head and neck trauma (Figure 10-1).<sup>21</sup> IEDs are the most lethal weapons seen in modern warfare and are the leading cause of death



**Figure 10-1.** Improvised explosive device injury.

on the battlefield. IEDs include a plethora of weapons that can be divided into three categories: (1) roadside explosives or blast mines usually formed from conventional ordinance; (2) explosive-formed projectiles with penetrator devices designed to breach armored vehicles; and (3) suicide bombings, including human-borne and vehicular IEDs.<sup>10,11</sup> IEDs combine blunt, penetrating and burn injuries, resulting in a chain of events after the detonation of the explosion causing widespread damage.<sup>3,10</sup> The chain of events includes the initial shock front of the blast (primary injury), followed by the blast wind propelling multiple penetrating fragments (secondary injury), which are the predominant wounding agent.<sup>10</sup> The wind also propels large objects into people or people into large objects, causing blunt or crush injuries (tertiary injuries).<sup>10</sup> Finally, heat, flames, gas, and smoke cause burns, inhalation injuries, and even asphyxiation (quaternary injuries).<sup>10</sup> If bacteria and radiation are added to the IED, these agents cause additional short-term and long-term morbidity (quinary injuries).<sup>10</sup>

### PENETRATING MISSILE CATEGORIES

Penetrating missiles seen in combat may be divided into three general categories: (1) knives, (2) single projectiles, and (3) multiple projectiles.<sup>23</sup> Each of these missiles has unique wound characteristics that will guide definitive treatment.

The first category, knives, generally travel in a straight line through tissue, but the direction of penetration and damage may be difficult to ascertain. The head and neck tissue injury will correlate

IEDs produce the “ultimate polytrauma,” resulting in potentially lethal high-velocity injuries to multiple anatomic locations.<sup>10</sup> An anatomical study of IED wound patterns demonstrated that IED survivors were wounded in 2.61 anatomic locations, while IED fatalities were wounded in 4.67 anatomic locations.<sup>22</sup> Research is ongoing to further improve the survival of service members wounded by IEDs.

### Physiology of High-Velocity Trauma

The severity of a projectile injury is directly related to the kinetic energy imparted by the missile to the tissue.<sup>23</sup> The equation determining kinetic injury is

$$KE = \frac{1}{2} m (V_1 - V_2)^2$$

where KE: kinetic energy; m: missile mass;  $V_1$ : entering velocity; and  $V_2$ : exiting velocity.<sup>23,24</sup> The most lethal projectiles are high-velocity missiles that impart all their energy into the tissue, with a high entering velocity and without exiting the tissue ( $V_2 = 0$ ).<sup>23</sup> A high-velocity missile is a projectile with a velocity greater than 610 m per second.<sup>24</sup> It should be noted that a projectile travelling only 50 m per second will break skin, and a projectile traveling only 64 m per second will break bone.<sup>24</sup>

High-velocity projectiles form two wound cavities on impact. A permanent cavity is caused by the direct impact of the projectile, with a size three to four times the cross-section of the projectile.<sup>24</sup> A temporary cavity is proportional to the kinetic energy of the projectile and may be up to 30 times the cross-section of the projectile.<sup>24</sup> Consequently, high-velocity projectiles cause a large temporary cavity with extensive tissue damage and high morbidity and mortality. After high-velocity injury to the facial soft tissues, the temporary cavity resulting from the high kinetic energy of the missile may partially devitalize a large area of soft tissue surrounding the wound. Even with the large blood supply to the face, “doing too much too soon” with extensive soft tissue undermining and flap rotation may result in dead tissue.

with the size and type of blade (blade length, blade width, single edge versus double edged serration). In addition, the direction of entry can be estimated by the relative position of the attacker, the hand the attacker used, and whether the blade was held upward or downward.<sup>25</sup> However, since the blade may twist and rotate within the tissue, the ultimate track of the blade cannot be fully predicted based on the above factors.

Single projectile weapons include high-velocity rifles and low-velocity handguns.<sup>23</sup> Handguns range from .22- to .45-caliber weapons and impart between 100 ft-lb to over 1,000 ft-lb of energy to tissue.<sup>24</sup> The muzzle velocity of handguns ranges between 210 and 600 m per second, defining them as low-velocity weapons.<sup>24</sup> Rifles range from .17 to .46 caliber and can impart over 3,000 ft-lb of energy to tissue.<sup>24</sup> The muzzle velocity of a rifle exceeds 610 m per second, which is the definition for a high-velocity weapon.<sup>24</sup> As previously discussed, a weapon with a muzzle velocity of only 50 m per second will break skin and a muzzle velocity of 64 m per second will break bone.<sup>24</sup> High-velocity missiles with high kinetic energy produce a large temporary cavity within the head and neck, resulting in extensive soft tissue and bony damage.

