Penetrating Neck Injury

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Johno Breeze and David Powers

18.1 Introduction

The neck is inherently vulnerable to penetrating injury as large vascular structures, and the airway, lie relatively superficial to the skin. It has little native protection from ballistic projectiles with the exception of the spinal cord, which is covered by vertebrae throughout its length. The structures at highest risk are the great vessels, namely the paired carotid arteries and internal jugular veins. These structures run in parallel with one another in conjunction with the vagus nerve, and any injury to one vessel should be assumed to have damaged the other until proven otherwise. The vessels increase in size and run deeper as they travel towards the mediastinum, making direct compression, as well as surgical access, more difficult. Surface markings for these vessels are the anterior border of the sternocleidomastoid (SCM) muscle, as it runs from the mastoid down to insert into the medial third of the clavicle. The trachea starts immediately under the larynx and is palpable for the first one or two rings in most individuals with the neck extended. The cricothyroid membrane is found by running a finger below the thyroid cartilage and is easily penetrated to gain access to the airway at a point below the vocal cords. Surgical tracheostomy is undertaken usually by cutting a window into the trachea at the level of the second or third tracheal rings. Pertinent anatomy includes the isthmus of the thyroid gland, and the laryngeal nerves that run bilaterally between trachea and oesophagus (Fig. 18.1).

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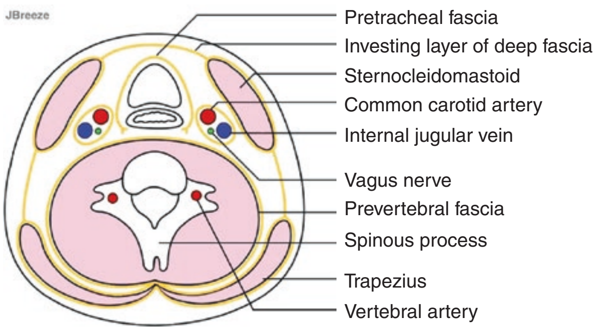

Fig. 18.1 A simplified demonstration of pertinent neck anatomy in the axial plane

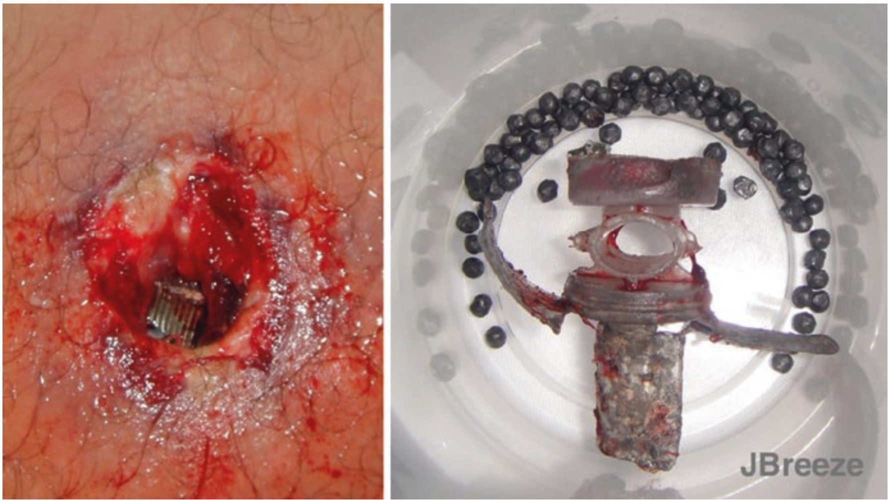

Fig. 18.2 Energised fragments can be irregular in shape and deposit energy rapidly into the target tissue (*left*). Multiple spherical fragments are produced by explosive ordnance such as from this cluster bomb (*right*)

Mortality from penetrating neck injury (PNI) is from large vessel haemorrhage, spinal cord trauma or from airway compromise due to direct laryngotracheal damage or haemorrhage into the airway [1]. The most commonly violated vessels are the carotids followed by the internal jugulars [2] reflecting their relative superficial course in the neck [3]. Despite recent diagnostic and surgical advances, the mortality of civilian firearm injuries to the neck is still greater than 10% [4]. Mortality rates from military wounds remain significantly higher, reflecting the nature of the wounding agents, as well as the time to available surgical care. Explosive events produce multiple energised fragments, each capable of damaging vital structures, with a resultant mortality quoted as greater than 40% (Fig. 18.2). During the recent conflicts in Iraq and Afghanistan, a high velocity projectile directly hitting the neck had a mortality of greater than 75%, reflecting the huge energy transfer produced by such weapons and that no practicable personal armour is currently capable of protecting soldiers [5].

