Curr Surg Rep (2020) 8:15
https://doi.org/10.1007/s40137-020-00258-2

Current Management of Penetrating Traumatic Cervical Vascular Injuries

Lillian N. Jenkins[1] · Joao B. Rezende-Neto[2]

Published online: 5 June 2020

Abstract
Purpose of Review Penetrating neck injuries constitute 5–10% of all emergency trauma presentations and are associated with a relatively high risk of mortality. The most common significant injury encountered in penetrating neck trauma is injury to the vasculature of the neck. This article reviews penetrating cervical vascular injuries, including initial assessment, immediate, and definitive management techniques.
Recent Findings Assessment and management of penetrating injuries to the neck have traditionally been approached according to the location of the injury in relation to anatomic zones of the neck. More recently, due to advancements in imaging techniques and endovascular therapies, there is a trend towards non-operative management. This has resulted in a decrease in the rate of non-therapeutic surgeries.
Summary Penetrating traumatic cervical vascular injuries are potentially life-threatening and require appropriate clinical assessment to rapidly identify patients who need immediate surgical intervention. However, patients without hard signs of vascular injury should undergo imaging, most commonly in the form of computed tomographic angiography. For patients who require operative intervention, surgical techniques include vessel ligation, direct repair or angioplasty, interposition grafts, and damage control procedures. Endovascular techniques are particularly useful in the management of vascular injuries of the vertebral artery.

Keywords Penetrating neck injury · Vascular trauma · Cervical vessel injury · Neck zones · Carotid artery · Vertebral artery

This article is part of the Topical Collection on *Trauma Surgery*.

✉ Joao B. Rezende-Neto
Joao.Rezende-Neto@unityhealth.to

[1] Clinical Fellow in Trauma and Acute Care Surgery, Department of Surgery, University of Toronto, Toronto, Canada

[2] Trauma and Acute Care Surgeon, Department of Surgery, St. Michael's Hospital, University of Toronto, Toronto, Canada

Introduction

Penetrating neck trauma defined as full thickness breach of the platysma muscle constitutes 5–10% of all emergency trauma presentations and is associated with a relatively high risk of mortality [1, 2••]. Vascular injuries occur in approximately 25% of all penetrating neck traumas [3].The general mortality rate linked to penetrating injuries to the neck is between 3 and 10% with 50% of those deaths resulting from severe bleeding from vascular injuries [3–5]. The unique complexity of the anatomy of the neck with vital vascular structures in close proximity with the aerodigestive tract and neurological system is important factors leading to the high mortality rate [6, 7]. Particularly in penetrating injuries to the cranial and the caudal cervical regions where surgical access to the aforementioned structures can be very challenging. Globally, the most common mechanism of injury in penetrating neck trauma is from stab wounds related to violent assault or self-harm, followed by low velocity and then high velocity ballistic traumas [1]. However, in countries with high homicide rates and poor gun control, the incidence of penetrating neck injuries from stabbings and ballistic traumas is equivalent [8•]. In ballistic trauma, the distinction between low velocity and high velocity projectiles is important. Velocity is a major determinant of the kinetic energy of a projectile. However, in addition to velocity, the shape, mass, and the distance to the target are all important factors in the wounding potential of a missile [9]. In penetrating injuries to the neck caused by ballistic trauma, this is particularly important given that vascular injuries related to cavitation and thermal energy could extend beyond the immediate trajectory of the missile. Less common causes of penetrating neck trauma include motor vehicle accidents and injury from other miscellaneous objects (Fig. 1) [10].

