Penetrating neck injuries are commonly related to stab wounds and gunshot wounds in the United States. The injuries are classified by penetration site in terms of the three anatomical zones of the neck. Based on this zonal classification system, penetrating injuries to the head and neck have traditionally been evaluated by conventional angiography and/or surgical exploration. In recent years, multidetector-row computed tomography (CT) angiography has significantly improved detectability of vascular injuries and extravascular injuries in the setting of penetrating injuries. CT angiography is a fast and minimally invasive imaging modality to evaluate penetrating injuries of the head and neck for stable patients. The spectrum of penetrating neck injuries includes vascular injury (extravasation, pseudoaneurysm, dissection, occlusion, and arteriovenous fistula), aerodigestive injury (esophageal and tracheal injuries), salivary gland injury, neurologic injury (spinal canal and cerebral injuries), and osseous injury, all of which can be evaluated using CT angiography. Familiarity with the complications and imaging characteristics of penetrating injuries of the head and neck is essential for accurate diagnosis and optimal treatment.

Keywords: penetrating injury, head and neck, CT angiography, vascular injury, aerodigestive injury

Introduction

Penetrating trauma to the head and neck accounts for 5–10% of all trauma cases that present to emergency departments in the United States. Significant penetrating neck injury violates the platysma by definition. Most commonly these injuries are secondary to stab wounds or gunshot wounds (Fig. 1) in the United States, whereas penetrating neck injuries are rare in Japan and the most common causes of such injuries in Japan are self-harm and stab wounds from accidents. Boston Medical Center is the largest and busiest provider of trauma and emergency services in the Greater Boston area with over 130,000 emergency encounters each year. The trauma service treats and evaluates 3,000 and admits over 2,000 injured patients annually. We see approximately 80% blunt injuries and 20% penetrating injuries, and these are broken down evenly between gunshot and stab wounds.

The mortality rates for penetrating neck injuries can be as high as 10%. Therefore, these injuries require immediate medical attention by surgeons and radiologists. The imaging modalities for penetrating neck injury patients are radiography, endoscopy, ultrasound, computed tomography (CT), and magnetic resonance imaging.

CT angiography (CTA) is increasingly used in the workup of penetrating injury patients without indications for immediate surgical exploration. CTA can delineate vascular injury, which is seen in up to 25% of penetrating wounds. CTA can also reveal non-vascular injuries and the trajectory of the wound.

The aims of this article are to review common penetrating injuries to the head and neck, the anatomic classification of the neck zone, and CTA findings of vascular/extravascular injuries and to describe the traditional diagnostic algorithm and the impact of CTA on the diagnostic algorithm and injury management.

Definition of Penetrating Injury of the Head and Neck

By definition, a penetrating neck injury violates the full thickness of the platysma: if the platysma is intact, the wound is considered superficial. Penetrating neck injuries are classified by penetration site into the three anatomical zones of the neck (Fig. 2) as described by Monson et al. and Roon et al. Zone I extends from the clavicles to the inferior border of the cricoid cartilage. Important structures in zone I include segments of the innominate artery and brachiocephalic veins, segments of the subclavian arteries and veins, the common carotid and vertebral arteries, esophagus, trachea, and thyroid.

Zone II extends from the inferior border of the cricoid cartilage to the angle of the mandible. It is the most common area affected by penetrating injuries. Important structures in zone II include the common, internal, and external carotid arteries and jugular veins, larynx, upper esophagus, and pharynx.

Zone III extends from the angle of the mandible to the skull base. Important structures in zone III include the...
internal carotid and vertebral arteries, external carotid artery branches, internal jugular vein, and pharynx.

**Imaging Techniques and Practical Tips for Assessing Penetrating Injury of the Head and Neck**

CTA is increasingly used in the workup of patients with penetrating injury who do not require immediate surgical exploration.6–12 At most institutions, CTA has replaced angiography as the initial method of diagnosis in patients with penetrating head and neck injuries. At Boston Medical Center, CTA is performed using a 64-multidetector-row CT scanner with a 0.625-mm configuration from the aortic arch to the skull base for neck CTA or to the vertex of the skull for head and neck CTA. The patient is injected intravenously with 100 mL of iodinated contrast material (350–370 mgI/ml) at 5 mL/s through an 18-gauge catheter located in an antecubital fossa vein. Right-sided injection is preferred to improve the bolus of contrast agent by limiting venous regurgitation from compression of the brachiocephalic vein by the aortic arch. We use an automated triggering device with a region of interest placed in the carotid bifurcation. Scanning parameters common to the examinations are tube potential of 120 kVp and a use of automatic exposure control systems (max 660 mA). Axial, sagittal, and coronal multiplanar reformation (MPR) and maximum intensity projection (MIP) reformats with 5-mm slice thickness at 2-mm intervals are generated. Additional three-dimensional (3D) reconstructions with volume renderings are performed in a 3D Lab or by attending radiologists at independent workstations.

