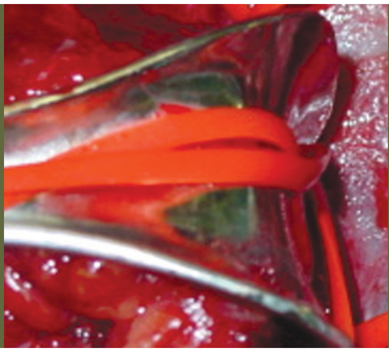
Chapter VIII
VASCULAR TRAUMA



VIII.1
Innominate Vein Injury

CASE PRESENTATION

This 20-year-old male soldier was injured in the right neck when his 40-mm grenade launcher misfired and exploded as he attempted to clear it. The patient presented completely alert with normal vital signs. He did complain of mild hoarseness. Examination revealed that a fragment entered through the right neck in zone II. There were no overt signs of vascular injury. On chest X-ray (CXR), the fragment appeared to be lodged behind the sternoclavicular joint (Fig. 1). During neck exploration, profuse bleeding was encountered. Resection of the medial left clavicle failed to allow access to the area of bleeding where a large fragment was palpable, prompting median sternotomy. This maneuver adequately exposed the fragment embedded in the innominate vein. The fragment was removed (Fig. 2) and the injury controlled with digital pressure. It was repaired using a running 5-0 Prolene suture (Figs. 3 and 4). No other vascular injuries were noted. After washout of a concurrent hand injury and a period of observation, the patient was evacuated from the combat support hospital (CSH) without difficulty to a level IV medical treatment center.

TEACHING POINTS

1. This is an example of a symptomatic (hoarseness), but stable, patient with a possible zone I and/or zone II neck injury. The size of the fragment and the mechanism of injury increased the concern of serious injury, but all zone II neck injuries with penetration of the platysma should be explored in the combat environment. Symptomatic zone I and III injuries should be explored if an arteriogram is not available (Fig. 5).
2. Zone II injuries are relatively easy to expose by a standard approach anterior to the sternocleidomastoid muscle. Occasionally, local wound exploration will identify the wound tract and fragment. In this case, exploration was limited. Frequently, a fragment cannot be identified, and the surgeon must specifically rule out injury to the carotid artery, internal jugular vein, trachea, or esophagus. In this case, zone II exploration was negative. Resection of the medial portion of the left clavicle revealed the fragment was in the innominate vein. However, this approach inadequately exposed the fragment and vessel necessitating median sternotomy (Fig. 6). Once the specific injury was identified and properly exposed, it was relatively easily repaired.

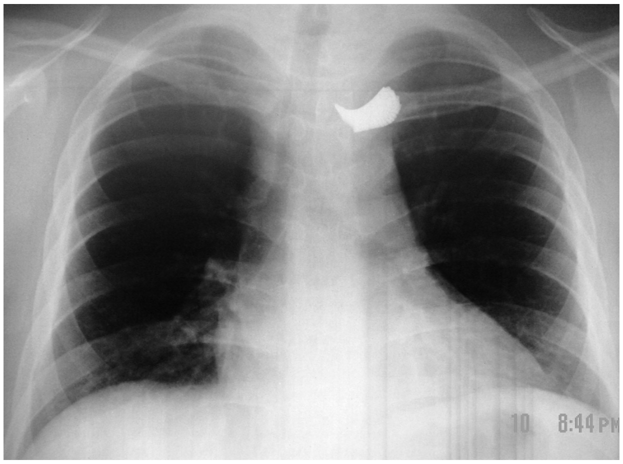


FIGURE 1. *This CXR was obtained preoperatively and demonstrates a large fragment from a 40-mm grenade overlying the left sternoclavicular joint on single frontal view.*

