Neck Injuries

Neck injuries are notoriously difficult to evaluate and treat because of the complex anatomy and the dense concentration of numerous vital structures in a small anatomical area. The clinical evaluation can challenge the skills of the less experienced physician and significant injuries may easily be missed. The radiological evaluation of these injuries has undergone major changes in the last few years and shifted from invasive diagnostic procedures to noninvasive methods. The selection of the most appropriate investigation remains a controversial issue. The surgical exposure of some neck structures such as the distal carotid artery, the subclavian vessels, and the vertebral artery can challenge the surgical skills of even the most experienced trauma or vascular surgeons and requires excellent knowledge of the local anatomy. The management of some of these injuries, such as carotid injury in the presence of neurological deficits or blunt carotid trauma, still remains controversial. The advancement of interventional radiology has revolutionized many aspects of the management of some complex vascular injuries that are difficult to manage operatively. This monograph discusses in detail these issues and provides practical guidelines and algorithms for the safe evaluation and management of patients with penetrating and blunt injuries of the neck.

Penetrating Neck Injuries

Epidemiologic Features

Firearms are responsible for approximately 44%, stab wounds for approximately 40%, shotguns for approximately 4%, and other weapons for approximately 12% of all penetrating neck injuries (PNIs) in urban trauma centers in the United States.1 Gunshot wounds (GSWs) are significantly more likely to be associated with large neck hematomas, hypotension on admission, and vascular or aerodigestive injuries than knife wounds.1,2 In a prospective study of 223 patients with PNIs in Los Angeles, GWSs were 3 times more likely to cause a large hematoma than stab wounds (20.6% vs. 6.7%), twice as likely to be associated with hypotension on admission (13.4% vs. 7.9%), twice as likely to result in a
vascular injury (26.8% vs. 14.6%), twice as likely to cause injury to the aerodigestive structures (7.2% vs. 3.4%), and 13 times as likely to cause spinal cord injury (13.4% vs. 1.1%).1,2 Overall, approximately 35% of all GSWs and 20% of stab wounds to the neck are associated with significant injuries to vital structures, but only 16.5% of gunshot wounds and 10.1% of stab wounds require a therapeutic operation. Transcervical GSWs are associated with significant injuries to vital structures in 73% of victims, although only 21% require a therapeutic operation.3 Shotgun injuries account for approximately 4% of civilian PNIs, often cause injuries to multiple structures, and pose major evaluation and management problems. The mechanism of war injuries is significantly different from civilian trauma. In a study of 117 patients with PNIs during the 1991-1992 war in Croatia, the wounds were mostly inflicted by shell or bomb fragments and only approximately 25% were due to GSWs.4

Overall, in penetrating trauma the most commonly injured structures in the neck are the vessels, followed by the spinal cord, the aerodigestive tracts, and nerves.1 The incidence of injuries to the various neck structures, according to mechanism of injury, is summarized in Table 1.

### Table 1. Incidence and type of injuries according to mechanism of injury (N = 223 patients)

<table>
<thead>
<tr>
<th>Injury</th>
<th>All mechanisms (%)</th>
<th>GSW (%)</th>
<th>SW (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vascular</td>
<td>21.5</td>
<td>26.8</td>
<td>14.6</td>
</tr>
<tr>
<td>Aerodigestive</td>
<td>6.3</td>
<td>7.2</td>
<td>3.4</td>
</tr>
<tr>
<td>Spinal cord</td>
<td>6.7</td>
<td>13.4</td>
<td>1.1</td>
</tr>
<tr>
<td>Peripheral or cranial nerves or sympathetic</td>
<td>9.0</td>
<td>12.4</td>
<td>4.5</td>
</tr>
<tr>
<td>Hemo or pneumothorax</td>
<td>17.9</td>
<td>15.5</td>
<td>13.5</td>
</tr>
</tbody>
</table>


GSW, Gunshot wounds; SW, stab wounds.

Anatomic Features

The anatomy of the neck is characterized by a very dense concentration of vital structures, enveloped in tight fascia compartments, in a small anatomical area. This anatomy predisposes to significant injuries of vital structures and potentially lethal complications following penetrating trauma. Thorough knowledge of the local anatomy is essential for the management of PNI. The fascial planes of the neck play an important role in the clinical presentation and complications following penetrating trauma. The superficial fascia lies under the skin and encompasses the platysma. The platysma originates at the upper part of the chest, spreads
over the clavicle, continues upward to the mandible, and blends with the superficial facial muscles. The deep cervical fascia is under the platysma and branches into the investing, pretracheal, and prevertebral layers. The investing fascia splits to envelop the sternomastoid, omohyoid, and trapezius muscles. The pretracheal fascia extends from the thyroid cartilage to the retrosternal tissues and encloses the thyroid gland, trachea, and esophagus. The prevertebral fascia covers the prevertebral muscles. All 3 layers of the deep cervical fascia contribute to the formation of the carotid sheath that surrounds the carotid artery, the internal jugular vein, and the vagus nerve. The lower cervical nerve roots and the subclavian artery are invested by a pouch of the prevertebral fascia, which becomes the axillary sheath at the axilla. These tight fascial compartments play a dual role after penetrating trauma. On the one hand, they may contain bleeding from vascular injuries and prevent exsanguination and death. On the other hand, tense hematomas within these closed compartments may cause compression and potentially lethal obstruction of the airway.

In penetrating trauma the neck is divided into 3 anatomical zones for evaluation and therapeutic strategy purposes. Zone I comprises the area between the clavicle and the cricoid cartilage (Fig 1). This zone includes the innominate vessels, the origin of the common carotid artery, the subclavian vessels and the vertebral artery, the brachial plexus, the trachea, the esophagus, the apex of the lung, and the thoracic duct. The surgical exposure of the vascular structures in zone I is difficult because of the presence of the clavicle. Zone II comprises the area between the cricoid cartilage and the angle of the mandible and contains the carotid and vertebral arteries, the internal jugular vein, trachea, and esophagus. This zone is more accessible to clinical examination and surgical exploration than the other zones (see Fig 1). Zone III extends between the angle of the mandible and the base of the skull and includes the distal carotid and vertebral arteries and the pharynx. Zone III is not amenable to easy physical examination or surgical exploration.

Overall, zone II is the most commonly injured area (47%), followed by zone III (19%) and zone I (18%). In 16% of cases there is involvement of more than 1 zone.1 The incidence of vascular and aerodigestive injuries according to zone, in a prospective study of 223 patients with PNI,1 is shown in Table 2. In series with predominantly stab wounds, zone I is the most commonly injured area (44%), followed by zone II (29%) and zone III (27%).5 Most stab wounds involve the left side of the neck (74% of cases), presumably due to the predominance of right-handed assailants.5
Prehospital Management

In an urban environment with short prehospital times, “scoop and run” to the nearest trauma center is the only acceptable policy and offers the best chance of survival in patients with vascular injuries or airway compromise. The scene time should be kept as short as possible. Attempts to resuscitate the patient with intravenous fluids or perform a prophylactic endotracheal intubation for airway protection are ill-advised and potentially dangerous. Bleeding control can be achieved by direct pressure in most patients. In some cases, with bleeding from the vertebral or subclavian vessels, external pressure may not be effective in controlling...
the hemorrhage. Digital compression with a gloved index finger inserted into the wound may be more effective.

Intravenous line placement should be attempted in the ambulance during transportation and no valuable time should be lost at the scene. In cases of suspected subclavian venous injuries the intravenous line should be inserted in the opposite arm, to avoid extravasation of infused fluids or medications from a proximal venous injury. Patients with active bleeding should be placed in the Trendelenburg position to reduce the risk of air embolism.

Airway problems following PNI can occur either due to laryngotracheal injuries or due to external compression by a large hematoma. Attempts to manage the airway at the scene should rarely be made because they delay the definitive care and may be potentially dangerous. Oxygen administration by mask or nasal cannula and rapid transportation to the nearest trauma center is the safest approach. The presence of a large hematoma or edema or laryngotracheal trauma make the endotracheal intubation difficult and dangerous, even in an ideal environment. Prehospital endotracheal intubation in patients with penetrating injuries of the neck should be attempted only in patients with anticipated prolonged transport time who are in respiratory distress or imminent cardiac arrest. The orotracheal route is the preferred approach. The use (or not) of neuromuscular agents in the prehospital setting is controversial and depends on the protocols of the local paramedic agencies. Although there are reports supporting prehospital blind nasotracheal intubation for patients with PNI in an urban environment, this approach should be avoided because of the potential risks and the significant delays in reaching definitive medical care. Even in the fairly controlled environment of the emergency room the failure rate of blind nasotracheal intubation is 25% and the mortality directly related to the failed blind intubation is significant.

Neck wounds with air bubbling should be covered and compressed firmly with a gauze. Assisted ventilation with bag-valve-mask (BVM)

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**TABLE 2. Incidence of vascular and aerodigestive injury according to zone (223 patients)**

<table>
<thead>
<tr>
<th>Zone</th>
<th>No. of patients</th>
<th>No. of patients with aerodigestive or vascular injury (%)</th>
<th>No. of patients with therapeutic operation (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>41</td>
<td>14.6</td>
<td>12.2</td>
</tr>
<tr>
<td>II</td>
<td>105</td>
<td>22.9</td>
<td>14.3</td>
</tr>
<tr>
<td>III</td>
<td>42</td>
<td>23.8</td>
<td>4.8</td>
</tr>
<tr>
<td>Multiple</td>
<td>35</td>
<td>31.4</td>
<td>20.0</td>
</tr>
</tbody>
</table>

may aggravate the situation in the presence of an open laryngotracheal wound by causing massive subcutaneous emphysema or even air embolism if there is an associated venous injury.\textsuperscript{2} Cervical spine protection by means of a neck collar remains a common practice during the prehospital transportation of patients with PNI. The value of this practice is questionable and may be harmful in some patients. It certainly has absolutely no role in patients with stab wounds to the neck. Its value in cases with gunshot wounds is limited. It is rarely that low-velocity gunshot wounds result in spinal instability. In a series of 1300 patients with gunshot wounds of the spine, Meyer and colleagues\textsuperscript{8} found no unstable fractures. However, it has been reported, and it is also our experience, that in rare occasions a low-velocity GSW can cause unstable spinal fractures without cord injury.\textsuperscript{9} In high-velocity wounds massive destruction of the bone and ligament structures of the cervical spine may cause instability. However, these injuries are always associated with irreversible cord destruction, making spinal immobilization of limited practical value. Application of a cervical collar in the presence of a large or expanding hematoma may cause respiratory obstruction. It is recommended that in knife injuries no cervical collar is applied. In GSWs a collar may be applied, always monitoring for expanding hematoma or respiratory distress. In these cases the collar should be loosened to relieve the airway obstruction.

**Emergency Room Management**

The initial evaluation and management should follow the Advanced Trauma Life Support (ATLS) protocols. During the primary survey the following life-threatening conditions from the neck should be identified and treated as soon as possible: 1) airway obstruction due to laryngotracheal trauma or external compression by a large hematoma; 2) tension pneumothorax; 3) major active bleeding, externally or in the thoracic cavity; and 4) spinal cord injury or ischemic brain damage due to carotid artery occlusion. During the secondary survey the following neck injuries should be identified: 1) occult vascular injuries; 2) occult laryngotracheal injuries; 3) pharyngoesophageal injuries; 4) cranial or peripheral nerve injuries; and 5) small pneumothoraces.

**Airway Management.** The airway management is the first and most challenging priority in the management of severe PNI. Approximately 8% to 10% of patients with PNI present with airway compromise.\textsuperscript{10-12} In patients with laryngotracheal injuries approximately 30% require emergency room airway establishment because of threatened airway loss.\textsuperscript{12} Airway problems may be due to direct trauma or severe edema to the
larynx or trachea, or from external compression by a large hematoma. Small penetrating injuries to the airway tract by knife or low-velocity bullets rarely cause respiratory problems. However, major laryngotracheal transections or high-velocity GSWs often cause respiratory problems. In a prospective study of 223 patients with PNI, approximately 3% had major direct laryngotracheal trauma and approximately 13% had a large neck hematoma.1 Gunshot wounds were significantly more likely to result in large hematomas than knife wounds (20.6% vs. 6.7%).1

Air bubbling through a neck wound is pathognomonic of laryngotracheal injury. Firm manual compression over the wound reduces the air leak and usually improves oxygenation. Orotracheal intubation in these cases may be dangerous because of the risk of further damage to the larynx or trachea or misplacement of the tip of the tube into the paratracheal tissues. Emergency room endotracheal intubation should be considered only in patients who fail to improve after firm occlusion of the wound with the air leak.

In general, orotracheal intubation in the emergency room should be performed only in patients with severe respiratory distress or imminent cardiac arrest. The airway management of these patients should be undertaken by the most experienced physician and a surgeon should always be present in case a surgical airway is needed. The technique of endotracheal intubation in the presence of a large, expanding hematoma or major air leaks from the wound should be individualized, taking into account many factors: 1) the severity of respiratory distress, 2) the hemodynamic condition of the victim, 3) the nature of the local neck pathology (size and site of any hematoma and presence of an open wound with air bubbling), and 4) the experience of the trauma team.2

In patients with large neck hematomas who are not in respiratory distress, fiberoptic intubation is the safest approach (Fig 2). However, this procedure requires experience and skill, it can be performed only semi-electively, and the reported failure rate is approximately 25%.12 The presence of severe respiratory distress or apnea are absolute contraindications for fiberoptic intubation.