It has been shown that utilization of CTA decreases the need for surgical exploration.11 Some studies have shown 100% sensitivity in detecting arterial lesions using direct signs and indirect signs.1,2,13 The direct signs are wall irregularity, contrast extravasation, lack of vascular enhancement, and caliber changes; the indirect signs are bone and bullet fragments less than 5 mm from a major vessel or in the path of injury through a vessel and hematoma in the carotid sheath.13

CTA has many advantages over conventional catheter angiography. CTA is a rapid, non-invasive, and relatively inexpensive modality. CTA also reveals the trajectory of the wound track and non-vascular injuries. Determination of the trajectory is important because the organs lying along the wound track have a high likelihood of injury.2 However, there are some limitations of CTA. Streak artifact from shoulders, retained metallic fragments, and dental fillings can prevent adequate visualization of vessels (Fig. 3). Also, suboptimal timing of contrast or failed intravenous injection may lead to decreased opacification of vessels, which can impair the detection of vascular injury (Fig. 4).

Other imaging modalities for evaluating penetrating injuries include ultrasound and MRI.2,14 Ultrasound is a quick, non-invasive, and readily available tool; however, the technique is highly operator-dependent, and air from the injury, artifacts from retained metallic fragments, and hematoma can limit evaluation of vital structures. MRI provides superior soft tissue contrast and is performed in patients with suspected spinal injury, cerebral injury, or soft tissue injuries including those of the salivary glands. MR angiography has also been proposed in the evaluation of vascular injury.15 Although MRI has many advantages, it is unlikely to become a first-line imaging modality in the emergency setting because it is time consuming and also because metallic foreign bodies can preclude the patient from safely entering the MRI suite.

**Management of Penetrating Head and Neck Injuries**

Surgical access to zone I and zone III injuries is challenging because of the inherent difficulties in accessing the thoracic or intracranial cavity. Zone II, on the other hand, is readily surgically accessible. Traditionally, in the evaluation of hemodynamically stable patients with penetrating neck trauma, patients with zone I and zone III injuries were evaluated with conventional angiography, whereas zone II patients were explored surgically.1–3,14,16 Patients with hemodynamic instability who present with clinically detectable signs of injury such as expanding hematomas, active hemorrhage, neurologic symptoms, bruit, thrill, hematemesis, hemoptysis, stridor, or air leak undergo immediate surgical exploration.3,14,16

In recent years, with evolution of CT, CTA has become increasingly used for the initial evaluation of penetrating...
Imaging of Penetrating Head and Neck Injuries

Vascular injury

Arterial injuries are seen in about 25% of patients with penetrating neck injuries. Carotid artery injuries are seen in 80% of vascular injuries, and vertebral artery injuries are seen in 43%. Approximately 20% of vascular injuries involve venous structures. Venous injuries are more commonly clinically silent when compared with arterial injuries, and injuries of peripheral branches of the cervical veins are often treated conservatively. Therefore,
imaging should be focused on the identification of more clinically significant injuries. The optimal imaging strategy for diagnosis of cervical venous injuries has not yet been determined; however, CTA has been shown to demonstrate these injuries well. Vascular injuries seen on CTA include extravasation, pseudoaneurysm, dissection, occlusion, and arteriovenous (AV) fistula.

**Extravasation**

CTA demonstrates extravasation (Fig. 7) as contrast pooling outside the vascular lumen. Proximity to known vasculature can help identify the injured vessel. Lack of vascular enhancement in the parent vessel can also be seen in the setting of extravasation.

**Pseudoaneurysm**

Pseudoaneurysm formation (Fig. 8) results from partial or complete disruption of the vessel wall. It is a relatively common type of vascular injury and accounts for 33%
of internal carotid artery lesions after penetrating trauma.\textsuperscript{18,20} CTA shows an outpouching of contrast from the lumen with widening of the vessel contour.\textsuperscript{2,6–12,20} Treatment consists of ligation, embolization, or bypass surgery. Occasionally conservative management is utilized.

\textbf{Dissection}

Dissection (\textbf{Figs. 9 and 10}) is rare in penetrating trauma, affecting less than 2\% of patients.\textsuperscript{20} CTA demonstrates an enlarged vessel diameter with narrowed eccentric lumen secondary to an intramural hematoma. Non-occlusive dissection can appear as focal intraluminal filling defects.\textsuperscript{2,6–12,20} Conservative treatment consists of anticoagulation; however, in the setting of other injuries such as hematoma and solid organ lacerations, heparin may be contraindicated. Aspirin is used in this setting at Boston Medical Center. Endarterectomy, bypass, interposition graft, and ligation are surgical options.

