Imaging Evaluation of Penetrating Neck Injuries

Scott D. Steenburg, MD • Clint W. Sliker, MD • Kathirkamanathan Shanmuganathan, MD • Eliot L. Siegel, MD

Penetrating neck injuries are a significant source of morbidity and mortality. Diagnostic imaging plays an integral role in the diagnosis and management of these injuries. Although clinical management of penetrating injuries to the neck remains controversial, many institutions have shifted away from mandatory surgical exploration of most penetrating neck injuries toward use of endoscopy, various imaging modalities, and selective surgery to manage specific injuries diagnosed with these techniques. Much of this shift can be attributed to computed tomographic (CT) angiography, a fast, reliable, and noninvasive procedure that provides a global assessment of the neck, thereby reducing the frequency of nontherapeutic surgical neck explorations and limiting the need for diagnostic conventional angiography. Therefore, radiologists interpreting images from CT angiography should be prepared to provide management recommendations on the basis of the CT angiographic findings. An appreciation of the value, roles, and limitations of multidetector CT angiography and other imaging modalities can position the radiologist as a vital participant in the care of patients with penetrating trauma to the neck. Supplemental material available at http://radiographics.rsna.org/lookup/suppl/doi:10.1148/rg.304105022/-/DC1.

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Abbreviations: CCA = common carotid artery, ICA = internal carotid artery, MIP = maximum intensity projection

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1From the Department of Diagnostic Radiology and Nuclear Medicine, University of Maryland Medical Center and R. Adams Cowley Shock Trauma Center, 22 S Greene St, Baltimore, MD 21201. Recipient of a Cum Laude award for an education exhibit at the 2009 RSNA Annual Meeting. Received February 5, 2010; revision requested February 23 and received March 5; accepted March 8. E.L.S. serves on the speakers bureau of FeraRecon; the board of directors of Carestream Health; and the advisory boards of Fovia, McKesson, Medrad, and Mercury Computer Systems; he also receives research grants from Anatomic Travelogue, Anthro, Barco, Evolved Technologies, GE, Herman Miller, Hitachi, Intel, Philips, RedRick Technologies, Siemens, Steelcase, Vital, and XYBIX Systems; all other authors, editors, and reviewers have no relevant relationships to disclose. Address correspondence to S.D.S. (e-mail: ssteenburg@umm.edu).

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Introduction
Penetrating neck injuries can be the result of low- or high-energy projectiles. These wounds are associated with a high risk of clinically significant injury because a high concentration of vital structures, all of which are essential for survival, is closely packed within a small anatomic area. The mortality from penetrating neck injuries ranges from 2% to 10% (1–4), and thus these injuries require immediate medical attention by surgeons experienced in managing such injuries.

The classic management of penetrating injuries to the neck has been dictated primarily by the location and depth of the injury, in addition to clinical signs of active hemorrhage, airway compromise, and injuries to the pharynx or upper esophagus, with some patients undergoing surgical exploration to both diagnose and treat injuries and others undergoing various diagnostic tests instead of immediate surgery. As experience with penetrating neck trauma accrued, management evolved into a more selective approach, with many patients in stable condition evaluated with conventional angiography, endoscopy, and esophagography. Spurred primarily by advances in diagnostic imaging, particularly multi-detector row computed tomography (CT), management of cases of penetrating trauma to the neck further evolved, with management decisions guided by the results of multidetector CT angiography.

Penetrating neck injuries can be quickly evaluated with multidetector CT angiography by noninvasive means, as it provides a global assessment of large anatomic regions with high spatial resolution. Multidetector CT angiography can provide information about the integrity of the neck vasculature, skeletal structures, airway, and digestive tract. By delineating the wound track, it can be used to determine the potential for injury to vital structures when a definitive diagnosis cannot be rendered; this can be especially useful when evaluating pharyngoesophageal injuries. As a result, multidetector CT angiography can be used to determine the need for further diagnostic evaluation with endoscopy, esophagography, or conventional angiography, in addition to helping definitively identify injuries that require surgical or endovascular repair.

In this article, we discuss the evolution of the diagnosis and management of acute penetrating neck injuries. The role that imaging plays in diagnosing injuries and directing patient care is presented, and, reflecting current trends, special attention is given to the use of multidetector CT angiography, with emphasis on the use of three-dimensional volume viewers. A wide variety of vascular injuries are illustrated, in addition to injuries to the spine, spinal cord, esophagus, and airway.

