

# Chapter 13

## HEMORRHAGE MANAGEMENT AND VASCULAR CONTROL

STEVEN HONG, MD,\* AND CHRISTOPHER KLEM, MD, FACS<sup>†</sup>

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\*Captain, Medical Corps, US Army; Chief Resident Otolaryngology—Head and Neck Surgery, Tripler Army Medical Center, 1 Jarrett White Road, Honolulu, Hawaii 96859-5000

<sup>†</sup>Colonel, Medical Corps, US Army; Chief, Otolaryngology—Head and Neck Surgery, Tripler Army Medical Center, 1 Jarrett White Road, Honolulu, Hawaii 96859-5000; Assistant Professor of Surgery, Uniformed Services University of the Health Sciences, University of Hawaii

## INTRODUCTION

Management of vascular injuries has been practiced and refined since antiquity. Papyrus records from 1600 BCE describe Egyptians using mineral and vegetable matters to control bleeding in traumatic wounds.<sup>1</sup> Historically, wars have catalyzed advances in methods of hemostasis, from the advocacy of ligatures for hemostasis by an Alsatian army surgeon in 1497, to the refinement of compression dressings with specialized fibrin sealants by the US Army in the 20th century.<sup>2</sup> One of the first clearly recorded major artery ligation for traumatic injury of the carotid artery was performed by a naval surgeon in 1803.<sup>3</sup>

Algorithms often used for the management of traumatic injuries to the neck are primarily derived from civilian trauma centers and may not apply to the type of wounds encountered on the modern battlefield. For example, secondary injury from high-velocity gunshot wounds and explosive shrapnel typically seen in wartime extends well beyond the damage inflicted by the projectile's immediate path. The extensive shock wave from a high-velocity projectile can cause vascular thrombosis, embolism, and pseudoaneurysm.<sup>4</sup> After more than a decade of unconventional warfare in Operation Enduring Freedom (OEF) and Operation Iraqi Freedom (OIF), invaluable knowledge and data on combat trauma has been gathered. Head and neck surgeons serving in OIF and OEF have continued to innovate, rewriting the algorithms for managing penetrating neck and cervical vascular injuries in the combat environment.

As body armor has improved, combat wounds to the torso have decreased, while injuries to the more exposed extremities, head, neck, and face have increased in frequency. Combatants in modern warfare often target these vulnerable regions due to the well-known lack of protection.<sup>5</sup> The head and neck region of the body comprises only 12% of body surface area, yet 20% to 40% of total combat injuries in OIF and

OEF involved the head, face, or neck.<sup>6-8</sup> A review of World War II and Vietnam War vascular trauma demonstrated that cervical vascular injuries accounted for less than 5% of total vascular injuries.<sup>9,10</sup> When focused on injuries specifically to the neck, vascular injuries account for 3% to 4% of combat-related injuries in those conflicts.<sup>9,11</sup> A comprehensive review of head and neck trauma from OIF and OEF by Feldt et al shows similar results to prior conflicts, with major vessel injuries accounting for 4.35% of head and neck soft tissue trauma.<sup>12</sup>

Mechanisms of injury have also changed. A review of combat injuries from Lebanon, Slovenia, Croatia, Iraq, Somalia, and Afghanistan from 1982 to 2005 by Rustenmeyer et al showed a higher incidence of wounds caused by fragments compared with gunshot injuries, which predominated in the Vietnam War.<sup>6</sup> Blast injury from improvised explosive devices (IEDs) are the most common mechanism of injury in the modern military environment, causing 78% of combat casualties in OIF and OEF.<sup>7</sup> IEDs are indiscriminate weapons, with secondary blast effects that typically result in small fragments penetrating variable tissue depth in oblique directions via multiple scattered, sub-centimeter wounds. These injuries can be deceptively lethal, with "small holes equaling big pathology."<sup>13</sup>

Despite the challenges of the devastating wounds suffered in OIF and OEF, survival from combat injuries is higher than at any point in history. As a result of numerous advances including the use of tourniquets, standardized combat soldier battlefield medical training, and rapid evacuation from the battlefield, more casualties with extensive injuries survive and reach the combat medical system alive.<sup>7</sup> Consequently, modern warfare obligates the combat surgeon to rapidly assess and treat multiple critically ill patients who might not have survived in prior conflicts.

## ANATOMY

Management of penetrating neck trauma is most often divided into three anatomic zones of injury, as classically defined by Roon and Christensen.<sup>14</sup> Although beneficial pedagogically, the system's utility is limited for managing many of the complex penetrating neck wounds caused by high-velocity projectiles, which frequently involve multiple zones of the neck.<sup>15</sup> The cervical spine and vertebral arteries can be encountered and injured in all three zones of the neck. Otherwise, each region has unique anatomic challenges to consider.

### Zone I

Zone I is bordered inferiorly by the clavicles and superiorly by the inferior border of the cricoid cartilage. Significant vascular structures in this zone include large vessels of the thoracic inlet such as the subclavian and innominate vessels, the common carotid artery, and the internal jugular vein. Emergent exploration in this area presents unique anatomic challenges due to the thorax and clavicles. Injury to zone I carries a fairly high mortality rate of 12%.<sup>16</sup>

Fortunately, injury to this area is uncommon, occurring at a rate of 10% in a recent review of modern combat trauma.<sup>17</sup>

## Zone II

Zone II lies between the inferior border of the cricoid and the angle of the mandible. Major vascular structures in this region consist of the internal and external carotid arteries and the internal jugular vein. Zone II is the area most frequently involved in penetrating injuries (60%–75%).<sup>18</sup> Although it is technically the most accessible region in the neck, zone II also elicits the most controversy in management, as will be discussed below.

