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MANAGEMENT OF PENETRATING NECK INJURIES

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Penetrating neck injury is defined as traumatic breach of the platysma muscle. It accounts for 5-10% of traumatic injuries in adults and has a mortality rate of 5% both in civilian and war settings. Haemorrhage is the principal cause of death. There has been a paradigm shift in its management over the past decades, from mandatory exploration to selective conservative management based on clinical assessment and special investigations. Management is also determined by availability of diagnostic resources and technical expertise.

SURGICAL ANATOMY

Exploring a traumatised neck can be extremely challenging due to its complex anatomy, even for experienced head and neck surgeons *(Figure 1)*.

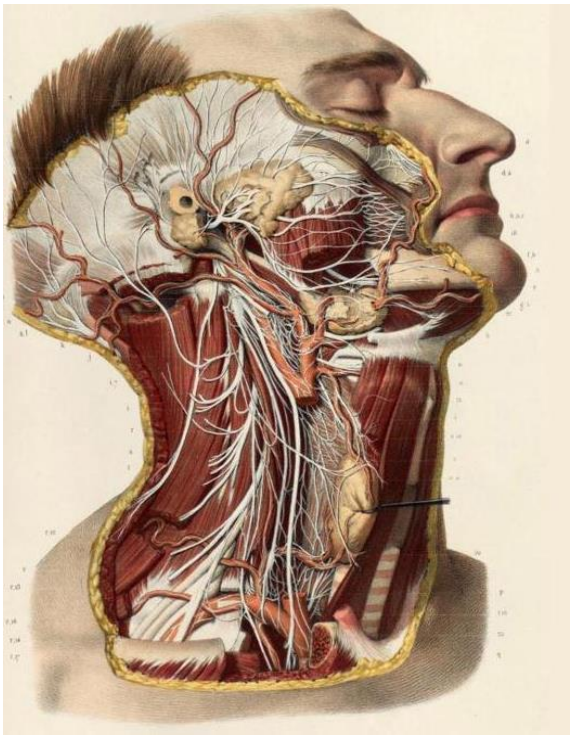


Figure 1: Complex anatomy of neck

Readers are referred to the following resources to familiarise themselves with the detailed anatomy of the neck and emergency procedures.

- Modified and Radical Neck Dissection
- Neck dissection technique (video)
- Submandibular gland excision
- Submandibular gland excision (video)
- Parotidectomy
- Parotidectomy (video)
- Total laryngectomy
- Tracheostomy
- Percutaneous tracheostomy
- Cricothyroidotomy
- Oesophagoscopy and bronchoscopy

RESUSCITATION PRINCIPLES

The Advanced Trauma Life Support (ATLS®) guidelines outline resuscitation principles.[1]

Airway and Cervical Spine Protection

- Patency of the airway may be affected by soft tissue swelling, haematoma, bleeding into the airway, facial fractures, or foreign bodies
- Airway compromise presents with stridor, stertor or respiratory distress
- Patients considered at risk of obstruction must be closely monitored
- Prophylactic airway intervention may be required
- Repeated failed attempts at intubation can cause bleeding obscuring the larynx and trachea, can aggravate lacerations in the pharynx and larynx, or cause false tracts
- Intubation should therefore be attempted by an experienced member of the team in a setting where an emergency surgical airway can be created if required

- Either a cricothyroidotomy or tracheotomy may be done depending on skill sets of treating physicians and patient factors
- Cricothyroidotomy is converted to a formal tracheostomy within 24hrs because a smaller tube may compromise ventilation and cleaning of the tube
- Rates of subglottic stenosis and other complications of cricothyroidotomy vs. tracheostomy are similar [2]
- An endotracheal tube can be inserted directly into the trachea through a blowing cervical wound to temporarily secure the airway *(Figure 2)*

Figure 2: Patient intubated directly through a penetrating neck injury

Breathing

- Confirm chest wall movement and bilateral air entry
- Tension pneumothorax and haemothorax are life-threatening emergencies
- Tension pneumothorax is a clinical diagnosis and presents with hypoxia, restlessness, hyper-resonance on percussion, reduced air entry, tracheal shift to the contralateral side, and raised jugular venous pressure *(Figure 2)*
- Tension pneumothorax requires immediate decompression prior to X-rays or other investigations
- Decompress a tension pneumothorax by needle thoracocentesis. Insert a large bore needle through the 2nd intercostal space in the midclavicular line
- This should be followed by insertion of an intercostal drain

Circulation and Perfusion

- Control active bleeding from the wound with a non-circumferential compressive dressing or with digital pressure
- If haemostasis fails, insert a large Foley catheter into the wound, inflate the bulb and cross-clamp the catheter to prevent blood draining through the lumen of the catheter *(Figure 3).* The capacity of the bulb of the Foleys catheter is more important than the French Gauge, as up to 10-20ml of saline may be required to inflate the balloon to adequately tamponade bleeding

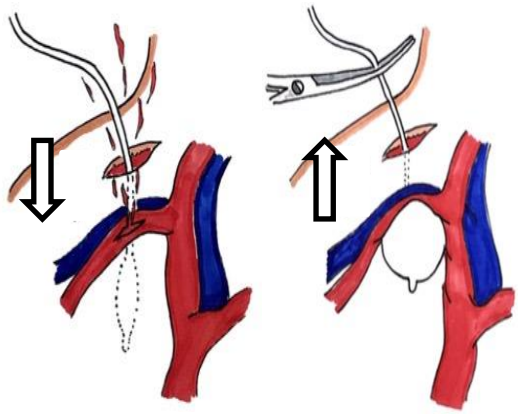


Figure 3: Foley catheter balloon tamponade technique

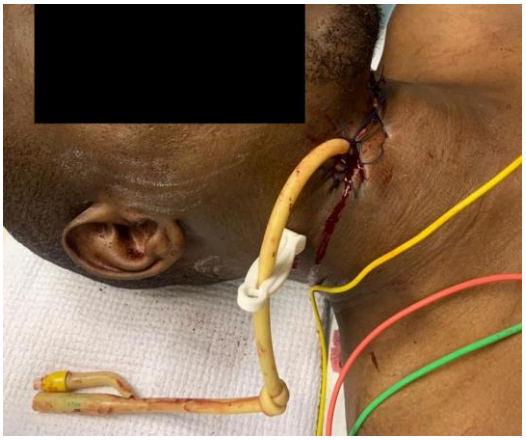


Figure 4: Foley catheter balloon tamponade technique with catheter clamped and knotted

