

TITLE: Management of Penetrating Neck Trauma
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Management of penetrating neck trauma is a controversial issue in that there are a wide variety of pathways to identify serious injuries in these patients. Controversy exists because the "gold standards" for diagnosis (arteriogram and exploratory neck surgery) are quite costly and carry with them some morbidity. This Grand Rounds examines pathophysiology of penetrating neck trauma, its traditional surgical management, and recent literature regarding less invasive strategies to identify patients who will need exploratory surgery and angiography.

Ballistics:

The kinetic energy of the weapon determines the damage imparted to tissue in penetrating neck trauma. The formula $K=1/2mv^2$ applies in this situation. While the kinetic energy is directly proportional to the *mass* of a weapon, it is proportional to the square of the *velocity* of a weapon. The velocity of the weapon has a greater influence than its mass on the amount of tissue damage inflicted. Therefore, penetrating neck trauma mechanisms are most appropriately divided into two general categories: high velocity injuries and low velocity injuries. Low velocity injuries are caused by impaling objects such as glass or metal in an automobile accident, knives, or ice picks. A low velocity mechanism of injury generally leads to a straight trajectory of tissue damage, with minimal collateral damage.

High velocity injuries include bullet wounds from handguns, rifles, and shotguns. Among the high velocity weapons, most pistols are of comparatively low velocity, with a kinetic energy of less than 400 ft/lb delivered at the muzzle. In contrast, rifle bullets commonly strike with energies approaching 3000 ft/lb. Shotguns are unique in that the distance at which the gun is fired is a very important factor in the level of tissue damage. Long-range injuries (>7 yards) are characterized primarily by subcutaneous and deep fascia injuries, whereas close range injuries (<3 yards) typically create massive tissue destruction and contamination of soft tissue with the "wadding" material from the shotgun shell (1).

The aerodynamic properties of a bullet in flight play an important role in the amount of damage inflicted to tissues. Flying bullets are similar to spinning tops: they exhibit properties such as yaw, precession, nutation, and tumbling (see slide 4). These deviations from straight-line

motion tend to stabilize the bullet in flight, but also can result in a larger surface area of the bullet being presented to the target producing greater amounts of tissue damage. The phenomenon of cavitation occurs with high speed bullets, especially rifle injuries. When penetration of a high velocity bullet occurs, there is rapid energy release. As the energy is absorbed by tissue, the tissue starts to flow forward and outward, simultaneously creating a vacuum that sucks in contaminants, and impacting adjacent tissue not in direct contact with a bullet (2). In thick tissues, the cavity may be entirely concealed by small entry and exit wounds, leading to an underestimation of the amount of tissue damage (see slide 6).

Relevant Anatomy:

The areas of the neck that can be injured in penetrating trauma were first divided into three zones by Monson, *et al* in a paper from Cook County Hospital (3), based mainly on patterns of vascular injury. Zone 1 is the area from the cricoid cartilage to the clavicles. It contains the inferior trachea and esophagus, and the vessels of the root of the neck: the brachiocephalic trunk, the subclavian arteries, the common carotid arteries, the thyrocervical trunk and the corresponding veins, as well as the thoracic duct, thyroid gland, and spinal cord. Zone 2 is the area from the cricoid cartilage to the angle of the mandible. It contains the common carotid arteries, the internal and external carotid arteries, the internal jugular veins, the larynx, hypopharynx, and cranial nerves 10, 11, and 12, and the spinal cord. Zone 3 is the area from the angle of the mandible to the base of the skull. It contains the carotid arteries, the vertebral arteries, the internal jugular veins, the pharynx, and multiple cranial nerves, and the spinal cord.

Frequency of injury of neck structures:

The different zones of the neck are injured with differing frequencies. Zone 2 is the most common sight of injury followed by zones 1 and 3. McConnel and Trunkey (5) combined data from 16 papers from 1963 through 1990 to estimate the frequencies of various kinds of injuries in a total 2,495 patients. According to their findings, aerodigestive tract injuries as a group were the most frequently injured organs in the neck, with 10% of the study group having injuries in the larynx or trachea. 9.6% of patients had pharyngeal or esophageal injuries. 9.0% of patients had internal jugular vein injuries. The carotid artery was the most commonly injured artery, with injury occurring in 6.7% of patients. Interestingly, the spinal cord was injured in only 3.0% of patients in this study. Other less common areas of injury included the subclavian artery (2.2%), vertebral artery (1.3%) brachial plexus (1.9%), cranial nerves 9 and 10 (.9%) and the thoracic duct (<0.1%) (see slide 11). The average mortality in the group was 4.2%, with a higher mortality from gunshot wounds than from stab wounds. The majority of deaths were caused by exsanguination.

