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Neuroradiology/Head and Neck Imaging *Pictorial Essay*

Role of imaging in penetrating vascular injuries of the craniocervical region

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ABSTRACT

Penetrating vascular injury has become the topic of interest with increased gun violence in the United States. The radiologist plays a crucial role in establishing and systemizing the signs of vascular injury such as intimal flap, dissection, pseudoaneurysm, rupture, and arteriovenous fistula. Various imaging techniques such as ultrasound Doppler, computed tomographic angiography (CTA), magnetic resonance angiography, and conventional angiography are being employed based on clinical recommendations. Of all the techniques, CTA has been shown to embrace a promising role in identifying vascular injuries with superior sensitivity, specificity, and accuracy. An acquaintance of the imaging features has been shown to improve the approach to trauma patients in clinical settings. This article details the imaging modalities and the features of the head-and-neck penetrating vascular injury.

Keywords: Head trauma, Gunshot imaging, Vascular trauma, Neck vascular imaging, Head-and-neck

INTRODUCTION

Penetrating injury to the craniocervical region constitutes 5–10% of cases presented at the emergency department. By definition, the penetrating injuries of the neck breach the full thickness of the platysma muscle. The severity of head-and-neck vascular injuries may range from minor damage to fatal vascular rupture that may require no intervention to extensive surgery.[1] Penetrating cerebrovascular injury most commonly involves peripheral cortical branches than the proximal vessels of the circle of Willis.[2] At the same time, branches of the external carotid artery are more prone to extravasation or occlusion in the neck and may result in airway compromise.[2] Signs of vascular injury may range from minimal intimal separation and dissection to pseudoaneurysm formation and complete occlusion [Table 1].[3] Arteriovenous fistula (AVF) may also occur in cases where rupture of the artery and vein leads to a connection between the two vascular lumens.

IMAGING OF PENETRATING VASCULAR INJURY TO THE HEAD-AND-NECK

It is critical to be familiar with the range of clinical findings and imaging pitfalls associated with the diagnosis of traumatic craniocervical vascular injury. Conventional angiography, computed

Table 1: Hard and soft signs of arterial injury.

Hard signs of arterial injury	Soft signs of arterial injury
Severe uncontrolled external arterial bleeding	History of extensive bleeding on scene
Rapidly expanding or pulsatile hematoma	Proximity of trauma to major vessel
Palpable thrill	Subjective diminished pulse
Audible bruit	Small non-pulsatile and stable hematoma
6 P's (absent or diminished pulse, pallor, paralysis, paresthesia, and poikilothermia)	Injury to the anatomically related nerve
Neurologic deficit	Abnormal ABI (<0.9)
Refractory hypotension	Abnormal flow-velocity waveform on Doppler ultrasound
	Delayed capillary refill

tomographic angiography (CTA), and magnetic resonance angiography (MRA) are the major techniques that are being employed in clinical practice. Conventional angiography is the gold standard in detecting vascular injuries.[4] It has the benefit of performing a therapeutic intervention for vascular injury in the same setting. Although the role of conventional angiography has been replaced by the CTA over the past 15 years, there are certain situations where catheter angiography remains the gold standard. Such situations include patients with the computed tomography (CT) artifact from bullet fragments, dental implants, and metals, or hemodynamic instability requiring endovascular intervention. The major disadvantage of conventional angiography is that it is an invasive procedure with the complications such as hematoma, thrombosis, embolization, ischemia, and intimal dissection in 0.16–2% of cases.[4]

There is an emerging application of CTA in all hemodynamically stable patients with penetrating craniocervical trauma who are not candidates for immediate surgical exploration. In any patient with traumatic craniocervical vascular injury, the imaging shall be performed through the arch of aorta to the circle of Willis, as the primary damage may be away from the visualized signs of trauma.[5] It is unvarying in patients with blunt craniocervical vascular injuries. Various criteria, such as Denver and Memphis, were studied in the literature to include the CTA in the clinical workup of blunt craniocervical injuries.[6] Denver and Memphis criteria demonstrated 18–34% and 16–29% screening yield, respectively, in identifying 80% and 63–84% of the blunt craniocervical vascular trauma, respectively.[7]

Alongside the routine interpretation of thin-section axial CTA images, various post-processing techniques including multiplanar reconstruction, volume-rendered images, bone subtraction, and maximum intensity projection (MIP) can aid to identify vascular injuries such as dissections and occlusions. Recently, the material decomposition capability of DECT is being applied to subtract bone through calcium-subtraction techniques. Such images can be utilized to create the MIP images without the confounding bone. The low-energy virtual monoenergetic images (VME) increase the iodine attenuation and thereby improving contrast-noise-ratio and image quality. The deployment of low-energy VME in clinical practice reduces the required volume of contrast and radiation exposure.[8]

A dissection commences as a tear in the tunica intima or directly in the tunica media. Mural hematoma is a hypoechoic area along the vessel wall on color duplex US. However, US sensitivity decreases in dissection cases with low-grade stenosis. The accuracy in identifying craniocervical dissection can be improved using the B-flow US to visualize the intimal flaps and intramural hematoma. The color Doppler US is 95–96% sensitive in the diagnosis of internal carotid artery (ICA) dissection and 75% sensitive in vertebral artery (VA) dissection.[9] Although ultrasound is readily available, it has limited value in case of deeply located injuries. On digital subtraction angiography (DSA), features of vessel dissection include (i) irregular vessel wall, (ii) string sign (flow of contrast distal to stenotic foci), (iii) "string and pearl sign" (focal narrowing and distal dilatation of the vessel), and (iv) pseudoaneurysm formation.[10]

MR imaging has an advantage in detecting minor injuries manifested as a small subintimal hematoma. Acute thrombus on MRI appears as a crescent sign with high-signal intensity, best observed on T2-weighted imaging or T1-weighted fat saturation imaging sequences obtained during the acute phase of dissection.[11] The intimal flap appears as a curvilinear T2 and the intramural hematoma is hyperintense on the T1 fat-suppressed MRI technique. The T1 shortening depends on the methemoglobin level with the hematoma evolution.[12,13] The T2-weighted imaging also shows absent flow-void in patients with dissection. Contrast-enhancement along the peripheral and luminal margins of the artery may be observed.[13]

The sensitivity of CTA in detecting head-and-neck vascular injuries is 72.7% and 98–100%, respectively.[14] CTA guides clinicians in deciding the proper dissection management for good clinical outcomes. The variation in vessel caliber is the hallmark of vascular injury on imaging. The normal artery maintains the constant vessel caliber and consistently rounded cross-section, except on turns, from the proximal to the distal part. The subtle change in vessel caliber but maintained cross-section indicates minimal intimal injury or dissection.[12] Signs of CTA in patients with dissection include expansion of dissected vessel, an abnormal vascular contour, eccentric crescent-shaped thrombus in the periphery, thin ring-shaped