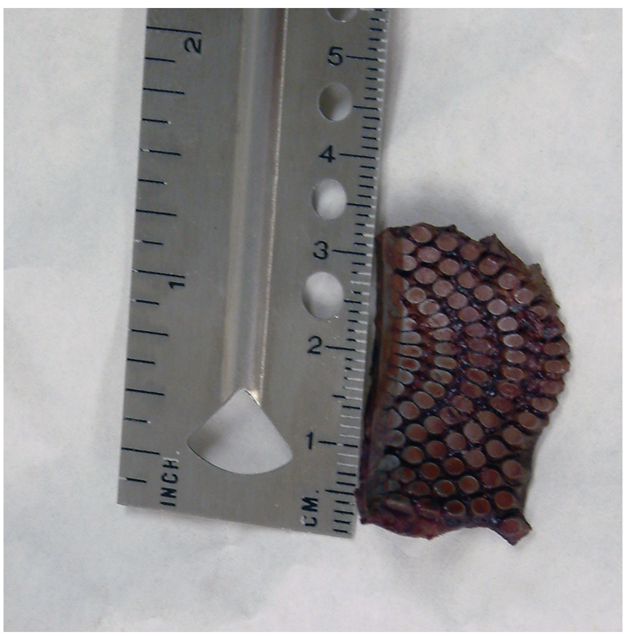


FIGURE 2. *This is the fragment that was lying in the innominate vein.*

3. This case emphasizes the importance of ruling out vascular injury in all neck injuries prior to evacuation. It is not possible to intervene surgically if this type of patient becomes unstable in flight.
4. This type of case is technically more difficult to perform at the Forward Surgical Team (FST) facility and emphasizes the importance of bringing stable patients from the point of injury directly to level III whenever possible.
5. Distal injury of the subclavian arteries is more difficult to address and may require a supraclavicular approach or resection of the proximal clavicle to allow adequate exposure (Fig. 7). The combination of a median sternotomy with an anterior thoracotomy and supraclavicular incision (trapdoor) can also be used.

CLINICAL IMPLICATIONS

Twenty percent of penetrating neck injuries result in vascular injury. Mortality may occur from exsanguination or less commonly from esophageal injury that progresses to mediastinitis. Tracheal injuries must be excluded. The presence of any of the following symptoms mandates exploration:

1. Obvious bleeding.
2. Expanding hematoma.
3. Bruit or thrill in the neck.
4. Hypotension.
5. Dyspnea, hoarseness, or stridor.
6. Absent or decreased pulses in the neck or arm.
7. Focal neurological deficit or mental status changes.
8. CXR with hemothorax or widened mediastinum.

Signs of esophageal or tracheal injury include the following:

1. Crepitus or subcutaneous emphysema.
2. Dyspnea or stridor.
3. Air bubbles in wound.
4. Tenderness or pain over trachea.
5. Odynophagia (pain on swallowing).
6. Hoarseness.
7. Hematemesis or hemoptysis.

DAMAGE CONTROL

Hypotensive patients with suspected zone I injury of the common carotid artery or subclavian artery and vein can be approached through a median sternotomy or an extended left anterior thoracotomy (clamshell incision). Generally, the median sternotomy is an optimal approach for the aorta, innominate, and proximal