Signs and Symptoms of Injury:

There are many recognizable symptoms and physical findings of significant neck injury. Signs of vascular injury include hemodynamic instability (shock), profuse bleeding, evolving stroke, expanding hematoma, hemoptysis, hematemesis, unequal upper extremity pulses, and presence of a bruit or thrill over the wound.

Penetrating wounds of the larynx and trachea result in subcutaneous emphysema, hoarseness, and occasionally in respiratory distress and stridor. Patients may present with bubbles of blood emitting from an adjacent neck wound. Zone 1 tracheal injuries can produce a pneumothorax.

Esophageal injury often presents with few symptoms, making early diagnosis by physical findings alone somewhat difficult. The most important finding suggesting possible esophageal injury is a bullet trajectory near the esophagus. Neck pain and blood in the saliva or nasogastric aspirate are clues. Late findings include inflammatory findings such as fever, increasing neck pain, and odynophagia.

Signs of spinal cord injury include neck pain, hemiparesis (Brown Sequard syndrome), quadriparesis, or a “spinal shock” syndrome in which hypotension is not accompanied by tachycardia.

Surgical exposure of the neck for trauma exploration:

Surgical exposure of the neck varies based upon zone of injury and is best performed in consultation with a vascular surgeon or trauma surgeon. Exposure for injuries in left zone 1 is best achieved by left anterior thoracotomy. Left posterolateral thoracotomy can be used for wider exposure of the aortic arch, the proximal left subclavian, and the left common carotid artery. For right zone 1 injuries, a midline sternotomy is most helpful and can be extended to the right supraclavicular region with removal of the medial one third of the clavicle (4). Care must be taken to avoid injury to the vagus and phrenic nerves in these approaches. Zone 2 is best exposed by a “hockey stick” incision with the long limb parallel to the anterior border of the sternocleidomastoid muscle. The wound is opened in layers, and the sternocleidomastoid muscle is retracted laterally to expose the common, internal and external carotid arteries as well as jugular vein. Methylene blue can be injected into the pharynx to check for leaks in the esophagus (5).

Extension of exposure into zone 3 requires mandibulotomy or mandibular subluxation techniques to visualize the distal-most parts of the internal carotid artery. Exposure of the proximal vertebral artery requires a transverse supraclavicular incision on either side of the neck. The vertebral artery enters the foramen transversarium at C6. The zone 2 incision can be utilized to visualize the vertebral artery more distally by exposing the prevertebral fascia and sweeping the longus colli laterally and removing the costotransverse bar. The third part of the vertebral artery is found by opening the prevertebral fascia parallel to the accessory nerve and dividing the origin of the upper levator scapula and detaching the tendon of the splenius cervicis. This allows visualization of the C1-C2 interspace (5).

Esophageal and laryngeal evaluation are performed via barium esophagram in the stable patient followed by direct esophagoscopy and direct laryngoscopy intraoperatively. The combination of barium esophagram with direct esophagoscopy has been shown to drastically decrease the rate of missed esophageal injuries (1).

Management of Specific Injuries:

Data have clearly shown that injury to major neck vessels is the largest cause for mortality from penetrating neck injury. Repair of major vessels while attempting to preserve blood flow to the brain is the major task of the surgeon when vessel injury is encountered. Vascular repair is best performed by or in conjunction with a surgeon skilled in vascular surgery techniques. Repair of the common carotid artery is preferred to ligation, even if the patient is comatose as long as prograde flow in the artery is present. Repair may require an autologous saphenous vein graft. Ligation should only be performed in comatose patients in which there is no prograde arterial flow and/or repair is technically impossible (5). Internal carotid artery repair often requires shunt placement to ensure adequate cerebral blood flow. Thrombectomy should be attempted for proximal thrombi with no evidence of distant emboli.

