Introduction

Penetrating neck trauma may pose a diagnostic and therapeutic dilemma to emergency physicians and trauma surgeons. Approximately 5% to 10% of all trauma involves penetrating neck trauma, with multiple structures being injured in 30% of patients. Thorough knowledge of the anatomy of the neck, physical assessment, and current recommendations for diagnostic and therapeutic interventions are necessary for appropriate management. Expeditious decision making often is required to prevent catastrophic airway, vascular, or neurologic sequelae.

Overall mortality because of penetrating neck trauma is as high as 11%. Injury to certain anatomic structures (e.g., the carotid or subclavian vessels) may be fatal in two thirds of cases, however. Compounding difficulties in evaluation and management is the complicated anatomy of the area, in which a dense concentration of vital vascular, aerodigestive, and nervous system structures are located within a very small space. In addition, there is a lack of consensus among trauma surgeons regarding injuries that mandate surgical exploration and those in which a conservative selective approach can be taken.

Historical Perspective

The treatment of penetrating neck injury is described as early as 1522. Ambrose Pare then noted that the most expeditious and safe method to treat such injuries was to ligate all major vessels at the site of the injury. This was the procedure of choice through World War I. Associated mortality rates of neck injuries were recorded as high as 60%. Significant neurologic impairment was noted in about one third of patients, likely due to carotid ligation in those with an incomplete Circle of Willis. During WWII, management changed to mandatory exploration of all penetrating wounds through the platysma. Fogelman and Stewart reported Parkland Memorial Hospital’s experience of early mandatory neck exploration in 1956. They found a mortality rate of 6% for early exploration versus a 35% mortality rate for delayed explorations. The present mortality for civilian wounds is 4-6%, with most deaths occurring from vascular injuries prior to arriving in the emergency room.
Mechanism of Injury

The energy imparted into tissue by a penetrating projectile is determined by its kinetic energy (KE): KE=1/2MV^2. Since the velocity is squared in the equation, high-velocity projectiles impart significantly larger amounts of energy into the tissue impacted. In other words, a projectile with twice the velocity will have four times the kinetic energy of a lower-velocity projectile.

Typically, firearms are divided into two groups by their muzzle velocity: low velocity (less than 1,000 feet per second) and high-velocity (more than 1,000 feet per second). Most handguns are low-velocity weapons, with muzzle velocities between 300 and 800 feet per second. A typical shotgun has a muzzle velocity of 1,200 feet per second, and a 30-30 rifle has a muzzle velocity of 2,200 feet per second.

Gunshot wounds cause tissue injury by three mechanisms: direct tissue injury, temporary cavitation, and transmission of shock waves. Cavitation refers to the creation of a temporary cavity surrounding the actual bullet path. This temporary cavity results in tissue necrosis adjacent to the missile path. This is an important concept for the treating physician to understand: anatomic structures may be significantly damaged by a gunshot wound without being actually penetrated by the projectile. In addition to the formation of a temporary cavity, distant shock waves may also be transmitted from the bullet’s path to adjacent tissue and may result in adjacent or distant tissue damage. Because of their high kinetic energy, high-velocity weapon injuries tend to have greater cavitation and transmission effects than low-velocity injuries.

In addition, bullets or pellets in flight have several components to their rotation. These rotational characteristics increase the potential that a bullet may take an erratic course after impact and also may increase the amount of direct tissue injury. Bullets from high-velocity weapons often have exaggerated amounts of yaw, precession, and rotation, with the resultant potential for more severe injury. Further, projectiles may shatter on tissue impact, resulting in secondary projectiles with the potential for additional injury. Similarly, impacted bone may also shatter, and secondary bone fragments may cause further damage.