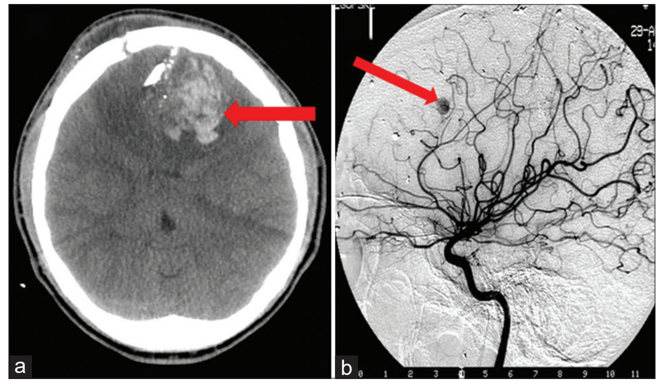

Figure 1: A 35-year-old patient presented with a gunshot wound to the cranium. (a) Axial non-contrast computed tomography of the head demonstrates hemorrhagic left lobar brain contusion (arrow). (b) Internal carotid artery angiogram depicts the frontal pericallosal ACA branch pseudoaneurysm (arrow).

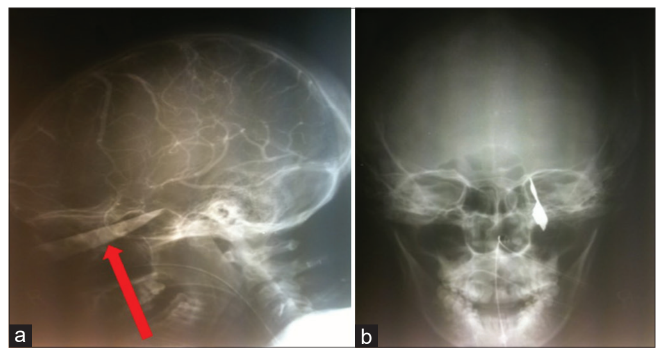

Figure 2: A 45-year-old patient presented with a penetrating injury to the right orbit. (a) Lateral and (b) anteroposterior radiograph demonstrating the knife (arrow) penetrating the orbit.

enhancement along the vessel wall, and a dissecting aneurysm. Vessel wall hematoma appears hyperattenuating and isoattenuating on unenhanced CT and CTA corrected for window settings. While 55% of traumatic dissections improve on follow-up angiography, 25% of the lesions progress to complete vessel occlusion.[11]

Conventional angiography is the gold standard for diagnosing traumatic intracranial aneurysms (TICA).[15] The TICA can be differentiated from congenital aneurysms by (i) the absence of an aneurysmal neck, (ii) irregular aneurysmal sac, (iii) lesion located at an unusual site, and (iv) delayed filling and emptying of the sac than the adjacent vessels. DSA also assists in screening for TICA in penetrating trauma patients with a sensitivity and specificity of 74–98% and 84–100%, respectively.[15]

The criteria for diagnosing AVF on color Doppler and duplex ultrasound include low to high-resistance flow in the affected artery, high velocity and arterialized waveform in the affected vein, and high-velocity turbulent flow in the fistular area.[16] The AVF demonstrates early opacification of the venous component on conventional CTA and MRA. The DSA aids in visualizing the feeding arteries and elaborating the vascularity map for endovascular management.[16] The arterial steal distal to the fistula can be observed on CTA as the asymmetric enhancement of the venous aspect of the fistula. The arteriovenous combinations associated with high-flow fistulous connections are common or ICA/internal jugular vein, external carotid artery/internal jugular vein, and VA/internal jugular or vertebral vein.

Despite the multiple studies and recommendations on the role of CTA in evaluating vascular injury, there are a few limitations to its application in certain circumstances. Bullets, metallic objects, and dental amalgams may cause streak artifacts that obscure blood vessels' visualization. The entirety of the vessel cannot be studied in the case of arteries enclosed in a bony canal such as ICA as it traverses the skull base or the VA through the foramen transversarium.[12] CT angiography requires a higher amount of contrast material than conventional angiography. In addition, it is limited by the lower spatial resolution and the fact that intervention cannot be performed simultaneously.

PENETRATING INJURIES TO THE HEAD

Penetrating brain injuries (PBI) are life-threatening, with gunshot wounds being the most common cause (12%) [Figures 1-9].[17] Around 80% of such injuries traverse the skull.[18] Because of higher mortality rates, the actual incidence of intracranial vascular injuries is unclear. The arterial injuries happen secondary to shock waves or cavitation from the kinetic energy transfer of the penetrating object.[19] The AVF (86%) is the most common imaging sign in PBI, followed by the pseudoaneurysm (12%), occlusion (2.4%), and transection (2.4%).[14] Risk factors of intracranial vascular injury include bi-hemispheric trajectory, entry wound located over the fronto-baso-parietal area, trajectory adjacent to the circle of Willis, and intraventricular hemorrhage (IVH) and IVH score, and subarachnoid hemorrhage (SAH) and SAH score.[20] The trajectory path in proximity to the circle of Willis (within 2 cm of the suprasellar cistern) comprises the most crucial risk factor for arterial injury.[20,21] Complications secondary to intracranial vascular injuries may lead to hemorrhage, ischemia, and neurological damage, constituting the primary cause of vegetation or death.[22]

The imaging workup of penetrating head injury depends on the type of injury [Table 2].[57-62] MRI is not routinely recommended in gunshot wounds due to the probability of remnant metal in the body. The DSA is the standard imaging modality to evaluate the intracranial vascular injury. However, the significant limitations are that it is expensive, requires intense labor, and is challenging in situations with limited qualified personnel.[20] DSA can be

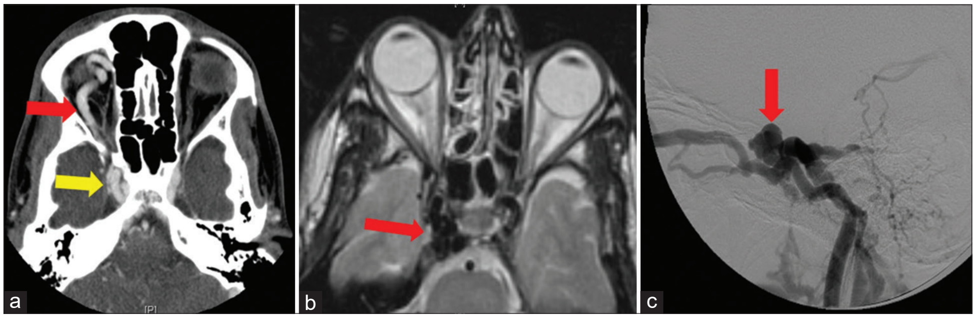

Figure 3: A 41-year-old patient presented with penetrating trauma to the cranium. (a) Axial post-contrast computed tomography shows enlarged right cavernous sinus (yellow arrow) with the dilated superior ophthalmic vein (red arrow). (b) T2-weighted MRI demonstrates mild proptosis of the right globe with multiple flow voids due to a CCF in the same patient (red arrow). (c) Right internal carotid artery (ICA) angiogram demonstrates opacification of the cavernous sinus due to fistulous communication at the C3 portion of the ICA and cavernous sinus (red arrow).