## Zone III

Zone III consists of the space between the angle of the mandible extending superiorly to the base of the skull. The critical vascular structures in this zone are the internal and external carotid arteries and the internal jugular vein. This area is difficult to access surgically due to the skull base and mandible. To achieve hemostasis, the mandible often must be either displaced or divided for access. High carotid injuries may require a craniotomy for exploration and control. Additionally, the intimate relationship of the skull base and cranial nerves can be useful to signal possible great vessel injury when cranial nerve deficits are present on physical examination.<sup>19</sup>

## Vertebral Arteries

The vertebral arteries begin at the root of the neck as the first branches of the subclavian arteries. They ascend the entire length of the neck through the transverse foramina of the first six cervical vertebrae. The atlantic portion of the vertebral arteries at vertebra C1 perforates the dura mater and arachnoid to pass through the foramen magnum.<sup>20</sup> The vertebral arteries then fuse to become the basilar artery and contribute to the posterior cerebral circulation. In regard to surgical anatomy, the vertebral artery is divided into four parts: V1, V2, V3, and V4.<sup>15</sup> All four segments are difficult to access surgically. The approach often requires mobilization of the subclavian artery for proximal control.<sup>21</sup> Traumatic vertebral artery injuries are rare but can have devastating consequences. Clinically, these injuries manifest themselves with delayed neurologic deterioration owing to subarachnoid hemorrhage, ischemic stroke, or steal phenomena related to a diverting fistula. Without recognition or treatment, mortality rates are reported as high as 31%.<sup>22</sup>

Based on civilian series, the common carotid artery is often cited as the major vascular structure most frequently injured by penetrating neck trauma.<sup>23,24</sup> In contrast, in OEF and OIF, the internal and external carotid arteries were the most vulnerable to injury.<sup>7</sup> In a retrospective review of OIF and OEF patients with cervical vascular trauma, Meghoo et al noted injury to the internal carotid artery at 28%, the external carotid artery at 56%, and the common carotid artery at 7.8%. Venous injuries made up 40% of vascular injuries.<sup>7</sup>

## MANAGEMENT

### Initial Survey

In mass casualty situations, the availability of an operating room or additional resources may be a luxury. Therefore, in the combat environment, emergent evaluation and accurate triage of penetrating neck injuries are paramount. The leading cause of death in penetrating neck injuries is hemorrhage from cervical vascular injury. Although this chapter focuses on acute management of cervical vascular injuries, the basic tenets of trauma care should not be delegated to the periphery. The surgeon must integrate achieving hemostasis within the framework of comprehensive trauma care to avoid overlooking other potential injuries.

On initial assessment, American College of Surgeons Advanced Trauma Life Support (ATLS) guidelines dictate a rapid, yet thorough, primary survey. With the exception of controlling obvious sources of massive hemorrhage, the initial focus should be on securing the airway. This can be done via direct intubation,

cricothyroidotomy, or tracheotomy. Airway protection is especially critical in patients with penetrating neck trauma because hematoma or edema can lead to rapid deterioration and turn an urgent airway into an emergency situation.

Airway evaluation in ATLS calls for cervical spine precautions, though this is controversial in the acute combat trauma environment. A review by Ramasamy et al notes that the majority of casualties with cervical spinal cord injuries associated with combat penetrating ballistic neck trauma die at the scene.<sup>25</sup> In his review, of the three patients who survived initial injury (3.3% overall), two patients died shortly after arrival to the hospital. Operative findings for the one patient who survived suggested that injury to the cervical spinal cord was caused by the initial trauma rather than by being moved without immobilization. Arguably, in unstable or symptomatic patients with penetrating neck injuries, cervical spine precautions should not delay critical interventions.

Resuscitation is also a critical component of comprehensive trauma care. Moreover, shock has been proven to correlate with adverse neurologic outcomes in extracranial carotid injuries.<sup>26,27</sup> Experiences from OIF and OEF have shaped a damage control resuscitation strategy incorporating early and balanced use of packed red blood cells and frozen plasma with encouraging outcomes.<sup>28</sup> However, balanced intravascular fluid resuscitation in hemorrhagic patients is not a substitute for definitive control of bleeding.

The importance of a thorough physical examination in penetrating neck injuries cannot be overstated. Initial physical exam should include evaluation for “hard signs” of vascular trauma such as bruits, hematoma, shock, external bleeding, carotid shrills, unresponsive shock, pulse deficits, and diminished ipsilateral radial pulses. In one series of combat penetrating neck vascular trauma, nearly 75% of patients presented with a hard sign of vascular injury.<sup>7</sup>

Physical examination of a penetrating neck injury should include the use of a stethoscope to auscultate for shrills or bruits. A thorough neurologic examination is essential because 30% of patients with injury to the carotid artery demonstrate some level of neurologic deficit.<sup>29</sup> Additionally, for patients with cervical spine injuries, the surgeon should thoroughly evaluate the cervical vasculature. Recent combat experiences in Iraq and Afghanistan found that cervical spine injuries were associated with cervical major vascular injury 40% of the time.<sup>30</sup> Finally, an intraoral exam should be performed in patients with zone III injury to look for expanding hematoma or edema.