18.2 Pre-Hospital Care

In addition to direct pressure applied with a bandage, the use of pre-hospital haemostatic agents is recommended, but should only be gently packed for fear of further damage to the underlying vasculature [6]. The probability of cervical spine instability from a firearm injury in a patient who is conscious and neurologically intact is low and immobilisation is on balance not recommended. Barkana *et al.* studied all Israeli soldiers who sustained penetrating neck injuries over a 4-year period. All patients were transported to a trauma centre will full cervical spine immobilisation. The incidence of cervical spine column injury was approximately 2%, with only 1% of patients having actual spinal cord injury. They found no survivable injury that would have benefited from spine immobilisation [7]. Arishita *et al.* evaluated over 4000 cases of PNI sustained in the Vietnam War and noted that less than 2% of patients with cervical spinal column involvement "might" have benefited from immobilisation. They concluded as well that cervical spine immobilisation in penetrating neck trauma is "neither prudent nor practical." [8]. Such a premise also applies to soldiers injured by explosively propelled fragments in a military environment unless the tactical situation allows [9]. Cervical spine fracture should be suspected in casualties exposed to an explosive event who may have been thrown against objects by the blast wave. Careful oral intubation is recommended to secure the airway, even should tracheal injury be suspected.

18.3 Damage Control Surgery for Penetrating Neck Injury

Damage Control Surgery (DCS) is the principle by which early identification of life-threatening injuries is made and the decision to avoid complicated, sometimes lengthy, definitive repairs in an unstable patient [10]. DCS involves the rapid control of the patient's airway, followed by packing or employment of catheters for haemorrhage control. Patients with 'hard signs' of PNI, particularly active bleeding, expanding haematoma, or airway compromise should be taken immediately to the operating room for exploration (Table 18.1). Intubation can be complicated by the associated expanding neck hematoma, laryngotracheal injury, and suspicion of an associated cervical spine injury. Early intubation is the key to control of a situation that can quickly deteriorate into multiple unsuccessful intubation attempts if deferred. The most experienced person available should be designated for control of the airway [4]. Active bleeding, if encountered, should be controlled with digital

Table 18.1 Clinical "hard signs" of penetrating neck injury warranting immediate surgical exploration

Vascular: ongoing bleeding from the neck region that is not amenable to pressure, an expanding haematoma and a bruit or thrill in the neck
Aerodigestive injury: crepitus or subcutaneous emphysema, dyspnea or stridor, air bubbling from wound, tenderness or pain over trachea, hoarse or abnormal voice, hematemesis or hemoptysis

pressure. This should be continued throughout the skin preparation and until proximal and distal control is obtained. Wounds should not be probed or locally explored as these manoeuvres can dislodge clot and lead to uncontrolled haemorrhage or embolism. A chest radiograph may demonstrate a potentially life-threatening issue that should be addressed prior to transport to the operating room such as a pneumothorax, haemothorax or tension pneumothorax [4].

18.4 Physical Examination

Some centres rely solely on serial physical examinations to guide their decisions for operative or non-operative management, whereas others will employ a cadre of diagnostic tests to definitively exclude injuries to the structures within the neck. Although recommended in a civilian environment, the role of serial physical examinations alone in the military setting is questionable due to the risk of occult injury [11], especially if injured by blast [12]. Asymptomatic patients injured by fragmentation were found to have vascular damage in 25% of cases even when no wound tract seem to involve vessel and no fragment in close proximity [12]. The presence of 'soft' and 'hard' physical signs, remain a useful adjunct when in situations where imaging is not available [2]. "Soft" signs include hematemesis, hemoptysis, hoarseness or change in voice, dysphagia, or odynophagia. In the stable patient, these signs mandate further evaluation and exclusion of vascular and aero-digestive injury. Prior to considering non-operative or selective management on a patient with penetrating neck trauma, one must consider the diagnostic modalities that are available and what degree of reliability can be placed on each of them. For penetrating neck injuries both the Glasgow Coma Scale (GCS) and a peripheral neurological exam should be performed to rule out direct spinal cord trauma or indirect damage due to vascular ischaemia.