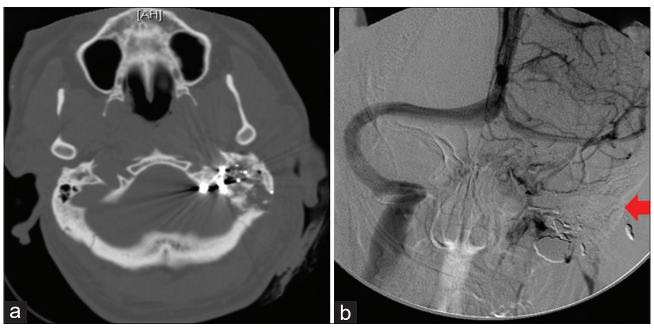

Figure 4: A 23-year-old patient presented with a gunshot wound to the left temporal bone. (a) Axial computed tomography demonstrates the fragmented left temporal bone secondary to the gunshot. (b) Cerebral venogram demonstrating an occluded left sigmoid sinus (arrow).

justified in case of highly probable arterial injury, and such probability is determined based on several CT imaging signs such as IVH score (Modified Hijdra score) and SAH score (Modified Graeb score).[21] In addition, DSA may be considered if the CTA is inconclusive or compromised by the metal artifact.[23] The non-invasive CTA has substituted DSA, with a reported sensitivity and specificity of 73% and 94%, respectively.[24]

Dissections are frequently observed in the proximal portion to the M1 section of the middle cerebral artery, VA, and basilar artery.[25,26] Findings of arterial dissection on imaging include intramural hematoma, double lumen, aneurysmal dilatation, saccular aneurysm, pearl and string sign, occlusion, and stenosis.[13] Visualizing and differentiating dissection flaps from atherosclerosis or vasculitis on CTA are challenging. In such situations, MRI aids in diagnosis through an enhanced signal-to-noise ratio in conjunction with blood flow, cerebrospinal fluid, and fat suppression techniques. The double lumen sign is more appreciable on MRA compared to CTA. TICAs are observed in 3–42% of patients who survived PBI.[20] The pseudoaneurysms are more prevalent in the branches of vertebral and anterior cerebral arteries compared to the ICA or circle of Willis.[27,28] CTA is 100% sensitive and specific in patients with TICA.[24] Identifying extraluminal contrast on CTA, described as a "spot sign," highly suggests active hemorrhage due to TICA.[17] The higher SAH score is considered the sole risk factor in patients with TICA.[20]

Injury to the dural venous sinus (DVS) is associated with an increased morbidity and mortality (20–41%).[29] The pattern of injury can vary from compression, occlusion, and fistula formation. The compression is secondary to the adjacent blood product accumulation which may result in an increased intracranial hypertension. The presentation of DVS compression is similar to DVS thrombosis and can be distinguished on a CT venogram. Criteria for DVS compression include hematoma extension beyond the sinus or the visualization of extra-axial gas within the hematoma that is compressing the sinus. Whereas DVS thrombosis can be identified through (i) delta sign, (ii) extended hematoma into adjacent sinus, and (iii) enlarged DVS compared to adjacent venous sinuses. Penetrating DVS injuries pose a high risk of DVS thrombosis in 23–41% of patients.[30,31] The DVS thrombosis appears as a tubular-shaped hyperattenuation on CT examination. The "empty-delta sign" or luminal-filling defect is seen on contrast-enhanced CT or MR imaging. The DECT techniques, iodine material decomposition, and quantification can be used to differentiate the iodine flux artifact in the normal sinus and the iodine load in the thrombosed sinus. Calcium-subtraction techniques improve the conspicuity of thrombus through bone subtraction.

Dural AV-fistula (dAVF) between the dural sinus and middle meningeal artery is seen in 2% of trauma cases.[25] It is extraparenchymal and located in the arachnoid or dural membrane. Radiographically, prominent vessel clusters

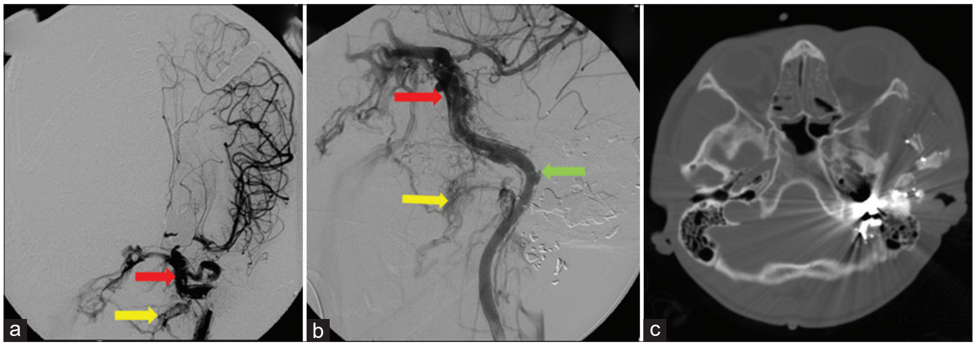

Figure 5: A 38-year-old patient presented with gunshot wound to the cranium. (a and b) Left internal carotid artery angiogram demonstrating traumatic arteriovenous fistula between the second portion of the left internal maxillary artery (pterygoid portion) to the left pterygoid venous plexus (red arrow). There is a second arteriovenous fistula of the petrous portion of the LICA to the left cavernous sinus (yellow arrow). Small pseudoaneurysm in the petrous portion of the LICA (green arrow). (c) Axial non-enhanced computed tomography of the same patient with GSW to face and skull base.

Figure 6: A 35-year-old patient presented with a stab wound to the cranium. Venogram demonstrates occluded and/or transected left jugular vein (arrow).

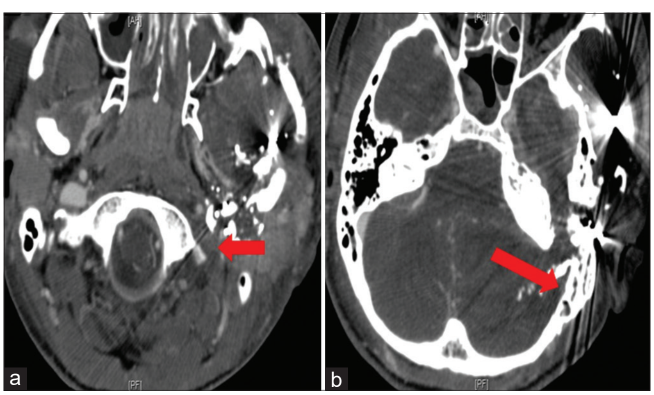

Figure 7: A 25-year-old patient presented with a gunshot wound to the cranium. (a and b) Axial computed tomography of the head demonstrating occlusion (arrow) of the internal jugular and sigmoid sinus in a patient with GSW.