- Prevent air embolism occurring via large lacerated exposed veins by maintaining a recumbent position, or by covering wounds with occlusive dressings when a patient needs to sit upright
- Avoid blind probing or clamping vessels through open wounds as it may cause major haemorrhage
- A shocked patient with warm peripheries, low blood pressure and bradycardia may have neurogenic shock secondary to spinal cord injury, potentially masking a vascular injury

Aetiological classification

- Stab wounds from assaults account for 70% of penetrating neck injuries, followed by gunshot wounds (GSWs) (20%)
- GSWs may be low kinetic energy (handguns) or high kinetic energy (military, rifles, magnums) or shotguns
- GSWs are more destructive than stab wounds and have a higher mortality

Types of Assault and Neck Injury

- The nature and velocity of a projectile can guide risk stratification of injury severity
- Higher velocity wounds cause more soft tissue trauma, aerodigestive and vascular injury and have a higher mortality
- Injury may occur well beyond the predicted path of a projectile
- A bullet's trajectory through the neck is often non-linear
- The tract of a stab wound may be unpredictable depending on the length of a blade and whether a stab was delivered over- or underhanded
- Shotgun injuries vary depending on the shooting range and the type of pellets (buckshot vs birdshot)

Zones of Neck

Roon & Christensen's classification of the neck into 3 Zones is commonly used to describe neck trauma ***(****Figure 4)*. [3] The classification has been employed to predict vascular, digestive, and respiratory structures at risk of injury, and facilitates standardization of reporting, risk stratification and institution of management directives. However, there is poor correlation between the Zone of an entry wound and the injured structures. It also does not take into account transcervical injuries that cross the midline which are associated with an increased rate of both vascular and aero-digestive injuries.

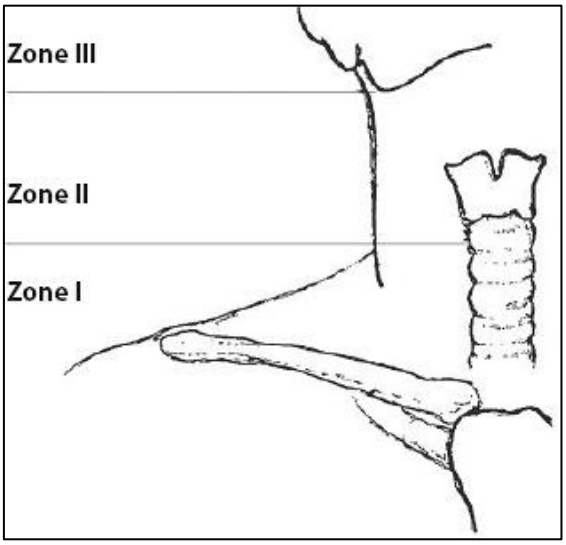


Figure 4: Roon and Christensen zonal classification [3]

Zone I

- Sternal notch/clavicle to cricoid
- Structures at risk
  - Vascular: Common carotid artery, vertebral artery, subclavian artery, aortic arch, superior vena cava, internal jugular vein, brachiocephalic vein and trunk, thyrocervical trunk
  - Aerodigestive: Trachea, lung apex, oesophagus, hypopharynx
  - Neural: Spinal cord, Xn, XIn, recurrent laryngeal nerve (RLN), phrenic

nerve, brachial plexus, sympathetic trunk
    - Other: Thyroid gland, thoracic and lymphatic ducts
- Challenging access/exploration
    - Constraint of bony thoracic inlet
    - May need sternotomy and/or thoracotomy
- Recommendation according to "Zone-based approach"
    - Surgical exploration not mandatory in stable patients
    - Consider angiography and contrast swallow

Zone II

- Cricoid to angle of mandible
- Structures at risk
    - Vascular: Common, external and internal carotid arteries, vertebral artery, internal jugular vein
    - Aerodigestive: Larynx, oropharynx, hypopharynx, proximal oesophagus
    - Neural: Spinal cord, IXn, Xn, XIn, XIIn, sympathetic trunk
- Comparatively easy access for clinical evaluation and surgical exploration
- Recommendation according to "Zone-based approach"
    - May consider upfront exploration

Zone III

- Angle of mandible to base of skull
- Structures at risk
    - Vascular: External and internal carotid arteries, vertebral artery, basilar artery, internal jugular vein
    - Aerodigestive: Larynx, oropharynx, hypopharynx
    - Neural: Spinal cord, VIIn, IXn, Xn, XIn, XIIn, sympathetic trunk
    - Other: Parotid, submandibular, sublingual salivary glands
- Challenging access/exploration
    - Many critical neurovascular structures
    - Access limited by skull base and mandible
    - May need mandibulotomy or craniotomy to access injuries
- Recommendation according to "Zone-based approach"
    - Surgical exploration not mandatory in stable patients
    - Consider angiography and contrast swallow

Mandatory vs selective exploration

Based on experience in World War II and subsequently, early exploration of penetrating neck injuries reduced mortality; hence early exploration of all penetrating injuries that breached the platysma was standard practice. In 1963, Stone questioned mandatory exploration for civilian injuries.[4] Following Roon and Christensen's in 1979, a "Zone" based approach was widely adopted. [3]

Immediately life-threatening injuries

- Require urgent surgical exploration
- Exploration is prioritized over special investigations
- Examples: Uncontrollable bleeding, haemorrhagic shock not responding to resuscitation, expanding haematoma, airway compromise and massive haemothorax

Stable penetrating neck injuries

- Management is controversial
- Three approaches
    1. Upfront mandatory exploration
    2. Mandatory investigations with selective exploration or observation of stable penetrating neck injury
    3. Selective investigations with selective exploration or observation
- Dictated by institutional bias, clinical context, available resources and expertise