Damage to the hypopharynx and oesophagus may be clinically silent initially if the airway is not compromised. Missed oesophageal injuries are the cause of the majority of delayed complications seen with penetrating neck injuries [13]. Early signs of oesophageal injury include subcutaneous air, crepitus, dysphagia, odynophagia, drooling, and hematemesis [14]. When an oesophageal leak progresses to mediastinitis, morbidity and mortality are significant. Early diagnosis may allow primary repair to be performed and generally results in superior outcomes [15].

18.5 Computerised Tomographic Angiography (CTA)

Patients presenting with haemodynamic instability or with "hard signs" of injury (Table 18.1) should undergo immediate operative exploration and repair and are not candidates for imaging triage. Otherwise Computerised Tomographic Angiography (CTA) remains the backbone of diagnosis with sensitivity and specificity quoted as 90% and 100% respectively for diagnosis of carotid and vertebral arterial injuries [16] (Figs. 18.3 and 18.4). It should be noted however that its specificity is less when used to assess airway or oesophageal damage [17]. In the military setting CTA

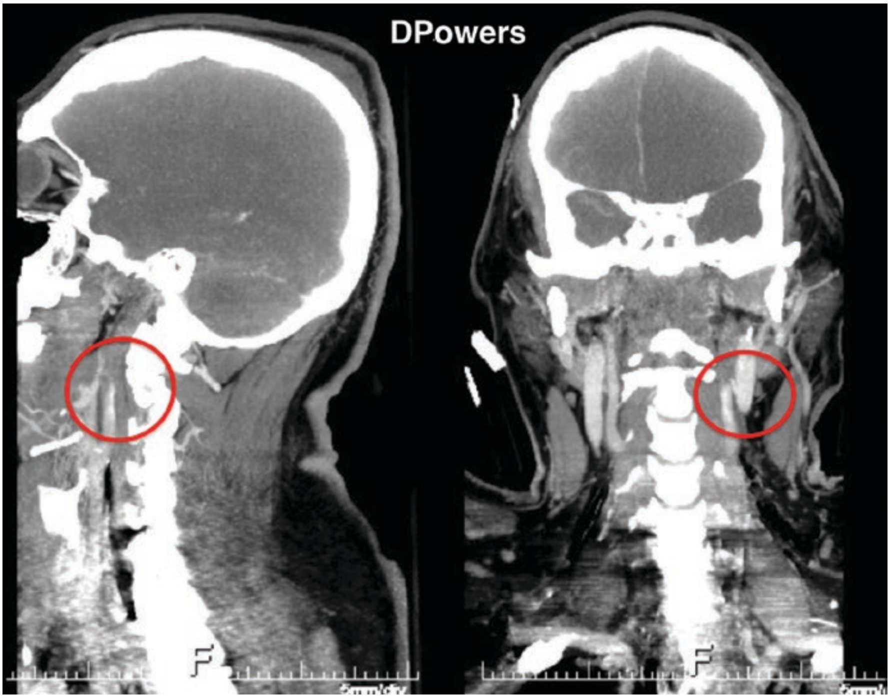

Fig. 18.3 A CT angiogram of the neck in a patient with a penetrating injury transecting the internal carotid artery

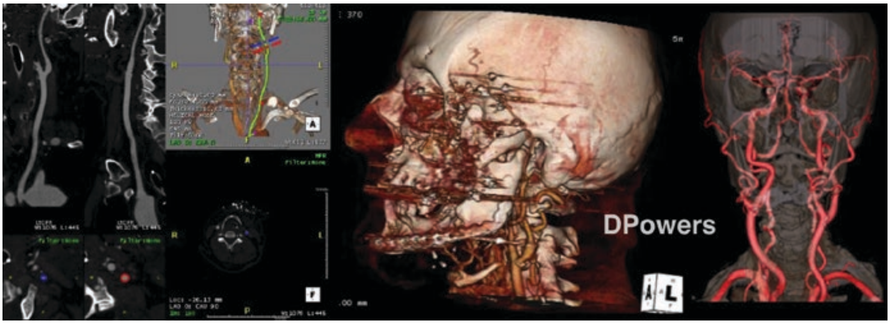

Fig. 18.4 CT angiograms with 3D reconstruction, which can serve as a valuable resource in the identification of potential vascular injury to the vessels of the head and neck

can be non-diagnostic in up to 20% cases due to metallic artefact [2]; these patients should ideally have digital subtraction angiography or duplex ultrasound but it is recognised that this unlikely to be available on current deployments [18]. CTA is performed using a helical CT scanner with approximately 100 ml of contrast injected and data acquired after a brief delay of 10–15 s.