The type of tissue penetrated also influences the effects of a penetrating projectile injury. Tissues with low elasticity (e.g., bone) tend to shatter or fragment and undergo greater damage than more elastic tissues (e.g., muscle). Similarly, tissues with high density or specific gravity (e.g., brain) tend to undergo greater damage than less dense tissue (e.g., lung parenchyma).12

Initial Evaluation

The basic principles of trauma management apply to all patients with penetrating face and neck trauma. These trauma principles are easily remembered using the mnemonic ABCDE. A denotes assessment of airway and cervical spine, B stands or assessment of breathing, C refers to assessment of circulation, D denotes assessment of disability and neurologic status, and E stand for exposure and overall evaluation of the patient for other injuries. The overall prevalence of cervical spine fracture in patients with cervicofacial trauma is less than 2%, but all patients should be considered to have a cervical spine injury until proven otherwise.
In the emergency center, in addition to cervical spine x-ray films, all patients with penetrating cervicofacial trauma should have an AP and lateral skull, face and neck xrays. These films can identify remaining bullets, bullet fragments, and bony fragments and may help define the path of the projectile. In stab wounds where the weapon is still present, the depth of penetration may be identified. Further, these films may reveal the presence of subcutaneous air or tracheal deviation.

Evaluation of the airway should be the first priority for all patients with penetrating face or neck trauma. Most patients can be carefully intubated transorally; if a cervical spine injury is suspected, the patient may be intubated while continuous in-line neck stabilization is applied. If the airway is unstable, and there is significantly bleeding or edema in the oral cavity or pharynx, the patient should undergo cricothyroidotomy or urgent tracheotomy. Blind nasotracheal intubation should be avoided, although in the stable patient a fiberoptic guided transnasal approach may be appropriate. In penetrating injuries to the neck with obvious tracheal injury (e.g., sucking wound, significant subcutaneous emphysema), the trachea may be carefully intubated through the entry wound itself using a reinforced endotracheal tube.

Once the airway has been stabilized, the remainder of the examination may be completed, including a careful assessment of entry and exit wounds. The physician should be aware that projectiles and bones may fragment or shatter, and projectiles may ricochet and change directions through the tissue ¾ both of which may lead to secondary injuries. Probing entry and exit wounds or removing blood clots in the ER should be avoided because this may stir up significant bleeding. In addition, all patients with penetrating face or neck trauma should be considered for tetanus prophylaxis. ¹²

**Anatomy**

The sternocleidomastoid muscle divides the cervical region into two designated triangles— anterior and lateral. The anterior triangle is bordered by the anterior margin of the sternocleidomastoid muscle and by the inferior margin of the mandible, and the anterior neck is divided into two bilateral halves by the vertical midline from the mental symphysis to the suprasternal notch. The lateral triangle is bordered by the anterior margin of the trapezius muscle, by the posterior border of the sternocleidomastoid muscle, and by the middle third of the clavicle. The part of the neck covered by the trapezius muscle in continuity with the posterior cervicooccipital region is the posterior neck.

The anterior neck contains the cervical parts of the aerodigestive tract: larynx and trachea, hypopharynx and esophagus, thyroid and parathyroid glands, carotid sheath and the large neurovascular structures contained therein, and suprathyroid and infrathyroid strap muscles, as well as a host of associated neurovascular and lymphatic structures. The anterior neck extends cranially to the mandibular margin and caudally to the chest of the thoracic inlet. The inferior margin of the mandible, along with the digastric stylohyoid–mylohyoid muscle complex, outlines the submandibular area (submandibular triangle). The submandibular area contains the submandibular gland, associated fasciae, lymphatic structures, parts of the anterior facial vein and facial artery, and the marginal mandibular branch of the facial nerve.
The position of the omohyoid muscle demarcates (1) the upper part of the anterior neck known as the carotid triangle, where the carotid sheath structures are relatively superficial in their location, and (2) the lower and anterior part of the neck known as the muscular triangle, which contains the infrahyoid muscle strap muscles, the aerodigestive tract, and the thyroid gland complex.