Orotracheal intubation, with or without neuromuscular paralysis, is the most common method of airway management and it is used in approximately 80% of patients requiring emergency endotracheal intubation for PNI.12 With appropriate selection of patients and experience, the success rate is very high.12,13 The use of neuromuscular paralysis during orotracheal intubation in the emergency room in cases with PNI is controversial and has major advantages and disadvantages. Orotracheal intubation without neuromuscular paralysis is difficult and any coughing
FIG 2. In patients with large neck hematomas who are not in respiratory distress, fiberoptic intubation is the safest approach. Fiberoptic intubation is contraindicated in patients who are uncooperative or in respiratory distress or hemodynamic instability. (Color version of figure is available online.)
or gagging may worsen bleeding and increase the size of the hematoma. On the other hand pharmacological paralysis may be dangerous if the cords cannot be visualized because of a distorted anatomy due to a compressing hematoma or significant local edema. It has been suggested that abolishment of the muscle tone after pharmacological paralysis results in further displacement of the airway, leading to total obstruction.\textsuperscript{14} Orotracheal intubation, with or without pharmacological paralysis, should be performed by the most experienced physician present and with a surgeon ready to intervene and perform a surgical airway. In a review of 76 patients with laryngotracheal trauma in Los Angeles, 16 cases (21\%) required emergency room airway establishment. Although rapid sequence induction was successful in most cases, in 12\% the orotracheal intubation failed and a cricothyroidotomy was performed.\textsuperscript{13}

Blind nasotracheal intubation without the use of pharmacological paralysis has been occasionally used in cases with neck hematomas. This approach should rarely be used because of the reasons mentioned previously, the reported high failure rate, and the potentially lethal consequences associated with failed attempts.\textsuperscript{7}

In rare occasions with visible large laryngotracheal wounds the endotracheal tube can be inserted under direct view into the distal transected segment through the neck wound. The distal larynx or trachea should be grasped and secured with a tissue forceps before insertion of the tube to avoid complete transection or retraction into the mediastinum.

Cricothyroidotomy in the emergency room may be necessary in approximately 6\% of all PNIs\textsuperscript{7} or approximately 12\% of laryngotracheal injuries.\textsuperscript{13} In the presence of large midline hematomas the procedure is difficult and may be associated with severe bleeding.

In summary, the airway management of PNI should be individualized according to the condition of the patient, the nature of the injury, and the experience of the trauma team. Alternative approaches should be planned in advance and be immediately available in case the initial attempt is not successful.

**Bleeding Control.** In the presence of active bleeding the patient should be placed in the Trendelenburg position to reduce the risk of air embolism in cases with venous injuries. Intravenous lines should be avoided in the arm on the side of the neck wound. External bleeding can successfully be controlled by direct pressure in most cases. However, bleeding from the vessels behind the clavicle or near the base of the skull or the vertebral artery is often difficult to control by external pressure. In these cases digital compression with a gloved index finger through the wound should be attempted. For these situations, we have successfully used balloon
The technique involves insertion of a Foley catheter into the wound and advancement as far as it can go. The balloon is then inflated with water until the bleeding stops or moderate resistance is felt. If the bleeding continues after this maneuver, the balloon is deflated and the catheter is slightly withdrawn and reinflated. Significant bleeding through the catheter is suggestive of bleeding distal to the balloon and repositioning should be attempted. In periclavicular injuries the bleeding may occur in both the intrathoracic cavity and externally. In these cases a Foley catheter is advanced into the chest cavity through the neck wound, the balloon is then inflated, and the catheter is pulled back until some resistance is felt. In this position the balloon compresses the bleeding vessels against the first rib or the clavicle (Fig 3). The traction is maintained by application of a Kelly forceps on the catheter, just above the skin. If external bleeding continues, a second Foley catheter is inserted and inflated in the wound tract. Blind clamping of suspected bleeding should be avoided because it is rarely effective and the risk of further vascular or nerve damage is very high.

Many patients with major injuries to the neck vessels reach the hospital in cardiac arrest or imminent cardiac arrest. These patients may benefit
from a resuscitative thoracotomy. Bleeding from the left subclavian vessels can be controlled with a vascular clamp applied under direct view through the thoracotomy. Besides the usual resuscitation measures, the right ventricle should be aspirated for air embolism. In our experience, the survival rate following resuscitative thoracotomy for PNI is very poor.\textsuperscript{17}

**Clinical Examination**

Physical examination, preferably according to a written protocol, remains the most reliable diagnostic tool. The physical examination should be systematic and specifically directed to look for signs or symptoms of injuries to the airway tract, the vessels, pharyngoesophageal tract, spinal cord, nerves, and the lungs. The clinical signs are classified into “hard” signs, which are pathognomonic of injury, and “soft” signs, which are suspicious but not diagnostic of significant injury.\textsuperscript{1,18} The incidence of the various signs and symptoms is influenced by the mechanism of injury. In GSWs, the most common clinical sign is a moderate or large hematoma (20.6%), and in stab wounds is painful swallowing (14.3%) and hemo/pneumothorax (13.5%).\textsuperscript{1} Table 3 summarizes the incidence of the various signs and symptoms according to mechanism of injury in a prospective study of 223 patients with PNI.

**Evaluation for Laryngotracheal Injuries.** Hard signs highly diagnostic of significant laryngotracheal trauma include respiratory distress, air bubbling through the neck wound, and major hemoptysis. In the presence of any of these findings an operation is indicated without any specific

<table>
<thead>
<tr>
<th></th>
<th>Overall (%)</th>
<th>GSW (%)</th>
<th>SW (%)</th>
</tr>
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<tbody>
<tr>
<td>Severe/moderate bleeding</td>
<td>5.8</td>
<td>4.1</td>
<td>6.7</td>
</tr>
<tr>
<td>Large/moderate hematoma</td>
<td>13.0</td>
<td>20.6</td>
<td>6.7</td>
</tr>
<tr>
<td>Shock</td>
<td>9.9</td>
<td>13.4</td>
<td>7.9</td>
</tr>
<tr>
<td>Diminished peripheral pulse</td>
<td>4.9</td>
<td>8.2</td>
<td>3.4</td>
</tr>
<tr>
<td>Pain on swallowing</td>
<td>15.7</td>
<td>15.8</td>
<td>14.3</td>
</tr>
<tr>
<td>Hoarseness</td>
<td>8.3</td>
<td>10.5</td>
<td>8.3</td>
</tr>
<tr>
<td>Subcutaneous emphysema</td>
<td>6.9</td>
<td>9.5</td>
<td>5.9</td>
</tr>
<tr>
<td>Air bubbling through wound</td>
<td>2.8</td>
<td>4.2</td>
<td>2.4</td>
</tr>
<tr>
<td>No signs of vascular injury</td>
<td>71.7</td>
<td>64.9</td>
<td>80.9</td>
</tr>
<tr>
<td>No signs of aerodigestive injury</td>
<td>70.4</td>
<td>64.2</td>
<td>77.4</td>
</tr>
<tr>
<td>Spinal cord injury</td>
<td>6.7</td>
<td>13.4</td>
<td>1.1</td>
</tr>
<tr>
<td>Nerve injury</td>
<td>9.0</td>
<td>12.4</td>
<td>4.5</td>
</tr>
<tr>
<td>Hemo-pneumothorax</td>
<td>17.9</td>
<td>15.5</td>
<td>13.5</td>
</tr>
</tbody>
</table>


GSW, Gunshot wounds; SW, stab wounds.
diagnostic studies. Soft signs are present in approximately 18% of PNI\textsuperscript{1} and include subcutaneous emphysema, hoarseness, and minor hemothysis. These patients need further diagnostic evaluation to identify those with significant injuries requiring surgical repair. Only approximately 15% of patients with soft signs have a significant laryngotracheal injury.

Subcutaneous emphysema is the most common soft sign and is found in approximately 7% of PNIs.\textsuperscript{1} It may be secondary to laryngotracheal or esophageal injury or an associated pneumothorax. In approximately 15% of the cases there is no obvious source explaining the subcutaneous emphysema and it is assumed that the air came from outside, through the wound.

**Evaluation for Vascular Injuries.** Hard signs of significant vascular trauma include severe active bleeding, large expanding hematoma, absent or diminished peripheral pulse, bruise on auscultation, and unexplained hypotension. In a group of 29 patients with hard signs, 28 (97%) had significant injuries.\textsuperscript{1}

Soft signs of vascular trauma include stable, small to moderate size hematomas, minor bleeding, mild hypotension responding well to fluid resuscitation, and proximity wounds. Patients with soft signs need further investigation because only approximately 3% require a therapeutic operation. In a prospective study, which included 34 patients with soft signs who underwent angiographic evaluation, 8 (23.5%) had an angiographically detected abnormality but only 1 (3%) needed an operation.\textsuperscript{1}

**Evaluation for Pharyngoesophageal Tract Injuries.** There are no hard signs diagnostic of pharyngoesophageal injuries. Soft signs that require evaluation of the pharynx and esophagus include painful swallowing, subcutaneous emphysema, and hematemesis. These symptoms are present in approximately 23% of patients with PNI and they are not specific. Only approximately 18% of patients with these findings have pharyngoesophageal trauma.\textsuperscript{1}

**Evaluation for Nervous System Injuries.** The clinical examination should include assessment of the Glasgow Coma Scale (GCS) score, localizing signs, pupils, cranial nerves (VII, IX-XII), spinal cord, brachial plexus (eg, median, ulnar, radial, axillary, musculocutaneous nerves), the phrenic nerve, and the sympathetic chain (Horner syndrome). The GCS may be abnormal due to ischemia secondary to a carotid injury or due to an associated intracranial missile injury.

The clinical examination should ideally be performed according to a written protocol. Failure to follow this recommendation, especially by the less experienced surgeon, may result in missing significant signs and symptoms. The written examination protocol that has been in use at the
PROTOCOL FOR CLINICAL EXAMINATION IN PENETRATING INJURIES OF THE NECK

A. SYSTEMIC EXAMINATION
1. Dyspnea: □ yes □ no
2. Blood pressure:
3. Pulse:

B. LOCAL EXAMINATION

VESSELS
1. Active bleeding: □ minor □ severe □ no bleeding
2. Hematoma: □ small □ large □ no bleeding □ expanding
3. Pulsatile hematoma: □ yes □ no
4. Peripheral pulses (compare with normal side):
   □ normal □ diminished □ absent
5. Bruit: □ yes □ no
6. Ankle-Brachial Index (ABI):

LARYNX-TRACHEA-ESOPHAGUS
1. Hemoptysis: □ yes □ no
2. Air bubbling through wound (ask the patient to cough): □ yes □ no
3. Subcutaneous emphysema: □ yes □ no
4. Pain on swallowing sputum: □ yes □ no

NERVOUS SYSTEM
1. Glasgow Coma Scale (GCS):
2. Localizing signs (describe):
3. Cranial nerve injury:
   ■ Facial nerve: □ yes □ no
   ■ Glossopharyngeal nerve: □ yes □ no
   ■ Recurrent laryngeal nerve: □ yes □ no
   ■ Accessory nerve: □ yes □ no
4. Spinal cord: □ normal □ abnormal (describe):
5. Brachial plexus injury:
   ■ Median nerve: □ yes □ no
   ■ Ulnar nerve: □ yes □ no
   ■ Radial nerve: □ yes □ no
   ■ Musculocutaneous nerve: □ yes □ no
   ■ Axillary nerve: □ yes □ no
6. Horner's syndrome: □ yes □ no

FIG 4. The LAC+USC Trauma Center Protocol for local examination in penetrating injuries of the neck.

Los Angeles County and University of Southern California Trauma Center for many years is shown in Figure 4. This protocol has been tested in large prospective studies of 223 patients in Los Angeles and 335 patients in Johannesburg, South Africa. Clinical examination according to this protocol reliably diagnoses or highly suggests all significant...
injuries. The absence of any clinical signs or symptoms suggestive of vascular or aerodigestive injury reliably excludes significant injuries to these structures requiring therapeutic intervention. In a prospective study of 335 patients with predominantly stab wounds to the neck, 269 (80%) had no symptoms or signs suggestive of vascular or aerodigestive injuries and were selected for nonoperative management. Only 2 of the observed patients (0.7%) required semi-elective operation for vascular injuries. In both cases a bruit was detected the day after admission and angiography demonstrated an arteriovenous fistula.\(^5\) In another prospective study of 223 patients with PNI, predominantly GSWs, 160 (71.7%) had no clinical signs suggestive of vascular trauma. None of these patients required operation or another form of treatment (negative predictive value [NPV], 100%). Angiography was performed in 127 asymptomatic patients and revealed 11 vascular injuries (8.3%), none of which required treatment. The most common angiographically detected abnormality was occlusion of a vertebral artery (4 cases).\(^1\) In the same study there were 152 patients with no signs or symptoms of aerodigestive injuries and none of these asymptomatic patients had a significant injury requiring operation (NPV, 100%).

**Investigations**

The mechanism of injury and clinical examination should determine the need and type of specific investigations in the evaluation of PNI. Patients with hard signs of major vascular or laryngotracheal injuries should undergo an operation without any delay for definitive investigations. If time permits, chest and neck radiographs may be helpful in locating foreign bodies or diagnosing an associated hemopneumothorax that requires treatment (Fig 5). There is good evidence from large prospective studies that patients with no signs or symptoms of vascular or aerodigestive injuries do not have significant injuries requiring treatment and they are very unlikely to benefit from routine angiography or esophageal studies.

**Plain Chest and Neck Radiographs.** Chest radiographs should be obtained in all fairly stable patients with penetrating injuries in zone I or those with any other wounds that could have violated the chest cavity. Approximately 16% of GSWs and 14% of stab wounds to the neck are associated with a hemo/pneumothorax.\(^1\) Other important radiological findings include a widened upper mediastinum that is suspicious of a thoracic inlet vascular injury, subcutaneous emphysema, fractures, and missiles (Fig 6).
FIG 5. Chest and neck radiographs may be helpful in locating foreign bodies. This patient has retained bullets in zones 1 and 3.
Angiography. Angiographic evaluation of the neck vessels following PNI remained a standard practice in many centers for many years. Sclafani and colleagues in a review of 72 asymptomatic patients with proximity PNI who underwent routine angiography reported a high incidence of vascular injuries. The authors suggested that routine angiography, in asymptomatic patients with PNI that violate the platysma, should be the standard of care until additional data were available. Since then, numerous publications have suggested that routine angiography in asymptomatic patients is unnecessary, has a low yield, and does not offer any benefit over physical examination and other noninvasive investigations. In a prospective study from Los Angeles, 127 asymptomatic patients examined according to a written protocol were evaluated
angiographically at a cost of $254,000 and 11 vascular injuries not requiring any form of treatment were identified. Clinical examination alone would not have missed any significant injury requiring treatment. The combination of clinical examination and color flow Doppler (CFD) diagnosed all vascular injuries. In another prospective study of 335 patients with PNI, 269 (80%) were selected for nonoperative management. Angiography was performed on only 7 cases. There were no deaths or significant complications in this group of patients. Early follow-up (mean, 16 days) of 192 patients or late follow-up (mean, 48 days) of 111 patients did not identify any significant missed vascular injuries.

