Penetrating neck injuries

ABSTRACT

Penetrating neck injuries are becoming more common because of the increasing prevalence of knife and gun crimes. The immediate and long-term consequences of injury to the neck can be significant because of the close relationship of important anatomical structures in a confined space. Delayed recognition of major injury and inadequate treatment results in high morbidity and mortality. Developing a clear understanding of the underlying anatomy, common mechanisms of injury and principles of management will provide first responders, emergency doctors and trauma surgeons with confidence in appropriate evidence-based management. Early involvement of otolaryngologists or head and neck surgeons is advisable. Two cases of penetrating neck injury from the June 2017 London Bridge terror attack are discussed.

Penetrating trauma is increasingly common with rising knife crimes, gun crimes and terrorism-related ballistics in the civilian arena (House of Commons Library, 2017a,b). Neck trauma is the reason for 2.29% of all trauma-related attendances with a case fatality rate of 17.76% (American College of Surgeons, 2016). The incidence of penetrating neck injuries currently stands at 4.3 cases per 100 000 people in London (Harris et al, 2012). Although the incidence of penetrating neck trauma in the UK is relatively low compared to that seen internationally, all emergency departments will likely encounter this injury, highlighting the need for efficient and accurate patient management. It is important for emergency departments to systematically manage these complex cases, although this is not helped by a paucity of high quality literature on this subject. A clear understanding of neck anatomy, typical mechanisms of injury, 'hard signs' of severe trauma and proven principles of patient management should allow clinicians to provide optimal safe care.

Anatomy of neck

Neck anatomy is complex (*Table 1*). Structures are best appreciated by considering the main fascial planes of the neck, namely the superficial and the deep cervical fasciae. The superficial fascia embraces the platysma muscle in the neck and is continuous with the superficial musculoaponeurotic system of the face. Injuries that do not penetrate this layer are invariably innocuous as there are no superficial vital structures. The deep cervical fascia is composed of three separate layers that encase many of the structures of the neck (*Table 2*). Conceptually these can be considered as tubes traversing the neck between the thorax and head. All three layers merge to form the carotid sheaths which surround the common carotid artery, internal jugular vein, vagus nerve and the deep cervical lymph nodes.

The most widely accepted anatomical classification used in penetrating neck injuries separates the anterior neck into three zones:

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Table 1. Anatomical components of the neck

System	Components
Respiratory	■ Larynx ■ Trachea
Vascular	■ Innominate artery and vein ■ Internal and external carotid artery and branches ■ Internal and external jugular vein and tributaries
Gastrointestinal	■ Oropharynx and hypopharynx ■ Oesophagus
Endocrine	■ Thyroid gland ■ Parathyroid glands
Lymphatic	■ Lymphatic network and lymph nodes
Nervous	■ Spinal cord ■ Cranial nerves ■ Cervical plexus ■ Brachial plexus
Skeletal	■ Vertebral column ■ Mandible ■ Laryngeal framework
Muscular	■ Platysma ■ Sternocleidomastoid ■ Suprahyoid musculature ■ Infrahyoid 'strap' musculature ■ Musculature surrounding vertebral column and skull

Table 2. Layers of deep cervical fascia

Layer	Relevant anatomy	Contents
Investing	■ Superior attachment: superior nuchal line, mastoid process, inferior border of mandible ■ Inferior attachment: thoracic outlet	■ Parotid gland ■ Submandibular gland ■ Sternocleidomastoid ■ Trapezius
Pre-tracheal	Situated anteriorly in neck ■ Superior landmark: hyoid bone ■ Inferior landmark: fuses with pericardium	■ Viscera: trachea, oesophagus, thyroid ■ Muscular: infrahyoid muscles
Prevertebral	■ Superior attachment: base of skull ■ Anterior: transverse processes and vertebral bodies of vertebral column ■ Posterior: ligamentum nuchae ■ Inferior: endothoracic fascia of ribs	■ Vertebral column

1. Clavicles to cricoid cartilage
2. Cricoid cartilage to angle of mandible
3. Angle of mandible to base of skull (Monson et al, 1969) (*Figure 1*).

There are many important structures that should be considered at each of these levels (*Table 3*). Traditionally, the zones of the neck have a bearing on subsequent management; however, improved trauma imaging modalities have made use of neck zones less important. Injuries of the posterior triangle of the neck are considered separately.