Anatomy
Penetrating neck injuries are characterized by the anatomic zone of the entry wound as determined by physical examination (Fig 1) (5–7), with the site of injury localized to one of three zones. Although its role in directing patient care is no longer as important in many contemporary centers, this anatomic classification system is still widely used by trauma surgeons. Thus, the radiologist involved in the care of patients with penetrating neck injuries should be familiar with this scheme to facilitate and clarify communication with the trauma surgeon.

Zone I is the most inferior of the three zones. It is bounded inferiorly by the sternal notch and clavicles and superiorly by the cricoid cartilage (Fig 1). At the inferior margins, there is considerable overlap with the thoracic inlet and superior mediastinum. Important structures within 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. In some patients, the aortic arch and lung apices may extend into this region. Given the overlap with the thoracic inlet, patients requiring surgical repair of injuries in zone I may require both transcervical and transthoracic approaches (5).
Zone II extends from the level of the cricoid cartilage to the angle of the mandible. 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 level of the mandible to the base of the skull. Important structures in zone III include the internal carotid and vertebral arteries, external carotid artery branches, internal jugular vein, and pharynx. Many of the vital structures in this region are poorly accessible to the surgeon because of their proximity to the skull base and overlying facial structures (5).

During the evaluation of patients with penetrating neck trauma, it is important to remember that the zone of injury refers to the site of the entry wound and that the wound track may cross into another zone or zones as well as the face, cranium, or thorax. Consequently, the location of an injury to any given vital structure may be in a zone or compartment remote from the zone of entry. This fact highlights the need for the radiologist to clearly localize the site of an injury or potential injury to a specific vital structure.

Evolution of the Management of Penetrating Neck Injuries

Penetrating neck injuries were described in the medical literature as early as the 1500s, when military surgeons reported ligation of injured vessels in attempts to control exsanguinating hemorrhage (5,8). This technique improved survival but was accompanied by significant morbidities, primarily stroke (8,9). Expectant, nonoperative management of penetrating neck injuries dominated from the Civil War era through World War II (5,7,10–13), an interval during which overall mortality rates ranged from 11% to 15% (10,14). Field triage, improvements in hemostasis, and emergent airway management during World Wars I and II resulted in only modest improvements in mortality rates over those seen in preceding decades. Near the end of World War II, the acceptably high rate of undiagnosed neurovascular injuries resulted in a shift away from expectant management to immediate surgical exploration for all patients with penetrating neck injuries violating the platysma (5,15–22). This trend continued through the Korean and Vietnam conflicts and into recent decades.

The post–World War II management approach (or classic management) of penetrating neck injuries incorporates surgical exploration and invasive diagnostic tests (19,20,23–27). This aggressive management philosophy was driven primarily by fear of missed vascular injuries at physical examination and the potential for catastrophic central nervous system complications (17,22). In patients in whom no clinical indications for immediate surgical exploration were found, the location of the entry wound(s) determined the approach taken. Zone II injuries (which tend to be more common because this is the largest zone) better lend themselves to surgical exploration because this zone is easily accessible to the surgeon. Although it facilitated rapid repair of many injuries, the philosophy of mandatory surgical exploration of all zone II injuries, regardless of clinical presentation, resulted in high rates of negative, nontherapeutic neck explorations, reportedly as high as 50%–60% (1–3,25,28).

In contrast, injuries involving zone I or III presented a dilemma, because surgical exposure of these regions can (a) be technically difficult (or impossible) and (b) may involve the thorax or intracranial cavity, respectively (5). With the classic approach, zone I or III injuries were therefore evaluated with angiography, endoscopy, laryngoscopy, and esophagography (23–27). Regardless of the zone of injury, immediate surgical exploration was indicated in clinically unstable patients, including those patients who exhibited massive hemorrhage, an actively expanding hematoma, shock, or airway compromise (2,5,20,24,29–33).