Perhaps the most difficult decision in cervical vascular management is in the context of triage of combat casualties within the US military roles of care. After Role 1 (combat medic) evaluation and management, a patient is typically transported either to Role 2 (forward surgical team) or Role 3 (combat support hospital).<sup>7</sup> The Role 2 medical facility is responsible for resuscitation and damage control that allows evacuation to a higher role of care as soon as the patient is stable enough for transfer. Forward surgical teams are limited in resources and lack access to computed tomography (CT) and CT angiography (CTA) imaging and endovascular capabilities. Additionally, technical expertise and specialized instruments for surgical access such as sternotomy or mandibulotomy are capricious at Role 2 facilities. In fact, the majority of vasculature injuries are repaired at Role 3.<sup>31</sup>

### Initial Hemorrhage Management

If there is need for immediate temporary control of hemorrhage from a suspected penetrating vascular injury of the neck and simple local compression

is not effective, digital compression of the common carotid artery against the carotid tubercle of the transverse process of the sixth cervical vertebra can be performed. Additionally, wound packing with gauze may be necessary, until proximal and distal control of the source of hemorrhage is obtained. Particularly in zone II, expanding hematoma frequently responds to direct pressure. Probing a neck wound should be avoided because it can lead to dislodgement of a clot.<sup>32</sup> Blind clamping should also be avoided because it can inadvertently injure surrounding blood vessels and important nerves.

The use of a Foley catheter balloon for tamponade in OIF and OEF has been described with promising results. Once a hemorrhaging wound is identified, an 18 Fr Foley catheter with a hemostat applied to the distal end is introduced, directed into the wound track, and inflated. In a cohort study of penetrating neck trauma patients from OIF and OEF, patients who had hemorrhage control using Foley balloon tamponade had significantly less mortality (5%) versus patients with external pressure hemostasis (23%).<sup>33</sup> Versatility for controlling bleeding in all zones of the neck, easy accessibility, and minimal operator expertise makes this technique an invaluable part of the combat surgeon’s armamentarium.

Although crucial, physical examination should not be relied upon as the sole diagnostic evaluation of a patient with penetrating neck injury, and radiographic imaging is frequently used. Studies in both the civilian and combat trauma literature suggest that if a patient has appropriate negative diagnostic imaging as well as a negative physical exam, the sensitivity and specificity is greater than 95% that the patient does not have a vascular injury.<sup>7,34</sup>

In many civilian trauma centers, the use of angiography is advocated in evaluating stable zone I and zone III injuries.<sup>30</sup> The accuracy of angiography (98.5%), as well as its use for both diagnostic and therapeutic intervention, has made it the gold standard.<sup>35</sup> If intervention by open or endovascular technique is necessary, arteriography can assess collateral circulation. In zone I, zone III, and vertebral artery injuries, endovascular management with stent grafting or embolization has been shown to be effective in the civilian literature.<sup>36</sup>

Arteriography is typically performed by physicians with specialized training, including radiologists, vascular surgeons, neurosurgeons, and general surgeons. Radiologists, neurosurgeons, and vascular surgeons who have extensive training in interventional techniques usually are the only providers who perform therapeutic endovascular procedures. Although formal arteriography is a proven method for assessing penetrating neck injuries for vascular trauma, there is a 1% incidence of stroke associated with the procedure.



Personnel and equipment shortcomings at treatment facilities on the battlefield often limit availability of specialized medical services. However, due to the tireless efforts of many providers in OIF and OEF, the accessibility and capabilities of angiography and endovascular intervention in the combat theater are becoming more prevalent.<sup>37</sup>

Short-term data on endovascular interventions in traumatic carotid artery injuries are encouraging.<sup>38</sup> The use of vascular stents has been very limited in OIF and OEF, partly due to logistical challenges, but primarily because placing synthetic grafts in a potentially contaminated field has been avoided. However, as noted by Fox et al, in cases of polytrauma with multiple vascular injuries, a synthetic stent may be the best option.<sup>37</sup> Additionally, a stent can be used as a temporizing measure until further definitive repair.

Due to its excellent imaging quality, speed, safety, and lack of inter-user variability, CTA has emerged as the diagnostic tool of choice in penetrating neck injuries at many institutions. The use of CTA in hemodynamically stable patients to diagnose and localize vascular injury in penetrating neck trauma is well accepted in civilian series, with sensitivity and specificity rates greater than 90%.<sup>39</sup> The use of CTA as a diagnostic aid in combat traumas has also become pervasive.<sup>17</sup> The vast majority of combat-injured patients with penetrating neck trauma suffer concomitant injuries, and typically undergo extensive CT scans once they reach a Role 3 treatment facility. However, sole reliance on CTA to evaluate for cervical vascular injuries in asymptomatic high-velocity penetrating neck injuries may be imprudent. Due to beam-hardening artifact from bullets and metallic objects, CTA results in a 1.2% to 2.2% incidence of nondiagnostic studies.<sup>40,41</sup> Additionally, a review by Fox et al showed the role of CTA to be less promising, with digital subtraction angiography performed an average of 8.5 days after injury demonstrating occult arterial injuries in 9.5% of high velocity penetrating neck trauma patients.<sup>11</sup> Lastly, the major disadvantage of CTA compared with traditional angiography is its lack of therapeutic potential.<sup>39</sup>

In a review of patients with vertebral artery injuries from OIF and OEF, the majority of patients (55%) were treated with observation and antithrombotic therapy.<sup>22</sup> Those who had a procedure (45%) underwent endovascular intervention with either stents or coils. Three out of eleven vertebral artery injuries were associated with concurrent spinal cord injuries, and five involved concomitant facial fractures. Overall, the majority of the patients were treated nonoperatively without major sequelae. In multitrauma patients, the use of anticoagulation therapy must be considered with caution to balance the risk of further hemorrhage.