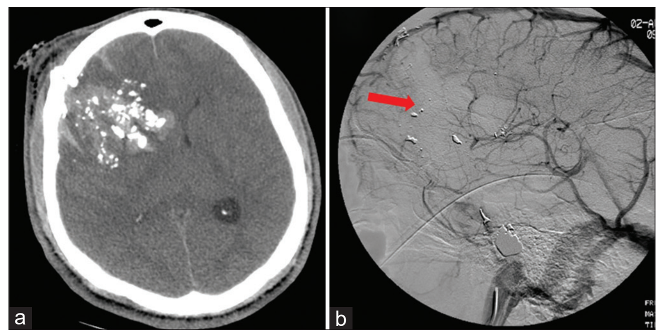

Figure 8: A 29-year-old patient presented with a gunshot wound to the cranium. (a) Axial computed tomography of the brain demonstrating hemorrhagic contusion in the right frontal lobe with overlying bullet fragments after GSW. (b) Delayed cerebral venogram of the same patient demonstrating occlusion (arrow) of the right superficial middle cerebral and vein of Trolard.

Table 2: Review of studies on the efficacy of computed tomographic angiography in the various regions of interests.

	Sensitivity	Specificity
Extremities[57]	95%	87%
Abdomen and pelvis[58]	80–97%	95%
Pelvis[59]	90%	98.6%
Proximal extremities[60]	95%	98%
Chest[61]	100%	81.7%
Lower extremities[62]	100%	100%

can be noticed near the dural sinus. CTA demonstrates high attenuation secondary to hemorrhage. The dAVF has increased death rate and requires a thorough angiographic evaluation.[13] Carotid-cavernous fistula (CCF) is a type of dAVF that is observed between the cavernous sinus and ICA.[25] It can be identified in 0.2% of traumatic brain injuries and 4% of basilar skull fractures.[32] On imaging, CCF can be classified into four types Barrow Type A-B, depending on the arterial and venous component of the fistula [Table 3].[33] Although CT and MRI aid in identifying CCF, a definitive diagnosis can be attained through DSA. Enlargement of the cavernous sinus, superior ophthalmic veins and extraocular muscles, proptosis, and reticulation of orbital fat are the imaging findings of CCF.[23] MRA may show enhanced flow-related signals in the superior ophthalmic veins and cavernous sinus and the absent flow-related signs in the ICA.[23] Abnormal enhancement of small vessels can be noticed around the cavernous sinus on CTA/MRA.

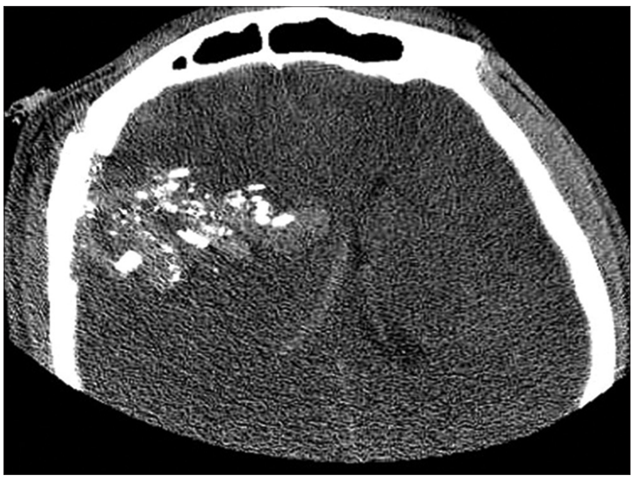

Figure 9: A 43-year-old patient presented with a gunshot wound to the cranium. Axial section of computed tomography head demonstrating hemorrhagic contusion in the right frontal lobe with overlying bullet fragments.

PENETRATING INJURIES TO THE NECK

Penetrating neck injuries, by definition, involve the entire thickness of the platysma. They account for 1% of trauma encounters in the United States and are associated with a 2–10% of mortality rate and 5% of morbidity rate.[4] Penetrating injuries are due to firearms, stab wounds, and shotguns in approximately 45%, 40%, and 4%, respectively [Figures 10-19].[34,35] The tight and complex neck space

Figure 11: A 27-year-old patient presented with a penetrating injury to the neck. Common carotid artery angiogram demonstrates a focal dissection of the common carotid artery (arrow) with a non-occlusive intimal flap in Zone 2 of the neck.

Figure 10: A 23-year-old patient presented with a gunshot wound to the neck. Internal carotid artery angiogram demonstrating a large pseudoaneurysm (arrow) of the common carotid artery in neck Zone I.

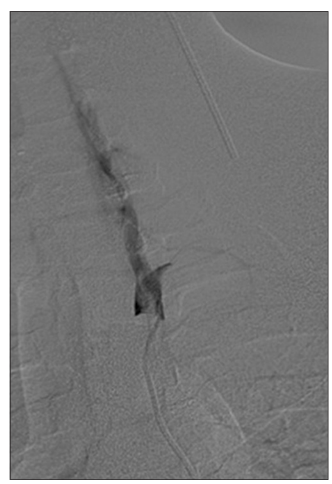

Figure 12: A 31-year-old patient presented with a stab wound to the neck. Vertebral angiogram demonstrating flow limiting dissection in the vertebral artery.

Table 3: Imaging signs of vascular injury.

Sign	US	CT
Intimal flap	Thin echogenic structures floating within the vessel lumen may cause turbulence or irregular flow on CFD; thrombosis is seen as an echogenic material on B-mode US and has absent flow on PWD and CFD.	Hypoattenuating linear or curvilinear defect arising from the vessel wall into the contrast-enhanced lumen.
Dissection	Hyperechoic mobile intimal flap, dividing the vessel into true and false lumens, can be seen on US. True lumen expands during systolic and compresses during diastolic phase of vascular supply. While false lumen is opposite. Velocity of true lumen is faster than false lumen on CFD.	Enlarged vessel with eccentric or narrowed vessel lumen; A linear hypoattenuation area (represent dissection flap) may be seen projecting into the vessel lumen; If associated with false luminal thrombosis, a crescentic focal narrowing of the vessel can be observed.
Pseudoaneurysm	Anechoic or hypoechoic image with moving echoes on B-mode US; May swell during systole; Typical swirling motion causing Yon-Yang sign on CFD; To-and-fro flow pattern may be observed.	Round, well-defined, outpouching hypoattenuating lesion from the adjacent artery; organized extraluminal collection of contrast through a disrupted vessel wall in all phases; Does not enlarge on delayed imaging.
Rupture	Hyperechoic irregular or fountain-like-jet or round spot in arterial and delayed phases of contrast-enhanced ultrasound can be noticed.	Irregular blush of contrast outside the vessel lumen; Arterial bleed: Iso -or hyper attenuated blood pool on arterial phase and subsequently enhancing attenuation on portal venous or delayed phase images. Venous bleed: Enhanced attenuation on portal venous phase that expand further on delayed phase images.
Arteriovenous fistula	Anechoic and anfractuous structure between the vein and artery on B-mode; Color mosaic (aliasing) on CFD due to multiple flow velocities in the fistular blood stream. High systolic and diastolic velocities on PWD.	Early and equal enhancement of major vein compared to the artery and asymmetric early filling of involved vein compared to uninvolved veins is observed.