The lateral triangle of the neck is often referred to as the posterior triangle and is bounded by the borders of the sternocleidomastoid muscle and trapezius muscle and the middle third of the clavicle. The contents of this triangle include fibrofatty lymphatic-containing tissue, cranial nerve XI, the superficial and cutaneous components of the cervical nerve plexus, and a host of small vascular bundles, the presence of which at surgery has in the past led to the description of this surgical area as “bloody gulch.” The presence of the lower muscle belly of the omohyoid muscle in the triangle just above the clavicle demarcates a small subclavian triangle in the lateral neck, carrying with it important surgical implications because in the depths of the subclavian triangle are found the cervical and thoracic outflow of nerves and vessels into the axilla—the brachial plexus from the interscalene muscle interval and the subclavian vessels arching over the first rib from the thorax to the axilla.13

There are two more anatomic orientations that help to illustrate the relationships within the neck. The first is fascial planes. The superficial fascia lies just beneath the skin and encompasses the body of the platysma. The platysma is a thin, superficial muscle that originates over the upper part of the thorax, passes over the clavicle, and continues upward in the neck, across the mandible and extends into the superficially located facial muscles. It is an important surgical landmark because penetration of the muscle has signified the need for surgical exploration. Underlying the platysma is the deep cervical fascia, which is subdivided into investing, pretracheal, and prevertebral layers. The investing fascia splits to enclose the sternocleidomastoid, omohyoid, and trapezius muscles as it encircles the neck. The pretracheal fascia attaches superiorly to the thyroid and cricoid cartilage and extends into the chest, where it blends with connective tissue between the sternum and pericardial sac. It encloses the major viscera of the neck including the thyroid gland, esophagus, and trachea. The pervertebral fascia surrounds the vertebral column and the muscles closely attached to it. As the lower cervical nerves and subclavian artery course between the anterior and medial scalene muscles, they are invested in a diverticulum of the pervertebral fascia that, as it approaches the axilla, becomes the axillary sheath. The carotid sheath is considered the major neurovascular compartment of the neck. It is composed of portions of all three layers or the deep cervical fascia and houses the internal jugular vein, common carotid artery, and the main trunk of the vagus nerve.

These tight fascial compartments of neck structures may limit external hemorrhage from vascular injuries, minimizing the chance of exsanguination, an apparently beneficial effect that is countered, however, by the effects of hemorrhage within these closed compartments, which frequently compromises the airway.

Anatomically, the neck can be divided into three major zones in order to aid in the decision making for diagnostic tests and timing of surgery. Zone I is below the cricoid and represents a dangerous area because the vascular structures in this zone are in close proximity to the thorax. The bony thorax and clavicle act to protect zone I from injury as do other bony structures at the
base of the neck. This osseous shield also makes surgical exploration of the root of the neck difficult. In zone I, injuries to the right side are often approached through a median sternotomy, while injuries to the left side are often managed by a left anterior thoracotomy to control the hemorrhage. Zone I has a fairly high mortality rate of 12%. Mandatory exploration is not usually recommended for zone I injuries; angiography is usually suggested to ensure that the great vessels are not injured.

Zone III is located above the angle of the mandible. This area also is protected by skeletal structures and is difficult to explore because of the skull base and the need to divide or displace the mandible. The necessity for craniotomy in exploration and control of high carotid injury in this location makes zone III treacherous. Recognizing injuries to many of the cranial nerves exiting the skull base in zone III is important because these injuries may be indicative of injuries to the great vessels due to their close proximity. An abnormal neurologic examination would suggest the need for angiography in the stable patient.

In view of the difficult surgical approaches to zone I and zone III, most authors agree that all patients with such injuries who are stable and without evidence of acute airway obstruction, significant bleeding, or expanding hematoma should be evaluated with angiography, with consideration of barium swallow. For zone III injuries, frequent intraoral examination should be performed to observe for edema or expanding hematoma within the parapharyngeal or retropharyngeal spaces.