- With increased use of advanced imaging, most centres advocate some form of selective conservative management

Mandatory exploration of stable patients

- Proponents believe the risk of missing vascular or aerodigestive tract injuries outweighs morbidity and expense of negative exploration
- Arguments in favour
  - Unreliability of clinical evaluation
  - Diagnostic studies not 100% sensitive to exclude oesophageal and vascular injury
  - Low morbidity of negative exploration
  - Time and effort associated with expectant observation
  - Morbidity and mortality associated with delayed detection and repair of oesophageal injury
- Arguments against
  - Vascular and oesophageal injuries can still be missed when neck is explored without preoperative angiography, oesophagography and/or oesophagoscopy
  - Expanding role for conservative non-surgical management of aerodigestive and vascular injures
  - Risk of anaesthesia, surgical iatrogenic complications and cosmetic implications associated with neck exploration
  - Increased burden on emergency operating theatre resources and personnel
- Mandatory exploration sensible in military field hospital or low resource settings where access to investigations is limited

Selective Exploration in stable patients

Zones-based approach [3]

- Zones-based approach has been generally abandoned due to poor correlation between Zone of an entry wound and injured structures, and limitations with transcervical injuries
- Zone II injuries
  - All are explored upfront
  - Relative ease of surgical exposure
- Zones I and III injuries
  - Consider conservative approach
  - Directed by special investigations

"No Zones" approach

- Safety of selective conservative management with active observation is well documented in multiple studies.[5,8,9-13]
- Most deaths are not due to selective nonoperative management but due to trauma outside the neck or massive haemorrhage
- Arguments for selective exploration
  - High rates (36–89%) of negative mandatory exploration [5-7]
  - Good sensitivity and specificity of special investigations (CT, angiography, doppler, barium swallow, rigid oesophagoscopy, and flexible laryngotracheobronchoscopy)
  - Expense of hospitalisation following negative exploration
  - Many injuries (thyroid, pharyngeal, venous etc.) found at mandatory exploration can be treated conservatively
  - Unsightly scars
- Exploration without a radiological 'road map' of potential injuries is more challenging and difficult to justify when available
- Protocols for selective exploration vary
  - Some employ routine upfront imaging of the vascular and digestive systems

- Others employ a pragmatic selective approach to imaging and investigations based on detailed clinical assessment
  - Imaging reserved for haemodynamically stable patients with "hard" or "soft" clinical signs of vascular or aerodigestive tract injury *(Table 1)*
  - Many routinely image GSWs and transcervical injuries

Hard Signs requiring emergency surgery	
Vascular	• Uncontrolled haemorrhage • Haemorrhagic shock not responding to fluid resuscitation • Expanding or pulsatile haematoma • Central neurological deficit • Pulse deficit
Airway	• Airway compromise • Large blowing wound • Massive haemoptysis
Digestive tract	• Massive haematemesis

Soft Signs for pragmatic selective approach	
Vascular	• Haemorrhagic shock responding to fluid resuscitation • Nonexpanding/stable haematoma • History of significant haemorrhage • Peripheral neurological deficit i.e. Horner's syndrome, lower cranial nerve palsy
Airway	• Haemorrhagic shock responding to fluid resuscitation • Nonexpanding/stable haematoma • History of significant haemorrhage • Peripheral neurological deficit i.e. Horner's syndrome, lower cranial nerve palsy
Digestive tract	• Dysphagia • Odynophagia • Subcutaneous emphysema • Saliva draining from wound • Blood in nasogastric tube

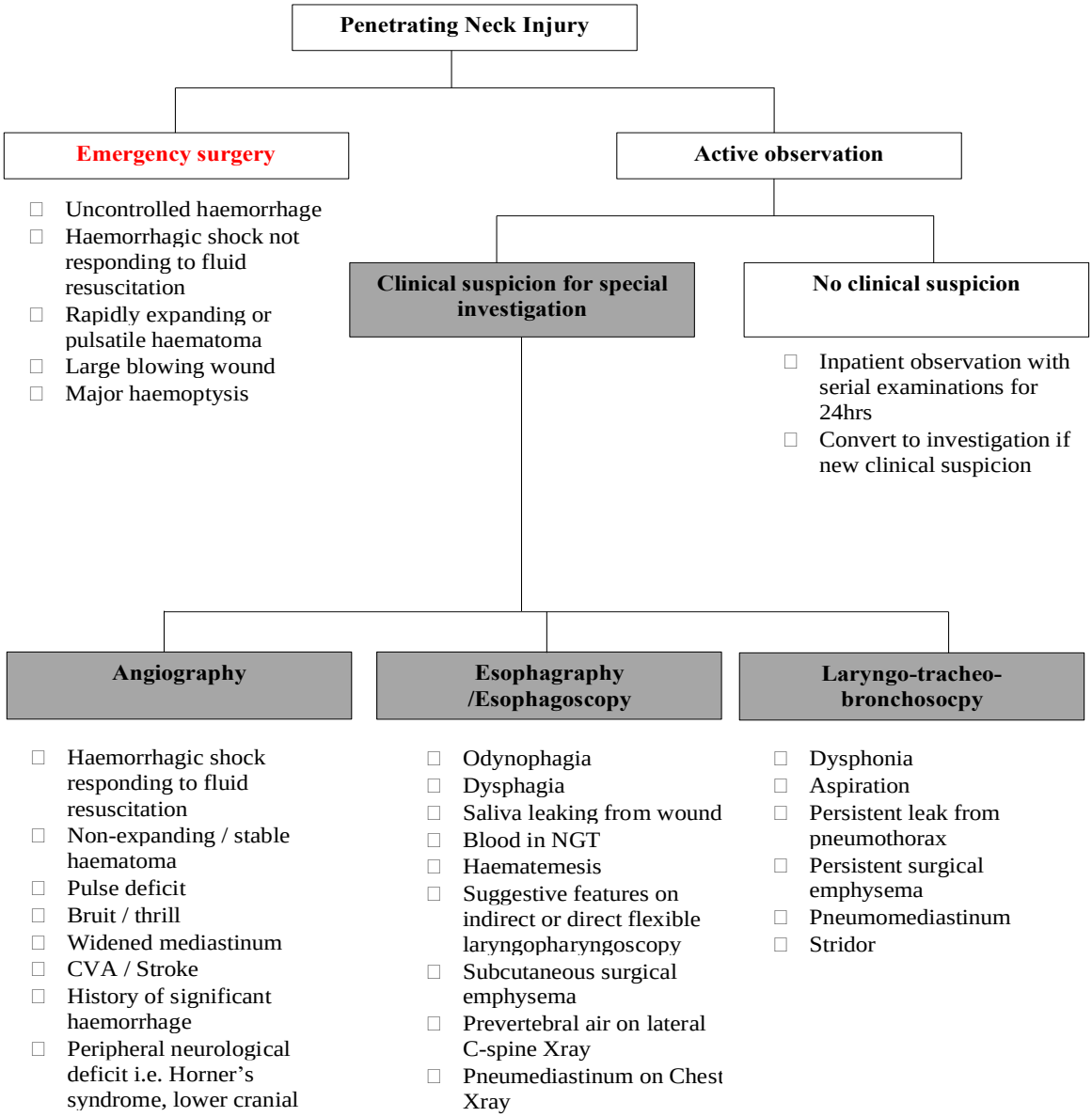
Table 1: Detailed clinical assessment for emergency surgery vs. selective conservative management