Pseudoaneurysms of the vertebral artery appear to be especially amenable to endovascular intervention. With open surgical treatments of vertebral arteries recording mortality rates as high as 50%,<sup>42</sup> the majority of vertebral artery injuries should be managed endovascularly to mitigate morbidity and mortality. The increased accessibility of endovascular therapies in the combat theater should greatly aid in treating vertebral artery injuries in the deployed setting. However, angiography and endovascular repairs are not without risks, including hematoma, intimal dissection, thrombosis, displacement of the coil or stent, and stroke.<sup>23</sup>

The controversy over mandatory versus selective neck explorations for zone II injuries is covered in Chapter 31, Management of Neck and Skull Base Vascular Trauma, and will not be discussed in detail. In a review of penetrating neck trauma in OIF by Brennan et al, the combat zone experience for selective neck explorations appeared to be fairly comparable to civilian traumas, with a negative exploration rate of 31%.<sup>17</sup>

### Surgical Management of the Neck

The surgical approach to most zone II injuries is via an oblique skin incision along the anterior border of the sternocleidomastoid muscle, which allows wide exposure of the great vessels of the carotid sheath from the clavicle to the angle of the mandible. However, the incision should be dictated by the clinical situation and mechanism of injury. For example, with IED blast injuries involving multiple small high-velocity wounds, increased exposure through a wide-apron incision is advised. In the event that the carotid artery is pulseless, retrograde dissection from external carotid branches may be helpful.<sup>30</sup>

When approaching injuries to zone III, an incisional limb placed higher in the neck may offer improved access. Division of the digastric muscle allows further exposure of the great vessels, but the surgeon must be prepared to perform a mandibulotomy to expose the internal carotid artery and internal jugular vein near the skull base.<sup>43</sup> This approach is similar to that used for excision of certain parapharyngeal space tumors. Dichtel et al note the use of a lateral mandibulotomy cut in a step-stair fashion to approach high zone III injuries.<sup>44</sup> It is argued that this access to the vessels is uncompromised and may reduce iatrogenic cranial nerve injury due to greater visualization. Furthermore, Brennan describes subluxation of the mandible for access to zone III in a combat environment.<sup>13</sup> Perry describes a method to achieve temporary hemostasis even with suboptimal access by passing a Fogarty catheter through a Pruitt-Inahara (LeMaitre Vascular, Burlington, MA) shunt to control distal bleeding

from the internal carotid artery.<sup>45</sup> The balloon is used to occlude the lumen and the shunt is advanced beyond the site of injury until adequate surgical access for definitive management of the injury is obtained.

Success in controlling active hemorrhaging in zone I is especially contingent upon adequate exposure. Hemorrhage from the distal aspect of the carotid or internal jugular vein maybe addressed with a low cervical incision. However, for more proximal great vessels such as the innominate artery, contending with the thorax, sternum, clavicles, or all three may be imperative. Using a powered saw, a median sternotomy can provide rapid access to the thoracic inlet for vascular control. This approach allows an optimal view of the aorta, innominate artery, and proximal subclavian veins. The additional benefit to this approach is the ability to digitally compress the subclavian vessels against the clavicles via the second intercostal space. A caveat to this approach is that in OIF and OEF, forward surgical teams often did not have reliable access to power saws. A hemi-clamshell or sternothoractomy can improve access to the proximal left subclavian artery and the descending aorta. Moreover, the trapdoor incision (sternothoractomy with supraclavicular extension) also provides excellent exposure to the thoracic inlet.<sup>31</sup>

Further exposure of the proximal portion of the right subclavian artery is via a transcervical approach. Resection of the medial third of the clavicle with disarticulation of the sternoclavicular junction will aid in the exposure if necessary. Exposure of the proximal portion of the left subclavian artery is via left posterolateral thoracotomy; whereas the more distal portion is accessible through a transcervical approach. When exploring zone I, gentle care must be taken when mobilizing and suturing the subclavian artery because of its fragility. Recognizing the potential for a pneumothorax when operating in this region is critical; this complication is easy to overlook, with potential lethal consequences.

### Vessel Management

After proximal and distal control has been accomplished, repair of the vessel should be carried out, if feasible. When assessing common or internal carotid injuries, an immediate decision should be made about whether to use a shunt. If the damaged vessel requires suture repair only, this can frequently be accomplished promptly without a shunt. However, if the injury is more extensive and requires grafting or bypass, the use of shunts is often preferred to minimize cerebral ischemia time and avoid hasty repairs.

Injury to the common carotid or internal carotid can be approached with ligation, vessel wall repair, resection and primary anastomosis, or grafting (autogenous or synthetic). Mittal et al noted no difference in postoperative complications relating to either resection with primary anastomosis versus interposition graft repair.<sup>46</sup> If the carotid vessels are severely contused and there is evidence of intraluminal clot and spasm, the clot should be carefully removed. If the walls of these vessels are severely damaged, it is best to resect the injured segment. It is important to note that high velocity injuries tend to damage the vascular intima for a substantial distance beyond the obvious site of injury, and may require meticulous debridement of the arterial wall to normal-appearing intima prior to repair.<sup>43</sup> If the area resected is not too extensive, end-to-end arteriorrhaphy is the preferred method of repair.<sup>21</sup> When primary repair of a damaged vessel is not feasible, interposition graft using autogenous vein graft should be performed. Autogenous material is often preferred in the presence of traumatic wounds because of the possibility of wound infections.<sup>46</sup> If the wound is exceptionally clean, a synthetic graft may be utilized.