The 1990s saw a re-evaluation of the established approach to managing cases of penetrating neck injuries, with a shift away from mandatory surgical exploration of many zone II injuries toward more selective use of surgical exploration. On the partial basis of several prospective and outcomes studies that suggested that physical examination alone is highly accurate for detection of internal injuries that require surgical repair, thereby limiting the utility of mandatory neck explorations, a selective approach was shown to decrease the rate of nontherapeutic neck explorations (1,4,5,13,17–21,34,35). However, as documented by other authors, the absence of overt clinical signs or symptoms of a clinically significant injury does not mean that one is not present, especially a vascular injury. For example, according to Fogelman and Stewart (14), 43% of patients with clinically significant cervical vascular injury have no evidence of hemodynamic instability, and 70% do not exhibit clinical evidence of active bleeding at the time of admission. In a study of 393 patients with penetrating neck injuries, Apffelstaedt and Müller (23) reported...
that clinical findings of cervical vascular injury were absent in 30% of patients with significant vascular injuries identified at surgery. Bishara et al (25) reported that 23% of patients with penetrating zone II neck injuries identified at surgical exploration were not suspected of having them at clinical examination.

Coupling the need to diagnose clinically significant injuries with the need to limit unnecessary surgical neck explorations, the approach to managing cases of penetrating neck injuries evolved into a selective one. This approach limited the influence of zone of injury on the decision to proceed to surgery in favor of physical examination and a variety of diagnostic tests, including radiography, conventional angiography, esophagography, endoscopy, ultrasonography (US), magnetic resonance (MR) angiography, and, later in the 1990s, CT angiography (5,13,17–21,33,36).

The further development of CT angiography, facilitated by recent advances in multidetector CT, has contributed to this shift in management philosophy. CT angiography has been shown to be a fast, safe, and reliable noninvasive method for evaluating patients with penetrating neck trauma (13,17,19–21,34,37). Several studies have indicated that the use of CT angiography can virtually eliminate nontherapeutic (ie, negative) surgical neck explorations (1,5,13,18,35). Direct and indirect signs of vascular injuries of the neck can be detected and often excluded on the basis of CT angiography. In addition, simultaneous evaluation of the osseous structures and upper aerodigestive tract can be performed (5,34).

Additional evaluation of the upper trachea and esophagus with laryngoscopy, endoscopy, and esophagography is still advocated by some authors for comprehensive evaluation of the patient with penetrating neck injuries (23–25,27). At our institution, the use of these procedures is most often limited to those patients in whom the wound track approaches the aerodigestive tract or in whom signs or symptoms of an aerodigestive injury are noted. The results of neck CT angiography often can be used to determine whether patients with such injuries would be better served with surgical or nonsurgical treatment. On the basis of our experience and the reported benefits of CT angiography, selective management has evolved into a CT angiography–based approach, and most patients with a history of penetrating neck trauma but without indications for emergent surgical exploration undergo neck multidetector CT angiography as the initial diagnostic examination.

**Mechanism of Injury and Ballistics**

In general, penetrating injuries can be classified as high- or low-energy injuries. Low-energy injuries typically are the result of low-velocity handgun ammunition and sharp objects, such as knives, glass, or other thin sharp objects. High-energy injuries are the result of high-velocity projectiles, such as those from military-style rifles, and typically have potential for more widespread tissue destruction than do low-energy injuries. The severity of a bullet wound depends on velocity, bullet characteristics, and the tissues through which the bullet travels (38).

The projectile can cause injury to a structure by direct impact, transfer of its kinetic energy through tissues with resulting shock wave formation and cavitation, or a combination of both. As a result, anatomic structures may be damaged even in the absence of direct contact with a projectile. Because they are associated with high kinetic energy distributed throughout the surrounding tissues on impact, high-velocity
projectiles tend to cause more cavitation than low-velocity projectiles and, consequently, more secondary damage. Bone fracture fragments and missile fragmentation can form secondary projectiles that cause additional injuries (38).

**Determination of Wound Trajectory with CT Angiography**

Determining the trajectory of the wound track aids in the evaluation of patients with penetrating neck trauma, because the organs lying along the track can be considered to have a high likelihood of being injured (16,17,38,39). If there is a single track with defined entrance and exit wounds, estimation of trajectory may be straightforward. However, the trajectory of penetrating injuries is often difficult to determine clinically.

For example, patients with gunshot wounds may exhibit multiple entrance wounds, multiple exit wounds, or entrance wounds without exit wounds. Many high-velocity projectiles are designed to fragment on impact and thus generate multiple secondary missiles. Although fragments typically follow the course of the main missile (Fig 2; see also Image Dataset [online]), they may veer off into differing trajectories and cause damage along a path separate from the main track (38). Missile impact with bone can result in deviation of the projectile from its initial trajectory and can create osseous fragments that can also serve as secondary projectiles, each of which may have a different trajectory, causing additional injury (38).