- Spiral CT angiography (CT-A)
  - Widely used to evaluate the neck
  - Gold standard for imaging the neck with sensitivity and specificity of 97% and 99% respectively [15]
  - Rapid, non-invasive
  - Significantly reduces negative neck exploration
  - May be used to assess possible aerodigestive injury
  - If CT shows that trajectory courses away from vital structures, then invasive studies are superfluous
- Prophylactic antibiotics and antifungals
  - Do not reduce wound complications
  - Consider for aerodigestive injury, clinical signs of infection and heavily contaminated or devitalized wounds
- Tetanus prophylaxis considered with vaccine and/or human tetanus immune globulin based on the patient's vaccine status and the type of wound

Authors' active observation practice
(Figure 5)

- Admit haemodynamically stable patients without symptoms and signs of aerodigestive or vascular injury to the high care ward for haemodynamic and airway monitoring
- 5-hourly clinical examination of neck
- After 24hrs of unremarkable observation, commence oral diet; if tolerated, discharge 12hrs later
- Provide patient with a *neck injury form* that lists 'alarm' symptoms and signs of vascular and/or aerodigestive injury; advised to return immediately if there are concerns
- 80% of transcervical GSWs may be safely managed nonoperatively by active observation and selective investigations [14]

Figure 5: Selective exploration algorithm



Upper digestive tract injury

- Upper digestive tract divided into oro-pharynx, hypopharynx, and cervical, intrathoracic, and intra-abdominal oesophagus
- Consider upper digestive tract injury in all penetrating and blunt injuries
- High index of suspicion required based on site of injury, as diagnostic delays are associated with increased morbidity and mortality from sepsis and mediastinitis
- Management may vary by Zone:
  - Zone I: Consider distal hypopharyngeal and oesophageal injury
  - Zone II: Consider hypopharyngeal injury
  - Zone III: Consider oropharyngeal injury
- Clinical symptoms and signs cannot reliably diagnose or exclude pharyngo-oesophageal injury

- Often non-specific
- Dysphagia, odynophagia, dysphonia, dysarthria, haemoptysis, haematemesis, cervical and thoracic surgical emphysema, chest pain, retrosternal pain, and saliva draining from the wound
- Food colouring or methylene blue can be administered *per os*, where subsequent effluence from the wound confirms the presence of a fistula; but has poor sensitivity and should not be used in isolation to exclude a digestive tract injury
- X-rays: retropharyngeal air or oedema, haematoma, tracheal deviation, and pneumomediastinum

Figure 6: Saliva bubbling from penetrating injury of hypopharynx

Pharyngeal Injury

- Risk of life-threatening sepsis comparable to oesophageal injury if not recognised and managed early
- Directly examine oropharynx with indirect laryngoscopy or flexible fibreoptic nasopharyngolaryngoscopy
- Features suggestive of pharyngeal injury include mucosal laceration, soft tissue oedema, haematoma, mass effect, or active mucosal bleeding.

- Contrast fluoroscopy/oesophagography
  - Traditionally most used for hypopharyngeal and oesophageal trauma
  - Can document size, extent, and degree of containment of a leak which may be used to guide nonoperative management *(Figure 7)*
  - Sensitivities of 48-100% and NPV of 96% for oesophageal injury
  - Possibly less sensitive for high hypopharyngeal injury [16]
  - Water soluble contrast (e.g. Gastrografin) should be used as barium may cause pneumonitis if aspirated, or mediastinitis
  - Not possible if patient is aspirating or is non-compliant

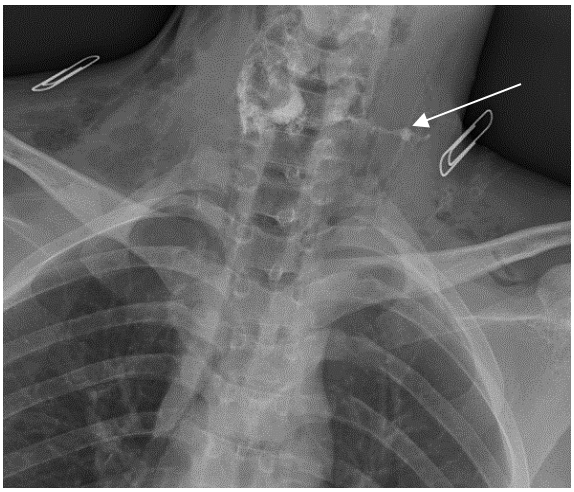


Figure 7: Contrast fluoroscopy demonstrating small left sided contained pharyngeal leak at the level of C4 with associated surgical emphysema