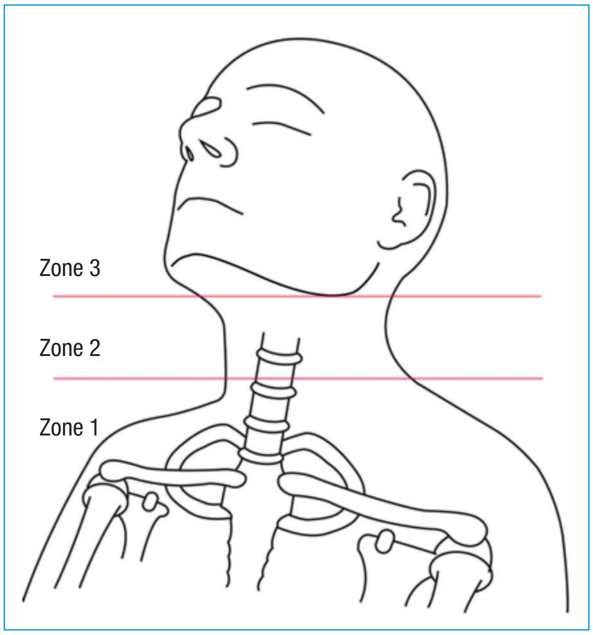
Mechanism of injury

Penetrating injuries can be classified as low velocity and high velocity. The most common causes of penetrating neck injuries are low velocity stab wounds and high velocity gunshot wounds. Understanding the exact mechanism of injury for each cause is important in predicting the possible injuries that might arise.

Stab wounds

Stab wounds are low velocity injuries caused by knives, razor blades, broken glass shards or other sharp instruments which tend to cut through the skin and subcutaneous tissue dividing structures. There has been a trend among crime gangs towards the use of large hunting knives with long serrated blades that are designed to inflect maximal soft tissue injury. Clinicians should be wary of the small entry wound sites typical of sharp objects. There is often an unclear depth of penetration and a breach of platysma that should raise concerns of serious injury to vital structures. Multiple stab wounds may present a particular problem with several entry wounds. Zone 1 is the most commonly affected area (Madsen et al, 2016). Haemopneumothorax is eight times more common in stab wounds than gunshot wounds (Madsen et al, 2016). This may be the result of stabbing often occurring in a downward trajectory from above the patient. Laceration of the inominate and subclavian vessels should also be considered.

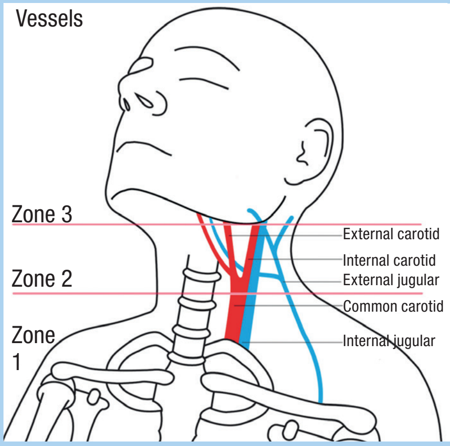
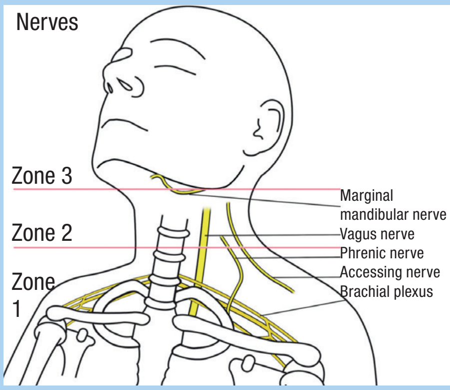
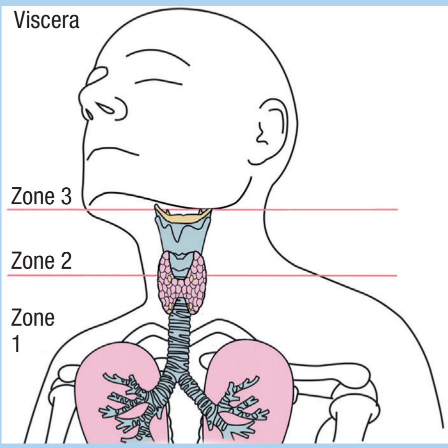
Figure 1. Zones of the neck.