Historical Perspectives

Many of the traditional approaches in the management of penetrating neck trauma are based on previous military experience, as with many areas of modern civilian trauma care. In conflicts predating World War II, the standard management practice for penetrating injuries of the neck was expectant. With this approach, reported mortality rates were quite high, upwards of 10% [11, 12]. Patients died not only from early exsanguination due to major vascular injuries, but also from delayed complications related to infection. During World War II (WWII), however, that management shifted towards early operative exploration and intervention in those patients who survived long enough to reach field hospitals capable of providing surgical care. Outcomes reported in the literature improved, likely as a result of a combination of more expedient retrieval of injured patients, access to medical care, and improvements in surgical techniques in general. In the decade following WWII, Fogelman and Stewart published a series of 100 patients with penetrating neck trauma [13]. They reported a substantial difference in mortality rates between patients undergoing early exploration compared to delayed or no exploration (6% vs 35%). Based on these findings, there was a general movement towards mandatory neck exploration for penetrating trauma.

Fig. 1 Penetrating neck injury in a motorcyclist who was clotheslined by glass-coated line that was being used to fly a kite

Although the neck is a relatively small anatomic region, there is significant variability in the surgical accessibility of the important structures, specifically with regard to cervical vascular trauma. Techniques for exposure of injuries to thoracocervical region and the base of the skull are more complicated than for injuries occurring in the mid-anterior neck. In an effort to guide surgical decision-making, Monson et al. subdivided the neck into three zones, with zone 1 located below the medial head of the clavicles, zone 3 extending from the angle of the mandible to the base of skull, and zone 2 encompassing the central area of the neck between zones 1 and 3 [14]. Monson's initial classification was modified by Roon and Christensen to the more widely used system today, which specifies the boundary between zone 1 and 2 as the inferior border of the cricoid cartilage while the division between zone 2 and 3 remained the angle of the mandible [15]. As zone 2 is by far the most readily accessible zone from an operative perspective and the most likely zone for significant injury, immediate and mandatory neck exploration for zone 2 penetrating neck injuries became firmly established surgical dogma. In contrast, for injuries in zone 1 and 3, there was a trend towards further imaging with angiography prior to surgical exploration, both as a means for diagnosis of vascular injuries which necessitated operative intervention, as well as to aide in surgical planning.

The practice of routine neck exploration in particular for zone 2 penetrating neck injuries persisted for several decades with multiple case series publications. Although the mortality rate certainly improved from the era of expectant management predating WWII, it was noted that the rate of negative or non-therapeutic neck explorations was high, in the range of 50% in many series [16, 17].

In the 1980s, several authors began to challenge the practice of routine neck exploration in favor of a more selective approach, whereby selective imaging or clinical examination was used to try to limit the number of patients undergoing non-therapeutic neck explorations. Management algorithms of this era still were largely based on the location of external injury in relation to the zones of the neck. For zone 1 and 3 injuries, angiography was the preferred imaging modality in stable patients, whereas for patients with zone 2 injuries, the choice of imaging/ investigations was based on clinical examination.

The traditional approach of utilizing the location of external injury and relating this to the zone of the neck has been further challenged in recent times for several reasons. First, multiple studies have raised concern over the ability to accurately correlate the external site of injury to the trajectory of the wound and therefore the extent of the injuries. For example, it is possible that a knife entering zone 2 aimed inferiorly may cause significant injuries to vascular structures in zone 1. Second, gunshot wounds cause significant damage to structures over an area wider than initially apparent on examination of the entry site, particularly high velocity missiles. Therefore, assuming that only a single zone is involved may overly simplify the assessment and lead to inadequate management.

Additionally, axial imaging, specifically multidetector computer tomography angiography (CTA), has become more widely accessible and is increasingly being considered the imaging investigation of choice for all patients with penetrating neck injury regardless of the external location of the wound (Table 1). Multiple studies published over the last decade support the "no zone approach." Those studies demonstrated low rate of missed injuries, reduction in unnecessary surgical explorations of the neck, lower cost from more judicious use of invasive imaging (i.e., angiography), and decreased hospital length of stay [8, 18••–22]

A summary of the largest case series published on penetrating neck injuries is shown in (Table 2).