Clinical examination alone may miss minor injuries to the neck vessels not requiring treatment. Many studies have suggested that clinically occult, angiographically detected injuries have a benign prognosis and do not require treatment. However, there is concern that minor carotid injuries may be different from extremity minor vascular injuries and it might be prudent to monitor them until complete healing. To address this concern we suggest that asymptomatic patients are evaluated with a combination of clinical examination according to a written protocol and CFD.

Although the absence of clinical signs suggestive of vascular trauma reliably excludes significant injuries requiring treatment (NPV, 100%), the presence of soft clinical signs does not reliably identify patients who will require an operation. In a subgroup of 34 patients with soft signs of vascular injury, angiography diagnosed injuries in 8 (23.5%) but only 1 (3%) needed an operation. It is obvious that angiography in this group of patients has a low yield. However, clinical examination according to a written protocol combined with CFD studies reliably diagnosed all vascular injuries.

Some surgeons suggested a policy of routine angiography only for injuries in zones I and III, regardless of the clinical findings. Such policy still has a very low yield at considerable cost and patient discomfort. Only 5% of 148 zone I and 13% of 92 zone III injuries require treatment for vascular injuries.

In summary, angiography for PNI should be reserved only for selected cases with specific diagnostic or therapeutic indications (Table 4).

**Color Flow Doppler (CFD)**

Color flow Doppler has been suggested as a reliable alternative to angiography in the evaluation of PNI. In a prospective study from Los Angeles, 82 hemodynamically stable patients were clinically examined according to a written protocol and subsequently had angio-
Color flow Doppler diagnosed 10 of the 11 angiographically detected injuries and missed 1 small intimal tear that did not require treatment. The study concluded that the combination of a careful clinical examination and CFD imaging is a safe and cost-effective alternative to routine angiography. In another prospective study with 25 patients with PNI who were evaluated by angiography and CFD, Corr and colleagues reached similar conclusions.

Color flow Doppler has the disadvantage of being operator-dependent and has some limitations in the visualization of the proximal left subclavian artery, especially in obese patients, the internal carotid artery near the base of the skull, and the segments of the vertebral artery under the bony part of the vertebral canal.

Computed Tomography. Computed tomography (CT) has become a very useful tool in the evaluation of PNI, especially in GSWs. At our center it has become the first line investigation in all hemodynamically stable patients with GSWs to the neck. The entry and exit of the bullet should be marked with radiopaque markers and 3-mm CT cuts should be obtained between the markers or between the entry and the retained bullet. Identification of the bullet trajectory is very helpful in determining the need for further invasive investigations, such as angiography or endoscopy. Patients with trajectories away from the major vessels or the aerodigestive structures do not need further evaluation. Gracias and colleagues is a study of 19 patients with PNI found that in 13 cases (68%) the CT scan showed trajectories away from vital structures and no further evaluation was required. In addition to the missile trajectory, the CT may provide information about the site and nature of any spinal fractures, involvement of the spinal cord, the presence of fragments in the spinal canal, and the presence of any hematomas compressing the cord.

Helical CT angiography has been used in the last few years for the evaluation of the major neck vessels following PNI. The reported results

<table>
<thead>
<tr>
<th>TABLE 4. Indications for conventional angiography</th>
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<tr>
<td>Diagnostic indications</td>
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<tr>
<td>Inconclusive CFD or CT angiogram</td>
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<tr>
<td>Shotgun injuries</td>
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<td>Gunshot wounds involving the transverse foramen of the spine</td>
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<tr>
<td>Widened upper mediastinum in zone I injuries</td>
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<tr>
<td>Therapeutic indications (possible stenting or embolization)</td>
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<tr>
<td>Bruit on auscultation</td>
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<tr>
<td>Diminished upper extremity pulse</td>
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<tr>
<td>Persistent slow bleeding from suspected vertebral artery injury or external carotid branches</td>
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CFD, Color Flow Doppler; CT, computed tomography.
are very encouraging and CT angiography has become an excellent initial investigation for suspected vascular injuries.33-35 Munera and colleagues33 in a prospective study of 60 patients with PNI compared conventional angiography and helical CT angiography. The performance of CT angiography was very good, with a 90% sensitivity, 100% specificity, 100% PPV, and 98% NPV. In another study of 175 patients, Munera and colleagues reported excellent results with CT angiography and suggested that it is a valuable investigation for evaluation of suspected arterial injuries of the neck.34 The study may have some limitations due to artifacts from metallic fragments or excessive air in the soft tissues.35 In these cases conventional angiography may be necessary for accurate evaluation.

A brain CT scan is indicated in patients with PNI and unexplained central neurological deficits, to evaluate for a possible anemic infarction secondary to a carotid artery injury or an associated direct brain injury due to a missile fragment.16

**Esophageal Studies.** Esophageal studies are recommended in stable patients with suspicious clinical signs, such as painful swallowing, hematemesis, or subcutaneous emphysema and in cases with a CT scan bullet trajectory toward the esophagus (Fig 7).

Contrast esophagography is the most commonly used study for the evaluation of the esophagus following PNI. It is used in approximately 82% of suspected esophageal injuries whereas esophagoscopy is used in approximately 18% of cases.1 There has been some concern that esophagography may miss small esophageal injuries. In a retrospective review of 23 cervical esophageal injuries, Armstrong and colleagues36 reported that contrast esophagography diagnosed only 62% of perforations, compared with 100% with rigid esophagoscopy. This is not our experience and at our trauma center, which is 1 of the busiest in the United States, we have not encountered any missed esophageal injuries by esophagography in the last 13 years. The technique of esophagography is important in avoiding false negative studies. The study is first performed with a water soluble contrast, such as gastrographin. If no leak is identified the study is repeated with thin barium. Gastrographin alone may miss small injuries.37

Esophagoscopy, if performed by an experienced endoscopist, may be a useful investigation in the evaluation of the cervical esophagus. Flexible endoscopy has been shown to have a negative predictive value of 100% but a positive predictive value of up to 33%.38,39 We reserve flexible endoscopy only for patients who cannot undergo esophagogram because of a depressed level of consciousness or intraoperatively. Rigid esophagoscopy may be superior to flexible endoscopy in the evaluation of the
upper esophagus and is the investigation of choice of some authors after esophagography. However, rigid esophagoscopy can be performed only under general anesthesia and many surgeons are not experienced with the technique. We reserve this procedure only for intraoperative evaluation of the esophagus.

**Studies for Laryngotraacheal Evaluation.** Indications for laryngotraacheal evaluation include proximity injury with soft clinical signs suspicious of airway injuries (eg, minor hemoptysis, hoarseness, subcutaneous emphysema) or CT scan findings showing a bullet track near the larynx or trachea.

Flexible fiberoptic endoscopy is the investigation of choice and it can be performed in the emergency room. The most common abnormal findings are blood or edema in the laryngotraacheal tract and vocal cord dyskinesia.1 Gunshot wounds are significantly more likely to be associated with abnormal endoscopic findings than knife injuries (24.6% vs. 8.5%). However, only 20% of patients with abnormal findings require an operation.1,41

The Los Angeles County and University of Southern California Trauma Center algorithm for the evaluation of penetrating injuries of the neck is shown in Figure 8.

**Definitive Management**

**Operative Versus Nonoperative Management.** For many years mandatory operation, for all patients with penetrating injuries of the neck that violated the platysma, remained the standard of care. However, this policy was associated with an unacceptably high incidence of unnecessary operations, ranging from 30% to 89%.42,43 The rationale for routine operation is that clinical examination is often not reliable and may miss significant injuries. In addition, it has been suggested that routine operation avoids expensive investigations and does not prolong hospital stay.43 This policy has now been abandoned by most trauma centers and has been replaced by a policy of selective nonoperative management. There is strong evidence that clinical examination is very reliable in identifying or highly suspecting significant injuries requiring treatment.1,2,3,5,22,23,44,45 Only approximately 17% of gunshot wounds and

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FIG 7. Esophageal studies are recommended in stable patients with suspicious clinical signs, such as painful swallowing, hematemesis, or subcutaneous emphysema and in cases with a CT scan bullet trajectory toward the esophagus. This patient has a significant leak in the cervical esophagus.
10% of stab wounds to the neck require a therapeutic operation. Subjecting the remaining 83% to 90% of patients to an unnecessary operation is not an acceptable practice.

The selection of patients for operation or observation is based on clinical examination and appropriate investigations. The indication and selection of the most appropriate investigation varies from center to center and is still a controversial issue. It is essential that clinical examination is performed systematically, preferably according to a written protocol (Table 5) and investigations are selected with the help of an algorithm that takes into account the experience and resources of the individual trauma center. Figure 8 shows the algorithms that have been in use at the Los Angeles County and University of Southern California Trauma Center for more than 10 years. Failure to follow written protocols and algorithms, especially in low-volume trauma centers or by an

FIG 8. Algorithm for the evaluation of penetrating injuries to the neck. CFD, Color flow Doppler.
inexperienced surgeon, may result in missing significant injuries or performing unnecessary operations.

Gunshot wounds are associated with a higher incidence of significant injuries requiring operative management than stab wounds. For this reason, it has been suggested that mandatory operation may be appropriate for patients with GSWs. However, more than 80% of GSWs to the neck do not require an operation and there is strong evidence that these patients can be identified safely and spared an unnecessary operation, on the basis of clinical examination and appropriate investigations.

Transcervical GSWs are associated with a much higher incidence of significant injuries than GSWs that have not crossed the midline (73% vs. 31%). For this reason, it has been suggested that all patients with transcervical GSWs should undergo an operation regardless of the clinical examination. However, many of these severe injuries, such as spinal cord or nerve injuries, do not require an operation. In a prospective study of 33 cases with transcervical GSW from Los Angeles, although 73% had injuries to vital neck structures, only 21% needed a therapeutic operation. It has been our practice for many years to evaluate and manage these injuries like any other penetrating injury of the neck. In our experience, a CT angiogram with thin cuts can reliably identify those patients who do not need further investigation or those who might benefit from specific studies by determining the bullet trajectory.

Blunt Trauma

Although management priorities for blunt neck trauma are the same as for penetrating injuries, an understanding of the differences in wounding mechanisms and injury patterns is essential to the prompt diagnosis and management of these rare but devastating injuries. Because the discussion of cervical spine fractures and cervical spinal cord injury are beyond the scope of this monograph, we will focus on blunt trauma causing laryngotracheal, pharyngoesophageal, vascular, and brachial plexus injuries in the neck.

Epidemiologic Features

Although blunt trauma to the neck is relatively common, when cervical spine injuries are excluded, injuries to the remaining cervical structures are relatively infrequent. Injuries to the aerodigestive tract in the neck are typically a result of direct blunt force to the anterior neck. Specifically to automobile crashes, unrestrained drivers will strike their anterior neck on the steering wheel. Both laryngotracheal and pharyngoesophageal injuries are rare after blunt trauma, occurring in 0.04% to 0.3% of all
 blunt trauma patients, much less common than the 5% to 15% rate of aerodigestive injuries seen after penetrating neck trauma. Similarly uncommon, but far more lethal, are blunt cervical vascular injuries. These include blunt injury to both the vertebral and the carotid arteries, which occurs in approximately 0.7% and 0.9% of blunt trauma patients, respectively. Although motor vehicle crashes are the cause of cervical vascular injuries in approximately 75% of cases, a variety of other mechanisms causing direct trauma or hyperextension to the neck has been reported.

High-velocity crashes are also the most common cause of nerve injuries in the neck, with brachial plexus injuries occurring in 0.7% to 1.3% of patients after automobile crashes, increasing to 4.2% after motorcycle crashes. Less commonly, the brachial plexus may be injured with a lower energy mechanism. During a fall, a patient may sustain significant distraction of the head from the shoulder causing an acute widening of the angle between the neck and shoulder, resulting in a traction injury to the brachial plexus.

**Investigations**

Although a thorough history and in-depth clinical examination are the foundations of suspecting and sometimes diagnosing injuries caused by blunt neck trauma, the adjunctive role of radiographic and endoscopic investigations of the neck can be critical to definitive diagnosis.

**Plain Radiographs.** Plain radiographs of the neck and chest are a quick and noninvasive start down the path of evaluating patients with suspected blunt neck injuries. Although normal plain radiographs of the neck and chest do not exclude significant injuries, certain abnormalities may guide further evaluation. Free air within the subcutaneous and other soft tissues may be a marker for an aerodigestive injury. In fact, cervical or mediastinal emphysema has been reported in as many as 95% of aerodigestive injuries. In addition, the amount of air seen may be a tipoff as to the location of injury. Typically, a small amount of cervical air will be seen with pharyngoesophageal injuries, whereas laryngotracheal injuries will manifest large amounts of cervical and mediastinal emphysema.

Plain radiographs of the neck and chest may also demonstrate a fracture, which would subsequently increase suspicion for an underlying vascular or brachial plexus injury. Cervical spine fractures of any type have been implicated as a risk factor for blunt cervical vascular injury. In particular, vertebral artery injuries are associated with complex cervical spine fractures with subluxation, extension into the foramen transver-
sarium, or fractures to the higher cervical vertebrae.\textsuperscript{55} Severe fractures of the scapula, humerus, or clavicle may be a marker for an underlying injury to the brachial plexus.

\textbf{Computed Tomography and Oral Contrast Studies.} Computed tomography has become the cornerstone of imaging for all blunt trauma patients. Although CT scan of the abdomen has been long accepted, the application of CT scan to diagnose blunt neck injuries is relatively recent. Although aerodigestive injuries are best visualized with panendoscopy (see later discussion), CT scan and gastrograftin or barium swallows may add significant information in patients with a high suspicion for injury. For laryngotracheal injuries, the CT scan is more sensitive than plain radiographs for identifying cervical emphysema. In addition, CT scanning allows excellent visualization of laryngeal anatomy, which is critical in the operative plan. CT scan, preferably with oral contrast, may also identify small amounts of cervical air or contained leak consistent with a pharyngoesophageal injury. Likely more useful is a gastrograftin or barium swallow, which will reveal an abnormality in 75\% to 100\% of cases of cervical esophageal perforation.\textsuperscript{61}

Although 4-vessel angiography remains the gold standard for the diagnosis of cerebrovascular injuries after blunt trauma, CT angiogram appears to be a promising tool for screening patients at risk for blunt carotid and vertebral injuries. However, thus far there have been conflicting results as to the utility of CT angiography in the setting of blunt trauma of the neck. Berne and colleagues\textsuperscript{62} found CT angiography to have a sensitivity of 100\% and specificity of 94\% when screening patients for blunt cerebrovascular injuries. On the contrary, Biffl and colleagues\textsuperscript{63} found sensitivity and specificity for CT angiography of 68\% and 67\%, respectively. Further studies are needed that directly compare conventional angiography and CT angiography for the diagnosis of blunt cerebrovascular injury.