Gunshot wounds

All gunshot wounds are high energy with the potential to cause devastating injury. The amount of energy imparted to the tissue depends upon several factors including the type of weapon, size (calibre) of the weapon's muzzle, distance between weapon and contact tissue, and finally the property (mass and velocity) of the projectile. With higher velocity injuries, more surrounding tissue is disrupted by the energy transfer. In handgun gunshot wounds, there is typically a small entry and exit wound. The tissue between these two points is lacerated and crushed. High energy gunshot wounds which typically result from rifle or automatic weapons are more unpredictable and often have unclear exit wounds as a result of the widespread shock wave and cavitations damage from the ballistic round. These result in significant destruction of soft tissues which greatly increases the amount of trauma to the patient.

Table 3. Contents of the neck

Structure	Contents
Vessels 	**Zone 1:** ■ Inominate vessel, vertebral artery, proximal carotid artery, internal jugular vein **Zone 2:** ■ Common carotid artery branching into the internal and external carotid artery, facial and lingual artery ■ Vertebral artery ■ Internal jugular vein and external jugular vein **Zone 3:** ■ Internal carotid artery ■ Vertebral artery
Nerves 	**Zone 1:** ■ Brachial plexus ■ Phrenic nerve **Zone 2:** ■ Spinal accessory nerve ■ Facial nerve ■ Vagus nerve ■ Recurrent laryngeal nerve ■ Cervical plexus ■ Lingual nerve ■ Hypoglossal nerve **Zone 3:** ■ Cranial nerves IX, X, XI and XII
Viscera 	**Zone 1:** ■ Apex of lung ■ Oesophagus ■ Trachea **Zone 2:** ■ Larynx ■ Oesophagus ■ Trachea ■ Thyroid and parathyroid glands **Zone 3:** ■ Parotid gland ■ Submandibular gland

Gunshot wounds are more common in zone 2 of the neck. If the larynx is damaged, emergency tracheostomy is the usual course of action. Oesophageal injuries, spinal cord injury, brachial plexus injury and cervical spine injuries are more common in gunshot wounds than stab wounds (Madsen et al, 2016).