Determining the trajectory of low-velocity objects can be especially difficult (Fig 3) (33), because entrance wounds often have no corresponding exit wounds and the diameter of the tracks may be small. Reliable prediction of the orientation of a stab wound is best made when the object is left in situ, a presentation not frequently encountered. Consequently, the role of imaging is vital in determining wound trajectory and thereby identifying those structures at risk for injury and limiting the number of diagnostic tests or procedures required to evaluate the patient (39).

Initial imaging with radiography can be used to determine the presence and number of foreign bodies and, if orthogonal views are obtained, to triangulate the locations of the foreign bodies. Despite the useful information obtained from radiography, the exact extent of internal injuries may not be precisely determined, and additional imaging evaluation is usually warranted (40).

At our urban level I trauma center, multidetector CT angiography is the primary means by which patients with penetrating neck injuries are imaged. In our experience, multidetector CT angiography regularly shows the trajectory of wound tracks. However, because wound tracks often are not oriented in standard axial, sagittal, and coronal planes, liberal use of an interactive viewer to manipulate the dataset is essential to appreciate the true orientation of the track. Often, the track can be displayed on a single image by this means (Fig 2; see also Image Dataset [online]). Interactive viewing may also help identify tracks caused by secondary projectiles.

At times, penetrating objects may leave behind no residual foreign bodies or bone fragments (Fig 3), thereby rendering identification of the track difficult if not impossible. We typically encounter this situation in patients with stab wounds. In such cases, foci of gas and small areas of hemorrhage or edema (ie, fat stranding) may be the only clues to the location of the track (Fig 4). Alternatively, creating a straight line that connects

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**Figure 3.** Evaluation of wound trajectory in an 18-year-old man with low-velocity gunshot wounds to the face and zone III. Image from multidetector CT angiography shows a right-sided zone III gunshot wound. Exact orientation of the wound track could not be determined because diffuse hemorrhage obscures fat planes (*), soft-tissue gas is confined to the anterior neck, and no foreign bodies are retained. The patient had a pseudoaneurysm of the common carotid artery (CCA).
definitively identified injuries can give a clue as to the trajectory and help identify other intervening structures that may be injured.

**Specific Penetrating Neck Injuries**

**Arterial Injuries**

Penetrating arterial injuries contribute substantially to negative clinical outcomes in penetrating neck trauma, primarily as a result of neurologic events such as stroke (4,30). Approximately 15%–25% of penetrating injuries to the neck result in an arterial injury (21,24,33). Among penetrating arterial injuries of the neck, up to 80% involve the carotid arteries and up to 43% involve the vertebral arteries. Carotid artery injuries are particularly devastating, leading to stroke in as many as 15% of patients and death in 22% (8,21,22,41).

Signs of arterial injuries at multidetector CT angiography include partial or complete occlusion (Figs 5–7; see also Image Dataset [online]).
Figure 6. Arterial occlusion in an 18-year-old man with a zone III gunshot wound. (a) Oblique sagittal MIP image from multidetector CT angiography depicts complete occlusion of the right ICA (arrow). (b) Unenhanced brain CT image obtained at admission demonstrates an infarct (arrowhead) in the right frontal lobe. (c, d) Diffusion-weighted MR image (c) and apparent diffusion coefficient map (d) show the infarct (arrowhead).

Figure 7. Arterial occlusion in a 25-year-old man with a zone II gunshot wound. (a) Axial CT image shows numerous metallic bullet fragments at the level of the skull base with associated artifact, which completely obscures the regional arterial structures. (b) Axial image from CT angiography, obtained at the level of the petrous apices, shows the enhanced right ICA but no enhancement of the left ICA (arrow) or basilar artery (arrowhead). Unenhanced brain CT showed severe diffuse cerebral edema resulting from extensive ischemia.
pseudoaneurysm (Figs 4, 8), intimal injuries (Fig 9), arteriovenous fistula (Fig 10), active bleeding (Fig 11; see also Image Dataset [online]), and luminal caliber changes (4,19,33,34,37,42). Because venous contamination may mask the hallmark early venous filling of an arteriovenous fistula when multidetector CT angiography is used, conventional angiography may be required when an arteriovenous fistula is suspected.