The use of four vessel angiography pre-operatively has led to identification of more vertebral artery injuries. Because the risk from vertebral artery injuries is low, therapies addressing injuries to these structures should also carry low morbidity. Ligation of this vessel can be attempted, though it carries a 1-3% risk of brainstem ischemia. Interventional radiologists can often identify and embolize distal vertebral artery bleeds and bleeds from the external carotid branches. The internal jugular vein can be repaired or ligated.

Esophageal injury is important to detect and repair early, before infection complicates the patient's course. A standard neck exploration incision can be used to expose the esophagus, followed by injection of air or methylene blue into the mouth to identify possible leaks. If the esophagus is beyond repair, a controlled fistula is established with a T-tube, or the wound is exteriorized if it is low in the neck. Injuries to the hypopharynx above the level of the arytenoid cartilages can be treated with parenteral antibiotics and without oral intake for 5 to 7 days. All other wounds should undergo two-layer watertight closure and extensive neck irrigation. Patients should be kept without oral intake for 5 to 7 days after the repair.

Tracheal injuries can usually be primarily closed in two layers, with an inner layer of absorbable suture incorporating the mucosa and an outer layer of submucosal permanent suture securing cartilage to cartilage. Patients can be kept intubated for 2-3 days. When loss of tracheal tissue occurs, superior and inferior tracheal release incisions aid in re-anastomosis.

Laryngeal injury usually requires tracheotomy followed by thorough direct laryngoscopy and bronchoscopy. Some injuries, such as a dislocated arytenoid cartilage can be repaired endoscopically. Endoscopic or CT evidence of laceration of the mucous membrane, exposed cartilage, immobility of the vocal folds, or displaced or comminuted fractures of cartilage are indications for open exploration. Exploration can often be performed through the standard neck exploration incision, with or without a horizontal incision at the level of the cricothyroid membrane. The infrahyoid strap muscles are separated in the midline and are retracted laterally to expose the larynx. The thyroid cartilage is incised vertically in the midline and the endolarynx is entered through the cricothyroid membrane inferiorly, with the incision extended superiorly to the thyroid membrane. All mucosal lacerations should be meticulously closed to minimize cartilage exposure with 5-0 or 6-0 fast absorbing plain gut suture. Mucosal advancement flaps may be used to achieve complete cartilage coverage. Cartilaginous fractures are fixed with wire,

nonabsorbable suture, or miniplates. The anterior margins of each true vocal cord are resutured to the thyroid cartilage followed by keel placement if the anterior commissure is devoid of epithelium. Use of laryngeal stents is rarely required in penetrating neck trauma, as the laryngeal framework is usually intact. However, multiple cartilaginous fractures that cannot be adequately stabilized can be treated with removable stents that are sutured in such a way that they move with the larynx during swallowing. Stenting increases the risk of granulation tissue and infection. Recurrent laryngeal nerve injury should be treated with reanastomosis, though synkinesis inevitably results. Cricotracheal separation should be treated with meticulous repair and fixation of the cricoid cartilage, rather than laryngotracheal reconstruction, when possible (13).

The Evolution of Management of Penetrating Neck Injuries:

Certain steps in the management of penetrating neck trauma have remained unchanged. These include cervical spine immobilization, establishment of an airway, and circulatory support with intravenous fluids and direct pressure for exsanguinating hemorrhage. Intubation can be attempted in the field if necessary or *en route*. Unsuccessful oral intubation should prompt establishment of a surgical airway as needed, even if this involves placing an endotracheal tube into a tracheal defect created by the weapon. In cases of evident laryngeal trauma, tracheotomy under local anesthesia may be preferred to orotracheal intubation to avoid further injury to the larynx. The patient's neck is carefully examined for entry and exit wounds to help determine the trajectory of the projectile. The unstable patient is always taken to the operating room for control of hemorrhage.