CT: Computed tomography

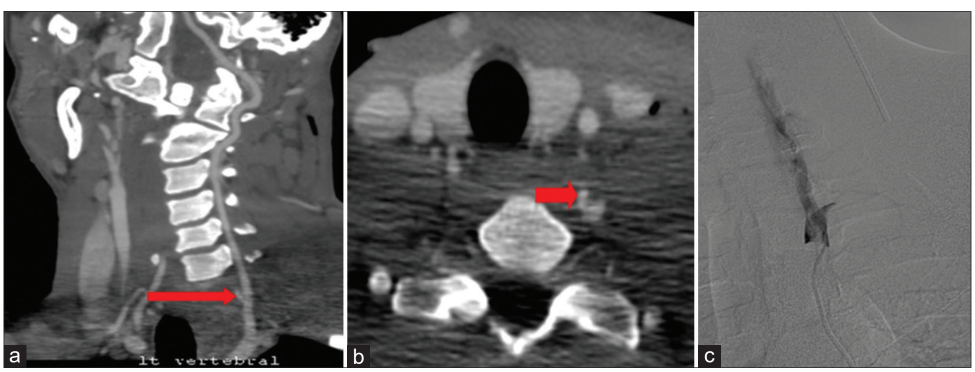

Figure 13: A 27-year-old patient presented with a stab injury to the neck. (a and b) computed tomographic angiography demonstrates a small focal aneurysm in the left V1 segment (arrow) (c) Subsequent angiogram shows slow flow through the left vertebral artery due to associated dissection.

anatomy predisposes a more significant potential for vascular, aerodigestive, neurologic, and endocrine injuries. Around 15–25% of penetrating neck injuries involve arteries, resulting in poor clinical outcomes due to neurological sequelae such as stroke or rapid exsanguination.[4,33-39] Roon *et al*. and Monson *et al*. divided the neck into three zones [Figure 20 and Table 4] to facilitate the injury assessment.[33-35] Around 47% of the neck injuries are reported in Zone 2, which can be explored efficiently with surgery.[40] There are several limitations to the zone-based approach; (i) Exclusion of posterior neck injuries, (ii) limited correlation between the location of the external wound and internal injury,[41,42] and (iii) situations where the injury is in more than one zone, and (iv) in patients with multiple sites of injury.[43]

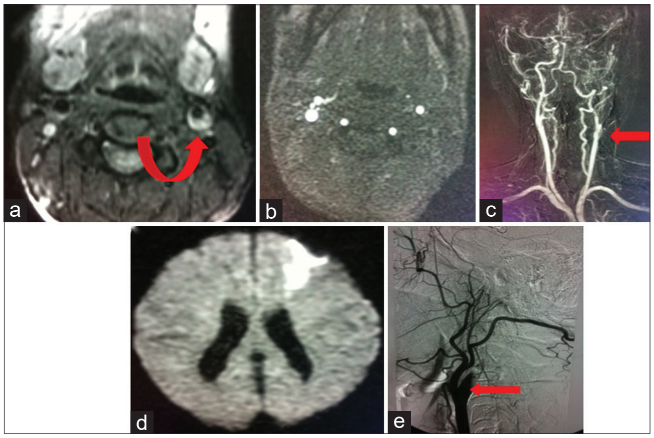

Figure 14: A 55-year-old patient presented with iatrogenic penetrating injury to the neck secondary to catheter intervention for aneurysm coiling. (a) Intramural hematoma (arrow) of the left internal carotid artery (ICA) wall is demonstrated on T1 fat-saturated pre-contrast MRI. (b) 2D flow image shows no flow in left ICA. (c) Contrast MRA shows complete occlusion (arrow) of left ICA. (d) Patient with stroke in watershed ACA/MCA territory. (e) Angiogram confirmed occlusive left ICA dissection (arrow).

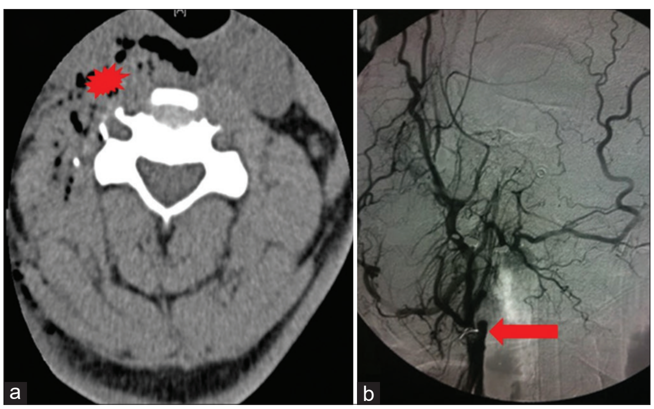

Figure 15: A 19-year-old patient presented with a stab wound to the right side of the neck. (a) Axial computed tomography head demonstrating air (star) secondary to stab wound. (b) Angiogram demonstrating the right carotid artery that shows complete occlusion.

The US Doppler is a useful diagnostic modality in stable patients with soft signs and provides anatomic and hemodynamic information about the damaged vessel. However, it is restricted to be used only in Zone II neck injuries.[44] All the limitations of conventional angiography and US Doppler and the advent of CTA lead to the consequent "no-zone approach." The no-zone approach depends on patient resuscitation, triage (based on hard and soft signs), CTA use in patients with soft signs, and observation in asymptomatic individuals.[45-48] The Western Trauma Association recommended CTA in all patients with penetrating neck injury irrespective of zones while considering Zone II injuries.[49] Among patients with a vascular penetrating neck injury, Ibraheem *et al*. reported the sensitivity and specificity of CTA in patients with hard signs as 83–90% and 100%, respectively.[50] While in stable patients with soft signs, the sensitivity and specificity were reported to be 89.5–100% and 61–100%, respectively.[50] Irrespective of hard or soft signs, Ibraheem *et al*. reported the sensitivity of CTA as 94–100% and specificity as 97–100% in hemodynamically stable patients.[50]

Carotid artery involvement can be observed in 80% of neck injuries, ensuing in a 15% of stroke rate and 22% of mortality.[36,51-53] Cerebral infarctions are the leading cause of death, constituting 80% of the cases, followed by uncontrolled hemorrhage.[43,54] Partial or complete vessel occlusion, which is observed in 36% of patients with penetrating trauma, is the most common carotid artery injury.[36] Vertebral arteries and venous structures involve 43% and 20% of vascular neck injuries.[53,55,56] The laceration to V2 and V3 segments of the VA is usually noticed in patients with cervical spinal fracture, as the artery travels through the transverse foramen of the cervical vertebral bodies.[5] Injury to V3 and V4 arterial segments is commonly observed without association with cervical spine fractures.[5] Therefore, neck injuries prompt immediate medical care by physicians.