The third missile category, multiple projectile weapons, include high-velocity close-range (<5 m) shotguns; low-velocity long-range (>5 m) shotguns; and high-velocity bombs, mortars, grenades, and IEDs.<sup>23,24</sup> Shotgun wound severity is determined by several factors including weapon-to-victim range, type of weapon, type of shot, and choke setting.<sup>26,27</sup> The Sherman classification of birdshot (shot diameter <0.14 in) shotgun wounds as modified by Ordog is as follows: Type 0: does not violate platysma; type 1: penetrates subcutaneous tissue

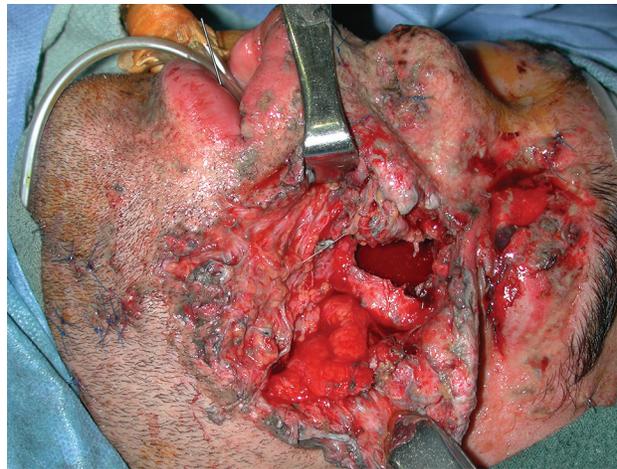


Figure 10-2. High-velocity head and neck injury.

to deep fascia; type 2: penetrates beyond deep fascia; type 3: extensive tissue maceration and damage.<sup>26,27</sup> The Sherman classification can be used to predict the mortality of shotgun wounds, ranging from 0% for type 0 injuries to 90% for type 3 injuries.<sup>26</sup> Buckshot (>0.14 in) are larger diameter projectiles, each with the potential for causing significant damage to facial tissue.<sup>26</sup>

## TYPES OF PROJECTILE WOUNDS

A head and neck surgeon working in a deployed setting or at a civilian trauma hospital may encounter eight specific types of projectile wounds to the head and neck: stab wounds, long-range shotgun wounds, long-range buckshot wounds, handgun wounds, close-range shotgun wounds, rifle wounds, rocket/mortar/grenade wounds, and IED wounds.<sup>27</sup> These eight types can be categorized as either low-velocity injuries (stab, long-range birdshot, long-range buckshot, handgun) or high-velocity injuries (close-range shotgun, rifle,

rocket/mortar/grenade, IED).

Low-velocity neck wounds are generally less lethal (mortality 0% to 6%) and present with up to a 50% incidence of major pathology found on exploration.<sup>26</sup> In contrast, high-velocity neck wounds present with as high as a 90% incidence of major pathology found on exploration and a mortality exceeding 50% in some series.<sup>26</sup> This increased morbidity and mortality is due the large amount of kinetic energy imparted to the tissues of the head and neck (Figure 10-2).

## SUMMARY

The pathophysiology of the combat wounds to the head and neck treated in Iraq and Afghanistan is different than that seen in previous armed conflicts. The high rate of devastating IED injuries in OIF and OEF far exceeds the historical explosive injury rate

of 10% seen in previous conflicts. Fortunately, the surgical advances described in this textbook have helped mitigate this devastating pathophysiology, contributing to the record survival rates witnessed in Iraq and Afghanistan.

## CASE PRESENTATIONS

### Case Study 10-1

#### Presentation

A 25-year-old Iraqi National Guard soldier was shot through the upper neck 3 days previously with an AK-47 assault rifle and was treated at an Iraqi Army hospital. The soldier presented with an entrance wound in zone 2 of his left neck and a large exit wound in zone 2 of his right neck. He reportedly had a stable airway with significant hoarseness on initial presentation. The Iraqi surgeons reportedly declared his wound “expectant” and treated him with comfort care. Figure 10-3 shows the patient with the gunshot wound traversing the neck superior to the hyoid cartilage. After the patient was observed at the Iraqi hospital for 3 days, he was transferred to the Air Force theater hospital in Balad, Iraq. On presentation to Balad, he had a Glasgow Coma Scale (GCS) score of 15, significant hoarseness, a stable airway with nasopharyngeal scope exam showing moderate laryngeal edema and ecchymosis with minimal bilateral true vocal cord motion and intact mucosa, and the zone 2 neck wounds noted above.