\textbf{Color Flow Doppler.} Color flow Doppler in blunt neck trauma patients may be useful in identifying dissections, thrombosis, or pseudoaneurysms of the carotid and vertebral arteries. Although duplex ultrasound has the theoretical advantages of being noninvasive, inexpensive, and repeatable, it is limited in visualization of the more distal carotid arteries and the portions of the vertebral arteries protected by the cervical spine. Cogbill and colleagues\textsuperscript{64} used carotid duplex in a multicenter trial of blunt cerebrovascular trauma, in which duplex was able to identify 86\% of injuries. Likewise, both Fry and colleagues\textsuperscript{27} and DiPerna and colleagues\textsuperscript{65} found that duplex ultrasound did not miss a significant carotid injury in patients with blunt neck trauma. However, all of these studies
included small numbers of patients and further prospective studies are needed to clearly define the role of CFD as a reliable investigation to identify blunt cerebrovascular injuries.

**Angiography.** In the past, 4-vessel angiography of the cerebrovascular system was the mainstay of screening and diagnosis of vascular injuries in the neck. The ideal candidates for screening or diagnostic angiography remain controversial. The group in Denver recommends 4-vessel angiography for all patients with signs or symptoms of cerebrovascular injury on clinical examination, as well as high-risk patients with significant mechanism of injury and any of the following: severe facial or cervical spine fracture, basilar skull fracture with carotid canal involvement, near-hanging injury with anoxia, and diffuse axonal injury with depressed mental status. The downside of angiography is its invasive nature, which may lead to hematoma, bleeding, or even cerebrovascular accidents. The risks and benefits of angiography must be considered when applying this sensitive tool in patients with blunt neck trauma. In our center we prefer CT angiography or CFD as the initial screening methods for suspected vascular injuries. We reserve angiography only in cases with inconclusive CT or duplex studies.

**Endoscopy.** Endoscopic evaluation remains a useful diagnostic adjunct when evaluating patients with suspected aerodigestive injury after blunt neck trauma. Although both rigid and flexible endoscopies are options, flexible endoscopy does not require a general anesthetic and can be performed while maintaining cervical spine immobilization in patients with suspected cervical spine injury. For laryngotracheal injuries the combination of flexible laryngoscopy and bronchoscopy can be used to rule out an airway injury. Injuries to the pharynx and cervical esophagus may be difficult to visualize due to blood in the pharyngeal space. If the area of interest cannot be visualized clearly or if there is any suspicion of an esophageal injury, the patient should undergo prompt evaluation with a contrast swallow.

**Specific Neck Injuries**

**Carotid Artery Injuries**

**Anatomic Features.** The left common carotid artery originates directly from the aortic arch proximal to the left subclavian artery; the right common carotid originates from the bifurcation of the brachiocephalic trunk. Both carotid arteries ascend into the neck posterior to the sternoclavicular joints and course lateral to the trachea in the carotid sheath (with jugular vein laterally and vagus nerve posteriorly), traversing
all 3 zones of the neck. The anatomic borders of the “carotid triangle” in
the neck are the superior belly of the omohyoid, the posterior belly of the
digastric, and the anterior border of the sternocleidomastoid muscles. The
common carotid arteries bifurcate into the internal and external carotid
arteries at the level of the superior border of the thyroid cartilage. The
internal carotid artery then courses superiorly, giving rise to no branches
in the neck, until it enters the petrous portion of the temporal bone via the
foramen lacerum.66

The common carotid artery is relatively unprotected in the lower neck,
making it susceptible to injury from a direct blow to that area. The
internal carotid artery lies on the lateral masses of the upper cervical
vertebrae until it enters the skull base at the foramen lacerum. Injury to
this area may occur when the artery is tethered across the lateral mass of
the vertebral body by neck hyperextension and then sheared by rotation of
the cervical spine. Alternatively, the vessel may be injured by compres-
sion between the mandible and the cervical spine with severe hyperflex-
ion. The petrous and cavernous portions of the internal carotid artery are
closely associated and fixed to the skull base, with injury usually resulting
from associated skull fractures or intraoral trauma.

Epidemiologic Features. The majority of traumatic carotid artery
injuries (90%) are due to penetrating trauma, although there is an
increasing incidence of blunt carotid injuries in recent series. These are
relatively uncommon injuries, accounting for 3% of all arterial injuries
and less than 0.2% of all hospital admissions for trauma.67,68 Injury to the
carotid artery occurs in approximately 4% to 15% of all penetrating neck
injuries, and may account for 20% to 80% of all cervical vascular
injuries.11,69,70 The most common mechanisms of penetrating injury in
civilian centers are low-velocity GSWs and stab wounds. In areas of
military conflict, shrapnel injuries are the most common mechanism
(46%), followed by high-velocity GSWs (33%).71

The majority of blunt carotid injuries are due to high-speed motor
vehicle collisions involving significant neck hyperextension and rota-
tion.72 Other mechanisms such as auto versus pedestrian, bicycle crashes,
or falls may produce enough cervical motion to cause carotid injury.
Although much less common, direct blunt force to the neck such as
assaults and strangulations may result in vascular injury, with up to a 2%
incidence of carotid artery injuries encountered following hangings or
near-hangings.73 Unfortunately, the majority of these mechanisms result
in injuries to the distal or intracranial internal carotid artery that may be
difficult to diagnose and are usually not amenable to surgical repair. The
most common type of carotid injury is an intimal dissection followed by
pseudoaneurysm, thrombosis, free rupture, and carotid-cavernous sinus fistula. Davis and colleagues\textsuperscript{74} studied the collision and occupant characteristics of 940 patients with blunt cerebrovascular injury (carotid and vertebral) from the National Automotive Sampling System. Vascular injuries were seen more frequently in vehicle drivers (76%), with airbag deployment (82%), and with seatbelt use (57%). The most frequent collision type was a frontal impact (76%) with a mean velocity change of 43.3 km/h.

Blunt carotid artery injuries were previously thought to be exceedingly rare, with only 96 reported cases by 1980.\textsuperscript{75} Since that time, blunt carotid injury has become an increasingly diagnosed entity, with a reported incidence ranging from 0.03% up to 1.55% in an aggressively screened population.\textsuperscript{76} Our analysis of 570 blunt carotid injuries from the National Trauma Data Bank\textsuperscript{TM} found an overall incidence of 0.16%.\textsuperscript{77} The true incidence of blunt carotid artery injury is unknown, as many lesions likely go undiagnosed and screening practices vary widely by institution. Injury to the common carotid artery is relatively uncommon in most series, with 60% to 100% of lesions localized to the internal carotid.\textsuperscript{62,78} Injury to the extracranial internal carotid is roughly twice as common as intracranial injury.\textsuperscript{79} Bilateral carotid injuries are not uncommon, occurring in up to 30% of cases, and an associated vertebral artery injury may be present in 13%.\textsuperscript{78,80} Associated injuries may be present in more than 90% of blunt carotid injury patients, with 50% of patients having significant intracranial or thoracic injuries.\textsuperscript{74,77} However, the majority of patients will have no other evidence of cervical trauma, such as a cervical spine fracture (28%) or soft tissue injury (21%).\textsuperscript{74}

**Clinical Presentation.** The clinical manifestation of carotid injuries depends on the mechanism of injury and the type of carotid trauma. Many patients with injury to the carotid artery die before reaching a hospital or present to the emergency department in full cardiac arrest. In a series of 124 patients with penetrating carotid injury, the prehospital mortality rate was 56%, with an overall mortality of 66%.\textsuperscript{81} The initial presentation of patients with vital signs on arrival may be highly variable, ranging from completely asymptomatic or subtle findings to active arterial hemorrhage, neck hematoma, and hemodynamic instability. The majority of patients with penetrating trauma present with 1 or more hard signs of arterial injury, making the subsequent initial management decisions relatively straightforward.

Blunt carotid injuries are often difficult to diagnose due to the extreme variability in clinical presentation and the frequent presence of associated injuries that may mask the presentation of the carotid injury. Neurologic
findings may include the typical ipsilateral motor and sensory deficits associated with anterior or middle cerebral distribution strokes. Local signs and symptoms of blunt carotid injury frequently include headache and neck pain, and cranial nerve palsy (most commonly hypoglossal) may be present in up to 12% of cases. However, with the high incidence of bilateral injuries and associated intracranial pathology, patients may present with nonfocal changes such as decreased mental status or coma. Any patient with neurologic deficits or deterioration that is not explained by the findings on head CT should undergo carotid evaluation.

Many patients with blunt carotid artery injury will present initially with no evidence of vascular injury and an intact neurologic examination, making early diagnosis difficult to impossible. Unfortunately, many of these lesions will not become symptomatic until hours to days after admission, missing a critical window for intervention before neurologic sequelae develop. In 1996, Fabian and colleagues found an average time to diagnosis of blunt carotid injury of 53 hours, with a range of 2 to 672 hours. The majority (78%) of patients had developed neurologic deficits before diagnosis, prompting a call for screening protocols aimed at early diagnosis and therapy of these injuries. In a follow-up study after initiating asymptomatic screening criteria they demonstrated a reduction in the mean time to diagnosis of 20 hours, with 38% of injuries diagnosed based on the screening criteria alone and only 34% of patients developing ischemic symptoms before diagnosis.

Investigations. The necessity, order, and timing of radiologic investigations to evaluate a potential carotid injury will be dictated by the clinical presentation as well as the injury mechanism, with the single most important factor being the hemodynamic status of the patient. In blunt trauma, patients with neck hematomas, seatbelt signs in the neck, severe hyperextension or hyperflexion of the neck, cervical spine fractures, basilar skull fractures involving the carotid canal, and unexplained neurological deficits should be evaluated for cervical vascular injury. Table 5 lists clinical factors and screening criteria that have been associated with blunt carotid artery injury, and which should prompt consideration of carotid artery evaluation. Although these and other studies have clearly demonstrated that aggressive screening can increase the number of injuries diagnosed and lead to earlier recognition and treatment, the ultimate impact on outcome remains unknown.

The most commonly used modalities by trauma centers for evaluation of the carotid arteries are angiography, CT angiography, and duplex ultrasound. Significant advances in imaging quality and experience with CT angiography and duplex ultrasound in the trauma population have
made these viable alternatives to angiography in patients with suspected carotid trauma. Helical CT angiography (HCTA) of the carotids with axial and reconstructed images can delineate specific injuries such as transection or thrombosis, intimal dissection, pseudoaneurysm, or arteriovenous fistula. When these findings are combined with indirect signs of penetrating vascular injury such as bone or bullet fragments within 5 mm of the vessel, trajectory through the vessel, or carotid sheath hematoma, the sensitivity of HCTA has been reported as 100%. Recent studies using newer CT scan technology reported excellent accuracy in the diagnosis of blunt carotid trauma.

The advantages and disadvantages of each investigation have been described in earlier sections. Our current imaging practice at Los Angeles County and University of Southern California Medical Center is guided by the mechanism and physical examination findings. Patients with suspected neck vascular injuries undergo CT angiography or duplex ultrasound. Angiography is reserved only for patients with shotgun injuries and those with inconclusive CT angiography or duplex ultrasound results or for therapeutic purposes, such as embolization or intravascular stenting.

**Management.** The selection of the appropriate therapeutic modality for the management of carotid injuries depends on the hemodynamic stability of the patient, the mechanism of injury (blunt vs. penetrating), the nature and severity of the vascular injury, the anatomical site of the injury, the neurological status of the patients, and associated injuries.

In penetrating trauma, although some minor carotid injuries such as small asymptomatic intimal defects or pseudoaneurysms may be managed nonoperatively, the majority of carotid injuries will require surgical repair or endovascular treatment. In blunt trauma the majority of carotid injuries are managed nonoperatively.

**Operative Management.** The patient is kept supine and in a slight Trendelenburg position with the neck extended and head rotated away from the side of injury. The patient is prepped from the chin down to the bilateral knees in anticipation of the need for a thoracic incision or saphenous vein harvest.

**Incisions and Vascular Exposure.** The most common incision for exposure of the unilateral carotid artery is a vertical oblique incision made over the anterior border of the sternocleidomastoid muscle (SCM), from the angle of the mandible to the sternoclavicular joint. Retraction of the SCM laterally will expose the internal jugular vein, with the carotid artery lying medial and deep to the vein. Mobilization of the common carotid artery is relatively easy, but care should be taken not to injure the vagus
nerve located in the posterior carotid sheath. Division of the facial vein will expose the carotid bifurcation and allow mobilization and control of the internal and external carotids. Simple lacerations of the internal jugular vein or external carotid artery may be repaired if conditions warrant, but in most cases these vessels can be ligated rapidly without significant consequence and attention turned to the carotid injury.

Some zone I injuries may be controlled and repaired through a cervical incision, but proximal zone I injuries may require extension inferiorly into a median sternotomy. Mobilization and superior retraction of the brachiocephalic veins will expose the aortic arch, brachiocephalic artery, and proximal common carotid arteries. Proximal control may be obtained with vessel loops or clamps, but care should be taken to avoid the recurrent

TABLE 5. Clinical factors associated with blunt carotid injury

<table>
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<th>Injury mechanism</th>
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<td>Severe hyperextension and rotation</td>
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<td>Severe hyperflexion</td>
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<tr>
<td>Hanging or near-hanging</td>
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<tr>
<td>Direct blow to anterior neck</td>
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<tr>
<td>Significant blunt intraoral trauma</td>
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<td><strong>Physical examination</strong></td>
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<tr>
<td>Arterial hemorrhage or expanding hematoma</td>
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<tr>
<td>Pulsatile anterior neck mass</td>
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<tr>
<td>Nonpalpable carotid or superficial temporal pulses</td>
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<tr>
<td>Carotid bruit or thrill</td>
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<tr>
<td>Anterior cervical soft tissue injury or “seatbelt sign”</td>
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<td>Horner syndrome</td>
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<tr>
<td>Cranial nerve deficit</td>
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<tr>
<td>Focal neurologic findings (cerebral or retinal ischemia)</td>
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<tr>
<td>Unexplained coma or neurologic deterioration</td>
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**Associated injuries**

| Cervical vertebral body fracture                      |
| Displaced midface or mandibular fracture              |
| Any facial fracture (odds ratio 16.8)*                |
| LeFort II or III (odds ratio 3.7)**                   |
| High risk basilar skull fracture (involving carotid canal) |
| Petrous bone fracture (odds ratio 2.6)**              |
| Traumatic brain injury                                |
| GCS < 7 (odds ratio 2.0)**                            |
| GCS ≤ 8 (odds ratio 14.8)*                            |
| Diffuse axonal injury (odds ratio 3.1)**              |
| Thoracic trauma                                       |
| Chest AIS > 3 (odds ratio 17.5)*                      |

GCS, Glasgow Coma Scale; AIS, abbreviated injury score


laryngeal nerves ascending posterior to the vessels. Zone III carotid injuries are the most difficult to obtain adequate exposure and distal control. The cervical incision should be extended superiorly into the posterior auricular area and the digastric muscle should be divided, with care taken to avoid injuring the hypoglossal, glossopharyngeal, and facial nerves. Exposure of the distal internal carotid artery may be obtained by anterior subluxation and fixation of the mandible (Fig 9), and further improved by mandibular osteotomy, excision of the styloid process, and removal of the anterior clinoid process. In the presence of ongoing and uncontrolled zone I or III hemorrhage, temporary control may be obtained by insertion of an embolectomy catheter through the arterial defect or an arteriotomy and inflation of the balloon tip.