Zone II is the most frequently involved region (60% to 75%), and injury in this zone has created a great deal of controversy in the literature over the past 15 years. There is an ongoing debate about the use of mandatory exploration versus selective exploration with serial examination, endoscopic tests, and angiography. In zone II, isolated venous injuries and isolated pharyngoesophageal injuries are the most common structures missed clinically in the preoperative evaluation. A substantial number of patients can be selectively managed depending on signs, symptoms, and direction of the trajectory. When patients are stable and lack physical signs of obvious major neck injury, they are evaluated by diagnostic radiologic and endoscopic techniques. All patients are admitted for observation. A hospital with a comprehensive trauma service with experienced personnel doing careful and repeated physical examinations and with 24-hour availability of radiologic and endoscopic capability is needed. If this is not available, then it is safer and more cost effective to take all injuries penetrating the platysma to the OR for exploration.

**Physical Examination**

A careful clinical examination with knowledge of the pertinent anatomy is an accurate predictor of the extent of injury in penetrating neck trauma. Clinical signs and symptoms of significant injury are as follows: (1) Vascular injury—shock, hemotoma, hemorrhage, pulse deficit, neurologic deficit, bruit or thrill in neck, (2) Laryngotracheal injury—subcutaneous emphysema, airway obstruction, sucking wound, hemoptyisis, dyspnea, stridor, hoarseness or dysphonia, (3) Pharynx/esophagus injury—subcutaneous emphysema, hematemesis, dysphagia or odynophagia. Of course, patients with refractory shock, uncontrollable hemorrhage, or evolving neurologic deficit should undergo immediate neck exploration. The surgeon should be prepared to control
and repair major injuries to the carotid artery or jugular vein. Patients who are clinically stable but have signs or symptoms of injury to a major neck structure should undergo directed evaluation with subsequent repair of injured structures. It is the management of the asymptomatic patient with penetrating neck trauma that has been debated.

Traditionally, all patients with penetrating neck wounds that penetrated the platysma—whether symptomatic or not—underwent neck exploration. The rationale was that the sensitivity of neck exploration was high, and the morbidity of the surgery itself was low, whereas the morbidity of a missed injury was potentially fairly high. If mandatory exploration was used, negative exploration rates of 30% to 50% could be expected. Over time, however, trauma surgeons have begun using the angiogram as a diagnostic tool in selected neck injuries. Further, as the techniques and skills of interventional radiology have developed, some vascular injuries are now amenable to definitive treatment by the interventional radiologist.

Zone I Injuries

Penetrating injuries that enter zone I of the neck are potentially fatal because of the potential for injury to the great vessels of the neck and mediastinum, as well as the cervical and thoracic esophagus. Most trauma centers advocate routine angiography of the aortic arch and great vessels, along with an esophageal evaluation—whether or not the patient is symptomatic. As many as one-third of patients with a clinically significant zone I injury may be asymptomatic at presentation. Angiography of the great vessels can identify those patients who need a midline sternotomy or thoracotomy for vascular control. Further, mandatory esophageal evaluation is recommended because a missed zone I esophageal injury is potentially different from a missed zone II injury. An esophageal or pharyngeal injury in zone II will usually develop clinical signs or symptoms (such as subcutaneous emphysema) within a few hours, and overall morbidity and mortality may not be affected. A missed esophageal injury in zone I, however, may be clinically silent until sepsis and mediastinitis develop. Opinions on the best diagnostic test for esophageal injury differ, but the sensitivity of both esophagoscopy and contrast esophagography are about 80% to 90%. Using both esophagoscopy and esophagography together probably increases sensitivity and specificity to near 100%.