18.6 Formal Percutaneous Angiography

Angiography remains the gold standard for evaluating and excluding arterial injury (Fig. 18.5). In addition, angiography can help in planning the operative approach in the patient with more than one zone involved. In evaluating the patient with PNI, an adequate angiogram should visualise the innominate artery, the common, internal, and external carotid arteries, the subclavian arteries, and both vertebral arteries as well. The facilities and expertise to perform formal angiography are limited in austere and military environments, leading to a lower threshold for surgical intervention should findings of vascular damage on CTA be equivocal.

Fig. 18.5 Formal percutaneous angiography of the carotid artery obtained in a field hospital for a patient with a penetrating neck injury. Note the limited field of view visualising only of the common carotid, internal carotid and external carotid arteries

18.7 Ultrasound and Magnetic Resonance Angiography

Colour doppler ultrasound has been proposed as a quick and efficient tool to evaluate stable patients penetrating neck trauma to exclude vascular injury. Although the equipment is readily available in most modern trauma centres, the technique is highly operator-dependent and cannot adequately assess the aerodigestive structures. Magnetic Resonance Angiography (MRA) is a sensitive imaging modality but is currently impractical due to its inconsistent availability, length of study time, and incompatible with various types of medical equipment. There is also minor concern regarding the presence of metallic fragments lodged in the cervical tissues being exposed to the high-powered magnet.

18.8 Investigations for Potential Airway Injury

Although injuries to the larynx and trachea are uncommon, they are associated with significant morbidity and mortality. The risk of death and complications associated with these injuries can be minimised by aggressive airway control and an expedient search for occult injuries, respectively. The endotracheal approach to intubation can be safely accomplished in selected patients with laryngo-tracheal injuries [19]. This approach allows for controlled placement of the endotracheal tube, as well as the evaluation of the hypopharynx, larynx, and proximal trachea through direct laryngoscopy. Once the airway is controlled, a careful evaluation of the laryngo-tracheal tree should be undertaken. Airway injuries are difficult to diagnose pre-operatively. Physical examination findings are sensitive for detecting airway injury but lack specificity. Clinical findings suggestive of hypopharyngeal penetration include dysphagia, odynophagia, hemoptysis, and subcutaneous emphysema. Diagnostic laryngoscopy identified injuries to the hypopharynx or larynx in over 90% of patients [20].

18.9 Investigations for Potential Oesophageal Injury

Physical examination does not appear reliable in excluding injuries to the oesophagus following gunshot wounds. Direct oesophagoscopy (preferably both flexible and rigid) provide the highest sensitivity for diagnosis of oesophageal injury but is technically difficult, especially in a patient with an immobilised cervical spine. A Gastrografin® contrast swallow imaging study is usually performed if suspicion of oesophageal injury exists [15]. Contrast studies require a stable, cooperative patient and are difficult to obtain in agitated or intubated patients. The sensitivity of contrast oesophagography in patients with oesophageal trauma varies from 48 to 100%

[21]. The contrast agent and technique employed for oesophageal evaluation both have a significant effect on the sensitivity and accuracy of this modality. Water-soluble agents are less viscous and dense and are, therefore, less likely to coat the mucosa adequately. Up to 55% of oesophageal perforations will be missed if a water-soluble agent is used alone. Patients unable to safely swallow should have the contrast agent instilled through a nasogastric tube under pressure. When used alone, oesophagoscopy and oesophagography have sensitivities of 60–80%. Combining the two, however, increases the sensitivity of detecting oesophageal injury following penetrating trauma to well over 90%. Demetriades and colleagues noted that physical examination combined with both endoscopy and oesophagography detected 100% of penetrating oesophageal injuries [22].

18.10 Trajectory Determination

A high index of suspicion, based on the bullet trajectory, is essential for early diagnosis of PNI, particularly aerodigestive injuries. Compared to missiles that do not cross the midline, transcervical GSW are twice as likely to injure vital structures in the neck [23]. This has led some authors to suggest that these wounds be considered as a separate category of neck trauma and even advocate mandatory exploration in this special population. However it is generally felt that a careful clinical examination combined with the appropriate diagnostic tests (particularly CTA) can safely select the appropriate treatment [23].