Clinical presentation and investigative modalities

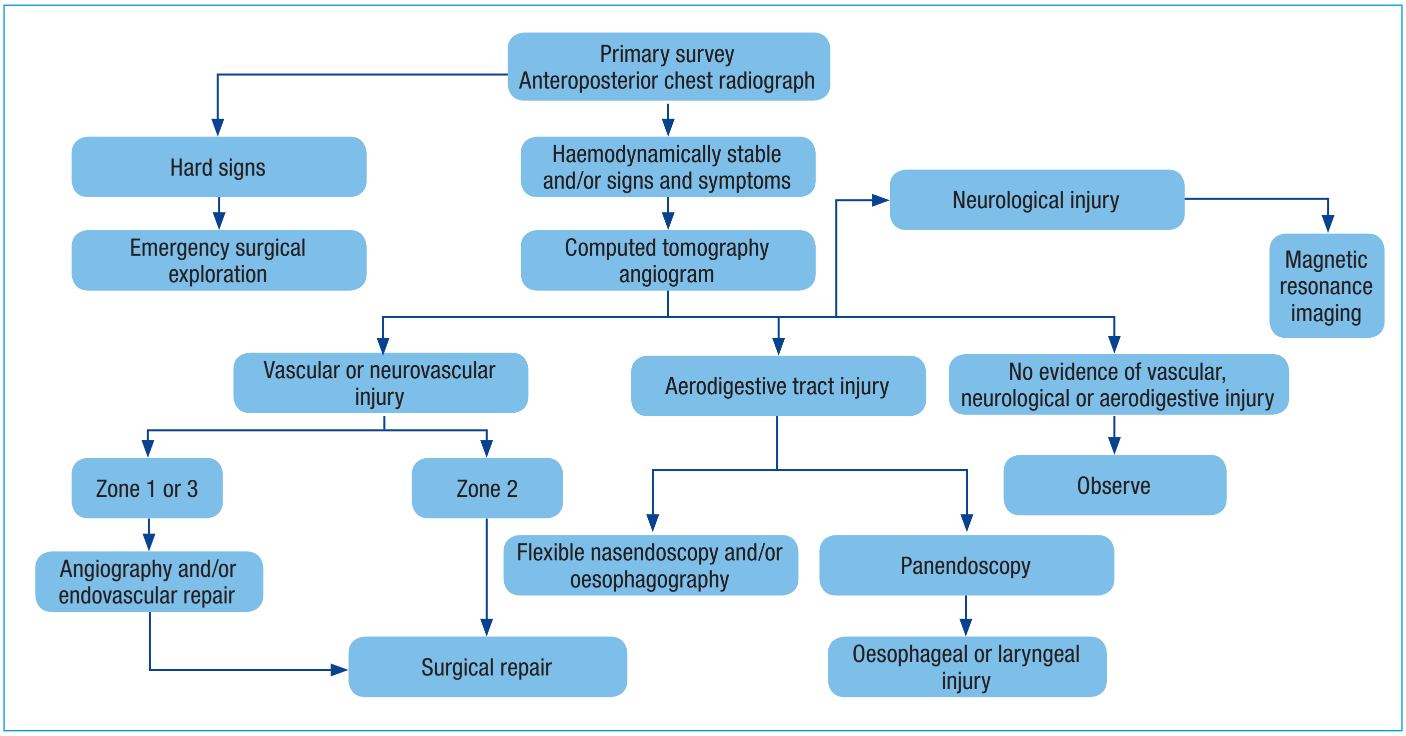
All patients who present in trauma should be managed according to the Advanced Trauma Life Support principles with immediate resuscitation and emphasis on the airway, breathing and circulation pathway (American College of Surgeons, 2012). This is followed by rapid identification of life-threatening injuries in an organized fashion with immediate correction of any physiological irregularities. In the context of penetrating neck injuries, stabilization of the airway may be compromised as a result of the injury transgressing the airway, so basic and advanced airway management techniques (such as cricothyroidotomy or tracheostomy) may need to be used. In threatened airway cases, pre-emptively establishing a definitive airway should be paramount; 11% of patients require immediate airway management in the pre-hospital setting or on arrival to the emergency department (Mandavia et al, 2000). The most common technique is rapid sequence induction with direct laryngoscopy and placement of an endotracheal tube. Direct laryngoscopy provides the advantage of visualizing the supraglottic area. Other possible techniques in a suspected difficult intubation include awake fibreoptic nasointubation, although if there is any risk of skull base injury caution must be exercised to avoid inadvertent intracranial passage. Intubation of patients directly through neck wounds has also been described. It is not uncommon for patients to require immediate cricothyrotomy or surgical tracheostomy by appropriate specialists depending on the nature of the neck injury.

Once resuscitation has been achieved, a systematic secondary survey to evaluate the severity and extent of the trauma is needed. A focused head and neck examination should aim to identify any aerodigestive, vascular or nervous abnormalities. Penetrating injuries that obviously do not breach the superficial cervical fascia do not require exploration and can be closed primarily. For deeper injuries, hard signs should be recognized during the primary survey (*Table 4*). These patients will need to undergo emergency operative management. Both entry and exit wounds should be identified in the context of their respective neck zones.

Table 4. Indications (hard signs) for immediate surgical management in penetrating neck trauma

Pulsatile bleeding
Airway compromise
Expanding haematoma
Bubbling wound or significant air escape
Subcutaneous emphysema
Massive haemorrhage and refractory shock
Stridor or hoarseness

Figure 2. Algorithm for managing penetrating neck injuries.



Although physical examination is effective in revealing most life-threatening vascular injuries, the absence of signs or symptoms does not rule out sinister pathology (Fogelman and Stewart, 1956). Therefore patients who lack hard signs should undergo further investigations before determining the next stages in management (*Figure 2*). The literature outlines both a classic and selective approach to managing these patients (Shiroff et al, 2013). The anatomically driven classic approach mandates surgical exploration for all zone 2 neck wounds that breach the platysma and simple observation or digital subtraction angiography for zones 1 and 3 injuries. This approach is now widely considered outdated as it is time-intensive, requiring multiple specialities to coordinate management, has a low diagnostic yield and a high non-therapeutic rate from mandatory surgical exploration. Additionally, mandatory neck exploration is not practical in countries with a very high incidence of penetrating trauma.