In extreme circumstances ligation of the artery may be necessary, though this should be reserved for situations in which the vessel cannot be reconstructed. Ligation of either the common carotid or internal carotid arteries carries a 30% to 50% risk of stroke, so all efforts should be made to repair the damaged vessels. Injuries of the external carotid artery and its branches may be treated with surgical ligation with minimal morbidity. Although hemorrhage control is paramount, in patients with concomitant large soft tissue defects, selective ligation of the external carotid artery or its branches is urged in consideration of possible future microvascular free-flap reconstruction. Early reconstruction of large soft tissue defects in trauma provides the best outcomes, and external carotid artery branches are especially useful as recipient vessels in microvascular reconstructive surgery of facial defects.<sup>47</sup>

Injuries to the great cervical veins are usually best handled by ligation and division of the vessels, except when both internal jugular veins are involved. In the event of bilateral internal jugular vein damage, reconstruction or repair of one of the veins should be attempted to reduce the risk of cerebral edema. Subclavian vein injury is another exception in which repair of the vein is preferable to ligation. Immediate compression of a distal portion of the damaged subclavian vein is paramount to prevent air embolism.<sup>21</sup>

## VASCULAR ANASTOMOSIS

### Primary Repair

Arterial repair with anastomosis may be completed via a variety of techniques. Vessels should always be handled with a gentle soft tissue technique to avoid further intimal damage and reduce the risk of thrombosis. The goal is to approximate and anastomose intima to intima or intima to graft. The needle should be placed through the entire wall of the vessel and may be placed from the outside in (adventitia to intima) or from the inside out (intima to adventitia). The preferred suture material is a monofilament, which is less reactive than absorbable suture and causes less friction and tearing while being passed through the vessel wall. Through-and-through running sutures are preferred in closures of vertical or longitudinal arteriotomies. For vessels of larger caliber, when performing end-to-end or end-to-side anastomosis, two separate continuous simple over-and-over sutures are used, each encompassing 180° of the diameter of the lumen. If an anastomosis between the wall of a vessel and a prosthesis is required, an end-to-end, end-to-side, or side-to-side anastomosis can be accomplished.<sup>21</sup>

### Grafts for Arterial Reconstruction

Autologous tissue such as vein grafts have a proven record of the best clinical results with regard to graft survival and patency.<sup>43</sup> Allografts consist of preserved or fresh vessel segments from human donors. The most commonly used allograft today is the glutaraldehyde-treated umbilical vein reinforced with Dacron (Invista, Wichita, KS) mesh.<sup>21</sup> The drawbacks to this graft have been disintegration and aneurysm formation after several years. Additionally, allograft material is not typically available in a combat zone medical facility.

Synthetic grafts are also an option for vessel repair. Two popular synthetic grafts in the head and neck are the Dacron and the expanded polytetrafluoroethylene (Teflon, DuPont, Wilmington, DE) graft. Woven Dacron appears to be good for larger blood vessel bypasses or replacements because it minimizes blood loss. Expanded Teflon is an electronegative material with poor porosity and is the most common arterial substitute graft for medium-sized arteries. Late thrombosis, however, has been a frequent complication of this graft material.<sup>21</sup>

### Bypass

In situations when vascular grafts and end-to-end arteriorrhaphy are not feasible, relocation bypass may be used. The bypass permits continued perfusion and

can serve as a valuable temporizing measure by allowing abbreviation of surgery in the damage control setting. There has been extensive literature on the use of vascular shunts in OEF and OIF and its success as a damage control intervention.<sup>43</sup> However, the majority of documented experiences have been in cases of distal extremity injuries with the end goal of extending the ischemia time for limb salvage with definitive repair. In cases of repairs of the carotid arteries, the consequences of mere minutes of ischemia time, clotting, and embolization can have devastating permanent sequelae.

In general, the shunt should be sized to avoid kinking of the proximal and distal vessels. Also, the intraluminal length of the tubing should be limited because this section of the vessel will be excised during the definitive repair. The shunt should be secured on either end, typically with silk ties or vessel loop, and should be tagged for easy identification.<sup>48</sup> Shunts for temporary revascularization can be classified as “in-line” or “looped” shunts. An in-line shunt such as the Argyle (Covidien, Dublin, Ireland) or Javid (Medline, Mundelein, IL) is technically very simple and quick to place, and therefore more practical in the damage control setting.<sup>49</sup> These shunts are placed intraluminally while the vessel wall is repaired, and removed before the placement of the last few sutures. If an interposition graft is required, a shunt is passed through the lumen of the graft prior to anastomosis to the native artery and then removed prior to placement of the last few sutures.<sup>43</sup>

### Ligation

The risk of hemorrhage and death must be weighed against the risk of known complications associated with ligation of the common carotid artery. In a controlled environment, the standard test to evaluate the collateral circulation from the contralateral carotid arterial system is the balloon test occlusion. This technique requires the patient to be awake for neurologic assessments, so the procedure is performed under local anesthesia. A femoral sheath with a diagnostic catheter is introduced into the femoral artery. The catheter is then used to perform a diagnostic four-vessel cerebral and cervical angiography. A nondetachable balloon catheter is then introduced and positioned into the internal carotid artery. With angiographic confirmation, the vessel in question is completely occluded. The surgeon then performs neurologic examination for a total of 30 minutes. The patient is assessed for any changes in sensorium as well as motor and cognitive functions.<sup>50</sup> In a series of 254 pa-



tients undergoing permanent vessel occlusion without balloon test occlusion, ischemic infarcts were reported in 26%.<sup>51</sup> There are multiple modifications to this standard technique using different radiographic media with variable results. These modifications are similar in purpose to the balloon test occlusion: to evaluate the carotid artery for adequate collateral circulation and perfusion. However, in a life-threatening situation from combat trauma, the use of a balloon test occlusion is unrealistic and impractical. If ligation of the common or internal carotid artery is necessary as a life-saving measure, it has a 30% stroke rate and a 45% procedural mortality rate.<sup>52</sup>