- CT scan *(Figure 8)*
  - Expanding role to assess aerodigestive tract injury, or to determine the need for further investigations
  - Concerning features: Tract passing through aerodigestive system; violation of deep neck spaces, transcervical trajectory, fluid in deep neck spaces, air in deep or superficial neck spaces, pneumomediastinum, or pneumothorax

- CT-angiography has sensitivity of 100%, specificity of 65.4%, PPV of 47.1% and a NPV of 100% for digestive tract injury [17]

Figure 8: CT scan illustrating extensive surgical emphysema of soft tissues and retropharynx secondary to a transaxial GSW with left lateral pharyngeal wall injury

- If emergency surgical exploration is performed for haemodynamic instability or for associated critical injury
  - Assess aerodigestive injury with rigid laryngopharyngoscopy and flexible or rigid oesophagoscopy while under anaesthesia
  - Consider repair and/or drainage of a hypopharyngeal injury depending on degree of injury and if injury already exposed during neck exploration
- Most hypopharyngeal injuries are managed conservatively
  - Mortality not increased if appropriately selected [18]
  - A collection in an unexplored neck is usually contained by unviolated soft tissues, but surgical exploration may disrupt tissue planes and cause salivary escape
  - Non-operative management
    - Prophylactic broad-spectrum antibiotics
    - Nasogastric tube with tip placed beyond the injury
    - Nil per mouth
    - Inpatient observation
    - Fluoroscopy @ day 7 / 10
    - Oral feeding commenced after radiographic resolution of extravasation and aspiration
  - Criteria for conservative management [19]
    - Haemodynamically stable
    - No significant sepsis
    - Contained leak on contrast swallow, *i.e.* localised extravasation of contrast which does not track down fascial planes or communicate with mediastinum or pleural cavity *(Figure 7)*
    - Some evidence for consideration of level of injury; supra-arytenoid hypopharyngeal injury may be managed conservatively vs. infra-arytenoid injuries that should be explored, repaired, and drained as for oesophageal injuries [20]

Oesophageal injury

- Early recognition and treatment are critical
  - Delayed diagnosis has high morbidity and mortality
  - Intervention delays of >12hrs for iatrogenic oesophageal injury have mortality of 40% vs. 9% if <12hrs [21]

- Clinical assessment [21]
  - Stabs: sensitivity 50%; specificity 64%
  - GSWs: sensitivity 100%, accuracy 72%
- Special investigations [21]
  - Barium swallow: sensitivity 48-100%
  - Rigid oesophagoscopy: sensitivity 89%, specificity 95%, accuracy 94%
  - Flexible oesophagoscopy: less reliable, especially in proximal oesophagus as mucosa cannot be effaced
  - Combination of oesophagography and oesophagoscopy: reported sensitivity 100%
- High-kinetic injuries: Explore all
- Low-kinetic energy GSW, stab wounds
  - Management more contentious
  - Varies from observation to simple repair +/− drainage of deep neck spaces, to primary diversion of salivary flow to the skin with partial or total exteriorization
  - Wound site, size, mechanism of injury, time delay, presence of sepsis, associated injuries, expertise with diagnostic tests e.g. oesophagography and oesophagoscopy, and availability of operating time all influence management
- If oesophagography is positive / equivocal, then proceed to rigid oesophagoscopy; if positive, explore the oesophagus
  - But if only a minimal leakage of contrast, then one may opt to manage conservatively with oesophagography repeated @ day 5 prior to commencing oral feeding [21,22]
- Surgical options
  - Primary repair (most)
  - Resect injured segment and do end-to-end anastomosis
  - Simple drainage
  - Lateral cervical oesophagostomy: if part of the oesophagus has been destroyed, if mediastinitis or sepsis already is present, or if oesophageal injury extends into the chest
- Surgical technique
  - No evidence to favour double- or single-layered repair
  - Sternocleidomastoid or infrahyoid strap muscle flaps can be used to buttress the repair or to interpose between an oesophageal injury and a vascular or tracheal repair
  - Suction/dependent drainage is important as fistulae are common
- Perioperative antibiotics
- Enteral or parenteral nutrition
- Barium swallow @ day 5-7 as many postoperative oesophageal fistulae and sinuses are asymptomatic
- Persistent leak
  - Oesophagocutaneous fistulae generally close spontaneously
  - If a leak is diagnosed, then retain the drain
  - If surgically repaired, it can be bolstered with a local muscle flap
  - Serious complications include abscesses, mediastinitis, septicaemia and death
  - Self-expanding endoscopically deployed stents
    - Increasing use with iatrogenic / other nontraumatic oesophageal perforations
    - Limited evidence to support their use in traumatic oesophageal perforations

Cervical tracheal injury

- Blowing wound, surgical emphysema, haemoptysis, dysphonia / hoarseness
- Often associated with oesophageal, vascular, or spinal injury
- X-rays: surgical emphysema, pneumomediastinum
- Diagnosis is generally apparent on exploring the neck
- Priority is to secure the airway

- Nasotracheal/orotracheal intubation can be attempted, despite risk that it may aggravate an existing tracheal injury or cause a false passage
- Upfront tracheotomy may be done for
  - Traumatised larynx to avoid further injury to the endolarynx
  - Laryngeal trauma when one cannot safely pass an endotracheal tube
  - If long-term ventilatory support is anticipated
  - Temporary intubation and ventilation are unavailable
- Distal tracheobronchial disruption
  - Bypass under direct vision with introducer passed through a rigid bronchoscope, or intubate over a flexible bronchoscope
  - Tracheobronchoscopy can be used to assess the injury
  - Extra-length / adjustable flange tracheostomy tube may be required to bypass distal tracheal injuries
- Minor tracheal injury
  - Manage conservatively
  - Surgical emphysema
    - Rarely compromises airway
    - Tracheotomy may accelerate resolution
- Tracheal repair
  - Interrupted absorbable sutures with knots placed outside lumen
  - Avoid tracheal devascularization by minimizing tracheal dissection
  - If oesophageal or vascular injury, repair can be bolstered with a local muscle flap
  - Tracheotomy or endotracheal tube may be used to protect tracheal repair in selected cases

Vascular injury

- May involve
  - Carotid artery - common, internal, external
  - Subclavian artery and branches
  - Vertebral artery and branches
  - Vertebral venous plexus
  - Jugular vein - internal and external
  - Brachiocephalic vein
  - Aortic arch and branches (Zone 1)
- Clinical evaluation of hard and soft clinical signs, as summarized in *Table 1* is imperative
- Debate centers on evaluation of asymptomatic patients and the optimal treatment of vascular injury

Arterial injury

The common carotid artery is most frequently injured and is the leading cause of death in penetrating neck injury.