18.11 Management Decisions

The management of ballistic trauma to the neck will ultimately be determined by the experience of the clinicians and the imaging facilities available. In trauma centres where CTA is rapidly available, as well as the facilities to perform tests such as oesophagography, a "*watch and wait*" policy is prudent if no damage is seen. In more austere environments, or where such imaging facilities are not available, management principles are still best guided by dividing the neck into zones (Fig. 18.6, Table 18.2). Zone I is from suprasternal notch to cricoid cartilage. Zone II is from cricoid cartilage to angle of mandible. Zone III is from the angle of mandible to base of skull [24]. Due to the inherent difficulty in evaluating and obtaining vascular control in this area, selective management of injuries to Zone III has arisen out of necessity. Good evidence now exists that casualties with Zone II injuries in a civilian setting without hard signs and no pathology on CTA can be managed conservatively without surgical exploration [25]. Casualties with Zone I injuries should have CTA and should there be any equivocation I n the result then formal percutaneous angiography performed. Casualties with Zone III injuries without hard signs should have frequent intraoral examination to observe for oedema or expanding haematoma within the parapharyngeal or retropharyngeal spaces. Nerves exiting the skull base are in close proximity to the great vessels, thus neurological deficits in a casualty are suggestive of injury to the great vessels [26]. However designing a management algorithm based on these anatomical zones is problematic, as classifying an external wound to a particular zone does not guarantee the trajectory of the missile. In addition the numerous fragments that are produced by fragmenting munitions in a military environment can produce complex cervical injuries that often cross all three of the traditional neck zones [2].

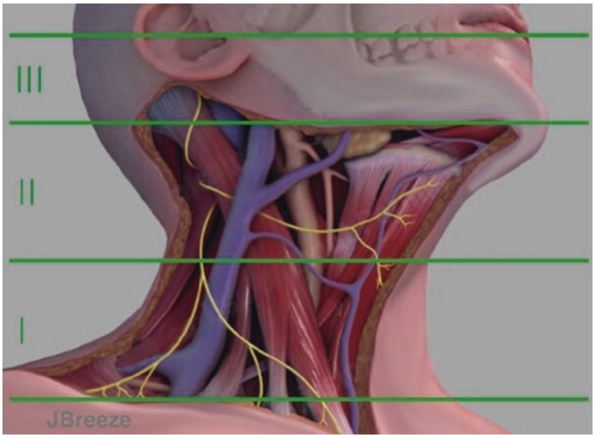

Fig. 18.6 The neck typically is divided into three zones of injury. Each zone has preferred diagnostic and therapeutic approaches. Zone I is from suprasternal notch to cricoid cartilage. Zone II is from cricoid cartilage to angle of mandible. Zone III is from the angle of mandible to base of skull

Table 18.2 Proposed management algorithms for penetrating neck injury in the deployed setting based upon neck zone of entry wound

Zone	Significance	Treatment if no 'hard signs' present	Treatment if 'hard signs' present
I	Mortality highest due to size of vessels and proximity to skin surface. Vessels difficult to access	Serial physical examination following CT angiogram. Formal arteriography as required	Median sternotomy or left anterior thoracotomy to control haemorrhage by appropriately trained surgeons
II	Management in a military hospital setting continues to be debated	Serial physical examinations with CT angiogram. In a military setting low threshold for surgical exploration if multiple penetrating wounds even in absence of hard signs	Incision parallel to sternocleidomastoid or horizontal neck dissection incision if access to mandible required
III	High mortality rate and access to vessels difficult due to skull base, styloid process, and mandible	Serial physical examination following CT angiogram. Formal arteriography as required	Temporary division of mandible or even craniotomy to control a high-carotid injury

Considerable care must be taken towards applying civilian management algorithms to military scenarios, as significant differences exist in the aetiology of injury and resources available. Civilian PNI is primarily from stab wounds and low velocity gunshot wounds, which is in direct contrast to military PNI of which 79% is due to explosive fragmentation and the remainder from gunshot wounds [12]. The action of explosive weaponry is to produce multiple small energised fragments, each with the chance of causing vascular perforation and therefore this mechanism greatly increases the probability of vascular perforation with resultant haemorrhage [11]. In the deployed military setting, the decision to surgically explore a neck wound that has breached platysma remains controversial and in many instances is dependent on the skill sets of the surgeons present [27]. A lower threshold for exploration is necessary in equivocal cases and if evacuation is potentially delayed. Even in asymptomatic patients, pathology was found in 78% of cases on neck exploration of soldiers injured by explosively propelled fragments. Consideration to removing larger fragments lying close to the great vessels or vertebral arteries should be made once the patient has been evacuated to the host nation but this should be an elective procedure with radiological assistance available [11].