\textbf{Occlusion}

Partial or complete occlusion (\textbf{Fig. 11}) is the most common type of vascular injury in penetrating trauma.\textsuperscript{20} CTA reveals the absence of vascular enhancement. Proximal dissection may or may not be present.\textsuperscript{2,6–12,20} Treatment consists of anticoagulation or revascularization.
AV fistula
Patients with a bruit typically undergo conventional angiography because the likelihood of an AV fistula is high and conventional angiography allows the opportunity of treatment. Direct communication can be demonstrated on CTA with the enhancement of venous structures being equal to that of the arteries²,⁶⁻¹²,²⁰ (Fig. 12). Treatment is typically surgical; however, embolization can be performed.

Aerodigestive injury
Esophageal injury
Traumatic injury to the esophagus is rare, being seen in 0.9–6.6% of penetrating neck injuries.² It has been shown that a delay in diagnosis and surgical intervention increases the number of complications resulting from mediastinitis, abscess, and sepsis.²¹ Early detection of esophageal injuries is imperative as mortality is estimated to be up to 20%.²,²¹,²²

CT findings of esophageal injury (Fig. 13) include esophageal wall thickening, periesophageal gas and fluid collection, mediastinal fluid collection, mediastinal inflammation, and focal esophageal wall defect.²,²³ MPR images provide a better appreciation of the extent
If esophageal injury is suspected, fluoroscopic esophagography and endoscopy are indicated.

Tracheal injury

Tracheal injuries are uncommon in penetrating neck injury, occurring in 1–7% of patients. If a wound track crosses the trachea or larynx, tracheal injury must be considered. CT reveals a focal defect or contour deformity of the tracheal wall, which are direct signs of tracheal injury.
Tracheal injury (Fig. 14). Other findings of tracheal injury are paratracheal air, pneumomediastinum, and soft tissue emphysema in the neck. Using MPR images with lung and soft tissue window settings is helpful to detect direct and indirect signs of tracheal injury on CT. It should be kept in mind that a tracheal diverticulum (Fig. 15) may be mistaken for tracheal injury in the trauma setting; however, knowing the common location of tracheal diverticula at the right posterolateral tracheal wall can assist in differentiating the two diagnoses.

Salivary gland injury

Salivary gland injury is a soft tissue injury of the neck, and salivary glandular damage (Figs. 16 and 17) can occur in penetrating neck trauma. Injury of Stenson’s and Warthin’s ducts can result in post-traumatic sialoceles and fistulas that may require surgery. Facial nerve injury may occur in cases of parotid gland injury.

Fig. 18 Epidural hematoma in spinal canal. Epidural hematoma with gunshot wound. CTA axial image demonstrates a high-density epidural hematoma (arrow) at the right lateral spinal canal deforming the thecal sac.

Fig. 19 Cerebral injury. Cerebral injury caused by an arrow. (A) Axial unenhanced CT demonstrates parenchymal hemorrhage (arrow) around the arrow in the left parietal lobe. CTA images (B: sagittal MIP, C: 3D VR (volume rendering)) demonstrate an arrow entering the nasal cavity and exiting posteriorly through the parietal skull. (D) Conventional angiogram demonstrates a left distal posterior cerebral artery pseudoaneurysm (arrow) after removal of the projectile. (E) The pseudoaneurysm was successfully coiled (arrow).
Neurogenic injury

Injury to the central nervous systems including spinal cord injury (Fig. 18) and cerebral injury (Fig. 19) can occur with penetrating trauma to the head and neck. Approximately 11–14% of spinal cord injuries are penetrating injuries to the cervical spine. Spinal cord injury is implied when a wound track extends through the canal. Gas, bone fragments, or foreign bodies in the spinal canal signify dural violation. MRI can be performed to confirm or further investigate neurogenic injury if there is no metallic foreign body present that precludes MRI.

Osseous injury

Fractures of the skull, facial bone, and cervical spine (Fig. 20) may be present in penetrating injuries to the head and neck. Temporal bone fracture (Fig. 21) is frequently associated with various complications such as nerve injury, ossicular chain injury, vascular injury, and cerebral injury.

Unstable cervical spine injuries are rare after penetrating trauma to the head and neck; however, thorough investigation of the cervical spine is needed. Cervical collars are not recommended in this setting as other injuries may be masked.

Conclusion

Stab wounds and gunshot wounds are the most common causes of penetrating trauma to the head and neck in the United States. For patients without indications for immediate surgical exploration, CTA has been demonstrated to have high sensitivity and negative predictive value for vascular injuries. CTA can also delineate extravascular injuries that may or may not be suspected on physical examination. Knowledge of management of penetrating neck injuries and their imaging characteristics is essential for making an accurate diagnosis and facilitating prompt treatment.

References

8. Osborn TM, Bell RB, Qaisi W, Long WB: Computed tomographic angiography as an aid to clinical decision making in the selective management of penetrating injuries to the neck: a reduction in the need for operative exploration. J Trauma 2008; 64: 1466–1471. [Medline] [CrossRef]