Management of the Injured Carotid Artery. Although carotid reconstruction is indicated in most patients with penetrating trauma, there is controversy regarding reconstruction versus ligation or nonoperative management in the patient with established coma or dense contralateral neurologic deficits. Although some earlier reports warned against performing revascularization in the presence of neurologic deficits due to the concern of converting an ischemic infarct to a hemorrhagic infarct, subsequent studies suggest that the best chance for neurologic improvement in these patients is timely revascularization. Richardson and colleagues examined the results of repair or ligation in 133 patients, including 27 with preoperative neurologic deficits. All patients with preoperative weakness or paralysis improved with revascularization, and 50% of obtunded patients improved with carotid repair. Among patients undergoing ligation, 20% improved and 60% worsened or died. Robbs and colleagues reported a series of 85 patients with cervical vascular injury; 4 comatose patients in this series underwent revascularization, with no mortality and complete recovery in 3 of the 4. We believe that the best chance for neurologic recovery, even in the patient who presents in coma, is urgent revascularization unless some other contraindication to operation is present. However, the patient who has been in a prolonged (>4 hours) established coma due to a carotid injury has an extremely poor prognosis regardless of treatment, and revascularization often exacerbates cerebral edema and intracranial hypertension. In these patients we recommend performing a brain CT scan and proceeding with revascularization only if there is no infarct present.

Once adequate exposure has been obtained and the extent of injury delineated, the first decision point is whether to proceed with repair or ligate the vessel. Although most external carotid injuries may be ligated without consequence, ligation of the common or internal carotid artery
can result in devastating neurologic sequelae in the presence of inadequate collateral circulation. Carotid ligation should be reserved for the patient in whom repair is not technically possible, such as in injuries at the base of the skull or in patients with established ischemic infarction of the brain (Fig 10). In hemodynamically unstable patients placement of a temporary intraluminal carotid shunt and delayed carotid artery reconstruction should be considered.

Once the decision has been made to proceed with operative repair, the injured area is mobilized and thoroughly inspected. Intravenous heparin may be administered if there are no other sites of hemorrhage or intracranial injury, preferably before clamping the artery. Alternatively, local administration of heparin at the site of injury may be performed.
Although adequate collateral flow may be present in many patients, we have found no reliable way to assess this in the trauma setting and therefore recommend routine use of an intraluminal shunt to provide antegrade flow in all complex repairs requiring a graft. Small lacerations may be repaired primarily using an interrupted or running suture after adequate debridement of the wound edges. If primary repair will result in stenosis of the lumen, then a vein or prosthetic patch plasty of the defect is performed. Clean transections, such as stab wounds, may be repaired by mobilization of the proximal and distal artery and primary end-to-end anastomosis. These types of repair should only be performed if there is no resultant stenosis of the vessel lumen and no tension on the anastomosis after mobilization and debridement.

Many carotid injuries, particularly from GSWs, are not amenable to simple primary repair or anastomosis due to the length of vessel that is compromised. Reconstruction with either a vein or prosthetic interposition graft is indicated in most cases. Saphenous vein is the preferred conduit for reconstruction of the internal carotid artery, with some evidence of improved patency and lower infection rates compared with prosthetic graft.101-103 Alternatively, reconstruction of the proximal internal carotid may be performed by transecting the proximal external carotid artery and transposing it to the distal transected internal carotid (Fig 11). Injuries isolated to the common carotid artery are best repaired using a thin-walled polytetrafluoroethylene (PTFE) graft, which has a better size match with the native artery and excellent long-term patency rates in this location.104 An intraluminal shunt may be passed through the graft and positioned to provide antegrade flow during the distal anastomosis and removed before completing the proximal anastomosis (Fig 12). If associated injuries to the aerodigestive tract have been repaired, they should be buttressed and separated from the carotid repair by well-vascularized tissue such as a sternocleidomastoid muscle flap.105

If the injury or dissection extends into the distal internal carotid artery (zone III), exposure and repair are significantly more difficult. Neurosurgical or maxillofacial consultation may be required to assist with exposure of the internal carotid at the skull base as previously described. Ligation or catheter-assisted thrombosis of the bleeding vessel should be considered in the asymptomatic patient or if the appropriate expertise is

**FIG 10.** Gunshot wound of the internal carotid artery with complete occlusion (A) and established neurological deficits. The CT scan (B) shows an anemic infarct. Revascularization is contraindicated.
not available to perform distal revascularization. Extracranial to intracranial carotid bypass may be performed, but requires significant exposure and dissection of the intracranial carotid artery. Alternatively, saphenous vein bypass from the proximal internal carotid to the petrous carotid artery or middle cerebral artery has been reported. This technique avoids intracranial dissection of the carotid artery and has been associated with excellent associated long-term outcome and graft patency.  

**Endovascular Management.** Catheter-based endovascular techniques are particularly useful in areas that are difficult to assess and intervene via a surgical approach, such as zone I or III vascular injuries. Angiographic embolization, balloon occlusion or plasty, and stent placement may be used in the patient with a carotid artery injury as a temporizing bridge to surgical repair, or increasingly for definitive treatment of select injuries.

Angiography with possible endovascular intervention should be considered in a select group of patients and injury types: 1) hemodynamically stable patients with either physical examination or radiographic evidence of a distal internal carotid artery injury, 2) stable patients with evidence of an arteriovenous or carotid-cavernous sinus fistula, 3) ongoing facial or intraoral hemorrhage from external carotid branches, and 4) small intimal defects or pseudoaneurysms in surgically inaccessible locations or in high-risk surgical candidates (Fig 13). Further experience with the use of interventional radiology for arterial injury will help clarify the optimal indications, timing, techniques, and outcomes.

**Anticoagulation Management.** In blunt carotid artery injuries, if the lesion is surgically accessible such as a direct blow to the common carotid artery, operative repair should be undertaken for all significant lesions. In most patients the management decisions will involve whether to administer some form of anticoagulation or antiplatelet therapy and whether or not endovascular intervention is indicated. With the high rates of associated injuries, including intracranial hemorrhage, there is often an absolute or relative contraindication to anticoagulation that must be balanced against the potential benefits. There have been no randomized or prospective controlled trials of therapy for blunt carotid injury. There is class III evidence that systemic anticoagulation or antiplatelet therapy improves survival and neurological outcome.  

It seems that anticoagulation therapy is more effective in cases with carotid dissection than in cases with pseudoaneurysms. Some studies failed to show any obvious benefit from systemic heparinization. With the usual pattern of
significant associated injuries and the high reported rates of heparin-associated complications, several authors have reported the successful use of antiplatelet therapy, such as aspirin, ticlopidine, or clopidogrel.64,80,109-111

**Controversies in the Management of Blunt Carotid Trauma.** The optimal management of blunt carotid trauma (operation vs. observations vs. anticoagulation vs. antiplatelet therapy vs. endostenting) is controversial and there are still many unresolved issues. Biffl and colleagues76,113 developed a widely used grading scale that provides information about prognosis and can be used to make decisions regarding optimal management strategies. Table 6 gives a description of the blunt carotid injury grading scale. Grade I injuries healed in the majority of cases with or without anticoagulation. Only 1 of 10 grade II injuries healed with anticoagulation, with the majority (60%) progressing to grade III lesions.

(pseudoaneurysms) on repeat angiography. Almost all grade III lesions (85%) remained unchanged, with 1 of 13 healing with heparinization and no grade III lesion resolving in the untreated group. Endovascular stents were used to treat the majority of persistent grade III lesions, with an 89% initial success rate. Grade IV injuries (occlusion) remained unchanged despite anticoagulation, but none of the patients treated with heparin developed a stroke. Grade V injuries were uniformly fatal in this series, despite attempts at angiographic embolization in 2 of the 4 patients. Arteriovenous or carotid-cavernous fistulae were not addressed in this study, but the authors have suggested categorizing these lesions as grade II (insignificant) or grade V (hemodynamically significant).

The use of endovascular stents in the management of pseudoaneurysms secondary to blunt carotid injury is promising although there are some concerns about long-term results. Further studies will be required to clarify the optimal indications and techniques for stent deployment as well as the natural history of medically managed carotid pseudoaneurysms.
In the absence of level I data (prospective, randomized study) regarding treatment of these injuries, management decisions must be based on the injury pattern, associated injuries, clinical condition of the patient, and the currently available literature. Our policy is to repair operatively all significant carotid injuries that are surgically accessible, with the exception of asymptomatic grade I lesions or patients with established neurological deficits. Anticoagulation with heparin to maintain a partial thromboplastin time of 40 to 60 seconds is used as the primary therapy for grade I through IV lesions, with antiplatelet agents used as second line therapy if heparin is contraindicated. Angioembolization or balloon occlusion is performed for control of distal arterial bleeding or arteriovenous fistulae. Selected lesions may be managed with placement of a carotid stent. Persistent pseudoaneurysms or lesions with worsening neurologic deficits despite anticoagulation may be considered for operative intervention skull base or intracranial dissection and repair.82

Prognosis and Outcomes. The outcome following carotid artery injury will be influenced by many factors, including: the mechanism of injury, the location and extent of carotid injury, the presence of associated injuries, prehospital and emergency department management, the patient age and comorbid conditions, and the time to definitive management.
The reported mortality rate from penetrating carotid artery injury is as high as 66%, with many patients dying before reaching medical care and a 10% to 20% mortality rate among those who survive to hospital admission.81 One of the strongest predictors of outcome is the presence or absence of neurologic deficits at presentation. Patients who present with a normal neurologic examination have an excellent prognosis, whether undergoing surgical repair of a significant injury or observation for minor injuries.116,117 Navsaria and colleagues69 reported 32 surgically managed carotid injuries and found a postoperative GCS of 15 and no focal neurologic deficits in 100% of patients who were neurologically intact at presentation. Neurologic deficits may be present in 14% of common carotid and 23% of internal carotid artery injuries.95 In a series of 38 patients with penetrating injury to the internal carotid artery the mortality rate was 18% overall, 20% in the presence of neurologic deficits at admission, and 57% among patients presenting with coma.118 Of the 5 patients who presented with lateralizing neurologic deficits, 2 deteriorated significantly and 1 died of irreversible brain damage.

The surgical management also appears to have a significant impact on neurologic outcome and mortality. Among patients with significant penetrating carotid injuries, arterial repair or reconstruction appears to be associated with improved neurologic outcomes compared with observation of a thrombosed vessel or ligation. Weaver and colleagues119 graded the neurologic outcome among 80 patients with carotid injuries using a Carotid Neurologic Score (CNS). The CNS was significantly higher among the 54 patients undergoing revascularization compared with the 18 patients who had ligation or nonoperative management of an occluded vessel, regardless of the initial

### TABLE 6. Blunt carotid injury grading scale and associated mortality and stroke rates

<table>
<thead>
<tr>
<th>Grade</th>
<th>Description</th>
<th>Severe head injury</th>
<th>Mortality</th>
<th>Stroke</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>luminal irregularity or dissection with &lt;25% narrowing</td>
<td>56%</td>
<td>11%</td>
<td>3%</td>
</tr>
<tr>
<td>II</td>
<td>dissection or hematoma with ≥25% narrowing, intraluminal thrombus, or raised intimal flap, or small AVF</td>
<td>33%</td>
<td>11%</td>
<td>11%</td>
</tr>
<tr>
<td>III</td>
<td>pseudoaneurysm</td>
<td>44%</td>
<td>11%</td>
<td>33%</td>
</tr>
<tr>
<td>IV</td>
<td>occlusion</td>
<td>56%</td>
<td>22%</td>
<td>44%</td>
</tr>
<tr>
<td>V</td>
<td>transection with extravasation or hemodynamically significant AVF</td>
<td>75%</td>
<td>100%</td>
<td>100%</td>
</tr>
</tbody>
</table>


AVF, Arteriovenous fistula.
neurologic presentation. Another series of 151 patients with penetrating injury to the extracranial cerebral vessels found an 18% mortality rate and a 12% stroke rate among patients undergoing revascularization versus a 45% mortality rate and 18% stroke rate with ligation.\textsuperscript{101} Other factors associated with worse short-term outcomes were injury to the internal carotid artery, complete arterial transection, hemodynamic instability, airway compromise, and associated aerodigestive injury. The long-term outcome and patency rates following penetrating carotid artery injuries remain unknown.

The outcome following blunt carotid artery injury will depend on a variety of factors, including the injury mechanism, injury grade, patient factors, presence and severity of associated injuries, and whether neurologic symptoms are present. Overall, blunt carotid injury has a 20% to 43% associated mortality rate and significant neurologic morbidity may occur in up to 58% of survivors.\textsuperscript{64,80,120} Table 6 lists the associated stroke and mortality rates by grade of injury, with mortality ranging from 11% with small dissections to 100% with carotid rupture. The outcome may also vary by the location of injury. McKevitt and colleagues\textsuperscript{79} demonstrated significantly worse outcomes among patients with injury to the intracranial portion of the internal carotid artery compared with those with extracranial injury. The mortality rate was 67% in the intracranial group versus 31% with extracranial injury, with lower neurologic scores following intracranial carotid injury.