Initial management of penetrating cervical vascular injuries

Penetrating neck injuries have a relatively high mortality rate; therefore, it is important that the initial management of these patients follow the Advanced Trauma Life Support Guidelines [28]. Exsanguinating external hemorrhage should be controlled with external compression if feasible and early control of the airway should be prioritized in patients with existing airway compromise or in those where it is anticipated. Other principles of ATLS resuscitation should also be followed including appropriate intravenous access, judicious fluid resuscitation with blood transfusion if indicated, a complete neurological examination, and a thorough secondary survey including log roll to ensure no missed injuries. A chest x-ray should be performed as part of adjunctive imaging to the primary survey to assess for hemopneumothorax. Depending on the mechanism of penetrating trauma plain x-rays of the neck, including a lateral view, may be considered, primarily to assess for foreign bodies (bullet or shrapnel).

There is controversy with regard to the need for cervical spine immobilization in penetrating wounds to the neck. In isolated penetrating injuries, particularly those caused by stabbings, there is an exceptionally low likelihood of an unstable spinal injury [29–31•]. Furthermore, cervical collars have been associated with a risk of missed injury hidden by the collar, a potential delay in transfer associated with collar application, and ultimately, in a review published by Vanderlan et al., an increased risk of death (OR 2.77, 95% CI 1.18–6.49, $p < 0.016$) [32•]. Therefore, c-spine immobilization is not recommended for patients with penetrating injuries to the neck unless there are focal neurological deficits or high index of suspicion of spinal injury based on mechanism in a patient where neurological assessment is not possible [29].

Clinical examination of the neck is an important component of the initial assessment and should focus on the identification of hard or soft signs of injury. Some studies have examined the feasibility of further imaging in hemodynamically stable patients who sustain penetrating wounds and present with hard signs [33]. However, the most accepted approach is immediate surgical intervention, particularly if the hard signs indicate a vascular injury, i.e., shock, pulsatile bleeding or expanding hematoma, and audible bruit [20, 22, 29]. In patients with active arterial bleeding, it may be necessary to gain temporary control in the trauma bay depending on local resources available. In many cases, direct external compression is feasible and controls the bleeding. However, for exsanguinating wounds at the root of the neck or high towards the base of the skull, direct compression may not be possible. Therefore, a damage control strategy is required, a useful alternative technique involves inserting a Foley catheter into the wound tract to achieve temporary balloon tamponade [34, 35••]. Other described techniques for achieving interim haemostasis involve the direct insertion of haemostatic sponges into the wound tract [36]. If the balloon tamponade technique is successful in attaining haemostasis, and the patient is otherwise stable without other hard signs mandating urgent surgery, the trauma surgeon must decide whether further imaging may be of benefit in guiding the next steps of management. Computer tomography angiography is useful to identify vascular injuries that may be more amenable to endovascular repair than open surgical repair, for example, injuries to the subclavian or vertebral arteries, or the internal carotid artery close to the base of skull. Furthermore, following a negative CTA in this situation, the balloon catheter can remain inflated in situ for 24–48 h for what is presumed venous bleeding. Following this time, it is removed in a controlled environment (operating room) where a neck exploration is only