### Complications

The most feared complication associated with repair or ligation of the common or internal carotid arteries is stroke. Severe hypertension is also

a known complication of carotid artery surgery due to stimulation of the chemo-baroreceptors. To avoid cranial nerve injury, comprehensive knowledge of the anatomy, avoidance of blind clamping, and careful dissection are critically important. Peripheral nerve injuries during carotid artery repairs have been reported to range from 1% to 16%.<sup>21</sup> Nerves that are particularly vulnerable to injury are the accessory nerve, hypoglossal nerve, vagus nerve, and superior laryngeal nerve. Postoperative hematoma may occur, especially if the patient receives postoperative antiplatelet therapy. In a series of 393 patients undergoing neck explorations for penetrating neck trauma, 69 arteries and 125 veins were repaired, with only one patient undergoing reexploration for hematoma.<sup>53</sup> Late postoperative complications are false aneurysm and arteriovenous fistulas; the former has potentially devastating consequences.

### SUMMARY

Insurgent tactics, with crude yet incredibly destructive weapons such as IEDs, have defined modern warfare in OEF and OIF. Due to the advanced protection of the torso from body armor and the indiscriminate nature of IEDs, head and neck injuries have increased dramatically from prior conflicts. However, mortality rates in combat-related penetrating neck injuries are lower than ever before. The experiences and innova-

tions from OEF and OIF have fundamentally changed the treatment paradigm in combat-related penetrating neck and vascular injuries. As conflicts continue to shift from conventional to urban tactical warfare, the head and neck region will continue to be an area of frequent of injury. It remains imperative for military surgeons to continuously innovate and improve surgical training in head and neck trauma.

### CASE PRESENTATIONS

#### Case Study 13-1

##### *Presentation*

A 22-year-old American soldier in Iraq presented with a rocket-propelled grenade injury and massive exsanguination from his oral cavity / oropharynx. The grenade caused massive soft tissue damage and loss to his lips and oral commissure, tongue, soft/hard palate, and maxilla/mandible (Figure 13-1). Profuse venous and arterial bleeding was noted from all these areas. The soldier had already been transfused over 20 units of packed red blood cells due to this injury and extremity injuries.

##### *Preoperative Workup/Radiology*

None.



**Figure 13-1.** American soldier with a rocket-propelled grenade wound to the face.



### *Operating Planning/Timing of Surgery*

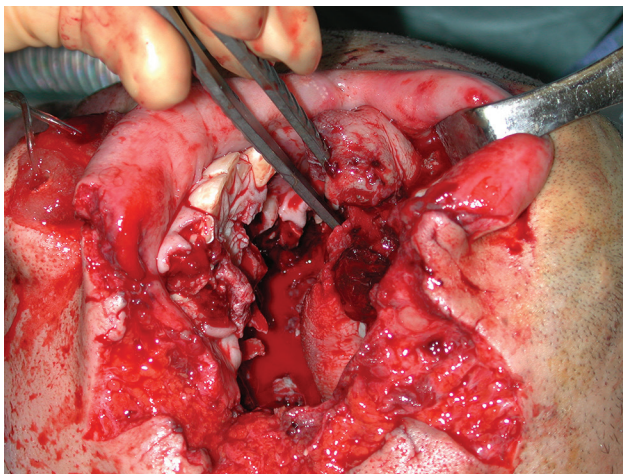
The patient was taken immediately to the operating room for control of bleeding.

### *Operation*

The patient had his airway secured with a tracheostomy, and the oral cavity/oropharynx was tightly packed with 4 × 4-inch gauze sponges. The sponges were sequentially removed and sutures and bipolar cautery were used to stop the bleeding. Multiple tongue lacerations were closed, which also improved hemostasis (Figure 13-2). Despite these efforts, the patient continued to bleed from multiple oral cavity/oropharyngeal sites and was considered coagulopathic (factor VII was given in addition to treatment with the massive transfusion protocol). The oral cavity and oropharynx were tightly packed with Surgicel (Ethicon Inc, West Somerville, NJ), and a Coban (3M, St Paul, MN) dressing was placed around his lower face. Nasal packing was also placed (Figure 13-3). These interventions stopped the bleeding, and the patient was sent to Landstuhl Regional Medical Center for possible interventional radiology.

### *Complication*

None.



**Figure 13-2.** Exploration of rocket-propelled grenade wound with hemorrhage control.



**Figure 13-3.** Oral cavity and oropharynx packing.

### *Lessons Learned*

With massive soft tissue facial damage, profuse bleeding, and continued hemorrhage despite bipolar cautery and sutures, tightly packing the wound with Surgicel or another hemostatic material can stop the acute bleeding. The packing can also act as a stop-gap measure that will allow the patient to be transported to a facility with interventional radiology for possible embolization. Ligation of the external carotid artery to stop bleeding should be avoided because it will prevent future endovascular embolization of the bleeding end-vessels.

### *Case Study 13-2*

#### *Presentation*

A 30-year-old Australian OEF contractor presented with profuse arterial bleeding from the oral cavity after sustaining an AK-47 gunshot wound to the right shoulder, with the bullet entering zone II of the right neck and exiting the left cheek (Figure 13-4).

#### *Preoperative Workup/Radiology*

None.

### *Operating Planning/Timing of Surgery*

The patient was taken immediately to the operating room to stop the active arterial bleeding.