Zone II Injuries

Patients with penetrating zone II injuries who are symptomatic should undergo neck exploration. Asymptomatic patients with penetrating zone II injuries may be treated with either mandatory exploration or directed evaluation and serial examinations, provided that the hospital has the facilities for regular examinations and emergent operations. Mansour et al. treated 188 patients with neck injuries to the anterior triangle that penetrated the platysma using the following protocol: All symptomatic patients were explored, although those with zone I and zone III injuries first underwent angiography. Asymptomatic zone I patients also underwent angiography and esophageal evaluation, but asymptomatic zone II and III patients were admitted and underwent ancillary testing (such as angiography) based on missile trajectory, followed by serial examinations by a physician every 6 hours. The authors noted that the observed patients did very well as a group, with virtually no missed injuries, morbidity, or mortality and a shorter average length of stay than the patients who underwent exploration.
Meyer et al.\textsuperscript{16} treated 120 consecutive patients with penetrating zone II injuries using the following protocol: All unstable patients underwent immediate neck exploration. All other patients (whether symptomatic or not) underwent clinical assessment, arteriography, laryngotracheoscopy, flexible esophagoscopy, and barium swallow, and then all patients underwent neck exploration. The authors reported that five patients had six injuries that had been "missed" by the diagnostic evaluation; they concluded that even a thorough clinical assessment was inadequate for detecting injuries to vital structures and recommended mandatory neck exploration for all zone II injuries. Therefore, some trauma surgeons have used these data to support directed evaluation with serial examinations for asymptomatic patients with zone II injuries, while other trauma surgeons recommend mandatory exploration.

In summary, asymptomatic patients with penetrating zone II injuries may be treated with either mandatory neck exploration or directed evaluation and serial examinations. However, a treatment protocol utilizing observation with serial examinations requires adequate physician manpower as well as a 24-hour facility prepared for emergency testing and surgery at any time. Early neck exploration with prompt discharge home for negative explorations is an efficient and time-tested method of managing penetrating zone II injuries and, in rural settings, may be more cost-effective than multiple tests and observation.\textsuperscript{12}

\textbf{Zone III Injuries}

Penetrating injuries to zone III have the potential for injury to major blood vessels and the cranial nerves at or near the skull base. As many as one-fourth of patients with arterial injuries may be asymptomatic at presentation. In addition, surgical exposure and control of bleeding in this location may be quite difficult. Further, some of these injuries are amenable to definitive treatment by an interventional radiologist, particularly injuries to the internal carotid artery at the skull base, branches of the external carotid artery, and the vertebral artery. Therefore, the injury may be treated under local anesthesia in the same setting as the diagnostic angiogram.

\textbf{MANAGEMENT OF VASCULAR PENETRATION}

Zone I vascular perforation requires thoracic surgery. Although a low cervical incision may result in sufficient exposure, a mediastinotomy extension or a formal lateral thoracotomy may be needed.

Zone III injuries at the skull base can be temporarily stabilized by pressure, but once delineated, access to the injury may require mandibulotomy in the midline similar to exposure for a parapharyngeal space tumor. A temporary arterial bypass of the carotid artery may be placed until the lacerated or aneurysmatic vessel can be approached safely.

All veins in the neck can be safely ligated to control hemorrhage. However, if both internal jugular veins are interrupted by the injury, an attempt to repair one is mandated. All external carotid artery injuries are easily managed by suture ligation because collateral circulation is good. Common carotid or internal carotid injury in zone II is explored once the diagnosis is made by an approach along the anterior border of the sternocleidomastoid muscle. To find the carotid artery in cases where the vessel is no longer pulsating (i.e., hematoma injury or proximal
interruption), the external carotid branches may be followed retrograde from the facial artery at the submandibular gland or from the superior thyroid artery at the superior cornu of the thyroid cartilage.

Techniques of lateral arteriorrhaphy for vascular repair have been suggested by several authors, but in all practicality should be performed by an experienced vascular surgeon. End-to-end anastomosis or autogenous grafting is recommended when stenosis is evident by arteriography. Ligation of the common or internal carotid injuries is generally reserved for irreparable injuries and in patients who are in a profound coma state with bilateral fixed and dilated pupils. Delayed complications from unrepaired vascular injuries include aneurysm formation, dissecting aneurysm, and arteriovenous fistulas.