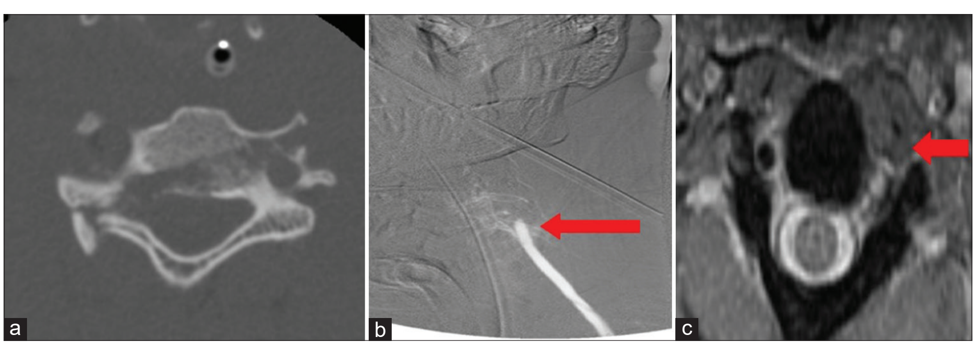

Figure 16: A 33-year-old patient presented with a gunshot wound to the back of the neck (C5 vertebra). (a-c) Axial computed tomography, angiogram, and axial T2 MRI demonstrate complete occlusion (arrow in b) of the left vertebral artery and absent flow void (arrow in c) on the axial T2 MRI sequence.

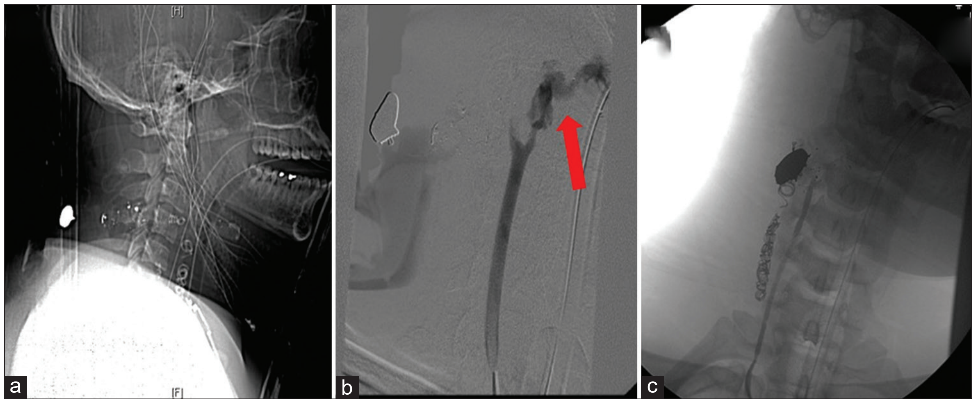

Figure 17: A 25-year-old patient presented with a gunshot wound to the neck (a) computed tomography scout demonstrating GSW to zone 2 of the neck (b and c) angiogram of the same patient demonstrating extravasation (arrow) from the right distal common carotid artery, which was embolized.

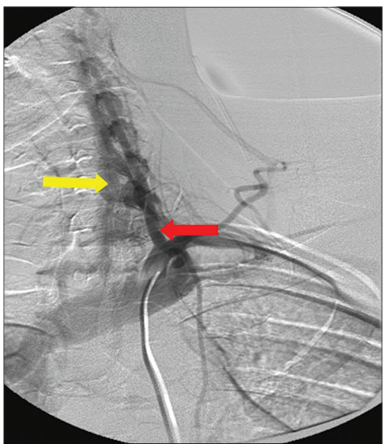

Figure 18: A 29-year-old patient presented with a stab wound to the neck. Left vertebral angiogram demonstrating traumatic arteriovenous fistula from the vertebral artery (yellow arrow) to the left internal jugular vein (red arrow).

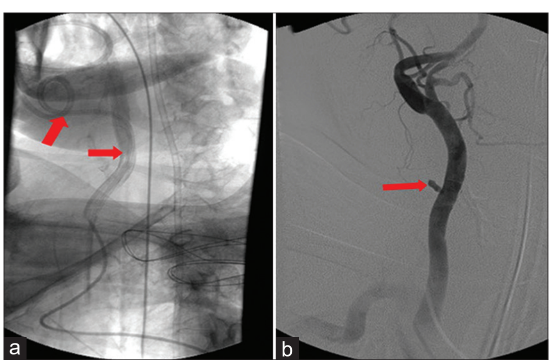

Figure 19: A 36-year-old patient with history of central line placement. (a and b) Angiogram demonstrating a pseudoaneurysm of the common carotid artery after inadvertent central line placement in CCA.

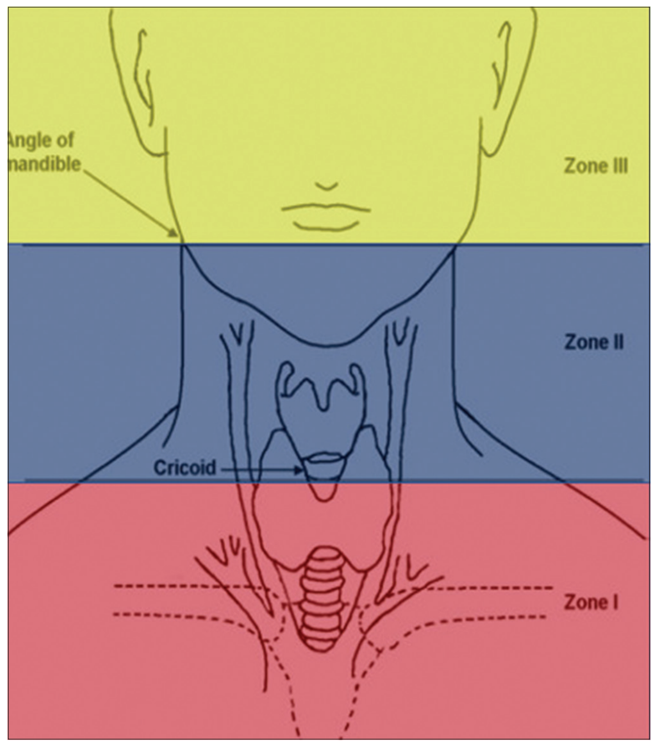

Figure 20: Zones of neck.