Table 1 Summary table of large case series published on penetrating neck

Author	Publication year	Location	Number of patients	Study Period	Short description of study
Roon	(1979) [15]	San Francisco General Hospital, USA	189	1970—1977	Retrospective review of patients with PNI managed with routine neck exploration 154/189 patients underwent neck exploration; rate of negative exploration—53%
Golueke	(1984) [23]	Kings County Hospital, NY USA	160	1977–1982	Patients with PNI randomized to routine exploration vs selective management. 46% negative exploration rate in routine exploration group. In selective management group 21% negative exploration rate. No statistically significant difference between mortality, morbidity or length of stay
Demetriades	(1993) [24]	Baragwanath Hospital and University of Witwatersrand, Johannesburg, SA	335	1989–1991	Prospective observational study reviewing the reliability of physical examination in PNI to detect significant injuries requiring surgical intervention. Findings—66/335 (20%) of patients had urgent surgical exploration (15% non-therapeutic). 269/335 patients initially managed non-operatively with 2/269 patients needing inpatient OR
Demetriades	1997 [25]	LSC & USC Medical centre, LA, USA	223	1993–1995	Prospective study of patients with PNI assessing the role of physical examination and accuracy of imaging (angiography, color doppler ultrasound)
Nason	(2001) [1]	Health Sciences Centre, Winnipeg, MB, Canada	130	1979–1997	Retrospective review of patients with PNI. Findings—78/130 patients had neck exploration with non- therapeutic neck exploration in 38%. 52/130 patients were observed with 2/52 patients requiring in patient operation
Bell	(2007) [11]	Legacy Emmanuel Hospital and Health Centre, Portland, Oregan USA	65	2000–2005	Review of management with 65 patients with PNI. 5 patients direct to OR, 60 patients had CT or CTA (CTA after 2003). In total 33/65 patients taken for neck exploration with overall negative rate of 42%
Osborn	(2008) [26]	Legacy Emmanuel Hospital and Health Centre, Portland, Oregan USA	65	2000–2005	Same study population as above study with aim to specifically compare outcomes in group undergoing CTA (24/65 patients) compared to no CTA (41/65 patients). Significantly fewer neck explorations performed in patients with CTA (6/24) compared to those not undergoing CTA (27/41). Negative exploration rate between CTA and non-CTA groups also significantly different (0% vs 48%)
Thoma	(2008) [27]	Groote Schuur Hospital, Cape Town, SA	203	2004–2005	Prospective observational study to validate the use of selective non-operative management in PNI. Findings—158/203 (78%) of patients managed without surgical or endovascular intervention. No clinically significant missed injuries
Inaba	(2012) [19]	LSC & USC Medical centre, LA, USA and R. Adams Cowley Shock Trauma Centre, Maryland, USA	453	2009–2011	Prospective multi-centre study to evaluate use of CTA in the initial screening exam in patients with PNI. Findings—CTA had 100% sensitivity and 97.5% specificity in detecting all clinically significant neck injuries in PNI
Low	(2014) [20]	LSC & USC Medical centre, LA, USA	146	2008–2011	Study designed specifically to correlate location of external PNI with internal injuries sustained. Overall 25% of patients had internal injuries identified, and these did not correlated with the site of external PNI

Table 1 continued

Author	Publication year	Location	Number of patients	Study Period	Short description of study
Prichayudh	(2015) [21]	King Chalalongkorn Memorial Hospital, Thailand	86	2003–2013	Retrospective review to evaluate outcomes of selective management approaches in PNI. Overall 52% of patients managed non-operatively with low rate of negative explorations (3/41) and no missed injuries
Ibraheem	(2018) [18]	Banner University Medical Centre, Tuscon, AZ, USA	337	2008–2015	Retrospective review assessing whether physical examination can guide CTA use in PNI
Borsetto	(2019) [6]	Queen Elizabeth Hospital, Birmingham, UK	67	2012–2018	Retrospective review aimed to assess diagnostic accuracy of CTA for vascular injuries in patients with clinically stable PNI. Findings—combined use of direct radiological signs with clinical signs 97.7% specific for vascular injury

PNI penetrating neck injuries

Table 2 Hard and soft signs of vascular injury and signs of aerodigestive tract injury in penetrating neck injuries

Hard signs of vascular injury	Soft signs of vascular injury	Signs of aerodigestive injury
Shock not responsive to intravenous fluid resuscitation	Hematoma (non-expanding)	Subcutaneous emphysema
Expanding/pulsatile hematoma	Venous bleeding	Dysphagia
Active major bleeding	Minor hematemesis	Dysphonia/hoarseness
Massive hemoptysis or hematemesis		Odynophagia
Thrill/bruit		Stridor
Absent or diminished peripheral pulse		Air bubbling through wound*

*Air bubbling through neck wound is considered to be a hard sign necessitating urgent surgical exploration

performed in the event of bleeding post-catheter removal [34].