18.12 Operative Surgical Approaches

The choice of surgical approach should be determined by the likely zone of injury and the type of structure requiring repair (Fig. 18.7).

18.12.1 Zone I

Injuries involving Zone I are the most technically challenging, generally have the highest mortality and therefore require the most pre-operative planning. Access is best achieved through a median sternotomy with supraclavicular extension or an anterior SCM incision. Vascular control of the vertebral arteries is among the most difficult to obtain, especially in the face of active haemorrhage. The majority of the vessel is contained within the bony foramina hindering adequate exposure. If one is required to obtain vascular control of a known vertebral artery injury, a supraclavicular incision will provide optimal exposure.

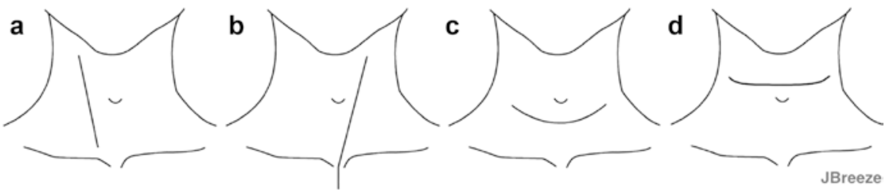

Fig. 18.7 Operative approaches to the neck include (**a**) anterior sternocleidomastoid incision, (**b**) sternocleidomastoid incision with sternotomy extension, (**c**) 'collar' incision, (**d**) 'visor' incision

18.12.2 Zone II

An anterior SCM incision allows for adequate exposure of unilateral neck injuries (Figs. 18.8 and 18.9). For transcervical or bilateral wounds, a transverse 'collar' incision can provide adequate exposure for the majority of Zone II injuries. Both the collar and the SCM incisions can be quickly extended into the chest should a sternotomy be required. Carotid injuries to Zone II can be adequately visualised through either incision. In the military setting it has been suggested that an extended collar incision is used, often termed a 'visor' approach, analogous to those used in an

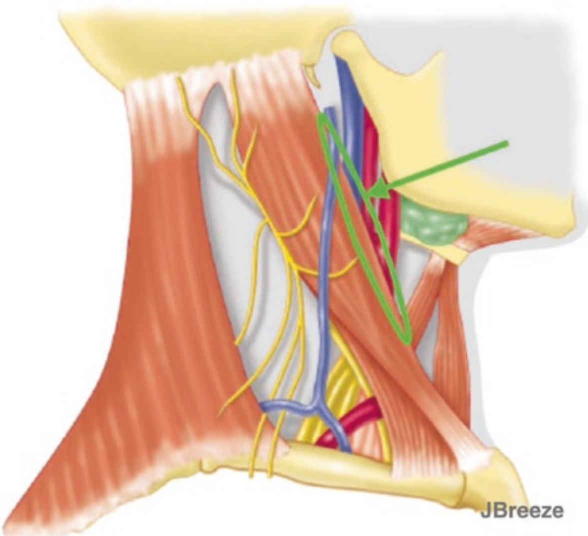

Fig. 18.8 Operative access to the carotid artery in Zone II of the neck is through an incision along the anterior border of the sternocleidomastoid muscle (*arrowed*)

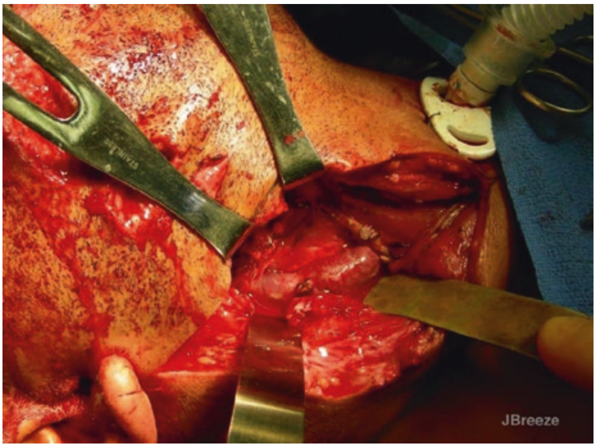

Fig. 18.9 Zone II exploration of the neck in a field hospital exposing the internal jugular vein and common carotid artery via the classic approach anterior to the sternocleidomastoid muscle