The selective 'no-zone' approach of managing penetrating neck injuries mandates those who lack hard signs to be observed and undergo computed tomography angiography. Computed tomography angiography has revolutionized trauma care with the distinct advantages of speed, high resolution and high sensitivity (up to 100%) in assessing injuries in all three zones (Inaba et al, 2006). Further investigative studies are then chosen according to the patient's symptoms and findings on computed tomography angiography. These can be tailored to identify vascular (angiography), laryngo-tracheal (flexible nasendoscopy or bronchoscopy), oesophageal (oesophagoscopy or oesphagography) or nervous (magnetic resonance imaging) injuries.

Cervical spine

The merit of neck immobilization in all penetrating neck injuries is debatable with only 1.4% of casualties benefiting from the intervention (Arishita et al, 1989). Suspicions should be raised in the context of gunshot wounds as the evidence suggests this mechanism is six times more likely to cause cervical injuries than stab wounds (Madsen et al, 2016). This is especially true if the projectile travels in a transcervical trajectory. The use of hard collars in all penetrating injuries may result in missing potentially life-threatening signs diagnosed on an exposed neck (Barkana et al, 2000). This demonstrates the need for thorough assessment of the neck during the primary survey, ideally with manual head immobilization while hard collars are temporarily removed.

Aerodigestive tract

Accurate assessment of the patient's airway is paramount. The aforementioned hard signs of stridor, hoarseness, bubbling wounds and subcutaneous emphysema suggest underlying laryngo-tracheal injury. Trauma teams should also consider direct (haemorrhage, foreign body) and indirect (expanding haematoma) causes of airway obstruction. Even a small amount of bleeding within the tight neck compartment may lead to life-threatening airway compromise, secondary to lymphatic obstruction and oedema.

Oesophageal injury is relatively uncommon but there should be a low threshold for further investigation if penetrating trauma occurs close to the oesophagus. The mortality is as high as 26% as a result of the patient subsequently developing mediastinitis (Asensio et al,

> Roughly 10% of vascular injuries following penetrating neck injuries will involve the carotid artery.

1997). A small tear in the oesophagus or pharynx can be managed conservatively with insertion of a nasogastric tube and enteral feeding. A water-soluble contrast study is performed after about 1 week in order to evaluate the integrity of the pharynx or oesophagus. A large pharyngeal or oesophageal leak that results in a pharyngo-cuteanous fistula for example may require neck exploration and repair.

Vascular

The vascular system is the most commonly affected in penetrating neck injuries (Bell et al, 2007). Following vessel injury, a haematoma may form which temporarily tamponades the bleeding. A traumatic aneurysm may result from arterial injury which may also lead to temporary cessation of bleeding. More significant bleeding may only occur when the patient is moved or dressings removed. In massive haemorrhage, active bleeding should be controlled with direct pressure in the first instance. Another recognized technique to control bleeding is the use of an 18- or 20-French Foley catheter balloon inserted into the wound and inflated to tamponade surrounding vessels (Navsaria et al, 2006).

Military personnel have been trialling battlefield haemostatic powder agents based on chitin that is derived from marine animal exoskeleton. This is inserted into the wound and direct pressure applied, and is used to act as a tamponade and assist stabilization until evacuation to a medical facility. Patients with significant bleeding from zone 2 should undergo immediate operative exploration. Owing to the difficulty in obtaining adequate vascular exposure, haemorrhage from zone 1 and 3 benefits from angiography and endovascular repair in the first instance if the patient's condition is stable. Failure of endovascular repair warrants immediate open surgical exploration and repair.

Principles of management

Operative management strategies vary depending on the clinical situation. A full description of surgical techniques is beyond the scope of this article. However, a number of key principles should be observed. Surgery can be divided into the following phases: access or approach, control and identification of the extent of injury followed by repair and reconstruction.

In the context of major haemorrhage the initial goal is to identify and control bleeding vessels. Defects of the common carotid, internal carotid or external carotid arteries should be repaired if possible. Larger defects may require ligation, primary re-anastomosis or grafting with autologous vein, polyester (Dacron) or polytetrafluorethylene (PTFE) material. If the patient is haemodynamically stable then endovascular repair by specialist neurointerventional radiologists or vascular surgeons may be attempted (McNeil et al, 2002).