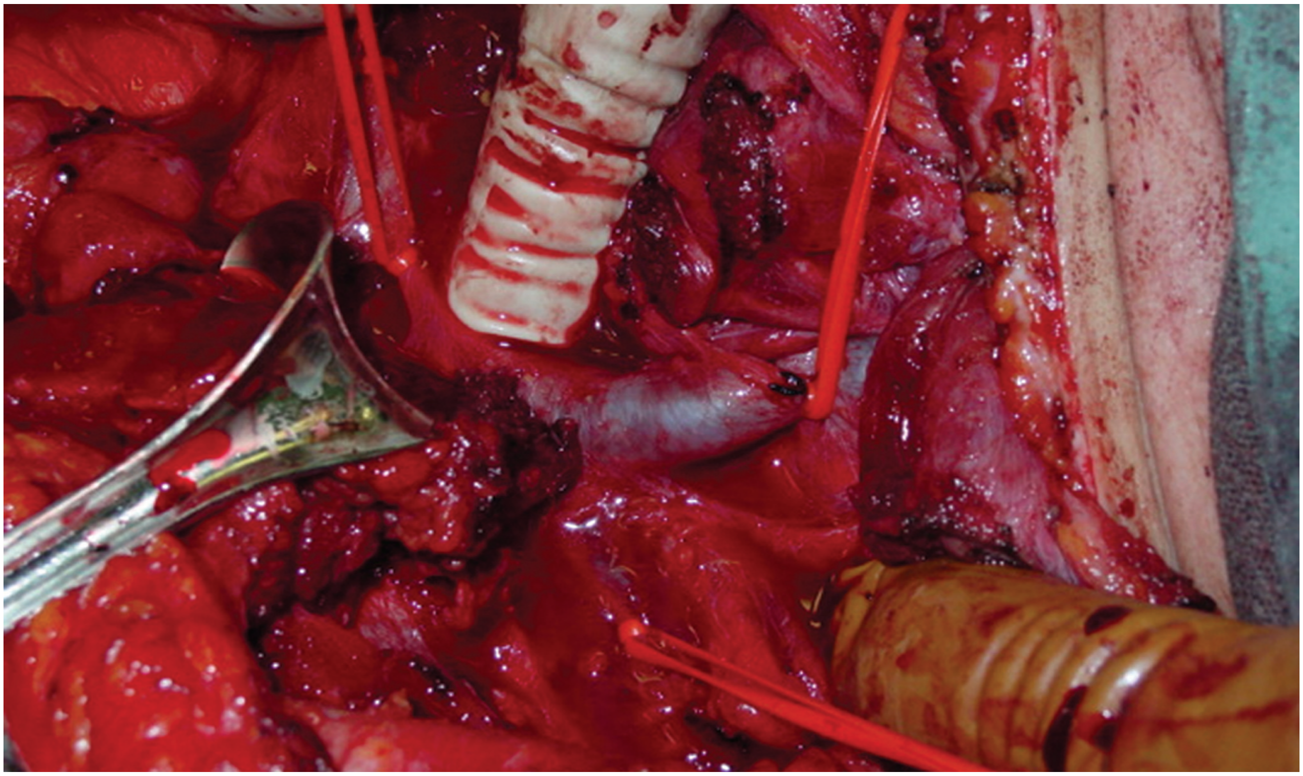


FIGURE 3. *The gloved finger at the top is occluding the hole in the innominate vein.*