#### Preoperative Workup

Computerized tomography angiography (CTA) showed a comminuted and displaced thyroid cartilage



Figure 10-3. AK-47 assault rifle wound to zone 2 of the neck.

fracture with a nondisplaced hyoid cartilage fracture. The remainder of the neck, including the great vessels, was intact.

#### Operative Planning/Timing of Surgery

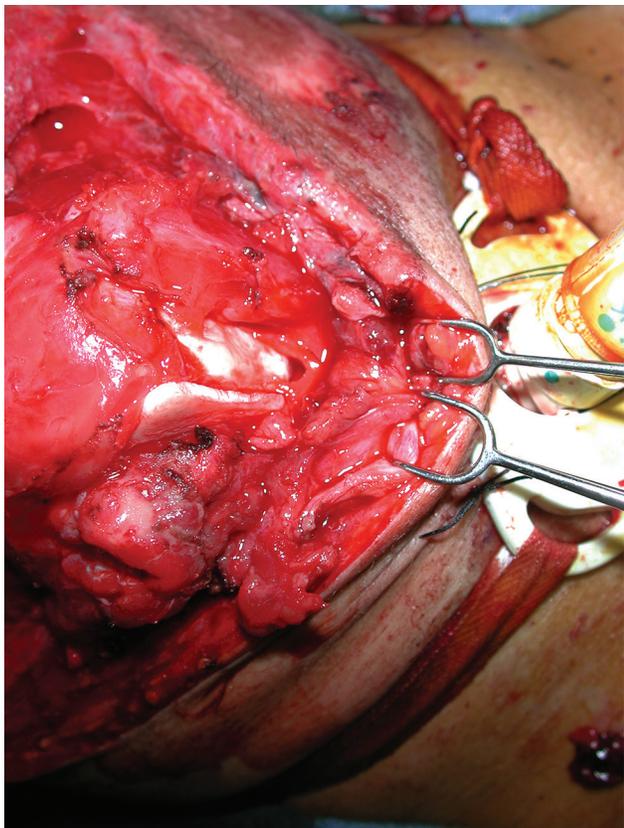
High-velocity penetrating neck trauma patients with comminuted and displaced thyroid cartilage fractures with moderate airway compromise need the airway to be secured and the laryngeal fracture repaired.<sup>28</sup> Awake tracheotomy in this type of head and neck injury with a compromised airway and distorted anatomy must be strongly considered.<sup>29</sup> Additionally, direct laryngoscopy to examine the internal laryngeal injuries (mucosal and structural) needs to occur before the laryngeal fracture is explored and repaired. Dozens of laryngeal fractures have been repaired in Iraq and Afghanistan, and the method of repair (30-gauge wire versus miniplates) has varied.<sup>28</sup>

#### Operation

The patient was taken to the operating room and awake tracheotomy was performed. Direct laryngoscopy showed laryngeal edema and ecchymosis without mucosal lacerations. Neck exploration revealed a permanent cavity traversing the upper neck, located above the hyoid cartilage and 2 to 3 cm from the thyroid cartilage (Figure 10-4). Nevertheless, the large temporary cavity caused by this high-velocity projectile shattered the thyroid cartilage into three pieces (Figure 10-5). The thyroid cartilage fracture was



Figure 10-4. Neck exploration for zone 2 injury.



**Figure 10-5.** Displaced thyroid cartilage fractures.

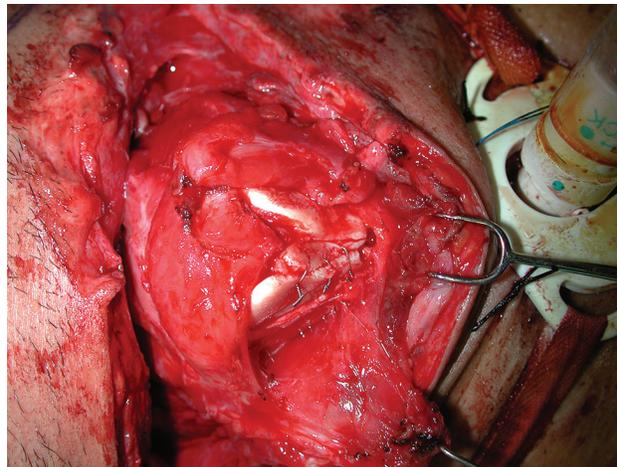
reduced and repaired with multiple 30-gauge stainless steel wires (Figure 10-6). The patient was then transferred to the intensive care unit.

### **Complications**

None.