Great care must be taken when selecting an operative approach. The ideal incision should allow adequate exposure of the injured zone with the ability to extend the incision if necessary. A plan for closure and whether a graft or flap is required should also be made. Incisions may be incorporated into existing neck wounds to allow wound debridement and optimization on closure. This will also provide evidence of the path of missile or weapon trajectory as the wound is exposed. Alternatively more commonly used head and neck surgery approaches can be used, providing a broad exposure to important structures and a degree of familiarity for the surgeon. Common incisions for zone 2 injuries are placed along the anterior border of the sternocleidomastoid muscle between the angle of the mandible and sternoclavicular joint. If access to zone 3 is required intraoperatively, the incision can be extended horizontally between the angle of mandible and mastoid process. Similarly, extension of the incision from the sternoclavicular joint along the superior border of the clavicle allows access to zone 1. Multidisciplinary involvement with otolaryngology, maxillofacial, neurosurgical and thoracic teams should be supported.

Once a flap has been raised, careful dissection through the zone of injury should commence. The carotid sheath and its contents will be encountered deep to the sternocleidomastoid. Obtaining adequate exposure of the common, internal and external carotid artery is needed to allow proximal and distal control of the vessel as options for open repair are considered as described above. The most common vascular structure damaged is the internal jugular vein as a result of its lateral position, relative size and thin wall (Madsen et al, 2016). The internal jugular vein can be repaired and if necessary ligated.

Roughly 10% of vascular injuries following penetrating neck injuries will involve the carotid artery (Bell et al, 2007). All patients who are neurologically intact should have their carotid artery repaired if possible. Even those with a neurological deficit preoperatively should be considered for repair instead of ligation (Liekweg and Greenfield, 1978). The carotid artery should not be sacrificed because of the risk of serious cerebrovascular accident.

If the injury affects the cervical oesophagus then repair in a one- or two-layered fashion should ensue. The surrounding strap muscles or sternocleidomastoid can bolster this repair. There should be liberal use of drains to reduce the risk of mediastinitis. Repair of laryngeal injury is dependent on the size of the defect. Primary aims are to allow future swallowing, speech and a safe airway. In simple lacerations, primary closure may be possible.

In more complex injury a tracheostomy may be necessary to bypass the upper airway during laryngeal repair and recovery, with the resultant oedema that will likely develop. It will also facilitate a safer return to theatre in the event of delayed presentation of other neurovascular injuries. Depending on the structures damaged, different approaches may be taken. Adequate exposure of the larynx can be obtained by performing a thyrotomy. This will allow visualization of the hyoid, cricoid and thyroid components of the larynx. Repair of these structures can ensue with an aim of rigid fixation, arytenoid re-suspension and cricoid stabilization. Ensuring sufficient haemostasis is paramount.

In the cases of gunshot trauma there may be significant tissue loss which may need debridement and reconstruction.

Below are two cases of penetrating neck injury that illustrate the importance of the Advanced Trauma Life Support principles, timely and appropriate investigative modalities and surgical intervention in the presence of hard signs.

Case 1

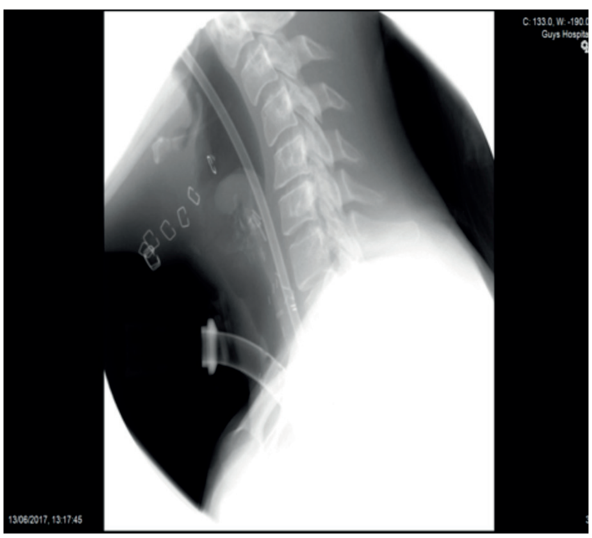
Patient A was a 34-year-old woman, with a single stab injury from a hunting knife as part of the London Bridge terror attack in June 2017. She walked into the accident and emergency department with a 3 cm left lateral neck injury in zone 2 and a 'sucking neck wound'. It was noted that when she spoke or coughed air leaked out of the neck.