**Figure 13-4.** AK-47 gunshot wound to right shoulder and zone II of neck.



**Figure 13-5.** AK-47 wound after neck exploration, tracheostomy, and hemorrhage control.

### Operation

The patient was intubated and the oral cavity was tightly packed, which slowed the arterial bleeding. The right neck was explored, and the carotid sheath vessels were found to be intact, but the lingual artery was actively bleeding and ligated. The oral packing was removed but the remaining source of arterial bleeding could not be identified due to difficulty in working around the oral endotracheal tube. The oral packing was replaced, a tracheostomy was performed, and the oral cavity was reexplored (Figure 13-5). Bleeding was noted from the facial and angular arteries, which were ligated. All bleeding then ceased.

### Complications

None.

### Lessons Learned

All penetrating neck trauma patients who are symptomatic (this patient had active bleeding) must be taken to the operating room for a neck exploration. It can be difficult to control bleeding from an oral cavity or an oropharyngeal source with the oral endotracheal tube in place. Moving the airway to the neck will allow better visualization within the oral cavity and oropharynx to control the bleeding.

### REFERENCES

1. Schwartz AM. The historical development of methods of hemostasis. *Surgery*. 1958;44:604–610.
2. Rich NM, Rhee P. An historical tour of vascular injury management: from its inception to the new millennium. *Surg Clin North Am*. 2001;81:1199–1215.
3. Flemming J. Case of rupture of the carotid artery and wound of several of its branches successfully treated by tying off the common trunk of the carotid itself. Coley RW, trans. *Med Chir J*. 1817;3–2.
4. Wang CHJ, Huang H, Yang K, et al. Patho-mechanism of shock wave injuries on femoral artery, vein, and nerve: an experimental study in dogs. *Injury*. 2002;33:439–446.
5. Mabry RL, Holcomb JB, Baker AM, et al. United States Army Rangers in Somalia: an analysis of combat casualties on an urban battlefield. *J Trauma*. 2000;49:515–529.
6. Rustemeyer J, Kranz V, Bremerich A. Injuries in combat from 1982–2005 with particular reference to those to the head and neck: A review. *J Oral Maxillofacial Surgery*. 2007;45:556–560.
7. Meghoo CA, Dennis JW, Tuman C, Fang R. Diagnosis and management of evacuated casualties with cervical vascular injuries resulting from combat-related explosive blasts. *J Vas Surg*. 2012;55:1329–1337.

8. Xydakis MS, Fravell MD, Nasser KE, Casler JD. Analysis of battlefield head and neck injuries in Iraq and Afghanistan. *Otolaryngol Head Neck Surg.* 2005;133:497–504.
9. Rich NM, Baugh JH, Hughes CW. Acute arterial injuries in Vietnam: 1,000 cases. *J Trauma.* 1970;10:359–369.
10. Debaeky ME, Simeone FA. Battle injuries of the arteries in World War II: an analysis of 2471 cases. *Ann Surg.* 1946;123:534–579.
11. Fox CJ, Gillespie DL, O'Donnell SD, et al. Contemporary management of wartime vascular trauma. *J Vasc Surg.* 2005;41:638–644.
12. Feldt BA, Salinas NL, Rasmussen TE, Brennan J. The Joint Facial and Invasive Neck Trauma (J-FAINT) Project, Iraq and Afghanistan 2003–2011. *Otolaryngol Head Neck Surg.* 2013;148:403–408.
13. Brennan J. Experience of first deployed otolaryngology team in Operation Iraqi Freedom: the changing face of combat injuries. *Otolaryngol Head Neck Surg.* 2006;134:100–105.
14. Roon AJ, Christensen N. Evaluation and treatment of penetrating cervical injuries. *J Trauma.* 1979;19:391–397.
15. O'Brien PJ, Cox MW. A modern approach to cervical vascular trauma. *Perspect Vasc Surg Endovasc Ther.* 2011;23(2):90–97.
16. Rao P, Bhatti MF, Gaudino J, et al. Penetrating injuries of the neck: criteria for exploration. *J Trauma.* 1983;23:47–49.
17. Brennan J, Lopez M, Gibbons M, et al. Penetrating neck trauma in Operation Iraqi Freedom. *Otolaryngol Head Neck Surg.* 2011;144:180–185.
18. Obeid F, Haddad GS, Horst HM, Bivins BA. A critical reappraisal of a mandatory exploration policy for penetrating wounds of the neck. *Surg Gynecol Obstet.* 1985;160:517–522.
19. Stewart, MG. Penetrating face and neck trauma. In: Bailey BJ, ed. *Head & Neck Surgery—Otolaryngology*. Vol 1. 4th ed. Philadelphia, PA: Lippincott Williams & Wilkins; 2006:1017–1026.
20. Moore KL. *Clinically Oriented Anatomy*. 5th ed. Philadelphia, PA: Lippincott Williams & Wilkins; 2006: 930–931.
21. Lore JM, Anain J, Castillo NB, Hopkins LN. Vascular procedures. In: Lore JM, ed. *An Atlas of Head & Neck Surgery*. 4th ed. Philadelphia, PA: Elsevier Saunders; 2005: 1233–1347.
22. Greer LT, Kuehn RB, Gillespie DL, et al. Contemporary management of combat-related vertebral artery injuries. *J Trauma Acute Care Surg.* 2013;74(3):818–824.
23. Ordog GJ, Albin D, Wasserberger J, Schlatter TL, Balasubramaniam S. 110 bullet wounds to the neck. *J Trauma.* 1985;25:238–246.
24. Demetriades D, Theodorou D, Cornwell E, et al. Evaluation of penetrating injuries of the neck: prospective study of 233 patients. *World J Surg.* 1997;21:41–47.
25. Ramasamy A, Midwinter M, Mahoney P, et al. Learning the lessons from conflict: pre-hospital cervical spine stabilization following ballistic neck trauma. *Injury.* 2009;40:1342–1345.
26. Ledgerwood AM, Mullins RJ, Lucas CE. Primary repair vs ligation for carotid artery injuries. *Arch Surg.* 1980;115:488–493.
27. Fabian TC, George SM, Croce MA, et al. Carotid artery trauma: management based on mechanism of injury. *J Trauma.* 1990;30:953–963.
28. Fox CJ, Bowman JN. Advances in resuscitation in the setting of vascular injury. *Perspect Vasc Surg Endovasc Ther.* 2011;23(2):112–116.