More recently, interventional radiologists have used angiographic techniques to treat vascular injury. In some instances, embolization procedures can help control arterial disruption. In areas of difficult vascular access at the skull base, detachable balloons or steel coils can be placed for carotid occlusion. Embolized bullets also can be retrieved by angiographic techniques. The possible complications of interventional angiography include blood vessel injury, inadvertent balloon detachment, ischemic events, pseudoaneurysm formation, and treatment failure.

DIGESTIVE TRACT EVALUATION

In the patient with a possible esophageal perforation, most radiologists recommend Gastrografin swallow as a first-order contrast study because barium extravasation radiographically distorts soft-tissue planes for other studies and is more toxic. There are mixed reports in the literature about which of these methods is more reliable in demonstrating a perforated esophagus or pharynx. A negative Gastrografin study should be followed by a barium swallow if suspicion remains high.

Many studies report the use of flexible esophagoscopy to circumvent the need for general anesthesia during rigid endoscopy. Several authors have reported a missed perforation near the cricopharyngeus, as well as the hypopharynx, where flexible endoscopy is least satisfactory due to mucosal redundancy. Missed esophageal tears represent most of the delayed injuries and, when they progress to mediastinitis, morbidity and mortality are considerable.

Some surgery services mandate neck exploration for patients who have air in the soft tissues of the neck despite yielding normal endoscopy results. At the time of exploration to rule out pharyngeal and esophageal injuries, a nasogastric tube can be gently pulled up to the level of the neck and methylene blue infused through the nasogastric tube to help localize the injury site. The combination of flexible endoscopy and rigid esophagoscopy to examine the entire cervical and upper thoracic esophagus also has been reported. No perforations were missed in those series using both techniques on all patients. If suspicion of a pharyngeal perforation remains unconfirmed by examination or even by exploration, the patient is given no food and is observed for several days. Fever, tachycardia, or widening of the mediastinum on serial chest radiographs requires that repeat endoscopy or neck exploration be considered. When an esophageal injury is found early, management involves a two-layer closure with wound irrigation, debridement, and adequate drainage. After repair of the mucosal perforation, a muscle flap may be interposed over
the esophageal suture line for further protection. If an extensive esophageal injury is present, it may necessitate a lateral cervical esophagostomy and definitive repair at a later date.\textsuperscript{13}

If the clinical examination is benign, follow-up examination is done frequently (at least three times every 24-hour shift) by a physician recording his or her observations. Frequent monitoring of vital signs, as well as examination of the neck and the entry wounds by the nursing staff, also is crucial. A 48- to 72-hour observation period should be used to monitor for changes in physical findings or vital signs that mandate urgent attention.

**MANAGEMENT OF LARYNGOTRACHEAL INJURY**

Laryngeal mucosal lacerations from penetrating injury should be repaired early (within 24 hours). According to Leopold\textsuperscript{14}, the time elapsed before repair has an effect on both airway stenosis and on voice. Significant glottic and supraglottic lacerations and displaced cartilage fractures need surgical approximation. Endoscopy and CT will differentiate between the patients that need only observation (small laceration, shallow laceration, nondisplaced fracture) and those that require a thyrotomy or open fracture reduction and mucosal approximation. A soft laryngeal stent may be needed for badly macerated mucosa.

Simple tracheal lacerations that do not detach a tracheal ring or encroach on the airway can be repaired without a tracheostomy. More severe disruptions (gunshot wound directly to the trachea) imply more soft-tissue injury and a 6-week tracheostomy either below or through the tracheal injury is the safest procedure. Later the stenosis may require sleeve resection, but if the stenosis is soft, it can often be managed by a T-tube tracheostomy tube.

**Summary**
FIG. 73-9. Algorithm for the initial management of patients with penetrating injuries to the neck.
(Modified from ref. 14, with permission.)

FIG. 73-8. Horizontal entry zones of the neck for penetrating injuries to the neck.
Bibliography