### **Lessons Learned**

Yellow or moderately compromised traumatic airways with distorted anatomy can progress to a red or emergent airway, especially if oral intubation attempts are unsuccessful and cause additional airway edema or bleeding. Consequently, awake tracheotomy should be strongly considered. Also, the head and neck surgeon should be vigilant during exploration of high-velocity head and neck trauma because a large temporary cavity may form due to the high kinetic energy of the missile. This patient had a shattered thyroid cartilage that was at least 3 cm from the bullet track (permanent cavity) but within the large temporary cavity caused by the projectile. Lastly, repair of thyroid cartilage



**Figure 10-6.** Open reduction and internal fixation of thyroid cartilage fracture with 30-gauge wires.

fractures can be effectively performed using multiple techniques, including stainless steel wires and miniplates.<sup>28</sup>

### **Case Study 10-2**

#### **Presentation**

A 22-year-old American soldier presented with an AK-47 assault rifle wound to zone 3 of the right neck. He presented with an entrance site at the right angle of the mandible and an exit site through his left anterior cheek (Figure 10-7). The young soldier had no active bleeding, a GCS of 15, a stable airway without



**Figure 10-7.** AK-47 assault rifle wound to zone 3 of the neck.

hoarseness, and stable vital signs. Because he presented during the Battle for Fallujah while multiple emergent and less stable Americans were waiting for surgery, he was transferred to the intensive care unit and a CTA was ordered pending an open operating room.

### *Preoperative Workup/Radiology*

The CTA showed a bullet track through his right face causing a small fracture of the corner of the right angle of the mandible, with an intact mandibular arch. The bullet fragment track could be seen traversing the right buccal mucosa and exiting the left buccal mucosa just lateral to the oral commissure. The internal carotid artery, external carotid artery, and internal jugular vein had flow and were noted to be intact. No other neck pathology was noted on CTA.

### *Operative Planning/Timing of Surgery*

While the patient was waiting in the intensive care unit for an operating room to open up, the nurse yelled that profuse bright red blood was pouring from his right cheek wound. Fortunately, the head and neck surgeon was in the intensive care unit with another patient, immediately tamponaded the bleeding with direct pressure, and rushed the patient to the operating room. The patient was emergently intubated, neck exploration was performed, and an urgent tracheotomy was placed due to persistent bleeding from the oropharynx, which was also explored. After packing the upper neck near the skull base to slow the arterial bleeding, proximal control of the internal carotid artery, the external carotid artery, and the internal jugular vein was performed. Further neck exploration revealed a complete transection of both the internal carotid artery and the branches of the external carotid artery near the skull base. After distal control was obtained, the trauma surgeon, who had been assisting the head and neck surgeon with the exploration, determined that the injury was too distal to allow placement of an interposition graft. Consequently, the internal carotid artery and the branches of the external carotid artery were ligated. The soldier was then transported to the intensive care unit after the wound was thoroughly irrigated and Penrose drains placed.

### *Complications*

None.

### *Lessons Learned*

The primary lesson learned is that a high-velocity

missile will create a large temporary cavity with resultant soft tissue damage that extends well beyond the direct path of the bullet.<sup>29</sup> CTA showed a bullet pathway located 2 to 3 cm anterior and inferior to the location of the internal carotid artery transection. It was unclear during neck exploration whether the internal carotid artery was sheared at the skull base due to the concussive effect of the bullet (temporary cavity) or whether secondary bony or metallic fragments ricocheted off the mandible and struck the carotid. CTA, while highly sensitive, sometimes (though rarely) misses traumatic vascular injuries, as shown in this case. The delayed bleeding in this patient occurred when the vasospasm of the lacerated carotid arteries resolved, resulting in profuse arterial bleeding. Also, in trauma patients with bleeding into the airway causing airway compromise, the bleeding must be temporarily controlled with direct pressure or other measures while the airway is secured with an emergent cricothyroidotomy. It should be noted that an "emergent" tracheotomy should not be done because a cricothyroidotomy is easier to perform for three reasons<sup>28</sup>: (1) the airway is closer to the skin at the level of the cricothyroid membrane than lower in the neck at the level of the trachea; (2) it is easier to cut through the cricothyroid membrane than through the tracheal cartilage, especially if this cartilage is ossified; and (3) the thyroid isthmus overlies tracheal rings 2 through 5 and bleeds profusely if incised. Also, during emergent neck exploration for presumed major vessel bleeding, the first steps are to obtain proximal and, hopefully, distal control of the great vessels before the area of vascular injury is dissected.<sup>29</sup>