Immediate operation is, for the most part, not required in patients with penetrating neck injuries without hard signs. Moreover, for patients with soft signs of vascular injury, including non-expanding hematoma, venous bleeding or oozing, history of prehospital bleeding only, or upper extremity peripheral pulse discrepancy, the imaging investigation of choice is CTA, regardless of the level of the external wounds, no zone approach. Patients with penetrating neck injuries with neither hard nor soft signs may undergo observation only depending on local protocols and resource availability. However, given accessibility to CTA and the low risk and cost associated with this imaging modality, many trauma centres follow protocols that include CTA for all patients with penetrating neck injuries with platysma violation [8]. This is supported by the fact that clinical examination alone is not that reliable.

General Principles for Operative Management of Cervical Vascular Injuries Due to Penetrating Neck Trauma

The patient should be positioned supine on the operating table with both the anterior chest and bilateral groins prepped in case of the need for either a median sternotomy or harvesting of saphenous vein. The most commonly described incision for access to the major vessels of the neck is through an ipsilateral oblique incision placed adjacent to the anterior border of the sternocleidomastoid (SCM) muscle. This incision, if necessary, can be extended from the clavicle to the mastoid process, with the proximal aspect curved slightly posteriorly above the upper third of the SCM in order to avoid the marginal mandibular branch of the facial nerve. The incision may also be extended to the anterior chest if a median sternotomy is required. In the case of bilateral neck injury, a second separate incision anterior to the contralateral SCM provides adequate access or a collar incision, which is often the preferred approach depending on the nature of the penetrating injury.

Once the skin, subcutaneous tissue, and platysma have been incised, the anterior border of SCM is identified, and the fascia anterior to the muscle is opened. Subsequently, the common facial vein should be identified and ligated at its confluence with the internal jugular vein. The common facial vein is a useful landmark for identification of the bifurcation of the common carotid artery.

Carotid Artery Injuries

At least one quarter of penetrating neck injury patients, taken urgently to operating room with hard signs of a vascular injury, will have injuries to the common carotid artery (CCA), external carotid artery (ECA), or the internal carotid artery (ICA) [18, 20].

The principles of management for carotid artery injury are based on adequate exposure of the injured vessel and establishing proximal and distal control prior to attempted repair. The decision as to which repair is most appropriate is based on characteristics of injury as well as the overall injury burden to the patient. This is often relatively straightforward for injuries that are located within zone 2 of the neck. For injuries to the CCA in zone 1, it may be necessary to perform a median sternotomy to gain proximal control of the vessel within the anterior mediastinum [37]. Several techniques have been described for injuries high in the neck, where distal control of the ICA is challenging to achieve. These include division of the posterior belly of digastric muscle, subluxation of the mandible, or performing a mandibulotomy. Although ligation of the carotid artery is described in the literature as a rapid means to control bleeding in dire situations, the carotid artery should be repaired or reconstructed whenever possible [38]. Albeit somewhat controversial, this includes patients in whom there is a pre-existing neurological deficit. In this setting, repair of the artery results in better neurologic outcome and lower mortality compared to simply ligating the artery [39].

Small lacerations to the carotid artery can be repaired with sutures, provided the repair does not narrow the lumen of the vessel. If primary sutured repair is not feasible, a patch angioplasty can be performed. The patch is commonly obtained from saphenous vein, although non-autologous tissue can also be considered [35]. For more extensive vascular injuries, including complete or near complete transection of the artery, or if there has been loss of a segment of arterial wall as is more commonly seen in firearm-related injuries, it may be necessary to use an interposition graft with reversed saphenous vein or a synthetic polytetrafluorethylene (PTFE) graft. In the case of major injury to ICA close to the bifurcation, one described option is replacement of the proximal injured ICA with the ECA [40]. In this case, the ECA is dissected free over the necessary length and its branches ligated prior to dividing the ECA and oversewing the distal stump. The injured ICA is suture-ligated close to the bifurcation and the proximal ECA is then anastomosed to the distal ICA.