Fig. 18.10 A neck injury to Zone II with a contemporaneous anterior mandible fracture can be approached through a 'visor' neck incision enabling potential treatment of both injuries

oncological neck dissection (Fig. 18.7). Such an incision can be cosmetically superior and provide access to the lower border of the mandible for contemporaneous bony exploration and fixation [28] (Fig. 18.10).

18.12.3 Zone III

Due to the inherent difficulty in evaluating and obtaining vascular control in this area, selective management of injuries to Zone III has arisen out of necessity (Fig. 18.11). In addition to subluxation of the mandible, resection of the angle of the mandible or styloid process has also been described. If proximal control can be obtained, distal control of Zone Ill (and even some Zone II) injuries can be obtained without such morbid manoeuvres through the placement of a Fogarty catheter.

18.13 Surgical Treatment of Vascular Injury

Carotid artery injuries account for 10–20% of life-threatening injuries that occur in patients with penetrating neck trauma [26]. The primary objective during operative management is to restore antegrade flow to the carotid and preserve neurological function. Carotid injuries should be repaired unless the surgeons is faced with: (1) uncontrollable haemorrhage, (2) haemodynamic lability, (3) a comatose patient presenting with no evidence of antegrade flow, or (4) a devastating vessel

Fig. 18.11 A penetrating injury into Zone III of the neck due to an explosively propelled fragment. Following CT angiography to exclude underlying injury this wound was superficially debrided but not formally explored

injury technically impossible to temporarily bridge with a vascular shunt. In these circumstances, ligation can and should be employed. Some authors also advocate ligation if there is little to no "back bleeding" from the carotid artery, citing the likelihood of worsening an established ischaemic infarct or risk of embolising a distal clot is increased with attempts at restoring blood flow. Another controversy is whether to use a temporary vascular shunt, as even elective repairs near the carotid bifurcation can be difficult. If technically possible, a primary repair should be attempted on all common and internal carotid injuries [26]. Those involving the external carotid, however, should be ligated unless they are at or near the bifurcation [29]. Ligation of the external carotid and internal jugular are generally well tolerated unless performed bilaterally but ligation of the internal carotid has an approximately 50% incidence of stroke [3]. Surgical access is generally though a vertical incision parallel to the SCM. If the defect is greater than 2 cm in diameter, primary repair should not be attempted due to the excessive amount of tension on the repair and a vein patch should be used [26]. The jugular vessels should not be utilised for conduit in this setting considering the disruption to venous outflow associated with their harvest. In addition polytetrafluoroethylene (PTFE) grafts have been employed with increased frequency when primary repair is not possible.

Vertebral artery injuries may present initially with severe haemorrhage or in a delayed fashion, while diagnostic studies are in progress. If the diagnosis is made in a haemodynamically stable patient without active external haemorrhage, the vertebral artery should be embolised using interventional radiology. If the patient presents with active haemorrhage or experienced personnel are not available for angiography and embolisation, an attempt at operative surgical ligation is indicated through a supraclavicular or SCM incision. Use of a Fogarty catheter is great assistance as the balloon can be positioned distal to the point of injury and inflated.

A follow-up angiogram is usually obtained in the weeks after embolisation or surgical ligation to demonstrate haemostasis and exclude arteriovenous fistulae formation. In institutions without interventional or endovascular support, the Fogarty may be left in place for approximately 72 h. This allows adequate time for thrombosis of the artery, at which point the catheter can be deflated and removed. Pseudoaneurysm formation in civilian injury is a rare complication but is more common in military environment, and is believed to be related to the effect of multiple small energised fragments [2].