Table 4: Calculation of radiation dose due to computed tomography imaging.

Region of body	Adult "k" coefficient
Head-and-neck	0.0031
Head	0.0021
Neck	0.0059
Chest	0.014
Abdomen and pelvis	0.015
Trunk	0.015

CONCLUSION

Penetrating vascular injuries are a severe and common presentation in the emergency department. They should be addressed early due to their increased morbidity and mortality. The various imaging modalities and the corresponding signs of injury guide the clinicians in proper and prompt patient management. The CTA retains a critical role in the acute setting due to its high sensitivity, fewer contraindications, rapid image acquisition, and availability in most institutions.

Declaration of patient consent

Patient's consent not required as there are no patients in this study.

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Conflicts of interest

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REFERENCES

1. Go JL, Acharya J, Branchcomb JC, Rajamohan AG. Traumatic neck and skull base injuries. Radiographics 2019;39:1796-807.
2. Choi DJ, Guerra ES, Dundadamappa S. Imaging of traumatic injury to neurovasculature. Semin Ultrasound CT MR 2018;39:336-46.
3. Kobata H. Diagnosis and treatment of traumatic cerebrovascular injury: Pitfalls in the management of neurotrauma. Neurol Med Chir (Tokyo) 2017;57:410-7.
4. Múnera F, Soto JA, Palacio D, Velez SM, Medina E. Diagnosis of arterial injuries caused by penetrating trauma to the neck: Comparison of helical CT angiography and conventional angiography. Radiology 2000;216:356-62.
5. Nace SR, Gentry LR. Cerebrovascular trauma. Neuroimaging Clin N Am 2014;24:487-511.
6. Rutman AM, Vranic JE, Mossa-Basha M. Imaging and management of blunt cerebrovascular injury. Radiographics 2018;38:542-63.
7. George E, Khandelwal A, Potter C, Sodickson A, Mukundan S, Nunez D, *et al*. Blunt traumatic vascular injuries of the head and neck in the ED. Emerg Radiol 2019;26:75-85.
8. Gaddam DS, Dattwyler M, Fleiter TR, Bodanapally UK. Principles and applications of dual energy computed tomography in neuroradiology. Semin Ultrasound CT MR 2021;42:418-33.
9. Rodallec MH, Marteau V, Gerber S, Desmottes L, Zins M. Craniocervical arterial dissection: Spectrum of imaging findings and differential diagnosis. Radiographics 2008;28:1711-28.
10. Zhao WY, Krings T, Alvarez H, Ozanne A, Holmin S, Lasjaunias P. Management of spontaneous haemorrhagic intracranial vertebrobasilar dissection: Review of 21 consecutive cases. Acta Neurochir (Wien) 2007;149:585-96; discussion 596.
11. Krings T, Geibprasert S, Lasjaunias PL. Cerebrovascular trauma. Eur Radiol 2008;18:1531-45.
12. Stallmeyer MJ, Morales RE, Flanders AE. Imaging of traumatic neurovascular injury. Radiol Clin North Am 2006;44:13-39.
13. Clement MO. Imaging of brain trauma. Radiol Clin North Am 2019;57:733-44.
14. Tunthanathip T, Phuenpathom N, Sae-Heng S, Oearsakul T, Sakarunchai I, Kaewborisutsakul A. Traumatic cerebrovascular injury: Clinical characteristics and illustrative cases. Neurosurg Focus 2019;47:E4.
15. Bhaisora KS, Behari S, Godbole C, Phadke RV. Traumatic aneurysms of the intracranial and cervical vessels: A review. Neurol India 2016;64:S14-23.
16. González SB, Busquets JC, Figueiras RG, Martín CV, Pose CS, de Alegría AM, *et al*. Imaging arteriovenous fistulas. AJR Am J Roentgenol 2009;193:1425-33.
17. Vakil MT, Singh AK. A review of penetrating brain trauma: Epidemiology, pathophysiology, imaging assessment, complications, and treatment. Emerg Radiol 2017;24:301-9.
18. Kim PE, Go JL, Zee CS. Radiographic assessment of cranial gunshot wounds. Neuroimaging Clin N Am 2002;12:229-48.
19. Steenburg SD, Sliker CW, Shanmuganathan K, Siegel EL. Imaging evaluation of penetrating neck injuries. Radiographics 2010;30:869-86.
20. Bodanapally UK, Saksobhavivat N, Shanmuganathan K, Aarabi B, Roy AK. Arterial injuries after penetrating brain injury in civilians: Risk factors on admission head computed tomography. J Neurosurg 2015;122:219-26.
21. Bodanapally UK, Krejza J, Saksobhavivat N, Jaffray PM, Sliker CW, Miller LA, *et al*. Predicting arterial injuries after penetrating brain trauma based on scoring signs from emergency CT studies. Neuroradiol J 2014;27:138-45.
22. Bell RS, Vo AH, Roberts R, Wanebo J, Armonda RA. Wartime traumatic aneurysms: acute presentation, diagnosis, and multimodal treatment of 64 craniocervical arterial injuries. Neurosurgery 2010;66:66-79.
23. Rincon S, Gupta R, Ptak T. Imaging of head trauma. Handb Clin Neurol 2016;135:447-77.
24. Bodanapally UK, Shanmuganathan K, Boscak AR, Jaffray PM, Van der Byl G, Roy AK, *et al*. Vascular complications of penetrating brain injury: Comparison of helical CT angiography and conventional angiography. J Neurosurg 2014;121:1275-83.
25. Ray CE, Spalding SC, Cothren CC, Wang WS, Moore EE, Johnson SP. State of the art: Noninvasive imaging and management of neurovascular trauma. World J Emerg Surg 2007;2:1-21.
26. Kanoto M, Hosoya T. Diagnosis of intracranial artery dissection. Neurol Med Chir (Tokyo) 2016;56:524-33.
27. Bodanapally UK, Sliker CW. Imaging of Blunt and Penetrating Craniocervical Arterial Injuries. In: Proceedings of the Seminars in Roentgenology; 2015. p. 152-64.
28. Schweitzer AD, Niogi SN, Whitlow CT, Tsiouris AJ. Traumatic Brain Injury: Imaging Patterns and Complications. Radiographics 2019;39:1571-95.
29. Kim YS, Jung SH, Lim DH, Kim TS, Kim JH, Lee JK. Traumatic dural venous sinus injury. Korean J Neurotrauma 2015;11:118-23.
30. Almandoz JE, Kelly HR, Schaefer PW, Lev MH, Gonzalez RG,