**Accuracy of CT Angiography in Evaluation for Neck Arterial Injuries.**—In acute penetrating trauma to the neck, exclusion of arterial injuries is often the most immediate concern given the risk of stroke or exsanguination. In this regard, CT angiography has several practical advantages over four-vessel conventional angiography, the traditional standard of reference. CT angiography is available in most contemporary emergency departments and trauma centers; it provides a global perspective of the vasculature, soft tissues, and osseous structures; it is fast; and it does not require mobilizing the additional personnel that constitute an angiography team.

Several groups have compared CT angiography with conventional angiography for detection of neck arterial injuries in the setting of penetrating neck trauma; all reported sensitivities and specificities for CT angiography in excess of 90% (4,5,13,17–19,37). In one study, Münera...
Figure 9. Intimal injury in a 25-year-old man with a zone II gunshot wound. (a, b) Axial (a) and sagittal oblique MIP (b) CT images show an eccentric intraluminal filling defect in the ICA (arrow). The filling defect is related to intimal injury and thrombus. (c) Image from digital subtraction angiography performed before endovascular repair shows the injury (arrow), which was successfully treated with a stent.

Figure 10. Arteriovenous fistula in a patient with multiple stab wounds to zone I. Axial (a) and coronal oblique thick-slab MIP (b) images from CT angiography show a direct communication (arrow) between the CCA (A) and internal jugular vein (V) with a large adjacent pseudoaneurysm (arrowhead). The enhancement of the internal jugular vein is comparable with that of the CCA. The patient was treated successfully with surgery.

Figure 11. Active bleeding in a 43-year-old man with a zone II gunshot wound. Axial image from CT angiography shows active bleeding in the sublingual region (arrowhead). The bleeding was treated with transcatheter coil embolization (see also Image Dataset [online]).
et al (4) evaluated 60 patients with penetrating neck trauma who underwent both helical single-section CT angiography and conventional angiography. Ten of these patients had cervical arterial injuries, which involved the carotid arteries in seven patients and the vertebral arteries in three patients. With conventional angiography used as the reference standard, single-section CT angiography had a sensitivity of 90%, specificity of 100%, positive predictive value of 100%, and negative predictive value of 98%. In the single false-negative case, a small pseudoaneurysm at the origin of the CCA, later seen with conventional angiography, was missed at CT angiography because the origins of the CCAs were not included in the acquisition.

In a follow-up study, Múnera et al (19) detailed their experience with an additional 175 patients who underwent single-section helical CT angiography after penetrating neck trauma. Although these cases were interpreted prospectively to aid the trauma surgeon in clinical decision making, statistical analyses were performed with data obtained by blinded retrospective consensus review performed within 72 hours of image acquisition. CT angiography demonstrated arterial injuries in 27 patients. With a combination of conventional angiography, surgical findings, and clinical follow-up used as the reference standards, the sensitivity, specificity, and positive and negative predictive values for CT angiography were 100%, 98.6%, 92.8%, and 100%, respectively.

In what, to our knowledge, is the only study reporting the use of multidetector CT angiography to diagnose penetrating arterial injuries of the neck, Inaba et al (43) used four-section multidetector CT angiography to prospectively screen 93 patients with penetrating neck injuries. With an aggregate of surgical, angiographic, and clinical follow-up used as the reference standards, the authors found that multidetector CT angiography had 100% sensitivity and 93.5% specificity for the detection of vascular and aerodigestive injuries. No injuries requiring intervention were missed with multidetector CT angiography, although there were five false-positive cases. Four patients suspected of having aerodigestive injuries had normal findings according to the reference standards (two underwent surgical exploration and two underwent endoscopy and esophagography), and one patient suspected of having a vertebral artery injury had normal findings at four-vessel angiography (43).

To our knowledge, no data have been published detailing the accuracy of 16-section multidetector CT (or higher-section-number multidetector CT) in penetrating neck injuries. On the basis of the aggregate single-section CT angiography and multidetector CT angiography data and the associated practical advantages, multidetector CT angiography has essentially replaced conventional angiography at many major trauma centers for the initial evaluation of patients with potential penetrating arterial injuries of the neck, with conventional angiography reserved as a problem-solving tool or a stepping stone to endovascular intervention (5).