The use of carotid artery shunts has also been described in the literature, both as a damage control technique, where they have been left in place successfully for up to 48 h, and as a means for maintaining cerebral perfusion during vascular repair [41].

Endovascular approaches to carotid artery injuries are also well described, predominantly for the management of injuries to the proximal CCA as well as the ICA in zone 3, in patients who present without hard signs of vascular injury [42]. Such endovascular techniques include stenting, embolization for pseudoaneurysm and arteriovenous fistula and balloon occlusion [43].

Vertebral Artery Injury

Vertebral artery injury from penetrating neck trauma is much less common than injuries to the carotid arteries as the vertebral arteries are mostly protected within the bony canal of the transverse foramina of the cervical vertebrae. However, this anatomical location also means that surgical access to the distal cervical vertebral arteries can be very challenging. Therefore, active bleeding frequently controlled with temporary measures, followed by definitive treatment via endovascular approach and embolization [39]. Temporary hemorrhage control includes balloon tamponade with a Fogarty catheter or direct compression with bone wax or gauze packing [35].

For patients who present with exsanguinating hemorrhage from the base of the neck necessitating immediate neck exploration, the recommended approach to control proximal vertebral artery bleeding is ligation of the artery via a supraclavicular incision [35, 40]. Unilateral ligation of the vertebral artery is generally tolerated due to collateral supply from the posterior circulation and Circle of Willis. Brain stem ischemia secondary to unilateral vertebral artery ligation is relatively rare [35, 39]. However, in a large South African series of over 100 patients with vertebral artery injuries, predominantly from penetrating trauma, outcomes were better in patients managed with arteriography and embolization compared to those who were managed with surgery first, without subsequent embolization [44].

Venous Injury

Injury to the internal jugular vein (IJV) is one of the most common cervical vascular injuries in penetrating neck trauma. The incidence of IJV injuries in penetrating trauma to zone 2 of the neck is 20%. However, due to the low pressure nature of the venous system, not all venous injuries require operative repair, and in many cases, patients who have an isolated venous injury suspected on CTA do not undergo neck exploration for surgical repair. If an injury to the IJV is identified intraoperatively, primary suture repair is recommended. If this approach is not possible, the usual accepted management is ligation of the vein. However, in patients with bilateral IJV injuries, it is advisable to repair one side whenever possible to avoid postoperative increase in intracranial pressure and facial oedema [35]. Any vascular injuries to the anterior or external jugular veins should be managed by ligation of these vessels.

Conclusion

Penetrating vascular injuries in the neck are potentially life-threatening. Patients without hard signs of injury should undergo imaging, most commonly CTA. Endovascular approach could be the definitive solution in some cases. For those patients who require operative intervention, there are multiple approaches including damage control procedures to temporize bleeding.

Funding The authors declare no funding for this article

Compliance with Ethics Guidelines

Conflict of interest The authors declare no conflict of interests with respect to the authorship or publication of this manuscript.

Human and Animal Rights and Informed Consent All articles published by the authors included in this study involving human or animal subjects were approved by research ethics board of the institution and had patient consent for publication.

References

Publications of particular interested have been highlighted as:

- • Of importance,
- •• Of major importance

1. Nason RW, Assuras GN, Gray PR. Lipschitz J (2001) Penetrating neck injuries: analysis of experience from a Canadian trauma centre. Can J Surg. 2001;44(2):122–6.
2. ••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.
3. McConnell DB, Trunkey DD. Management of penetrating trauma to the neck. Adv Surg. 1994;1994(27):97–127.
4. Saito N, Hito R, Burke PA, Sakai O. Imaging of penetrating injuries of the head and neck: current practice at a level 1 trauma centre in the United States. Keio J Med. 2014;63:23–33.
5. Steenburg SD, Sliker CW, Shanmuganathan K, Siegel EL. Imaging evaluation of penetrating neck injuries. Radiographics. 2013;30:869–86.
6. Borsetto D, Fussey J, Mavuti J, Colley S, Pracey P. Penetrating neck trauma: radiological predictors of vascular injury. Eur Arch Otorhinolaryngol. 2019;2019(276):2541–7.
7. Nowicki JL, Stew B, Ooi E. Penetrating neck injuries: a guide to evaluation and management. Ann R Coll Surg Engl. 2018;2018(100):6–11.
8. •Teixeira F, Menegozzo AM, Netto SDC, Pogeti RS, Silva FSC, Birolini D, Bernini CO, Utiyama EM. Safety in selective surgical exploration in penetrating neck trauma. World J Emerg Surg. 2016;11:32. https://doi.org/10.1186/s13017-016-0091-4.
9. Powers DB, Delo RI. Characteristics of ballistic and blast injuries. Atlas Oral Maxillofac Surg Clin North Am. 2013;21(1):15–24.
10. Rezende-Neto JB, Ferreira GC, Silva Filho AL, Fontes MOB, Bomfim F, Abrantes WL. Kiting injuries: report of two cases and review of the literature. J Trauma. 2000;48:310–1.
11. Bell BR, Osborn T, Dierks EJ, Potter BE, Long WB. Management of penetrating neck injuries: a new paradigm for civilian trauma. J Oral Maxillofac Surg. 2007;65(4):691–705.
12. Demetriades D, Asensio JA, Velmahos G, Thal. E. Complex problems in penetrating trauma. Surg Clin North Am. 1996;1996(76):661–83.
13. Fogelman MJ, Stewart RD. Penetrating wounds of the neck. Am J Surg. 1956;91:581–93.
14. Monson DO, Saletta JD, Freeark RJ. Carotid vertebral trauma. J Trauma. 1969;1969(9):987–99.
15. Roon AJ, Christensen N. Evaluation and treatment of penetrating cervical injuries. J Trauma. 1979;1979(19):391–7.
16. Apffelstaedt JP, Muller R. Results of mandatory exploration for penetrating neck trauma. World J Surg. 1994;1994(18):917–9.
17. Ayuyao AM, Kaledzi YL, Parsa MH, Freeman HP. Penetrating neck wounds Mandatory versus selective exploration. Ann Surg. 1985;202(5):563–7.
18. ••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;2018(221):113–20.
19. ••Inaba K, Branco BC, Menaker J, Scalea TM, Crane S, DuBose JJ. Evaluation of multidetector computed tomography for penetrating neck injury: a prospective multicentre study. J Trauma. 2012;72(3):576–84.
20. Low GMI, Inaba K, Chouliaras K, Branco B, Lam L, Benjamin E, et al. The use of the anatomic 'Zones' of the neck in the assessment of penetrating neck injury. Am Surg. 2014;2014(80):970–4.
21. Prichayudh S, Choadrachata-anun J, Sriussadaporn S, Pak-art R, Srriussadaporn P, Kritayakirana K, et al. Selective management of penetrating neck injuries using "no zone" approach. Injury. 2015;46:1720–5.
22. Shiroff AM, Gale SC, Martin ND, Marchalik D, Petrov D, Ahmed HM. Penetrating neck trauma: A review of management strategies and discussion of the 'No Zone' approach. Am Surg. 2013;2013(79):23–9.