Management of penetrating neck wounds was once greatly influenced by wartime experience. In such settings, without adequate adjuvant testing modalities, exploratory neck surgery was seen as the safest modality for diagnosis and treatment. A large civilian series in 1956 showed that the benefit of direct repair of arterial injuries was inversely related to the time to repair (6). This revelation led to a philosophy of immediate mandatory exploration of any neck wound penetrating the platysma, even in asymptomatic patients. The widening availability of the arteriogram modified this philosophy, as it proved to be a highly accurate tool in the diagnosis and localization of arterial injury in the neck. The four vessel arteriogram is widely viewed as second only to neck exploration for determining the nature and location of vascular neck injury. It identifies intraluminal abnormalities such as thrombi and intimal flaps as well as vessel wall compromise. Currently, interventional radiologists can also embolize bleeding vessels to control hemorrhage, particularly in zone 3 injuries. Arteriograms were used extensively for asymptomatic injuries in zones 1 and 3 (where physical exam was felt to be less reliable), and mandatory neck exploration was used for evaluation of zone 2 injuries, as advocated in a study by Monson *et al* in 1969. That study essentially recommended pre-operative arteriograms for zone 1 and 3 injuries in stable patients, as physical exam was felt to be of limited benefit in these areas.

A large number of studies since the 1970's have attempted to determine the reliability of the physical exam in screening patients who should undergo further evaluation and treatment for penetrating neck injuries. Mandatory neck exploration for penetrating neck wounds was often found to lead to a negative exploration rate in excess of 50%. A review of the literature

published in 1994 by McConnell *et al* (4) compares several studies that use physical exam to screen patients. The review notes that in those studies in which asymptomatic patients were placed in observation groups (serial q6 hour exams by a physician), the rate of negative neck exploration was low, while the rate of false negatives was negligible. A 1991 retrospective study by Mansour *et al* (7), in which all asymptomatic patients were placed in an observation group (except for zone 1 injuries, which underwent arteriogram and esophagoscopy, since physical exam was felt to be of limited value in these patients), had 63% of its study population in an observation group (see slide 18). The entire study population only had a 1.5% mortality rate, a rate similar to or less than other studies that studies that advocated a more aggressive approach.

A study retrospective by Biffi *et al* (8) of 312 penetrating neck wound patients used selective management in a protocol almost identical to that of Mansour *et al* above. All symptomatic patients were taken to the operating room after arteriograms for zone 1 and zone 3 injury patients and esophagrams for zone 1 injury patients. Asymptomatic patients were observed unless they had injury to zone 1, in which case they generally underwent esophagram and arteriogram. The study showed a negative exploration rate of 16%, with one missed injury, an ice pick injury to the esophagus and larynx in zone 1. This patient did not undergo esophagram for the zone 1 injury. This study strengthens the argument against routine neck exploration for penetrating trauma.

All of the studies mentioned to this point have advocated routine arteriogram for asymptomatic zone 1 injuries. Advocates for this practice point to studies such as one by Flint *et al* (9), which reports an absence of physical findings in 32% of patients subsequently found to have major vascular injury in the setting of penetrating injury to the base of the neck. However, a 2000 study by Eddy *et al* (10) calls into question this notion. Eddy *et al's* retrospective study combined the use of chest X-ray indicators of vascular injury (widened mediastinum, apical capping, pleural effusion, deviated trachea, deviated nasogastric tube, pneumothorax, pneumomediastinum or obscured aortic knob) with physical findings of vascular injury (as discussed previously). In a series of 184 patients with zone 1 injury, 36 patients were found to have no physical findings or chest X-ray findings consistent with vascular injury and were observed without arteriogram. These patients were discharged after 1 or 2 days of observation with an uneventful hospital course. 23 of these patients were confirmed to have no injury by arteriogram. The authors conclude that the negative predictive value of a normal physical exam and chest X-ray for zone 1 injury is 100%. They calculated a cost savings of \$72,000-\$90,000 if none their normal CXR and P.E. patients had undergone arteriogram. However, this is a retrospective study, and not all of the observed patients underwent arteriogram to document absence of injury. Still, it points to the value of selective testing over routine testing.

Other modalities than arteriogram and neck exploration exist to diagnose vascular injury of the neck. These include the CT scan and duplex ultrasonography. Either of these modalities can be an effective screening tool to determine which patients need arteriogram or exploration. Traditionally, computed tomography has not been used in the evaluation of penetrating neck trauma. However, CT can be used to determine the trajectory of a bullet or penetrating weapon and thus determine which structures require further workup. Gracias *et al* (11) performed CT scans in 23 hemodynamically stable patients out of a population of 68 patients presenting with penetrating neck trauma. They determined trajectory on the CT scan by identifying the skin

entry site for each neck wound with metallic markers and following the wound tract as it coursed through multiple slices of the scan. They used findings of skin violation, subcutaneous fat stranding, soft tissue air or hematoma, vertebral fracture, contrast extravasation, and missile location to identify the tracts. Based on CT findings of trajectory, they were able to avoid the need for arteriography in 50% of studied patients who would otherwise have automatically received it by other protocols (zone 1 and zone 3 injuries) and they were able to avoid the need for endoscopy in 90% percent of patients who might otherwise have received it (zone 1 injuries). With no false negatives for injuries, this study showed tremendous cost savings in these patients. However, the study group was small, and the authors themselves recommend a larger investigation.