At our institution, axial, sagittal, and coronal multiplanar reformation and MIP images are routinely generated as part of every neck multidetector CT angiography examination and can quickly be generated by the technologist without additional radiologist time. Furthermore, nearly every injury detected with these routine reformation techniques is further evaluated by using approaches similar to those shown by Velthuis et al (44) and Ferencik et al (45). When these additional postprocessing techniques are used, the source data are reviewed on an independent workstation with liberal dataset manipulation by means of interactive processing techniques, including off-axis and oblique multiplanar reformation, MIP, and even volume-rendered images. It is often on these tailored images that the extent of injury and precise injury morphology can be fully understood (Figs 2, 5, 6, 8–10).

Although multidetector CT angiography has advantages over conventional angiography, some limitations characterize this approach. Initial CT angiography may result in an overall large contrast material load if the patient later undergoes conventional angiography for problem solving or intervention. Open communication with the referring surgeons is important to maximize the information obtained while minimizing contrast material load. Conventional angiography should be considered first if assessment indicates that the patient will ultimately need angiography with or without intervention, especially if the patient is at risk for contrast material–induced nephropathy (although this may be a secondary consideration in young, healthy patients). Immediate therapeutic interventions cannot be performed after diagnostic multidetector CT angiography, a limitation not associated with diagnostic catheter angiography. In our experience, the advantages of CT angiography generally outweigh the disadvantages, which are significant in only a minority of cases.
CT Angiography: Limitations and Pitfalls.—Limitations of cervical CT angiography in penetrating trauma are largely related to imaging technique and artifacts. Suboptimal timing may result in poor visualization of the arteries, and venous contamination can mask early venous filling, which may signify an arteriovenous fistula. Body habitus can negatively affect image quality, particularly at the shoulders and lower neck, where image noise can significantly compromise visualization of the proximal common carotid and vertebral arteries. Motion artifact may either obscure or mimic an injury. Dental amalgam, spinal hardware, and metallic foreign bodies (eg, bullet fragments) can create significant beam-hardening artifact that can (a) simulate an injury, especially an intimal flap, or (b) partially or completely obscure an adjacent vessel. Occasionally, conventional angiography may be needed to adequately visualize an artery obscured by beam-hardening artifact from an adjacent bullet fragment or metallic shrapnel fragment (Figs 7a, 12). These potential limitations are fortunately uncommon, affecting approximately 1% of properly performed multidetector CT angiography examinations (19).

Despite a normal-appearing artery, indirect signs of vascular injury (eg, periarterial hematoma and fat stranding) or signs that the artery is within the wound track (eg, periarterial gas or a missile fragment within 5 mm of the artery) can create a diagnostic dilemma. Because of the potential for stroke or hemorrhage to occur owing to an injury overlooked at CT angiography, it has been recommended that the vessel in question be studied with conventional angiography or, at least, follow-up CT angiography (33) to more definitively exclude an injury. It is our opinion that outcomes studies will be needed to determine the significance of these findings in the absence of direct signs of vascular injury before their significance is dismissed.

MR Angiography.—MR angiography is an established means for evaluating the neck arteries. Although MR angiography can be used to diagnose blunt carotid and vertebral artery injuries (20,46,47), its use in penetrating trauma is limited, primarily by the potential presence of retained metallic foreign bodies, which may serve as contraindications to entry into the MR imaging suite. In addition, the role of MR imaging in diagnosis of other injuries, especially aerodigestive injuries, has not been explored, so that evidence is not yet sufficient to support its value as a comprehensive diagnostic tool. For these reasons, we do not believe that MR angiography and MR imaging should currently play a major role in evaluating patients with potential penetrating vascular injuries of the neck.

Conventional Angiography.—Digital subtraction angiography remains the standard of reference for diagnosis of arterial injuries of the neck.
However, it does not provide the comprehensive diagnostic evaluation afforded by multidetector CT angiography and has a relatively low rate of positive results (10%–30%) (16,33,48,49). Complications from conventional angiography are rare (0.16%–2%) but significant and include puncture site hematoma, access vessel thrombosis, thromboembolization distal to the access point, arteriospasm, ischemia, and arterial dissection (4). Thus, at our institution and others, conventional angiography (except as part of endovascular repair) has taken on the secondary role of a problem-solving modality.