Airway, breathing and circulation resuscitation was instituted and the primary and secondary survey identified no other injury.

The patient was intubated with an endotracheal tube by an anaesthetist as she developed progressive airway obstruction over the next few minutes. She was noted to have a difficult intubation as a result of oedema. A computed tomography scan was performed that identified no vascular injury.

The neck wound was explored under general anaesthetic where a 9 cm horizontal laceration to the larynx through the thyrohyoid membrane was found, with perforation of the pharynx and oesophagus and partial separation of the epiglottis from the larynx. Both carotid sheaths were intact. These injuries were repaired in layers with vicryl. A temporary tracheostomy was inserted. A gastrograffin study at day 7 showed complete healing of the pharynx (*Figure 3*). She was successfully de-cannulated at day 8 and the nasogastric tube was removed at day 14. She has subsequently made a full recovery.

Figure 3. Lateral radiograph during gastrograffin study showing the postoperative appearance at day seven. Note the surgical clips, nasogastric tube and tracheostomy in situ. Significant oedema of the posterior glottis should also be noted.



KEY POINTS

- Penetrating neck injuries are increasingly common as a result of increasing knife and gun crime.
- A structured Advanced Trauma Life Support approach to managing the patient is mandatory and allows early identification of life-threatening injuries.
- Penetrating neck injury with 'hard signs' mandates surgical exploration.
- Common structures injured include the vasculature, aerodigestive tract, nerves and cervical spine.
- Surgical specialism from head and neck, otolaryngology, cardiothoracic, vascular and neurosurgical specialists should be sought early to allow appropriate patient management.

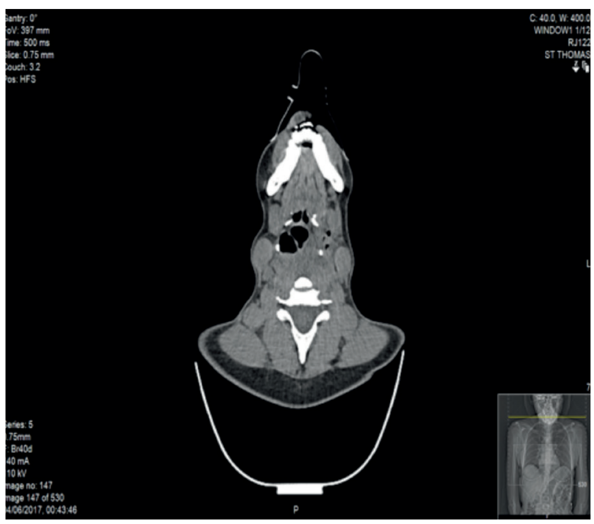
Case 2

Patient B was a 32-year-old woman who received a single stab injury to the left lateral zone 2 of the neck with a hunting knife as part of the same terrorist attack.

Airway, breathing and circulation resuscitation protocol was performed revealing no airway or acute vascular injuries. A computed tomography scan was performed (*Figure 4*) that identified soft tissue injury around the left hypopharynx with free air indicating perforation of the pharynx.

She was taken to the operating theatre and the neck was explored. This revealed no vascular injury and the pharyngeal defect was repaired in layers. She made a complete recovery and was discharged on the seventh postoperative day.

Figure 4. Axial computed tomography scan of the neck with soft tissue injury to left hypopharynx with gas locules indicating a pharyngeal laceration.



Conclusions

A reasonable understanding of penetrating neck injuries is important in all first responders, emergency physicians and trauma surgeons as a result of the increasing prevalence of knife and gun crimes. A structured approach to management by way of Advanced Trauma Life Support principles with emphasis on airway, breathing and circulation is important. Selective rather than mandatory neck exploration should be used depending upon the severity and extent of injuries. Damaged structures can be postulated based on the trajectory of insult and zone of the neck involved. Patients with hard signs should undergo emergency operative or endovascular repair. All other patients will require computed tomography angiography and subsequent management of any identified injuries by a multidisciplinary surgical team. **BJHM**

The authors would like to thank the two patients who have allowed them to share the management of their penetrating neck injuries.
Conflict of interest: none.

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