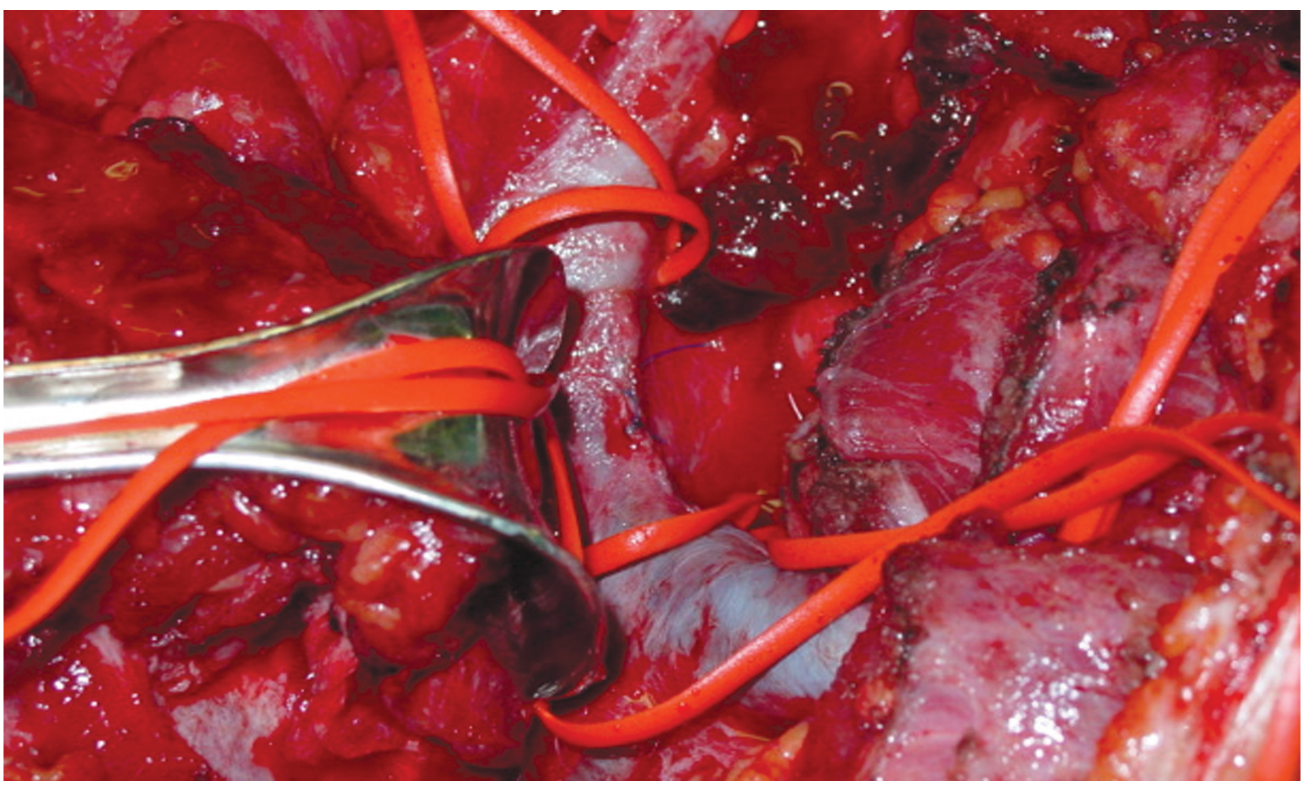
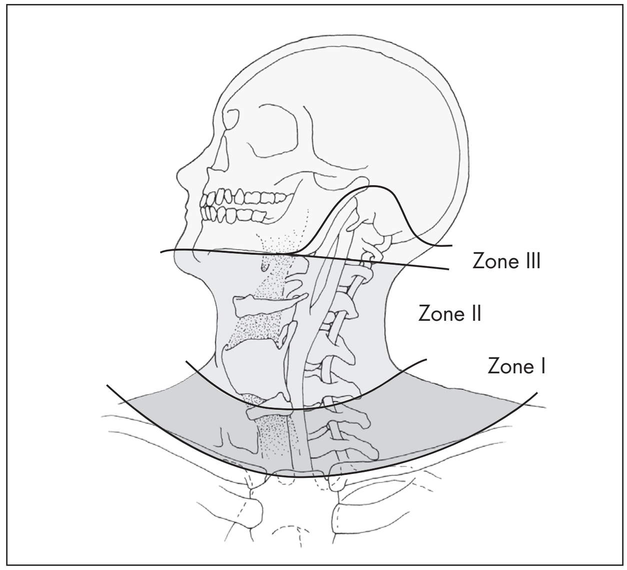