**Ultrasonography.**—Doppler US is another potential test for evaluation of the cervical vasculature in the setting of trauma (33,50–53). It can provide information on the patency of a vessel, as well as flow velocity, and can provide high-resolution images of the arterial wall. It is noninvasive, portable, and inexpensive compared with other imaging options, is free of ionizing radiation, and does not require contrast material.

Several studies report that US is a viable screening modality in the setting of penetrating neck trauma (50,51,53). In 1996, Montalvo et al (53) prospectively evaluated the accuracy of color Doppler US in 52 patients, with angiography and surgery used as the reference standard in 48 patients. They concluded that Doppler US is as accurate as angiography in screening for zone II and III vascular injuries in stable patients. Corr et al (50) in 1999 came to a similar conclusion when they prospectively studied 25 patients with penetrating neck injuries with both color Doppler US and angiography. Ten patients had positive findings, which were later confirmed at angiography or surgery, with no false-positive or false-negative Doppler US examinations.

In another study, Demetriades et al (51) evaluated a population of 200 patients with penetrating neck injuries, including 82 patients who underwent both angiography and color flow Doppler US. US allowed correct detection of 10 of 11 vascular injuries, with no false-positive cases. A small intimal injury seen at angiography in one patient was not detected with US, but no surgery or other intervention was required in that case. Color flow Doppler US had a sensitivity of 91% and specificity of 98.6% for detection of all vascular injuries, with 100% sensitivity and specificity for detection of surgical vascular injuries (51).

However, these apparent advantages are overshadowed by the limitations of this modality in the setting of penetrating neck trauma. Color Doppler US is operator dependent and may not be available at all times. In addition, visualization of the vasculature in lower zone I as well as zone III is limited with color Doppler US. Visualization of the vertebral arteries can also be limited by overlying bone (20,53,54). The presence of subcutaneous gas and limited acoustic windows because of wound bandages can also significantly limit visualization of the underlying vasculature. Moreover, US is of limited to no value in evaluation of the upper airway, esophagus, and spine. Because of these significant limitations, color Doppler US is not routinely used in initial evaluation of penetrating neck injuries.

**Venous Injuries**

Penetrating venous injuries are seen in 16%–18% of patients with penetrating neck trauma (23,43,55). Historically, cervical venous injuries were identified at surgical exploration, but the shift toward selective management has reduced the number of neck explorations. Although the optimal imaging strategy for diagnosis of cervical venous injuries has not yet been determined, CT angiography has been shown to better demonstrate these injuries (Fig 13), which are often missed at physical examination (55). In the series

![Figure 13. Venous injury in a 24-year-old man with a zone II gunshot wound. CT image shows a filling defect in the left internal jugular vein (curved arrow), a finding indicative of an intraluminal thrombus, which was presumably due to a mural injury. The adjacent CCA (A), gas (straight arrow), and metallic foreign bodies (arrowheads) are also seen. The vein was ligated at neck exploration.](image-url)
of Gonzalez et al (55), cervical venous injuries were the most frequently missed neck injury at physical examination, although no complications were noted, suggesting that imaging should be focused on the identification of other, more clinically significant injuries.

**Spinal Injuries**

Penetrating injuries to the cervical spine account for approximately 11%–14% of spine injuries (56–59). The diagnosis of injuries to the osseous spine in the setting of penetrating neck trauma is generally not a diagnostic dilemma, particularly with multidetector CT angiography (Figs 2, 14, 15). The radiologist should report fractures and the distribution and location of foreign bodies and describe any signs of dural violation, such as gas, bone, or foreign bodies in the spinal canal (60). Low-energy sharp objects do have the ability to cut bone without the fragmentation typically seen with high-energy penetrating injuries (Fig 16).
A wound track extending through the spinal canal implies the presence of a spinal cord injury (Fig 15) (59). With high-energy weapons, it is common for bone and metal fragments to align along the track through the spinal canal, but cord injury can occasionally result from secondary cavitation without the bullet entering the spinal canal (61). However, not all penetrating injuries to the spinal cord are straightforward, especially stab wounds (Fig 17). MR imaging can be used to confirm or better delineate spinal cord injuries, provided no contraindications to entry into the MR environment are present (eg, retained metallic missile fragments of unknown or ferromagnetic composition).