We have recently completed an analysis of 570 blunt carotid injuries from the National Trauma Data Bank\textsuperscript{TM} and found that only 33% of survivors were functionally normal (for feeding, locomotion, and expression) at the time of discharge.\textsuperscript{77}

**Vertebral Artery Injuries**

Clinically significant vertebral artery injuries are fortunately rare. For actively bleeding arteries, obtain proximal and distal control either surgically or with interventional radiology. For stable asymptomatic injuries found on radiographic evaluation, stenting, embolization, or anticoagulation therapy is appropriate. For thrombosed vertebral arteries, observation is warranted. These injured vessels are rarely repaired or bypassed unless it has been documented that there are no collaterals in the brain.

**Epidemiologic Features.** The true incidence rate in trauma is unknown but with improved diagnostic capability, we are identifying injuries more often. The most frequent cause is from GSWs since the human body has not evolved to protect this structure from this type of force. In a
prospective study of 223 patients with penetrating neck injuries, Demetriades and colleagues identified 13 (7.4%) patients with a vertebral artery injury out of 176 patients who underwent angiography. Injuries from stab wounds are much less common; Golueke and colleagues reported 23 patients with vertebral artery injuries over a 65-month period from a busy urban trauma center, but only 2 were from stab wounds. However, 1 of the largest series of vertebral artery injuries reported was from Cape Town, South Africa, and it reported 101 injuries over 7 years. In this series, 51 of the 92 penetrating vertebral artery injuries were from stab wounds.

Vertebral artery injuries following blunt trauma is much less common. A report from a prospective database that was kept on blunt trauma patients aggressively screened with angiography only identified 92 (0.7% of blunt trauma admissions) patients over 78 months. This group found that from 650 angiograms, the vertebral artery was injured 15% of the time. Vertebral artery injuries following blunt assaults are extremely rare and are mostly case reports. The remainder of reported vertebral artery injuries are from various causes including chiropractic manipulation, cervical spine surgery, venous catheter placements, sports injuries, and spontaneous dissections. Since the majority of these injuries are probably asymptomatic, the true incidence is unknown and mostly depends on the aggressiveness of screening and method used to identify the injury. For instance, using magnetic resonance imaging (MRI) of cervical spine fractures in 47 patients studied prospectively identified vertebral artery injury in 25% of those studied.

Anatomic Features. The vertebral artery is the first branch of the subclavian artery. Its takeoff is on the dorsosuperior aspect of the ascending subclavian artery (Fig 14). The left vertebral artery originates on the left side directly from the aorta on occasion (5%). The vertebral artery has 4 segments: 1) from the origin it goes anterior to the transverse process of C7 and enters the vertebral foramen at C6 but sometimes at a higher level, 2) from C6 to C2, 3) from C2 to the atlantooccipital membrane through the foramen magnum, and 4) intracranial segment to the basilar artery. In the cranium, it gives off a number of branches before finally uniting with its fellow artery from the other side to form the basilar artery. The basilar artery then joins the circle of Willis. The circle of Willis is not always standard. In a recent study using MR angiography, the circle of Willis was noted to be present in only 42% of randomly selected adults.

Clinical Presentation in the Emergency Department and Management. For blunt trauma the patients are often asymptomatic and the diagnosis is
established by radiographic evaluation. In penetrating trauma the patient may be asymptomatic due to thrombosis of the artery or have signs of active bleeding. A bruit on auscultation or a thrill on palpation can sometimes be found and is highly suggestive of vascular injury.

**Investigations.** Plain radiographs can be useful to identify and locate foreign bodies such as bullets and to determine if additional radiographic evaluation is needed. However, if it is certain that the patient is going to undergo CT angiogram or angiography, the plain radiographs can be superfluous. Computed tomography has become a useful screening tool because it is readily available and noninvasive. With the continued evolution of helical CT angiography, it is the screening modality of choice for penetrating injury of the neck. Color flow Doppler may be a useful screening investigation for vertebral artery injuries. Its strengths and weaknesses have been described in previous sections. Angiography is currently the gold standard for diagnosing vertebral artery injury, but it can also be therapeutic (Fig 15). Due to its invasive nature, we reserve it only for selected groups of patients with nondiagnostic CFD or CT angiography or for therapeutic purposes.

**Operative Management.** Operative management is almost always necessary when there is severe active bleeding from the vertebral artery. The head is turned away from the injured site and the neck is slightly extended. A generous incision is made on the anterior border of the sternocleidomastoid muscle. The fascia is incised and the SCM is retracted laterally. The omohyoid muscle is divided and the carotid sheath is exposed and retracted laterally or medially while the midline structures are retracted medially. A tissue plane will then be encountered that is anterior to the prevertebral muscles. This is opened but care must be taken at this stage because the ganglia of the cervical sympathetic chain is located there. Next the anterior longitudinal ligament is encountered and incised longitudinally. At this stage, the transverse processes are palpated and the overlying longus coli and the longissimus capitis muscle should be mobilized laterally with a periosteal elevator. The anterior aspect of the vertebral foramen is then best removed with rongeurs to expose the underlying vertebral artery (Fig 16). The artery can then be ligated. It should be kept in mind that the cervical roots are just behind the artery and care should be taken not to injure them and blind clamping or clipping should be avoided. Although the artery can be identified between the transverse processes, the venous plexuses can be troublesome and should be avoided.

Another option for rapid control of the proximal artery is to approach it at the base of the neck where the vertebral artery comes off the subclavian
artery. This can be performed 2 ways. The first method is to extend the incision toward the clavicle and transect the sternocleidomastoid muscle off the clavicle, retract the subclavian vein caudal, and transect or retract the anterior scalene muscle laterally. Medial to this muscle is the first portion of the subclavian artery and it gives off the vertebral artery, the thyrocervical trunk, and the internal mammary artery. The vertebral artery comes off the dorsosuperior aspect of the ascending subclavian artery. When approaching the left vertebral artery, care should be taken not to injure the thoracic duct. The second method is to cut down directly on the

FIG 14. The vertebral artery (VA) is the first branch of the subclavian artery. Its takeoff is on the dorsosuperior aspect of the ascending subclavian artery. (Color version of figure is available online.)

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clavicle and open the periostium. The clavicle can be disarticulated at the sternal border and sections cut or moved out of the way with towel clamps as a handle. If experienced this is a rapid way of identifying the artery.

When dealing with an active bleeding vertebral artery and obtaining vascular control is difficult, damage control surgery in the neck with packing is an option if bleeding can be controlled in this manner.\textsuperscript{130,131} The collaterals are usually sufficient to not cause an ischemic stroke. The repair of the vertebral artery in the acute setting is extremely difficult and is not usually attempted.

**Prognosis.** With a multidisciplinary approach the prognosis in isolated vertebral artery injuries is good and the mortality rate is approximately 4%. Since most of the clinically silent injuries are initially undiagnosed or not treated, some patients return months or years later with complications such as arteriovenous fistula, false aneurysms, or neurological deficits. It is advisable that untreated patients are monitored for late complications.

**Subclavian Vascular Injuries**

Injuries to the subclavian vessels are fairly uncommon and most surgeons have limited experience with them. The surgical exposure of

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**FIG 15.** Traumatic arteriovenous fistula involving the vertebral artery, successfully managed with angiographic embolization. (From Demetriades D. Vertebral Artery Injuries. Surg Clin North Am 2001;81:1345-55.)
these vessels, especially in the presence of active bleeding, can be very
difficult and may challenge the skills of any experienced surgeon.

Anatomic Features. Detailed knowledge of the anatomy is critical for
the surgical exposure of the subclavian vessels (Fig 17). The right
subclavian artery originates from the brachiocephalic (innominate) artery
and the left subclavian originates directly from the aortic arch. In some
patients the right subclavian artery may originate directly from the aortic
arch or have a common trunk with the right carotid artery. The artery is
divided by the scalenus anterior muscle into 3 parts. The first part is
located medial to the anterior scalenus muscle and is under the sternocleidomastoid and the strap muscles. It gives the vertebral artery, the
thyrocervical trunk, and the internal mammary artery. The second part of
the artery lies on top of the middle and upper trunks of the brachial
plexus, under the scalenus anterior muscle, and gives the costocervical
artery. The third part is situated lateral to the scalenus anterior muscle,
over the lower trunk of the brachial plexus, and gives no constant branches. The subclavian artery continues as the axillary artery at the middle of the clavicle. The subclavian vein is found in front and below the artery, over the anterior scalenus muscle.

**Epidemiologic Features.** Most subclavian and axillary vascular injuries are due to penetrating trauma. Overall, 3.5% of GSWs and 1.5% of stab wounds to the neck are associated with subclavian vascular injuries. In approximately 20% of patients with subclavian vascular injuries, both the artery and vein are injured.\(^{132,133}\) Blunt trauma to these vessels is rare. Fractures of the first rib or clavicle have been described to be associated with an increased risk of vascular trauma. Richardson and colleagues\(^ {134}\) reported 3 subclavian artery injuries (5.5%) in a study of 55 patients with first rib fractures. A review of 466 patients with clavicular fractures from our center showed only 1 case of subclavian vascular trauma (0.4%).

**Clinical Presentation.** Many victims with subclavian vascular injuries die before reaching medical care. In a study of 228 patients with subclavian vascular injuries, 61% were dead before arrival to the hospital.\(^ {135}\) In another study of 79 patients with subclavian or axillary vascular injuries, 23% were dead or near death on arrival to the hospital.\(^ {132}\) Only selected patients with short prehospital times and contained hemorrhage due to thrombosis or local hematoma reach the hospital in fairly stable condition.

All patients with periclavicular trauma should be evaluated for vascular trauma. Hard signs that are diagnostic of vascular injury include severe bleeding, unexplained shock or anemia, large expanding hematoma, absent or diminished radial pulse, and a bruit on auscultation. Soft signs suspicious of vascular trauma include a local stable hematoma, small continuous bleeding, mild hypotension or anemia, and a proximity injury. The presence of a peripheral pulse does not reliably exclude significant proximal arterial trauma. The Ankle Brachial Index (ABI) is useful and should be obtained in all stable patients with suspected subclavian or axillary artery injury. An abnormal ABI (<0.9) is diagnostic or highly suspicious of arterial injury. However, in our experience some significant subclavian or axillary artery injuries may be associated with a normal ABI.

Due to the close anatomical relationship of the neurovascular structures, the brachial plexus is injured in approximately one third of patients with subclavian vascular trauma.\(^ {132}\) Associated intrathoracic injuries are found in approximately 28% of patients.\(^ {132}\)

**Investigations.** Specific investigations such as CT scan, Doppler studies, or angiography should be reserved only for stable patients. In the
presence of severe hypotension or major active bleeding or a threatened limb, the patient should undergo emergency surgery. Plain chest and neck radiographs should be obtained whenever the hemodynamic condition of the patient permits it. The radiographs may show an associated hemothorax, missiles, a mediastinal hematoma, or fractures.

In our center, CFD is the first line of specific investigations and has largely replaced diagnostic angiography in most hemodynamically stable patients. It is noninvasive and is reliable in assessing both arterial and venous injuries. However, it has some limitations in visualizing the origin of the left subclavian artery, especially in obese patients, and is operator dependent. If the study is suboptimal further evaluation by other means should be performed.

Diagnostic angiography may be considered in cases in which CFD is not available or not diagnostic. Such cases include blunt trauma, suspected mediastinal vascular injuries, shotgun injuries, and inadequate visualization by CFD. Therapeutic angiography should be considered in selected cases in which stenting may be possible, such as false aneurysms, arteriovenous fistula, and stenosis (Fig 18).

**Emergency Room Management.** The initial assessment and management should follow the standard ATLS protocols and have been described earlier in this chapter in detail. Intravenous lines should always be inserted in the contralateral arm because of the possibility of a subclavian venous injury. In some cases external bleeding may be controlled by

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**FIG 17.** Anatomy of the subclavian vessels.
direct pressure over the wound. However, if the bleeding from a vessel behind the clavicle cannot be controlled by direct compression, the balloon tamponade technique described above may be helpful. More than 20% of patients with subclavian or axillary vascular injuries reach the hospital with no vital signs or with imminent cardiac arrest due to massive blood loss. These patients should be intubated and have an emergency room thoracotomy performed without any delay, as described above. The bleeding may be controlled by direct pressure, externally, or through the thoracotomy in the apex of the hemithorax (Fig 19).

**Operative Management.**

**Incisions.** The patient is placed in the supine position with the arm abducted at 30° and the head turned to the opposite side. Excessive abduction should be avoided because it distorts the local anatomy and makes the exposure more difficult. The chest and the groins should always be included in the preparation of the surgical field. The standard incision for subclavian and proximal axillary vessels starts at the sternoclavicular junction, extends over the medial half of the clavicle, and at the middle of clavicle it curves downward over the deltopectoral groove (Fig 20). For proximal subclavian injuries the described clavicular incision should be combined with a median sternotomy. This combination provides an excellent exposure for both left and right proximal injuries. It has been proposed that for left proximal subclavian artery injuries a “trap door” incision (Fig 21) is preferable to the clavicular/median sternotomy approach. This approach includes a clavicular incision, an upper median sternotomy, and an anterior left thoracotomy through the third of fourth intercostal space. This complex approach can not be supported by either the quality of surgical exposure or the associated complications. The trap-door incision is associated with significant bleeding because it involves the division of thick muscles, severe postoperative pain because of iatrogenic rib fractures, and a higher incidence of respiratory complications because of pain and the violation of the pleural cavity.

**Vascular Exposure.** For adequate exposure of the subclavian and proximal axillary vessels, the medial half of the clavicle should be excised or divided. In a first step, the medial part of the clavicle is stripped of the attachments of the platysma, the sternocleidomastoid, the pectoralis major, and the subclavius muscle. This is best accomplished with the help of a periosteal elevator and Doyen’s instruments. The retroclavicular space is then exposed by either removing the medial half of the clavicle or by dividing and retracting the clavicle or by disarticulating and retracting the clavicle at its attachment to the sternum (Fig 21). The retroclavicular tissues are then dissected carefully, avoiding injuries to the
brachial plexus, and the vessels are identified. The subclavian vein lies superficially and inferior to the artery. The artery is located fairly deep and in the absence of pulsation due to thrombosis or retraction of the transected ends it might be difficult to be found. For exposure of the first part of the subclavian artery a median sternotomy should be added to the clavicular incision. The anterior scalenus muscle must be retracted or divided, taking precautions not to injure the phrenic nerve, which lies on the anterior surface of the muscle.