18.14 Treatment of Vascular Injury by Interventional Radiology

If a patient is medically stable, angiography can be performed to both establish a firm diagnosis and proceed with endovascular treatment when indicated. The location of the injury as well as the collateral cerebral circulation must be evaluated prior to an intervention. Transarterial embolisation is a fast and effective method for the treatment of an active haemorrhage, in particular when the injured vessel is relatively small and the collateral circulation allows for vessel's sacrifice. Endovascular stent placement may be more appropriate for injuries involving large- and medium-size vessels that must remain patent, such as the common carotid, internal carotid, or vertebral arteries in the absence of adequate collateral circulation. Currently facilities for performing interventional radiological techniques in the deployed military setting are totally dependent on the resources made available by the medical command structure, but it is likely that those clinicians capable of performing selective intravascular embolisation will deploy in more established medical facilities in the future (Fig. 18.12).

18.15 Surgical Treatment of Laryngo-Tracheal Injuries

Patients presenting with such injuries can be approached using either an anterior SCM or collar incision, although the later provides greater access. Lateral dissection should be minimised to protect the laterally based blood supply. Following debridement most laryngeal defects from penetrating trauma can be repaired primarily. Small defects noted on endoscopy can usually be managed non-operatively with airway protection, elevation of the head of the bed, and voice rest. If the cartilaginous framework has been disrupted beyond management with a primary repair, the airway should be stented with an endotracheal tube or silicone stent [4]. Tracheostomy should be avoided in the area of injury, but if necessary should be placed distal to the repair to protect the anastomosis. Laryngeal defects up to 3 cm diameter can be repaired primarily in a single-layer fashion after adequate mobilisation. The role of tracheostomy in these patients remains controversial [4]. Tracheostomy in this

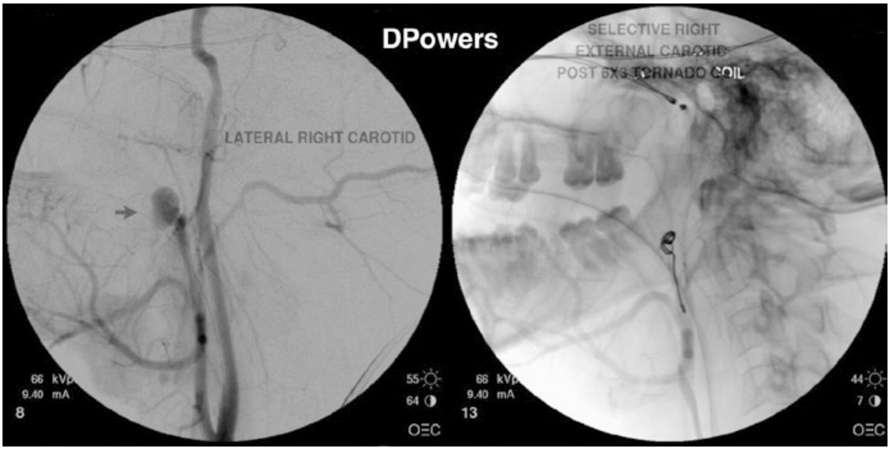

Fig. 18.12 A penetrating injury into Zone III of the neck due with injury to the external carotid artery presenting to a field hospital (*left*). The same wound after interventional treatment with a surgical coil (*right*)

setting has been associated with increased risk of infection, but many advocate its use in protecting the proximal repair.

18.16 Surgical Treatment of Oesophageal Injuries

The repair of an injury to the cervical oesophagus is best approached through an anterior SCM incision. Should there be an associated laryngotracheal injury, however, these combination injuries are best approached through a collar incision. Maximal exposure of the oesophagus is achieved through retraction of the trachea and thyroid medially and the carotid sheath laterally. An indwelling nasogastric tube can facilitate not only the localisation of the oesophagus, but also the identification of the oesophageal injury through the instillation of air or methylene blue. Nonviable edges should be sharply debrided prior to primary repair, which is then carried out in one of two methods. The two-layered repair is performed with an interrupted submucosal (resorbable suture) and a muscular layer (non-resorbable suture). Alternatively, a single layered interrupted repair can be performed with a non-resorbable suture. Whether a single or two-layered repair is chosen, good mucosal and muscular approximation is necessary to prevent delayed leakage [4]. The main complication from such injuries is the risks of tracheo-oesophageal fistula, although the majority of such fistulas will heal without surgical intervention. Their risk of occurrence can be minimised by using a tissue flap such as dividing the clavicular head of the SCM muscle and mobilising it to separate the trachea and oesophagus. All patients should remain nil by mouth until a barium swallow performed at 5–7 days postoperatively has excluded a leak.

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