Figure 16. Spinal injury in a 23-year-old man with upper extremity numbness and paresthesias after stab wounds to the posterior neck and upper arm. (a) Image from CT angiography shows small bubbles of soft-tissue gas (arrowhead) within the wound track, which extends to a fracture of the C4 left lamina (arrow). (b, c) Axial gradient-echo (b) and sagittal T2-weighted (c) MR images show a small hemorrhagic spinal cord contusion (arrowhead) at the C3 level; the hemorrhage is best demonstrated on the gradient-echo image. The C4 fracture and C3 cord contusion indicate a superiorly oriented stab wound. The sagittal image shows a defect in the nuchal ligament (N in c) in the suboccipital region and disruption of the ligamentum flavum at C3-C4 (arrow in c).

Figure 17. Spinal injury in a 21-year-old man with an upper extremity neurologic deficit after a stab wound to the posterior neck. (a) Image from CT angiography shows a small soft-tissue hematoma (white oval) but no active bleeding or fracture. (b) Axial gradient-echo MR image shows a small focal spinal cord contusion (arrowhead) at the C3-C4 level. The soft-tissue hematoma is also seen (white oval).
Injuries to the Esophagus
Cervical esophageal injuries are uncommon, seen in only 0.9%-6.6% of patients with penetrating neck trauma (5,36,62-64). Delayed diagnosis is the most important contributor to death from penetrating esophageal injuries, which occurs mainly as a result of mediastinitis and sepsis. Therefore, diagnosis and repair of esophageal injuries should be given high priority (5). Mortality from penetrating esophageal injuries is high, approaching 20% in some series (5,64-67). Mortality remains high even when the injury is promptly diagnosed. For example, in the series of Symbas et al (64), 12.5% of patients with penetrating cervical esophageal injuries who underwent immediate repair died. Therefore, esophageal injuries should be suspected when a penetrating injury is near the esophagus or the esophagus is directly in the trajectory of a penetrating injury (Fig 18).

The esophagographic procedure is typically biphasic, with an initial study performed with water-soluble contrast material. If results are normal, the initial study is immediately followed by one performed with a suspension of barium sulfate. However, it has been suggested that monophasic esophagography with water-soluble contrast material alone is safe, reliable, and cost-effective (36). It can be difficult, if not impossible, to perform esophagography in acutely injured patients.

Injuries to the Trachea and Larynx
Tracheolaryngeal injuries are seen in approximately 1%-7% of patients with penetrating neck injuries (62,68,69). Although they are rare, a high suspicion should be maintained because of the potential for life-threatening airway compromise. Imaging often allows direct identification of a penetrating injury to the trachea or larynx (Figs 19-21) and can help plan definitive therapy. CT is a rapid, noninvasive technique for visualizing the structures of the larynx and can be used as an important adjunct to clinical examination in determining the most optimal therapy (70). Even when an injury is not directly visualized, its presence can often be inferred when a wound track crosses or is close to the trachea or larynx.

Figure 18. Esophageal injury in a 24-year-old man with zone I stab wounds. (a) Axial CT image (lung window) shows multiple gas bubbles (arrow) in the posterior mediastinum in the region of the esophagus. (b) Anteroposterior chest radiograph obtained immediately after esophagography shows a contrast material leak (arrowhead), which was due to an esophageal injury at the thoracic inlet.
CT angiography. The need for surgery or further evaluation with endoscopy, esophagography, and conventional angiography is often directed by the results of CT angiography. Therefore, radiologists interpreting images from CT angiography should be prepared to provide management recommendations on the basis of the CT angiographic findings.

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References


The 1990s saw a re-evaluation of the established approach to managing cases of penetrating neck injuries, with a shift away from mandatory surgical exploration of many zone II injuries toward more selective use of surgical exploration.

Determining the trajectory of the wound track aids in the evaluation of patients with penetrating neck trauma, because the organs lying along the track can be considered to have a high likelihood of being injured (16,17,38,39).

However, because wound tracks often are not oriented in standard axial, sagittal, and coronal planes, liberal use of an interactive viewer to manipulate the dataset is essential to appreciate the true orientation of the track.

Penetrating arterial injuries contribute substantially to negative clinical outcomes in penetrating neck trauma, primarily as a result of neurologic events such as stroke (4,30). Approximately 15%–25% of penetrating injuries to the neck result in an arterial injury (21,24,33).

Several groups have compared CT angiography with conventional angiography for detection of neck arterial injuries in the setting of penetrating neck trauma; all reported sensitivities and specificities for CT angiography in excess of 90% (4,5,13,17–19,37).