Management of the Injured Vessel. Simple repair or debridement and end-to-end anastomosis may be possible in some injuries. However, in most GSWs or blunt trauma an interposition graft is usually required. The choice of graft (autologous vein or PTFE graft) is a matter of personal preference, availability of suitable size vein, and the general condition of the patient. There is no evidence of superiority of 1 over the other. The authors prefer a PTFE graft because of speed and convenience.

Ligation of the subclavian artery should never be considered, even in critically ill patients. Although ligation may be tolerated by some patients, in many others it results in ischemia and deterioration of the general condition of the patient. Temporary shunting with definitive repair at a later stage should be considered, instead of arterial ligation.

Venous injury repair should be considered only if it can be performed by simple suturing without producing severe stenosis and without the use of any complex reconstruction techniques, such as autologous grafts or patches. Ligation of the vein is usually well tolerated by almost all patients and there is no evidence that complex reconstruction reduces the probability of development of compartment syndrome. Following ligation, the patient often develops transient edema, which subsides within a few days.

In patients with arterial injury and prolonged limb ischemia, especially in the presence of associated venous trauma, perioperative administration of mannitol (0.5-1 g/kg) may prevent the development of compartment syndrome and avoid the need for fasciotomy. Mannitol is contraindicated in the presence of hypotension or uncontrolled bleeding.

The role of prophylactic upper extremity fasciotomy is controversial, with many authors recommending liberal use and others recommending fasciotomy on demand. The authors advocate against routine prophylactic fasciotomy because most patients do not need it, it is associated with significant morbidity and prolonged hospital stay, and there is good evidence that fasciotomy on demand is safe.

Wound Closure. After the definitive management of the vascular injury the divided muscles and clavicle should be reconstructed. A divided or
disarticulated clavicle is wired back in place, mainly for cosmetic reasons. Complete excision of the medial part of the clavicle does not result in functional disability, although the esthetic outcome is inferior to reconstruction. Partial regeneration of the bone may occur many months after the resection, in cases with subperiosteal excision of the clavicle.

The pectoralis major and minor muscles are repaired with heavy absorbable sutures and the rest of the wound is closed in layers over a closed drain.

**Prognosis.** The mortality of penetrating subclavian vascular injuries is high and many patients die before reaching medical care. In a series of 228 patients with subclavian vascular injuries, the overall mortality rate, including deaths at the scene, was 66%. Those reaching the operating room had a mortality rate of 15.5%. In a more recent study from Los Angeles the overall mortality rate for all patients reaching the hospital was 34.2% and of those reaching the operating room the mortality rate was 14.8%. There is evidence that venous injuries are associated with a higher mortality rate than arterial injuries. It is possible that venous injuries tend to bleed more because of the inability of the veins to

![FIG 19. The bleeding from the left subclavian artery may be controlled in the apex of the hemithorax through a left thoracotomy. (Color version of figure is available online.)](image-url)
constrict like transected arteries. Fatal air embolism is another potentially fatal complication associated with venous injuries.

**Role of Interventional Radiology.** Endovascular stent-grafts have been used successfully in selected patients with subclavian artery injuries. The ideal candidates are stable patients with false aneurysms, arteriovenous fistula, or arterial stenosis (Fig 18). This treatment modality has been used successfully in both penetrating and blunt trauma.\(^{140,141}\)

**Laryngotracheal Injuries**

Injuries to the larynx and trachea resulting from trauma are fairly uncommon. However, because of the risk of airway compromise, prompt diagnosis and intervention is mandatory. Although certain injuries to the larynx and trachea may be managed nonoperatively, the vast majority require early operative intervention.
**Anatomic Features.** The larynx is a continuation of the trachea. It has a specialized constrictor function that prevents aspiration of foreign material into the lower airway; and it also houses the vocal cords, which are responsible for phonation. The laryngeal skeleton is made up of the epiglottis, thyroid cartilage, cricoid cartilage, and hyoid bone, which are all, with the exception of the epiglottis, palpable in the anterior midline of the neck. The epiglottis, which attaches to the hyoid bone and thyroid cartilage, is an unpaired cartilage that forms the anterior border of the laryngeal inlet. The thyroid cartilage provides a fulcrum to which the vocal cords attach, thus making it very important to restore its normal anatomy and angulation during repair of injuries. The cricoid cartilage is the strongest cartilage and forms a complete ring immediately inferior to the vocal cords. Maintaining the shape and diameter of this cartilage is important in preventing subglottic stenosis.

**Epidemiologic Features.** Laryngotracheal injuries occur infrequently, accounting for only 1 per 30,000 emergency room visits. The majority of injuries are due to penetrating mechanisms. In a prospective study of 223 patients with penetrating injuries to the neck, laryngotracheal injuries were...
encountered in only 5 patients (2.2%). In a retrospective review over a 5-year period of 811 patients with penetrating neck injuries, 30 patients (3.7%) were found to have laryngotracheal injuries. Grewal and colleagues similarly found the incidence to be 4% in patients with penetrating neck injuries. Blunt trauma to the neck is a very uncommon cause of laryngotracheal injury, accounting for less than 1% of blunt trauma admissions. In a review of 11,663 patients with blunt trauma, laryngotracheal injuries were found in only 40 patients (0.34%). Blunt injuries often result from different mechanisms: direct blow to the anterior neck, deceleration injuries such as in high-speed traffic accidents, and anteroposterior crushing injuries to the chest with a sudden increase of the intratracheal pressure against a closed glottis, causing a linear rupture of the posterior membranous trachea.

**Clinical Presentation.** Laryngotracheal injuries vary from subtle disorders of vocal cord function to lacerations and fractures of the laryngotracheal skeleton. This corresponds to a varying spectrum of clinical presentations from dysphonia to stridor and impending airway obstruction. The mainstay of diagnosis is a careful clinical examination, which in awake, alert, clinically evaluable patients, can reliably diagnose or exclude injuries.

Air bubbling through a penetrating neck wound is the only hard sign diagnostic of laryngotracheal trauma. This finding is confirmed by asking the patient to cough. Other signs and symptoms seen with both blunt and penetrating injuries include subcutaneous emphysema, hemoptysis, odynophagia, hoarseness, and dyspnea. Tenderness on palpation, cervical ecchymosis, or hematoma may be suggestive of laryngotracheal injury in patients with blunt trauma. Although rare, cricotracheal separation may manifest with a triad of cervical ecchymosis, aphonia, and subcutaneous emphysema.

In the absence of any clinical findings suspicious for laryngotracheal injuries, it is highly unlikely that a significant injury exists. In a prospective study of 223 patients with penetrating trauma at the authors’ institution, 152 patients were awake, alert, and had no symptoms of aerodigestive tract injuries. None of these patients had significant injury requiring treatment. In summary, in awake, alert, and clinically evaluable patients, physical examination will identify or highly suggest all significant laryngotracheal injuries.

**Investigations.** Chest and neck radiographs may reveal subcutaneous emphysema, foreign bodies, spinal fractures, pneumothoraces, and tracheal deviation due to compressing hematomas. Triple endoscopy (laryngoscopy, bronchoscopy, and esophagoscopy) is mandatory for all stable
patients with penetrating neck wounds suspected of having upper airway injury.

In patients with suspected blunt laryngotracheal trauma, in addition to fiberoptic endoscopy, a CT scan of the cervical region is extremely valuable for the evaluation of the structures of the larynx and diagnosis of fractures or dislocations of the hyoid, arytenoids, and thyroid cartilages. CT scanning is also useful in identifying bullet trajectory in patients with penetrating wounds to the neck and may select patients who might benefit from further endoscopic or contrast swallow studies. If the bullet tract is away from the aerodigestive organs, no further investigations are required.

**Emergency Room Management.** The timing and method of airway control and the advantages and disadvantages of each method have been discussed extensively previously.

**Management.**

**Nonoperative Management.** Many patients with isolated minor blunt laryngotracheal trauma, such as minimal intralaryngeal injuries, nondisplaced fractures of the laryngotracheal skeleton, minor laryngeal mucosal lacerations, and lacerations of the trachea that are less than one third the circumference of the trachea, can safely be managed nonoperatively. In a study of 23 children with blunt laryngotracheal trauma reported by Gold and colleagues, 18 (78%) were successfully managed nonoperatively. In the 40 patients with blunt laryngotracheal trauma from the authors’ institution, 23 (57.5%) were managed successfully nonoperatively. Similarly, penetrating trauma small tracheal wounds with no tissue loss and well opposed edges, as documented by fiberoptic endoscopy, can be safely observed. In the prospective study of 223 patients with penetrating neck injuries at the authors’ institution, 80% of patients with abnormal endoscopic findings were successfully managed nonoperatively.

Nonoperative management requires close observation, probably in an intensive care unit, and serial endoscopy. The role of steroids in reducing posttraumatic laryngeal edema is controversial, as is the use of prophylactic antibiotics. With nonoperative management of appropriate injuries, good results in terms of voice quality and airway patency is expected.

**Operative Management.** A collar incision, approximately 2 cm above the sternal notch, gives the best exposure to the larynx. Patients with significant endolaryngeal injuries require a midline thyrotomy. Detailed description of the technical aspects in the management of these injuries are outside the scope of this monograph.

For patients with proximal tracheal injuries, a transverse collar or an anterior sternocleidomastoid incision is appropriate. For more distal
tracheal injuries, a median sternotomy may be necessary. For injuries in the distal third of the trachea, or injuries at the carina, a right posterolateral thoracotomy is the preferred approach. Small tracheal wounds are primarily repaired with interrupted 3-0 synthetic absorbable sutures. This seems to carry the least risk of granuloma formation. The usefulness of a prophylactic tracheostomy in these simple repairs is debatable, and probably not necessary.\textsuperscript{149,150} It may actually increase the infection-related morbidity rate.\textsuperscript{149} In our center, tracheostomies are only placed in patients with extensive tracheal injuries.

More complex and extensive tracheal injuries require individualized surgical technique. It is essential to achieve a tension-free, well-vascularized, mucosa-to-mucosa anastomosis. The blood supply to the trachea runs in the lateral aspects so that mobilization should be performed by anterior and sometimes posterior dissection. If the total length of damaged or debrided trachea is less than 2 or 3 cm, reapproximation of the free edges with interrupted absorbable suture without tension is feasible.\textsuperscript{11} For larger defects more complicated release maneuvers may be necessary. Thyroid or suprahypoid release, with flexion of the neck can provide up to 6 cm of further mobilization.\textsuperscript{11,151} Flexion of the neck is then maintained for 1 week postoperatively by securing a stitch from the chin to the preternal skin. Retention submucosal sutures can also reduce anastomotic tension.\textsuperscript{151} When wound closure cannot be achieved because of extensive defects, musculofascial flaps or synthetic material can be used.\textsuperscript{152,153} Tracheostomy alone is reserved for large anterior wounds or in cases in which the patient’s instability prohibits prolonged surgical exploration and tracheal reconstruction is postponed for a later time.\textsuperscript{11,144}

**Prognosis.** The mortality rate from laryngotracheal injuries is quite low, with deaths usually arising from associated vascular injuries. In a study of 1560 patients with blunt and penetrating neck injuries, there was no mortality due to the aerodigestive injuries.\textsuperscript{13} The prognosis for minor and moderate laryngotracheal injuries is excellent. In severe injuries that require complex repair or stents, the outcome is much worse. Patients may develop dysphonia, vocal fatigue, granulation tissue formation, glottic or subglottic stenosis, and late stricture formation. Delayed repair of significant injuries is also associated with poor outcome.

**Pharyngoesophageal Injuries**

**Epidemiologic Features.** Pharyngoesophageal injuries are rare. In a multicenter study involving 34 trauma centers over a 10.5-year period, 229 patients were identified with cervical esophageal injuries. This equates to 0.64 cases per year per institution.\textsuperscript{154} In our institution, we
identified 49 (2.8%) pharyngoesophageal injuries out of 1560 blunt and penetrating neck injuries over 5 years.\textsuperscript{13}

\textbf{Anatomic Features.} The pharynx begins at the base of the skull and terminates approximately 12 cm at the level of the lower border of the cricoid cartilage. The esophagus begins at the cricopharyngeus muscle at the level of C6 posteriorly and the cricoid cartilage anteriorly. The cervical esophagus extends for 5 to 6 cm to the T1 level.

\textbf{Clinical Presentation in the Emergency Department and Management.} Fortunately, pharyngoesophageal injuries are not immediately life-threatening. Since the neck is condensed with vital structures, associated injuries are the rule and they take higher priority. The first and most urgent priority is to ensure an adequate airway.

There are no hard signs diagnostic of pharyngoesophageal injuries; soft signs suggestive of pharyngoesophageal include odynophagia, subcutaneous emphysema, or hematemesis or hemoptysis.\textsuperscript{41} These symptoms are present in approximately 23\% of patients with PNI and they are not specific. Only approximately 18\% of patients with these findings have pharyngoesophageal trauma.\textsuperscript{1} In the complete absence of 1 of these findings including the absence of subcutaneous emphysema on radiologic evaluation, it is highly unlikely that the patient has an injury requiring treatment.\textsuperscript{1}

\textbf{Investigations.} Plain radiographs of the neck may show foreign bodies, spinal fractures, subcutaneous emphysema, peri and retropharyngeal air, pneumothorax, pneumomediastinum, and tracheal deviation from a compressing hematoma. These findings should prompt further evaluation. CT scan, endoscopy, and contrast swallow studies may be indicated in suspected pharyngoesophageal injuries.

\textbf{Operative Management.} A sternomastoid and occasionally transverse incision provide a good exposure to the pharynx and cervical esophagus. The investing fascia of the sternocleomastoid muscle is incised and retracted laterally. The omohyoid muscle is located in the pretracheal fascia and this can either be retracted or divided. The carotid sheath is mobilized and retracted laterally while the trachea and thyroid are retracted medially. The inferior thyroid artery and middle thyroid vein may be divided. Care should be taken to avoid injury to the recurrent laryngeal nerves located in the tracheoesophageal groove. Identification of this nerve is important if circumferential mobilization of the esophagus is needed. When small wounds are suspected, the nasogastric tube or a Foley catheter inserted into the back of the pharynx can be insufflated with air to look for bubbling. An alternative is to infuse fluid with methylene blue, but this risks aspiration even with the endotracheal tube
in place. During the insufflation of air, the distal esophagus should be manually compressed.