23. •Golueke PJ, Goldstein AS, Sclafani SJA, Mitchell WG, Shaftan GW. Routine versus selective exploration of penetrating neck injuries: a randomised prospective study. J Trauma. 1984;24(12):1010–4.
24. Demetriades D, Charalambides D, Lakhoo M. Physical examination and selective conservative management in patients with penetrating injuries of the neck. Br J Surg. 1993;80:1534–6.
25. Demetriades D, Theodorou D, Cornwell E, et al. Evaluation of penetrating injuries of the neck: prospective study of 223 patients. World J Surg. 1997;21:41–7.
26. Osborn TM, Bell RB, Qaisi W, et al. 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;64:1466–71.
27. Thoma M, Navsaria PH, Edu S, et al. Analysis of 203 patients with penetrating neck injuries. World J Surg. 2008;32:2716–23.
28. American College of Surgeons Committee on Trauma. Advanced trauma life support for doctors. 8th ed. Chicago: American College of Surgeons; 2012. p. 2012.
29. Burgess CA, Dale OT, Almeyda R, Corbridge RI. An evidence based review of the assessment and management of penetrating neck trauma. Clin Otolaryngol. 2012;2012(37):44–52.
30. Connell RA, Graham CA, Munro PT. Is spinal immobilisation necessary for all patients sustaining isolated penetrating trauma? Injury. 2003;2003(34):912–4.
31. •Rhee P, Kuncir EJ, Johnson L. Cervical spine injury is highly dependent on the mechanism of injury following blunt and penetrating assault. J Trauma. 2006;2006(61):1166–70.
32. •Vanderlan WB, Tew BE, McSwain NE. Increased risk of death with cervical spine immobilisation in penetrating cervical trauma. Injury. 2009;2009(40):880–3.
33. Schroll R, Fontenot T, Lipcsey M, Heaney JB, Marr A, Meade P, et al. Role of computed tomography angiography in the management of zone II penetrating neck trauma in patients with clinical hard signs. J Trauma Acute Care Surg. 2015;79(6):943–50.
34. Rezende-Neto J, Marques AC, Guedes LJ, Teixeira LC. Damage control principles applied to penetrating neck and mandibular injury. J Trauma. 2008;64(4):1142–3.
35. ••Strickland M, Roedel E, Inaba K. Penetrating cervical vascular injuries. Curr Trauma Rep. 2019;2019(5):40–7.
36. Warriner Z, Lam L, Matsushima K, Benjamin E, Strumwasser A, Demetriades D, et al. Initial evaluation of the efficacy and safety of in-hospital expandable haemostatic minisponge use in penetrating trauma. J Trauma Acute Care Surg. 2019;86(3):424–30.
37. Rodríguez-Luna MR, Guarneros-Zárate JE, Hernández-Méndez JR, Tueme-Izaguirre J, Noriega-Usi VM, Fenig-Rodriguez J. Defining Zone I of penetrating neck trauma: a surgical controversy in the light of clinical anatomy. J Trauma Acute Care Surg. 2016;80:670–3.
38. Demetriades D, Skalkides J, Sofianos C, Melissas J, Franklin J. (1989) Carotid artery injuries: experience with 124 cases. J Trauma. 1989;29(1):91–4.
39. Kesser BW, Chance E, Kleiner D, Young JS. Contemporary management of penetrating neck trauma. Am Surg. 2009;2009(75):1–10.
40. Biffl WL. Neck exploration. In: Cioffi, WG. (Ed). Atlas of trauma/emergency surgical techniques. Elsevier/Saunders 2014; pp 10–22.
41. Inaba K, Aksoy H, Seamon MJ, Marks JA, Duchesne J, Schroll R, et al. Multicentre evaluation of temporary intravascular shunt use in vascular trauma. J Trauma Acute Care Surg. 2016;80(30):359–65.
42. Herrara DA, Vargas SA, Dublin AB. Endovascular treatment of penetrating traumatic injuries of the extracranial carotid artery. J Vasc Interv Radiol. 2011;22(1):28–33.
43. Rezende-Neto JB, Marcuzzi D, Paskar D, Sadler E, Marshall S, Nixon K, Inglez J, Marshall J. Multidisciplinary damage control management of life threatening carotid blowout syndrome. Trauma Surg Acute Care Open. 2018;3:1–2.
44. Mwipatayi B, Jeffery P, Beningfield S, Motale P, Tunnicliffe J, Navasia P. Management of extra-cranial vertebral artery injuries. Eur J Vasc Endovasc Surg. 2004;27(2):157–62.