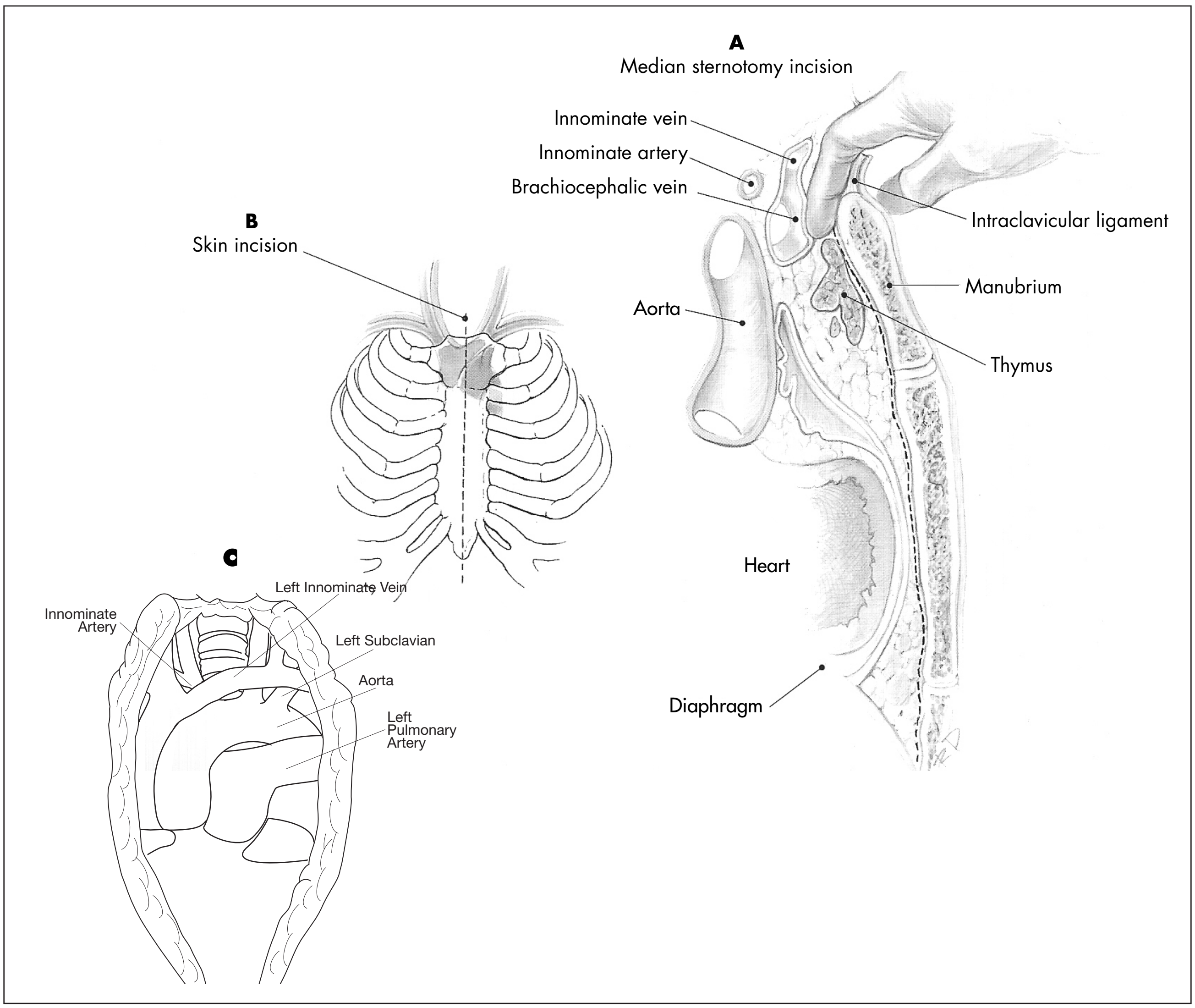


