Seminars in
ULTRASOUND
CT *and* MRI

Gunshot Injuries in the Neck Area: Ballistics Elements and Forensic Issues

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The neck is an interesting structure as far as penetrating trauma is concerned because of the multiple vital structures that are concentrated in a small anatomic area. Gunshot wounding is an interaction between the penetrating projectile, the anatomy of the wounded subject, and the chance occurrences that determine the exact missile path. The mass and velocity of the projectile establish the upper limit of possible tissue damage. Management of gunshot neck injuries depends on a clear understanding of the anatomy of the neck. The radiologist can contribute substantially to the successful treatment of the patient with a gunshot wound. Important analysis includes the assessment of the missile path in emergency conditions by using plain film and multidetector row computed tomography. The radiologist further evaluates the extent of wounding by determining missile fragmentation and secondary missile paths.
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Gunshot injuries are a major cause of morbidity and mortality in cities in the USA.

The age group most affected is 15-24 years.[1] The incidence is greatest among black males and lowest among white females. In several states, mortality rates from gunshot wounds already exceed mortality rates from motor vehicle accidents.[1] It has been estimated that 25% of patients with gunshot injuries have some form of vascular involvement.[2,3] Central nervous system ischemia is also a significant factor in morbidity and/or mortality after penetrating vascular injury.[4]

Bleeding, shock from injury to the major vessels in the neck, and compromise of the airway are the major factors causing death after penetrating neck injury. The clinical signs of arterial injury include pulse deficit, bruit, expanding hematoma, and arterial bleeding.[5,6]

The initial workup should always include conventional radiography: patients with penetrating trauma should undergo anteroposterior and lateral radiography of the neck with markers on the entrance and exit wounds to assess the trajectory of the injury and to look for missile fragments, fractures, and foreign bodies.[4,7]

Imaging evaluation of patients suspected to have arterial injuries of the neck has traditionally been performed by using conventional angiography as an alternative to surgical exploration.[8] However, there has been recent interest in and growing experience with the use of noninvasive imaging techniques for the assessment of vascular injuries. Contrast material-enhanced helical computed tomographic (CT) angiography is increasingly being used to evaluate trauma patients with gunshot injuries, because it allows detection of the presence of traumatic vascular lesions in the neck, such as partial or complete occlusion, pseudoaneurysm, intimal flap, dissection, and arteriovenous fistula.[8]

Moreover, CT angiography provides important information about the cervical soft tissues, aerodigestive tract, spinal canal, and spinal cord. In the same setting, the trajectory of the bullet and the locations of fragments can be assessed. With the advent of multidetector row CT and 3-dimensional postprocessing workstations, images can be more accurately reproduced, similar to the familiar angiographic display.[9-11]

Mechanisms of Gunshot Injuries

Ballistics is defined as the scientific study of projectile motion and is divided into 3 categories: internal, external, and terminal ballistics. Internal ballistics has to do with the projectile within the firearm. External ballistics has to do with the

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projectile in the air. Terminal ballistics has to do with what happens when the projectile hits its target.[1]

Wound ballistics is a subset of terminal ballistics and is the most important aspect of ballistics for physicians to understand.[12]

Weapons are classified according to muzzle velocity as either low velocity (<1200 ft/s) or high velocity (>2500 ft/s).[13] Handguns, rifles, and shotguns are the major types of firearms encountered in the USA. The nature and the severity of gunshot injuries depend on more than just the type of weapon and projectile. Local tissue factors and the distance (range) between the weapon and the victim both have a major effect on these injuries.[14,15]