Most wounds are repaired in 1 layer with 3-0 or 4-0 absorbable suture. For stabbing injuries, debridement is usually not necessary, but for GSWs it is most often the rule but it should not be overly aggressive. The strap muscles should be placed between tracheal and vascular injuries if possible. The wound is irrigated and closed over a drain.

Early surgical repair of esophageal injuries reduces septic complications and leaks. Velmahos and colleagues\textsuperscript{155} showed that in a study of 119 patients no deaths occurred in those patients treated within 24 hours. In this study 11 patients with delayed (more than 24 hours) treatment, 36\% died due to uncontrollable sepsis. Others have also reported that deaths were all associated with delayed repair.\textsuperscript{156} In neglected injuries requiring debridement a T-tube drainage is an option.\textsuperscript{157,158} This technique can convert the injury to a controlled fistula.\textsuperscript{159} Esophagectomy in the acute setting is rare and external diversion or exclusion is usually reserved for injuries with infection and abscess due to late presentation.

\textbf{Prognosis.} Injuries to the pharynx or cervical esophagus have an excellent prognosis, if treated timely. Most complications, such as leaks or abscesses, are usually successfully managed with drainage and antibiotics.

\textbf{Thoracic Duct Injuries}

Injuries to the thoracic duct are exceedingly rare and are usually seen in left-sided penetrating injuries to zone I.

\textbf{Anatomic Features.} The thoracic duct is the primary lymphatic vessel that returns lymph to the venous bloodstream from all of the lymphatic vessels of the body with the exception of the right chest, right upper extremity, and right side of the head and neck. The thoracic duct begins in the upper abdomen as a dilated structure, the cisterna chyle, located on the anterior surface of the first or second lumbar vertebral body. The duct passes through the aortic hiatus and ascends through the chest in the posterior mediastinum between the aorta and the azygos vein. It then crosses over to the left side of the esophagus at the level of the fifth thoracic vertebra and continues to ascend until it reaches the root of the neck, just anterior to the left subclavian artery. At the root of the neck, the duct is bordered anteriorly by the carotid sheath, laterally by the omohyoid muscle, posteriorly by the prevertebral fascia, and medially by the cervical esophagus. The duct then arches laterally, anterior to the anterior scalene muscle and phrenic nerve, and then inferiorly to termi-
nate into the venous system within 1 cm of the angle formed by the junction of the left subclavian vein and the left internal jugular vein.

**Epidemiologic Features.** Thoracic duct injuries from neck trauma are rare and data concerning the incidence is not well known. Most injuries are due to penetrating trauma and are often associated with cervical vascular injuries, most notably subclavian vascular and internal jugular venous injuries. In a review of the literature, Whiteford and colleagues reported 71 cases of thoracic duct injury in penetrating neck trauma for an incidence of 0.9%. Blunt trauma to the thoracic duct is even more rare. It occurs as a result of either laceration from clavicular fractures or as a result of stretching and tearing of the duct from sudden flexion/hyperextension injuries of the cervical spine.

**Clinical Presentation.** Injuries to the thoracic duct are often encountered during neck exploration where chylous fluid may be noted in the surgical field. Alternatively, injuries can manifest as chylous leaks from either the surgical wound or drain in the early postoperative period, or from the penetrating wound itself if no exploration was performed. In cases in which the pleural cavity was violated, injuries can manifest as chylothoraces. Rarely, injuries can manifest in a delayed fashion as cervical chylomas.

When drainage does not have the characteristic milky appearance, laboratory analysis of the fluid can confirm the diagnosis. A total protein level greater than 3 g/dL, a total fat content between 0.4 and 4.0 g/dL, a triglyceride level of more than 200 mg/dL, and a marked lymphocytic predominance in the white blood cell count of the fluid are virtually diagnostic of thoracic duct injury.

**Investigations.** Specific investigations for the thoracic duct are routinely not necessary. The diagnosis of an injury is made clinically in the operating room, or in the early postoperative period. If the diagnosis is in question, or if an injury must be localized for operative repair, then lymphoscintigraphy, lymphangiography, and CT have all been used to image duct injury.

**Conservative Management.** Injuries to the thoracic duct that are identified as persistent drainage from wounds, drains, or as chylothoraces respond very well to conservative treatment. Low fat diets or diets with medium chain triglycerides can reduce the amount of chyle produced, which can precipitate effective resolution of the chylous leak. If this does not decrease the amount of chyle leak, then total parenteral nutrition should help heal the fistula. Somatostatin, or its analog octreotide, has been shown to reduce thoracic duct flow and has been used with success in the management of persistent chylous fistulae.
Operative Management. Surgical intervention is rarely necessary, but should be considered in patients with persistent major leaks (greater than 2 weeks) with no signs of improvement. Several options are available for the management of thoracic duct leaks with varying degrees of success. Ligation of the thoracic duct in the right chest via thoracotomy or thoracoscopically has provided the best results. The preferred method is ligation of the duct en bloc between the aorta and the azygos vein, just above the diaphragmatic hiatus. Duct ligation is well tolerated, as collaterals develop fairly quickly. Thoracoscopic pleurodesis with tetracycline, talc, or a fibrin sealant has been described as well as thoracoscopic ablation with fibrin glue. Injuries to the thoracic duct encountered during the initial neck exploration are best addressed by identification and ligation of the free ends of the injured duct. Repair is not recommended because of the friability of the duct. Persistent leak from a postoperative neck wound or drain is best addressed by re-exploration of the neck wound and ligation of the injured thoracic duct. To enhance visualization of the duct, a bolus of cream may be administered via a nasogastric tube in the operating room. Intraoperative application of tissue glue on the ligated duct may be useful in both settings.

Prognosis. The long-term outcome of thoracic duct injury is not known, due to the rarity of the injury and lack of long-term follow-up. The mortality rate is probably a function of other associated vascular injuries.

Brachial Plexus and Other Nerve Injuries

Brachial Plexus. Brachial plexus injuries can lead to devastating disability if not diagnosed and treated efficiently and appropriately. A detailed understanding of wounding mechanisms to the brachial plexus, as well as its intricate anatomy, is central to a diagnostic and therapeutic plan.

Anatomic Features. Providing motor and sensory function to bilateral upper extremities, the brachial plexus is comprised of a complex network of nerves emanating from multiple spinal roots, usually extending from the fifth cervical (C5) nerve root down to the first thoracic (T1) nerve root (Fig 24). These nerve roots coalesce to form 3 trunks (upper [C5 and C6], middle [C7], and lower [C8 and T1]), which each bifurcate into an anterior and posterior division. The posterior divisions from the 3 trunks proceed to become the posterior cord. Although the anterior division of the lower trunk independently becomes the medial cord, the anterior divisions from the upper and middle trunks join to form the lateral cord. The roots transition to become trunks within the interscalene triangle,
the space formed between the anterior and middle scalene muscles. The trunks proceed to anterior and posterior divisions at the lateral border of the first rib, finally becoming the cords between the first rib and the clavicle while entering the axilla. The 3 cords (medial, lateral, posterior) are named for their relationship to the axillary artery. The 3 cords end in the terminal branches, which directly provide sensation and motor function to the upper extremities. Although the axillary and radial nerves originate from the posterior cord, the musculocutaneous nerve is a terminal branch of the lateral cord. The motor and sensory components of the median nerve originate from the medial and lateral cords, respectively. The medial cord also gives rise to the ulnar nerve as a terminal branch. A variety of other terminal branches, less important to the direct function of the upper extremity, arise throughout the length of the brachial plexus.

Classification of Nerve Injuries. In general and not particular to the brachial plexus, nerve lesions can be classified as open or closed, then further stratified according to the extent of nerve damage according to the Seddon classification scheme. Seddon classified nerve injuries into neuropraxia, axonotmesis, and neurotmesis. The mildest form of injury, neuropraxia, is characterized by a conduction abnormality at the zone of injury, but not evidence of macroscopic injury to the nerve itself. It often has complete motor loss with relative sparing of sensory function. Recovery is the norm and may occur from hours to months after injury. A more severe form of injury, axonotmesis, indicates rupture of the axons but preservation of the nerve sheath composed of the epineurium and perineurium. Wallerian degeneration will occur in the axons distal to the injury, followed by denervation. Axonotmesis is usually characterized by complete loss of motor and sensation. However, due to an intact neural sheath, regeneration is still possible from the proximal axons. The time to recovery will vary directly depending on the distance between the injured nerve and the first muscle distal to the injury, as well as the rate of recovery of the injured axons. In neurotmesis, the most severe form on nerve injury, the axons and their supporting connective tissue are completely disrupted. No recovery of a neurotmetic lesion is possible without surgical repair of the nerve.

Epidemiologic Features. In multiply injured trauma patients, brachial plexus injuries occur in 0.7% to 1.3% of patients after automobile crashes, increasing to 4.2% after motorcycle crashes. Gunshot wounds have been reported to account for up to one quarter of brachial plexus injuries.
Clinical Examination. General inspection of the neck and shoulders may reveal an obvious fracture, dislocation, hematoma, or penetrating wound, which would increase the index of suspicion of an underlying brachial plexus injury.

Many of the terminal branches of the brachial plexus can be examined directly during motor examination of the shoulder, arm, and hand. The median, radial, and ulnar nerve can be tested by thumb opposition, wrist extension, and finger abduction, respectively. Musculocutaneous nerve function can be examined by elbow flexion and the upper radial nerve is tested via elbow extension. More proximally, the axillary nerve can be evaluated with shoulder abduction. Finally, a complete sensory examination of the upper extremity should be performed and documented. However, the sensory innervation of the arm has a mixed nerve distribution and may be unreliable.

Investigations. Although plain radiographs of the neck, chest, and shoulders will not directly diagnose or rule out a brachial plexus injury, they may be quite useful in identifying an associated fracture, which could guide further diagnostic tests to evaluate a possible nerve injury. Although isolated plain radiographic myelography of the brachial plexus had been used extensively in the past, it has been significantly augmented by CT myelography. Computed tomographic myelography is most sensitive several weeks after injury because early after injury a hematoma within the area of an injury may displace contrast used for the myelogram. Abnormalities on CT myelogram that are indicative of a nerve root injury or avulsion are absence of continuity of the root with the cord or presence of a pseudomeningocele. Limitations of CT myelography include its limited ability to visualize the brachial plexus beyond the spinal foramen and the limited visualization of roots at C8 to T2 due to poor image quality at that level.

Although CT myelography remains the gold standard for imaging the brachial plexus after trauma, a commonly used adjunctive tool in imaging of the brachial plexus is MRI. Advantages of MRI over CT myelography include its noninvasive nature as well as its ability to visualize the more distal brachial plexus far beyond the spinal foramen. However, visualization of the intradural portions of the rootlets with MRI can be difficult. A newer modality, 3-dimensional MR myelography, has promise as a noninvasive imaging modality with the sensitivity of CT myelography.

Electrodiagnostic tests of the brachial plexus are essential tools in the preoperative, intraoperative, and postoperative evaluation and management of patients with brachial plexus injuries. Electrodiagnostic testing is likely most useful 3 to 4 weeks after injury, once Wallerian degeneration
has occurred. Options in electrodiagnostic testing include electromyography, nerve conduction velocities, somatosensory evoked potentials, and motor evoked potentials.

Management. A detailed discussion of treatment options for brachial plexus injuries is beyond the scope of this monograph. The necessity and timing of treatment for brachial plexus injuries are at the core of the discussion regarding management. Although most brachial plexus injuries are managed expectantly with delayed exploration, several situations require acute (within 72 hours) surgical intervention. In the presence of a major vascular injury, any concomitant brachial plexus lesion should be explored and repaired. Likewise, plexus lesions secondary to stab wounds or other sharp lacerations should be explored because an underlying laceration or transection of nerves is extremely likely and there is no role for expectant management. In addition, open wounds with significant contamination should be explored, debrided, washed out, and any nerve injuries repaired. If a nerve injury in-continuity is encountered during these early explorations, it is best left intact and followed with serial clinical and electrodiagnostic examinations to determine if it may regenerate without repair.

If none of the indications for acute surgical interventions are present, brachial plexus lesions should be managed in a delayed fashion. Patients should be followed for 8 to 12 weeks to determine the extent and location of injury and potential for regeneration. These patients should have a thorough radiographic and electrodiagnostic evaluation to plan potential operative therapy, if necessary. Certain lesions, such as GSWs and mild stretch sounds are neuropraxic in nature and will usually resolve over the first few months after injury. If no clinical or electrodiagnostic improvement is apparent, patients should undergo repair approximately 3 months after the initial injury.

Prognosis. Education of patients at the time of injury and before any treatment is essential, since outcomes after brachial plexus trauma are quite variable and can be extremely debilitating. Several factors influence the outcomes of traumatic brachial plexopathy. Certain lesions, such as mild stretch lesions and neuropraxia secondary to a GSW, often do not require operative intervention and resolve with good results. For those patients requiring surgical brachial plexus repair, variables associated with better outcome include younger age, earlier repair (around 3 months post injury), infraclavicular lesions, avulsions of the upper roots (C5-C6) versus the lower roots (C8-T1), and nerves than can be repaired primarily versus those requiring grafting. If injuries require grafting, those where a shorter nerve graft can be used will usually fare better.
Patients must understand that although they may regain function of more proximal muscles, complete return of hand function is less consistent. Since many of the factors influencing recovery of brachial plexus injuries cannot be controlled, the patient should clearly understand the wide array of outcome possibilities that may occur after treatment of these complex injuries.

**Other Nerve Injuries in the Neck.** Although rare, a wide array of other nerve injuries may occur following blunt or penetrating neck trauma. Horner syndrome, or oculosympathetic paresis, has a variety of causes including direct trauma to the neck in 4% to 13% of cases. The constellation of miosis, ptosis, and anhidrosis ipsilateral to the lesion due to loss of sympathetic fibers is characteristic of Horner syndrome. No specific treatment is available for posttraumatic Horner syndrome.

Other nerve injuries in the neck can also be identified by clinical examination. Damage to cranial nerves traversing the neck can be identified with physical findings such as facial paresis (cranial nerve VII), hoarseness (cranial nerve X or recurrent laryngeal branch), or glossal deviation (cranial nerve XII). The phrenic nerve (C3-C5) also courses through neck, but there is no reliable physical finding to rule out phrenic nerve injury. However, diaphragm paralysis should be readily visible on the chest radiograph, indicating a phrenic nerve injury.

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