Investigations

- Helical multi-slice CT Angiography (CTA)
  - Largely replaced angiography as initial investigation of choice in stable patients
  - Rapid, non-invasive, widely available
  - 90–100% sensitivity and specificity for arterial injury
  - Added advantage of providing cross-sectional imaging of other associated injuries
- Digital subtraction angiography (DSA)
  - Limited role as a first-line investigation
  - Gold standard in stable patients
  - When CTA equivocal or obscured by artefact
  - In Zone 1 injuries angiography should include carotid (common, external and internal) and vertebral arteries as well as aortic arch and its branches
  - Highly sensitive and specific
  - Identifies site of injury
  - Identifies subclinical vascular injury including vertebral artery trauma
  - Provides surgical roadmap
  - Delineates collateral circulation via Circle of Willis

    - Identifies injuries amenable to endovascular intervention
    - Is however invasive, requiring femoral artery cannulation with complication rates of up to 2%, including stroke
- Colour-flow duplex Doppler (CFD)
    - Sensitivity 91%, specificity 99% to detect vascular injury when combined with clinical examination [23]
    - Operator dependent
    - Avoid if cervical spine injury
    - May not clearly visualise origins of cervical arteries from aortic arch or arteries close to skull base or the vertebral arteries
    - Difficult to identify individual branches of external carotid artery
    - Artefact in soft tissues (subcutaneous air, bony fractures, metallic foreign bodies) can obscure visualisation of vasculature

Management of arterial injury

- Management is dictated by
    - Vessels involved.
    - Haemodynamic stability
    - Central neurological status
    - Concomitant injuries
    - Available resources and expertise
- Surgical decision-making algorithm *(Figure 5)*
    - External carotid artery and its branches: ligate or endovascular embolisation
    - Common and internal carotid arteries: open or endovascular intervention to mitigate current and future risk of stroke
- Surgical options for common or internal carotid injury
    - Ligation
    - Primary lateral arteriorrhaphy
    - End-to-end anastomosis
    - Interposition of saphenous vein
    - Synthetic graft
    - Patch angioplasty
    - Temporary carotid artery shunt has been described in damage-control surgery for up to 48 hours
- Cerebral reperfusion injury
    - Defined as converting an ischaemic infarct into a haemorrhagic infarct by reestablishing cerebral perfusion, thereby worsening neurological outcomes
    - It was an initial concern that fueled debate regarding the dilemma of ligation vs. reperfusion for carotid injuries
    - It has since been demonstrated that both patients with and without neurological deficits and carotid injury had significantly better results with reperfusion. Those with a significant drop in Glasgow coma score (GCS) (unresponsive to verbal stimuli) typically have a worse prognosis, but this group did better when ischaemia had been present for a short period of time prior to reperfusion [24,25] *(Figure 9)*
    - These findings are consistent with acute stroke data in the setting of large vessel occlusions requiring endovascular thrombectomy which has demonstrated an improvement in outcomes the sooner reperfusion is established from the time of onset of symptoms
- Pseudoaneurysms, intimal defects and intimal flaps with no focal neurological deficits
    - Managed conservatively but studies are small and safety of conservative approach, particularly with the carotid artery, has not been confirmed
    - Recommend serial imaging to confirm that lesions do not increase in size