Duplex ultrasonography can be utilized to identify vascular injury in patients. Ultrasound should be used to evaluate in stable patients the internal carotid, common carotid, external carotid and vertebral arteries as well as the internal jugular veins. A reliable technician and radiologist should be available 24 hours a day to make this method of evaluation feasible. A small double-blinded study by Ginzburg *et al* (12) showed a 100% true negative rate and 100% sensitivity and 85% specificity in detecting arterial injury, using arteriogram as the gold standard. Use of ultrasonography as a screening tool for arteriogram and neck exploration could result in a significant decrease in morbidity and cost as compared to mandatory arteriogram or neck exploration.

Conclusion:

The approach to managing penetrating neck trauma has changed with the awareness that modalities such as physical exam and noninvasive studies can achieve outcomes similar to routine arteriography and neck exploration. However, arteriography and neck exploration remain the gold standard for diagnosis of life-threatening injury. While controversy abounds as to when to use noninvasive diagnostic techniques, it seems appropriate to try them in asymptomatic patients, with an awareness that injuries in zones 1 and 3 are easier to miss on clinical examination alone.

Bibliography:

- 1) Stewart, Michael G. "Penetrating Face and Neck Trauma," Byron J Bailey's Head and Neck Surgery – Otolaryngology, pgs 813-821; Lippincott Williams and Wilkins 2001.
- 2) Osborne, Thomas E. and Bays, Robert A., "Pathophysiology and Management of Gunshot wounds to the Face," Raymond J. Fonseca and Robert V. Walker's Oral and Maxillofacial Trauma, pgs 672-701; W.B. Saunders Company 1991.
- 3) Monson DO, Saletta JD, Freeark RJ. "Carotid vertebral trauma." *Journal of Trauma* 1969; 9: 987-999.
- 4) McConnell, Donald B and Trunkey, Donald D., "Management of Penetrating Trauma to the Neck." *Advances in Surgery*, 1994; 27:97-123.
- 5) Maves, Michal D., "Management of Penetrating Injuries to the Neck." Byron J. Bailey's Atlas of Otolaryngology – Head and Neck Surgery. Pgs 168-169; Lippincott Williams and Wilkins 2001.
- 6) Fogelman MJ, Stewart, RD, "Penetrating wounds of the neck." *American Journal of Surgery*, 1956; 91:581-96.
- 7) Mansour MA, Moore EE, Moore FA, *et al*, "Selective management of penetrating neck trauma." *Archives of Surgery* 1981; 116:691-696
- 8) Biffi, Walter, Moore, Ernest E, *et al* "Selective management of penetrating neck trauma based on cervical level of injury." *American Journal of Surgery* 1997; 174: 678-682.
- 9) Flint LM, Snyder WH, Perry MO, Shires GT, "Management of major vascular injuries in the base of the neck: an 11 year experience with 146 cases." *Archives of Surgery*. 1973; 106: 407-413.
- 10) Eddy, VA *et al* "Is routine arteriography mandatory for penetrating injuries to zone 1 of the neck?" *The Journal of Trauma: Injury, Infection, and Critical Care*. 2000; 48: 208-214.
- 11) Gracias, VH *et al*, "Computed tomography in the evaluation of penetrating neck trauma: a preliminary study." *Archives of Surgery*. 2001; 136(11): 1231-1235.
- 12) Ginzburg, E *et al*, "The use of duplex ultrasonography in penetrating neck trauma." *Archives of Surgery* 1996; 131(7): 691-693
- 13) Schaefer, Steven D. and Stringer, Scott P. "Laryngeal Trauma." Byron J. Bailey's Head & Neck Surgery – Otolaryngology, pgs 741-749; Lippincott Williams and Wilkins 2001.