FIGURE 4. *Venorrhaphy has been completed with 5-0 Prolene.*

Figure 5. (Top) *Zones of the neck.*

Figure 6. (Bottom) *Approach to level I injuries.* (A) *Sagittal view of superior aspect of median sternotomy incision. Note proximity of the innominate vessels.* (B) *Median sternotomy incision.* (C) *Exposure of great vessels through median sternotomy incision.* Reprinted with permission (A and B) from Thal ER, Weigelt JA, Carrico J. *Operative Trauma Management: An Atlas.* 2nd ed. New York, NY: McGraw-Hill Professional; 2002. Copyright © 2002 The McGraw-Hill Companies, Inc.





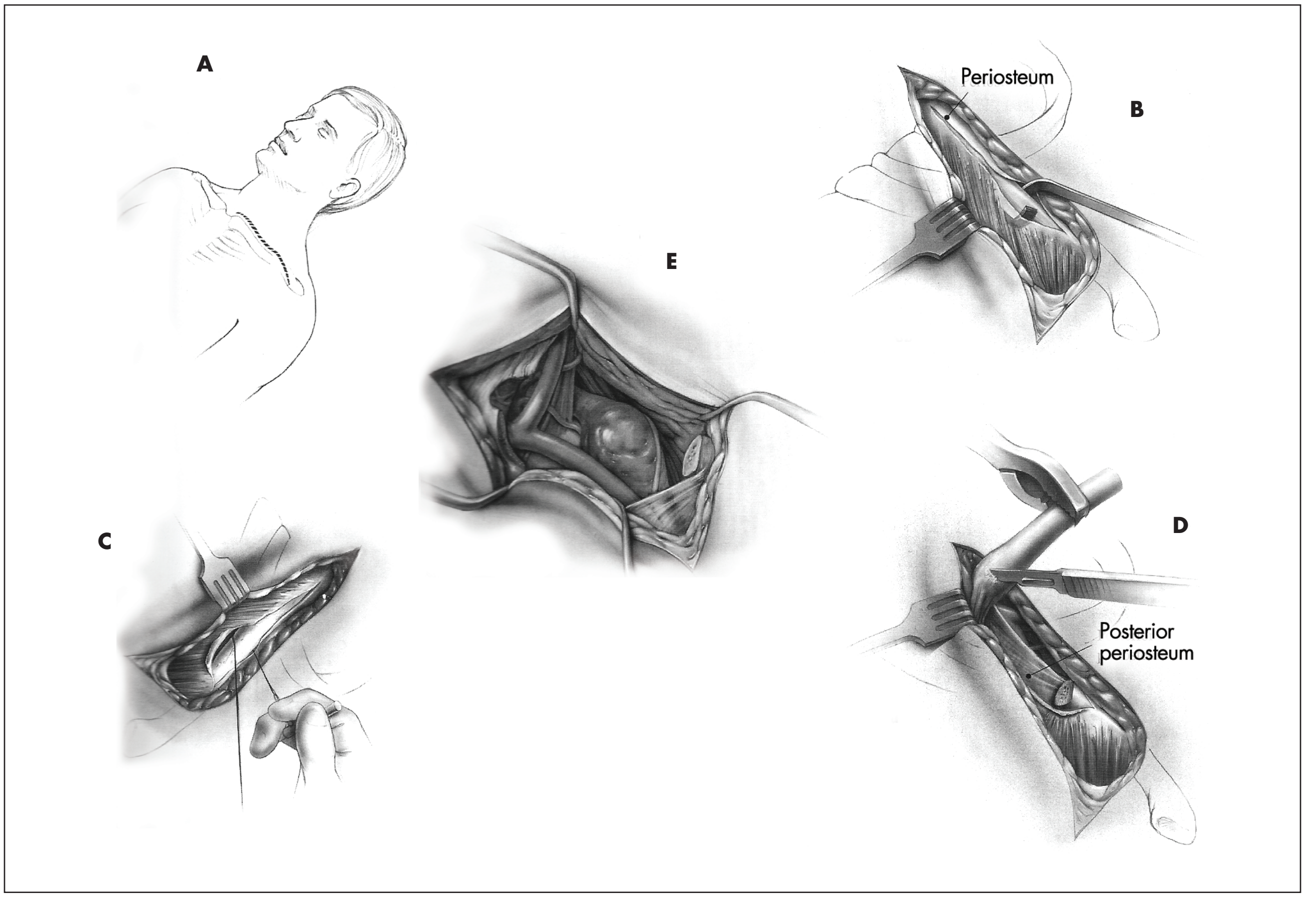


FIGURE 7. (A) *Supraclavicular incision.* (B) *Exposing the clavicle.* (C) *Dividing clavicle with a Gigli saw.* (D) *Dividing posterior periosteum.* (E) *Exposed left subclavian and common carotid arteries.* Reprinted with permission from Thal ER, Weigelt JA, Carrico J. *Operative Trauma Management: An Atlas*. 2nd ed. New York, NY: McGraw-Hill Professional; 2002. Copyright © 2002 The McGraw-Hill Companies, Inc.