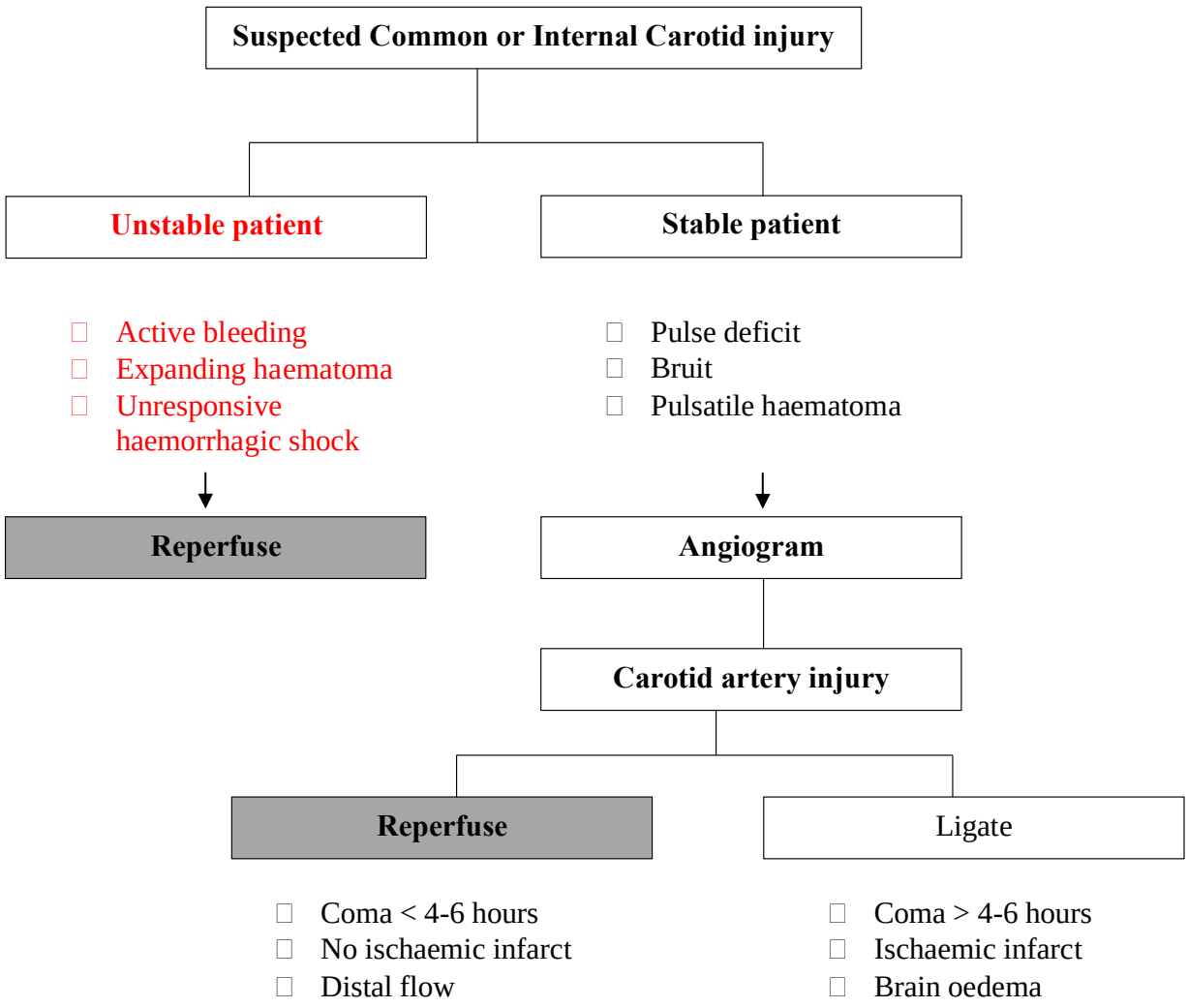


Figure 9: Carotid ligation vs. reperfusion

- Vertebral artery injury
  - May present with acute haemorrhage or delayed complications of thrombosis, pseudo-aneurysm, arteriovenous fistula, and stroke
  - More frequently recognized with increased use of angiography
  - Arteriovenous (AV) fistulae (also known as vertebrovenous fistulae) present with a bruit, thrill, neurological deficits, or cardiac failure
  - Neurological deficits are uncommon with normal contralateral vertebral artery and intact collateral circulation
  - Mortality from isolated vertebral artery trauma between 5% and 17%
  - Mostly managed by angiographic embolization
  - If an injury is discovered at emergency surgery, the vessel should be ligated. This is straightforward if the injury is located before the vertebral artery enters the foramen transversarium at the level of the 6th cervical vertebra
  - Once inside the vertebral canal, ligation may be achieved with Liga clips. Alternately, temporary control with bone wax/packing is used to

tamponade bleeding, followed by angiographic embolization

Venous injury

- Asymptomatic injuries are managed non-operatively
- A haematoma with a negative angiogram suggests a venous injury
- With Foley catheter tamponade and a negative angiogram, extract the Foley in the operating room so that if active bleeding occurs, the neck can be explored
- Ligate external jugular vein if injured
- Internal jugular vein may be repaired by lateral venorrhaphy or simply ligated
- If both internal jugular veins are injured
  - At least one should be repaired to prevent facial swelling, and sequelae of raised intracranial pressure which may result in death
  - A remnant of the contralateral internal jugular vein, external jugular or saphenous vein can be used as a graft *(Figure 10)*

Endovascular intervention

- There is an increasing role for endovascular management of acute and late manifestations of vascular trauma, particularly at the skull base
- Dependent on available resources and expertise
- May be used to control acute bleeding from arterial injury
- Dissections, pseudoaneurysms and arteriovenous fistulae can be treated by a range of different techniques which depend on the involved vessel, nature of the pathology and the robustness of collateral circulation through the Circle of Willis
- Interventions include parent vessel occlusion, trapping of lesion with detachable balloons or coils placed proximally and distally to lesion, bare metal stents, covered stents and balloon or coil occlusion of AV fistulae *(Figures 11, 12)*

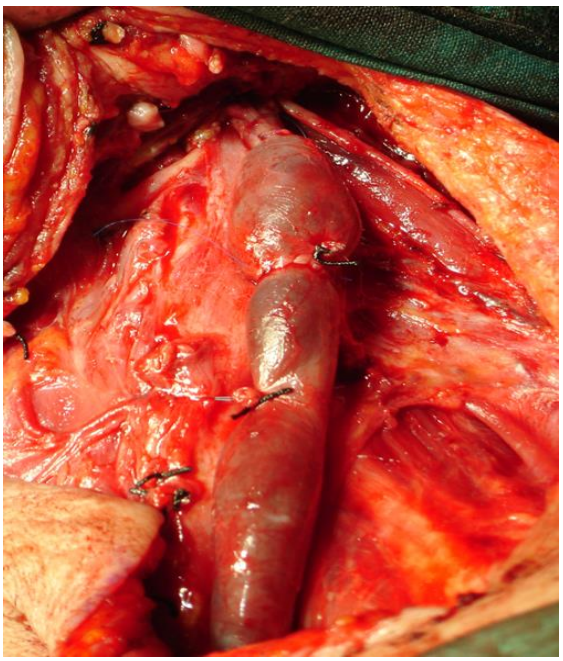


Figure 10: Segment of contralateral internal jugular vein used as interposition graft

Figure 11: False aneurysm of internal carotid artery, with caroticojugular fistula following stab wound at base of skull

Figure 12: False aneurysm and fistula trapped with coils by endovascular technique

Figure 13: (a) Coronal view with FCBT right zone 1, (b) Coronal view of CTA showing subclavian artery pseudo-aneurysm, (c) Digital subtraction angiogram (DSA) confirming subclavian pseudoaneurysm, (d) DSA after endovascular stenting with resolution of aneurysm [28]

Chylous injury

- The thoracic duct on the left *(Figures 14, 15)* or right lymphatic duct may be injured with penetrating injury or surgical exploration in Zone I
- Chyle is typically milky/creamy fluid in a non-starved patient.
- Chyle causes tissue inflammation, causes tissue breakdown and impairs wound healing