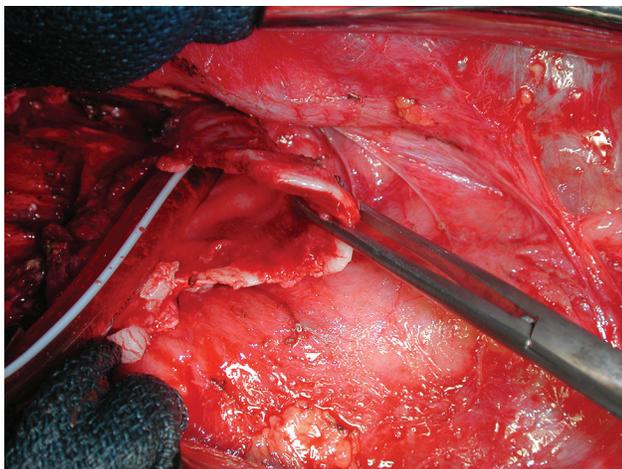
### **Case Study 10-3**

#### *Presentation*

A 20-year-old Iraqi National Guard soldier presented to Balad emergency room after a car bomb (vehicle-borne IED) exploded at the hospital gate at Bagram Air Base. The patient presented with gaping zone 1/2 neck wounds with a large amount of bleeding, and gurgling with obvious airway leakage through the wound (Figure 10-8). A trauma surgeon in the emergency room quickly placed an endotracheal tube into the open airway in the neck, and the patient was transported immediately to the operating room. The patient also had wounds to his chest, abdomen, and multiple extremities.

#### *Preoperative Workup/Radiology*

None.



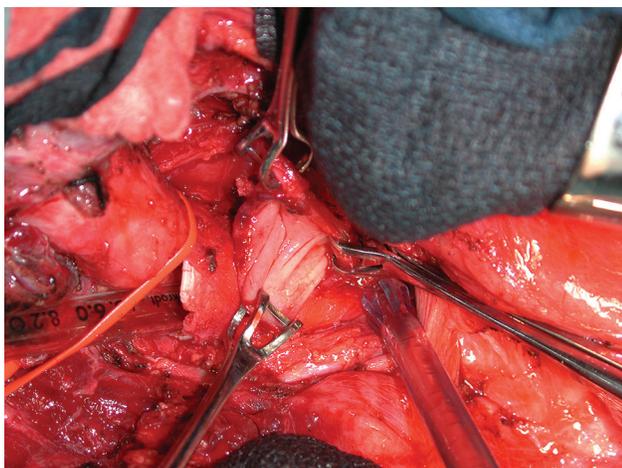
**Figure 10-8.** Zone 1/2 neck wound caused by an improvised explosive device.

**Operative Plan/Timing of Surgery**

Symptomatic trauma patients with a penetrating neck wound, an unstable airway, and active bleeding need immediate neck exploration.<sup>29</sup>

**Operation**

The head and neck surgeon explored the wound and identified a 6- to 7-cm tracheal disruption or tear that extended into the upper mediastinum. In addition, the patient had a 3-cm esophageal perforation (Figure 10-9). The esophageal perforation was repaired with a two-layer closure, and a nasogastric tube was placed. The trachea was then explored, and the patient was noted



**Figure 10-9.** Esophageal perforation.



**Figure 10-10.** Repair with resection of sternum and clavicular heads, ligation of innominate vein, and formation of a formal stoma in the midchest.

to have destruction of over 6 cm of trachea starting at the first tracheal ring and extending into the upper mediastinum. Primary tracheal repair with releasing maneuvers could not close this large defect, and the decision was made to oversew the proximal trachea just below the cricoid ring. The intact distal trachea was located in the upper mediastinum and a formal stoma could not be approximated to the neck skin. Consequently, the upper sternum and clavicular heads were resected, the innominate vein was ligated, and a formal stoma was created in the upper chest (Figure 10-10). The patient was then transported to the intensive care unit. Lastly, the other IED wounds necessitated chest tube placement, a thoracotomy, an abdominal exploration with colostomy formation, and extremity explorations.



**Figure 10-11.** The patient 3 weeks postoperative.

### Complications

None. After several weeks, the patient was taking food by mouth and using an electrolarynx (Figure 10-11).

### Lessons Learned

The pathophysiology of high-velocity missiles such as IEDs are devastating; such weapons can

cause extensive soft tissue injuries like this over 6-cm tracheal defect. To repair such high-velocity damage, extraordinary maneuvers such as establishing a formal stoma in the upper chest must be performed. In addition, most patients injured by IEDs present with severe multisystem trauma, which could cause death as a result of any of the separate injuries. Several surgical teams (head and neck, trauma, orthopedics) must work in coordination to ensure a successful surgical outcome.

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