29. Pearce WH, Whitehill TA. Carotid and vertebral arterial injuries. *Surg Clin North Am.* 1988;68:705–723.
30. Driscoll IR, Fuenfer MM, Shriver CD, et al. High velocity penetrating wounds to the neck: lessons learned from the battlefields in Afghanistan and Iraq. *J Am Coll Surg.* 2007;205:S67.
31. Nessen SC, Lounsbury DE, Hetz SP. *War Surgery in Afghanistan and Iraq: A Series of Cases, 2003–2007.* Washington, DC: Borden Institute; 2008.
32. Hom DB, Maisel RH. Penetrating and blunt trauma to the neck. In: Cummings CW, ed. *Cummings Otolaryngology—Head & Neck Surgery.* Vol 2. 5th ed. Philadelphia, PA: Elsevier Mosby; 2010: 1625–1635.
33. Weppner J. Improved mortality from penetrating neck and maxillofacial trauma using Foley catheter balloon tamponade in combat. *J Trauma Acute Care Surg.* 2013;75:220–224.
34. Osborn TM, Bell RB, Qaisi W, Long WB. Computed tomographic angiography as an aid to clinical decision making in the selective management of penetrating injuries to the neck: a reduction in the need for operative exploration. *J Trauma.* 2008;64:1466–1471.
35. Miller RH, Duplechain JK. Penetrating wounds of the neck. *Otolaryngol Clin North Am.* 1991;24:15–29.
36. Dubose J, Recinos G, Teixeira PG, Inaba K, Demetriades D. Endovascular stenting for the treatment of traumatic internal carotid injuries: expanding experience. *J Trauma.* 2008;65:1561–1566.
37. Fox CJ, Patel B, Clouse D. Update on wartime vascular injury. *Perspect Vasc Surg Endovasc Ther.* 2011;23(1):13–25.
38. Carducci B, Lowe RA, Dalsey W. Penetrating neck trauma: consensus and controversies. *Ann Emerg Med.* 1986;15:208–215.
39. Shiroff AM, Gale SC, Martin ND, et al. Penetrating neck trauma: a review of management strategies and discussion of the ‘no zone’ approach. *Am Surg.* 2013;79:23–29.
40. Jurkovich GJ, Zingarelli W, Wallace J, Curreri PW. Penetrating neck trauma: diagnostic studies in the asymptomatic patient. *J Trauma.* 1985;25:819–822.
41. Sclafani SJ, Cavaliere G, Atweh N, Duncan AO, Scalea T. The role of angiography in penetrating neck trauma. *J Trauma.* 1991;31:557–563.
42. Elkin DC, Harris MH. Arteriovenous aneurysm of the vertebral vessels. *Ann Surg.* 1946;124:934–949.
43. Kumar SR, Weaver FA, Yellin AE. Cervical vascular injuries: carotid and jugular venous injuries. *Surg Clin North Am.* 2001;81:1331–1344.
44. Dichtel W, Miller RH, Feliciano DV, Woodson GE, Hurt J. Lateral mandibulotomy: a technique of exposure for penetrating injuries of the internal carotid artery at the base of skull. *Laryngoscope.* 1984;94:1140–1144.
45. Perry MO. Injuries of the carotid and vertebral arteries. In: Bongard FS, Wilson SE, Perry MO, eds. *Vascular Injuries in Surgical Practice.* Norwalk, CT: Appleton & Lange; 1991.
46. Mittal VK, Paulson TJ, Colaiuta E, et al. Carotid artery injuries and their management. *J Cardiovasc Surg.* 2000;41:423–431.
47. Safak T, Akyurek M. Primary one-stage reconstruction of cheek defect after a shotgun blast to the face: use of the latissimus dorsi musculocutaneous free flap for soft-tissue repair and facial reanimation. *Ann Plast Surg.* 2001;47:438–441.
48. Chovanes J, Cannon JW, Nunez TC. The evolution of damage control surgery. *Surg Clin North Am.* 2012;92:859–875.
49. Subramanian A, Vercruysse G, Dente C, Wyrzykowski A, King E, Feliciano DV. A decade’s experience with temporary intravascular shunts at a civilian level 1 trauma center. *J Trauma.* 2008;65(2):316–324.



50. Chaudhary N, Gemmete JJ, Thompson BG, Pandey AS. Intracranial endovascular balloon test occlusion: indications, methods, and predictive value. *Neurosurg Clin North Am.* 2009;20(3):369–375.
51. du Toit DF, van Schalkwyk GD, Wade SA, Warren BL. Neurologic outcome after penetrating extracranial arterial trauma. *J Vasc Surg.* 2003;38:257–262.
52. Abud DG, Spelle L, Piotin M, Mounayer C, Vanzin JR, Moret J. Venous phase timing during balloon test occlusion as a criterion for permanent internal carotid artery sacrifice. *AJNR AM J Neuroradiol.* 2005;26:2602–2609.
53. Apffelstaedt JP, Muller R. Results of mandatory exploration for penetrating neck trauma. *World J Surg.* 1994;18:917–919.