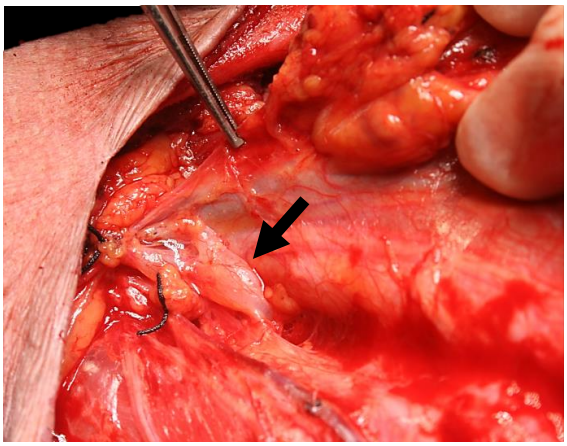


Figure 14: Distended thoracic duct (arrow) immediately lateral to the carotid artery and IJV in the (L) neck

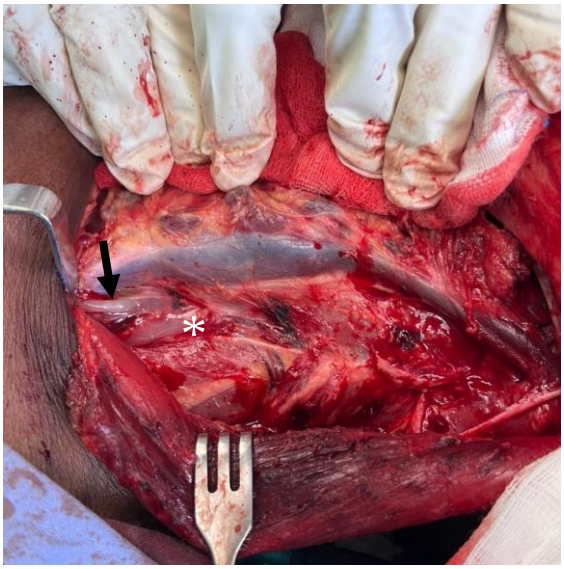


Figure 15: Injured thoracic duct (arrow) with chyle leak (asterisk) immediately lateral to the internal jugular in (L) neck

- Clinically a chyle leak presents with a persistently draining wound, localised subcutaneous collection, high postoperative drain output or chylothorax

- Intraoperative identification is aided by increasing intrabdominal and intrathoracic pressure with a Valsalva procedure, placing the patient in a Trendelenburg position, or applying direct pressure to the abdominal wall
- Biochemically triglyceride level of >100mg/dL and/or presence of chylomicrons
- If a leak is discovered at surgery
    - Ligate the duct with clips or non-absorbable sutures or ties
    - Or repair thoracic duct with 6.0 nylon or Prolene suture
    - One can reinforce the repair with a local muscle flap
    - Important to leave a suction drain in place
- If a leak is discovered during non-operative management of a penetrating neck injury
    - Restrict activity, maintain head elevation, stool softeners, and electrolyte and fluid management
    - Transitioned to non-fat / low-fat / medium-chain fatty acid diet
    - Rarely, parenteral nutrition
    - Octreotide (somatostatin analogue) or Orlistat (pancreatic lipase inhibitor) may be considered
    - Local wound care is paramount to avoid wound breakdown
    - Maintain suction drains if in place until the leak has stopped or the drain tract has matured
    - Vacuum dressing may be considered
    - Chylothorax is drained with pleurocentesis and an intercostal drain
- There is lack of consensus regarding the duration of a trial of conservative management
- If conservative management fails
    - Explore and ligate the duct (often unsuccessful due to inflammation and difficulty identifying the duct)
    - Ligate thoracic duct via right thoracotomy / thoracoscopic approach
    - Minimally invasive percutaneous transabdominal cannulation of thoracic duct at cisterna chyli with lymphography and selective embolisation of the duct has been described

Neurological injury

Penetrating neck injuries may injure the central or peripheral nervous systems, including brain, spinal cord, cranial nerves VII, IX, X, XI, XII, phrenic nerves, sympathetic trunk, and brachial plexus. Vagus nerve injury may present with dysphonia, aspiration, and swallowing difficulty and stridor. The reader is referred to chapters on vocal cord palsy and aspiration for management.

Brachial plexus injury involves C5-T1 nerves and can cause pain, muscular weakness and paraesthesia. Injuries should be explored and repaired within 24–72hrs.

Figure 16: Neurovascular structures in the left neck as seen at neck dissection: brachial plexus (1); phrenic nerve (2); spinal accessory nerve (3); cervical plexus (4); internal jugular vein (5);common carotid artery (6); thoracic duct (7)

Retained Foreign Body

- Retained blades or knives
    - Controlled extraction of a retained blade must take place in the ope-

rating room as haemorrhage may occur
    - Unstable patients are resuscitated and explored in the operating room
    - Stable patients are first investigated with relevant imaging and angiography
- Asymptomatic retained bullets and bullet fragments
    - Most units manage these conservatively unless there is local sepsis or an associated fracture
    - There is increasing concern for potential long-term sequelae of lead toxicity

NECK EXPLORATION: GENERAL PRINCIPLES

- IVI lines, suction, blood available in theatre
- General anaesthesia: rapid-sequence induction with cricoid pressure
- Airway
    - Nasotracheal/orotracheal intubation
    - Cricothyroidotomy or tracheotomy
- Position
    - Supine
    - Neck extended, turned to opposite side if no cervical spine injury
- Exposure
    - Chest and face for Zones I and III injuries to permit additional surgical exposure if required
    - Contralateral groin and lower leg to permit harvesting of saphenous vein for grafting
- Approach
    - Localised injury: horizontal skin crease incision, subplatysmal flaps
    - Wider exploration: long incision along anterior border of sternocleidomastoid muscle
- Additional exposure
    - Zone I: Divide omohyoid muscle; bilateral exploration: apron flap
    - Zone III: Anterior dislocation of mandible

SUMMARY

Management of penetrating neck injury remains controversial due to paucity of good prospective studies; uncommon occurrence of oesophageal injury; variable radiological and surgical expertise; wide spectrum of sites and severity of injuries and aetiologies; and lack of a uniform classification system when reporting neck injuries.

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