The fundamental law of physics for determining the kinetic energy of any mass that is moving is $KE = 0.5\ MV^2/g$, where KE = kinetic energy, M = mass, V = velocity, and g = gravity.[16] Doubling the mass of the projectile doubles the kinetic energy, but doubling the velocity quadruples the kinetic energy. Low-velocity missiles tend to crush and push tissue aside, creating a permanent tract that is nearly the same size as the projectile.[17] High-velocity missiles create a large temporary cavity that greatly exceeds the volume of the permanent tract. This is called cavitation. High-velocity weapons impart kinetic energy in a radial direction, stretching tissue and creating a temporary cavity that can be 30 times larger than the missile diameter.[17] As the bullet passes, tissue may be destroyed and either ejected out of the entrance or exit wound or compressed into the walls of the missile tract. This creates a permanent tract that is several times larger than the missile diameter[18] and may produce a large exit wound. Cavitation puts tissues that are outside the immediate path of the bullet at risk for injury. This is why some researchers advocate mandatory exploration of all wounds from high-velocity weapons.[18]

Fragmentation of the missile increases the area of the wound as the multiple fragments of irregular shape penetrate and destroy tissue. Bullets may fragment even if there is no contact with bone.[16]

Bullets are usually classified by caliber, which is a measurement of the diameter of the bullet, most commonly in decimals of an inch (eg, 0.308) or in millimeters (eg, 9 mm). The measurement of caliber does not address the weight of the bullet or the size of the charge, which are important factors in determining kinetic energy.[1] Bullet injuries are most severe in friable solid organs (eg, the liver and brain), where damage may be caused by temporary cavitation remote from the actual bullet track. Dense tissues (eg, bone) and loose tissues (eg, subcutaneous fat) are more resistant to bullet injury. Bones modify the behavior of bullets markedly, altering their course, slowing them down, and increasing their deformity and fragmentation.[1,19-21]

Classification of Neck Anatomy in Penetrating Trauma

There are 6 systems with important organs in the neck. The vascular system includes the innominate, subclavian, axillary, carotid, jugular, and vertebral vessels. The respiratory system includes the larynx, trachea, and the lung. The digestive system includes the pharynx and esophagus. The neurologic system includes the spinal cord, brachial plexus, cranial nerves, and the sympathetic chain. The endocrine system includes the thyroid and parathyroid. The skeletal system includes the cervical spine.[22]

The most common classification of neck anatomy, in penetrating trauma, is to divide the neck into 3 anatomic zones anterior to the sternocleidomastoid muscles.

Zone I is from the level of the clavicles and sternal notch to the cricoid cartilage. The structures contained in this zone include the proximal carotid arteries, subclavian vessels, major vessels in the chest, lung, and esophagus, trachea, and the thoracic duct. Zone II extends from the level of the cricoid cartilage to the angle of the mandible; included in this zone are the carotid arteries, jugular veins, larynx, and hypopharynx. Zone III injuries occur from the angle of the mandibles to the base of the skull; included here are the distal carotid arteries, jugular vein, and hypopharynx (Table 1).

Table 1 Contents of Zones I, II, and III

Zone	Contents
Zone I	Origins of great vessels (innominate artery, subclavian arteries, proximal common carotid and vertebral arteries); subclavian and innominate veins; thoracic duct; brachial plexus
Zone II	Distal common carotid arteries; proximal internal and external carotid arteries; mid vertebral arteries; internal jugular veins
Zone III	Distal cervical internal carotid arteries, external carotid artery branches, distal vertebral arteries

Role of Imaging

The primary objectives of imaging are to determine the path of the projectile or projectiles, assess which tissues have been injured, estimate the severity of injury, and determine what additional studies are needed.[23] The initial workup should always include conventional radiography (Fig. 1): patients with penetrating trauma should undergo anteroposterior and lateral radiography of the neck with markers on the entrance and exit wounds to assess the trajectory of the injury and to look for missile fragments, fractures, and foreign bodies.[4,7] To determine the course of the projectile or projectiles and to begin in assessing potential tissue damage, two perpendicular views are essential.[23]

CT can be helpful for preoperative planning. Careful evaluation of radiographs and CT images is generally more reliable than clinical evaluation for determining the direction of projectile travel and the tissue or tissues injured. Noncontrast CT may be indicated to assess injury to structures, such as the cervical spine or larynx, or to better assess the trajectory of a