Romero JM. Prevalence of traumatic dural venous sinus thrombosis in high-risk acute blunt head trauma patients evaluated with multidetector CT venography. Radiology 2010;255:570-7.
31. Slasky SE, Rivaud Y, Suberlak M, Tairu O, Fox AD, Ohman-Strickland P, *et al*. Venous sinus thrombosis in blunt trauma: Incidence and risk factors. J Comput Assist Tomogr 2017;41:891-7.
32. Ellis JA, Goldstein H, Connolly ES, Meyers PM. Carotid-cavernous fistulas. Neurosurg Focus 2012;32:E9.
33. Barrow DL, Spector RH, Braun IF, Landman JA, Tindall SC, Tindall GT. Classification and treatment of spontaneous carotid-cavernous sinus fistulas. J Neurosurg 1985;62:248-56.
34. Brywczynski J, Barrett T, Lyon J, Cotton B. Management of penetrating neck injury in the emergency department: A structured literature review. Emerg Med J 2008;25:711-5.
35. Arthurs Z, Starnes B. Vascular Trauma: Head and Neck. Rutherford's Vascular Surgery 7th ed Philadelphia PA: Saunders; 2010. p. 2318-29.
36. Núñez DB Jr., Torres-León M, Múnera F. Vascular injuries of the neck and thoracic inlet: Helical CT-angiographic correlation. Radiographics 2004;24:1087-98.
37. Asensio JA, Valenziano CP, Falcone RE, Grosh JD. Management of penetrating neck injuries: The controversy surrounding zone II injuries. Surg Clin North Am 1991;71:267-96.
38. Kendall JL, Anglin D, Demetriades D. Penetrating neck trauma. Emerg Med Clin North Am 1998;16:85-105.
39. Múnera F, Cohn S, Rivas LA. Penetrating injuries of the neck: Use of helical computed tomographic angiography. J Trauma 2005;58:413-8.
40. Demetriades D, Theodorou D, Cornwell E, Berne T, Asensio J, Belzberg H, *et al*. Evaluation of penetrating injuries of the neck: Prospective study of 223 patients. World J Surg 1997;21:41-8.
41. Madsen A, Bruce J, Oosthuizen G, Bekker W, Smith M, Manchev V, *et al*. Correlation between the level of the external wound and the internal injury in penetrating neck injury does not favour an initial zonal management approach. BJS Open 2020;4:704-13.
42. Monson DO, Saletta JD, Freeark RJ. Carotid vertebral trauma. J Trauma 1969;9:987-99.
43. Evans C, Chaplin T, Zelt D. Management of major vascular injuries: Neck, extremities, and other things that bleed. Emerg Med Clin 2018;36:181-202.
44. Karaolanis G, Maltezos K, Bakoyiannis C, Georgopoulos S. Contemporary strategies in the management of civilian neck zone ii vascular trauma. Front Surg 2017;4:56.
45. Shiroff AM, Gale SC, Martin ND, Marchalik D, Petrov D, Ahmed HM, *et al*. Penetrating neck trauma: A review of management strategies and discussion of the 'No Zone'approach. Am Surg 2013;79:23-9.
46. Prichayudh S, Choadrachata-anun J, Sriussadaporn S, Pak-art R, Sriussadaporn S, Kritayakirana K, *et al*. Selective management of penetrating neck injuries using "no zone" approach. Injury 2015;46:1720-5.
47. Ibraheem K, Khan M, Rhee P, Azim A, O'Keeffe T, Tang A, *et al*. "No zone" approach in penetrating neck trauma reduces unnecessary computed tomography angiography and negative explorations. J Surg Res 2018;221:113-20.
48. Inaba K, Branco BC, Menaker J, Scalea TM, Crane S, DuBose JJ, *et al*. Evaluation of multidetector computed tomography for penetrating neck injury: a prospective multicenter study. J Trauma Acute Care Surg 2012;72:576-84.
49. Sperry JL, Moore EE, Coimbra R, Croce M, Davis JW, Karmy-Jones R, *et al*. Western trauma association critical decisions in trauma: Penetrating neck trauma. J Trauma Acute Care Surg 2013;75:936-40.
50. Ibraheem K, Wong S, Smith A, Guidry C, McGrew P, McGinness C, *et al*. Computed tomography angiography in the "no-zone" approach era for penetrating neck trauma: A systematic review. J Trauma Acute Care Surg 2020;89:1233-8.
51. Parikh AA, Luchette FA, Valente JF, Johnson RC, Anderson GL, Blebea J, *et al*. Blunt carotid artery injuries. J Am Coll Surg 1997;185:80-6.
52. Ramadan F, Rutledge R, Oller D, Howell P, Baker C, Keagy B. Carotid artery trauma: A review of contemporary trauma center experiences. J Vasc Surg 1995;21:46-56.
53. Kuehne JP, Weaver FA, Papanicolaou G, Yellin AE. Penetrating trauma of the internal carotid artery. Arch Surg 1996;131:942-8.
54. O'Brien PJ, Cox MW. A modern approach to cervical vascular trauma. Perspect Vasc Surg Endovasc Ther 2011;23:90-7.
55. Meier DE, Brink BE, Fry WJ. Vertebral artery trauma: Acute recognition and treatment. Arch Surg 1981;116:236-9.
56. Apffelstaedt JP, Med M, Müller R. Results of mandatory exploration for penetrating neck trauma. World J Surg 1994;18:917-9.
57. Rieger M, Mallouhi A, Tauscher T, Lutz M, Jaschke WR. Traumatic arterial injuries of the extremities: Initial evaluation with MDCT angiography. AJR Am J Roentgenol 2006;186:656-64.
58. Hamilton JD, Kumaravel M, Censullo ML, Cohen AM, Kievlan DS, West OC. Multidetector CT evaluation of active extravasation in blunt abdominal and pelvic trauma patients. Radiographics 2008;28:1603-16.
59. Pereira SJ, O'Brien DP, Luchette FA, Choe KA, Lim E, Davis K, *et al*. Dynamic helical computed tomography scan accurately detects hemorrhage in patients with pelvic fracture. Surgery 2000;128:678-85.
60. Soto JA, Múnera F, Morales C, Lopera JE, Holguín D, Guarín O, *et al*. Focal arterial injuries of the proximal extremities: Helical CT arteriography as the initial method of diagnosis. Radiology 2001;218:188-94.
61. Gavant ML, Menke PG, Fabian T, Flick PA, Graney MJ, Gold RE. Blunt traumatic aortic rupture: Detection with helical CT of the chest. Radiology 1995;197:125-33.
62. Inaba K, Potzman J, Munera F, McKenney M, Munoz R, Rivas L, *et al*. Multi-slice CT angiography for arterial evaluation in the injured lower extremity. J Trauma Acute Care Surg 2006;60:502-7.

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