PENETRATING NECK TRAUMA

Introduction

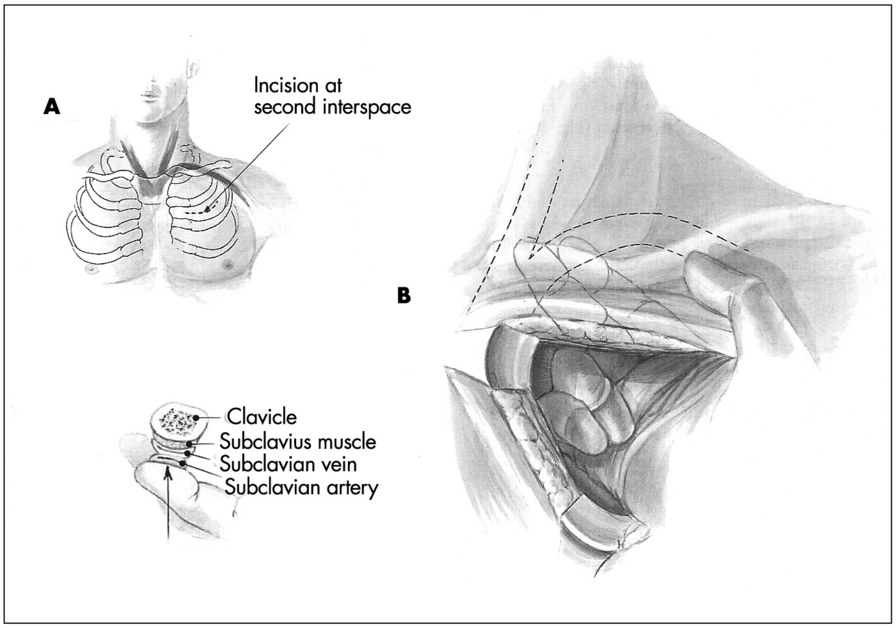
- Vascular injuries occur in 20% and aerodigestive tract in 10% of cases.
- Mortality is primarily due to exsanguinating hemorrhage.
- Esophageal injury, which results in mediastinitis and intractable sepsis, may also be fatal.

Anatomy

The neck is divided into three zones to aid in decision-making for diagnostic tests and surgical strategy. In each zone, the primary structures at risk of injury are different (see Fig. 5).

- ZONE I (clavicle to cricoid membrane): The structures of concern include large vessels of the thoracic outlet (subclavian artery and vein, common carotid artery), the lung, and the brachial plexus.
- ZONE II (cricoid membrane to angle of mandible): Structures of concern include the common carotid artery, internal jugular vein, esophagus, and trachea.
- ZONE III (angle of mandible to base of skull): The structure of concern is primarily the internal carotid artery.

FIGURE 8. *Temporary occlusion of a subclavian injury through a limited left thoracotomy. This is a temporary control measure to allow greater exposure.* (A) *Temporary control of subclavian artery injury may be obtained through a second intercostal incision.* (B) *Digital pressure is applied to the subclavian artery and vein.* Reprinted with permission from Thal ER, Weigelt JA, Carrico J. *Operative Trauma Management: An Atlas*. 2nd ed. New York, NY: McGraw-Hill Professional; 2002. Copyright © 2002 The McGraw-Hill Companies, Inc.



subclavian arteries. An anterior thoracotomy through the second intercostal space may allow digital pressure to be applied upward and medially (compressing the subclavian artery and vein against the clavicle) as a temporary measure to control bleeding (Fig. 8).

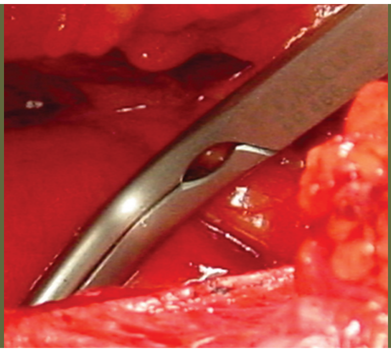
SUMMARY

This is a case in which suspected zone I and zone II neck injuries (see Fig. 5) required the combination of right neck exploration and ultimately median sternotomy to identify and repair the vascular injury suggested by the patient's hoarseness, mechanism of injury, entrance wound, and CXR.

Note: See discussion of this case on page 359.

SUGGESTED READING

Chapter 27: Vascular injuries. In: *Emergency War Surgery, Third United States Revision*. Washington, DC: Department of the Army, Office of The Surgeon General, Borden Institute; 2004.



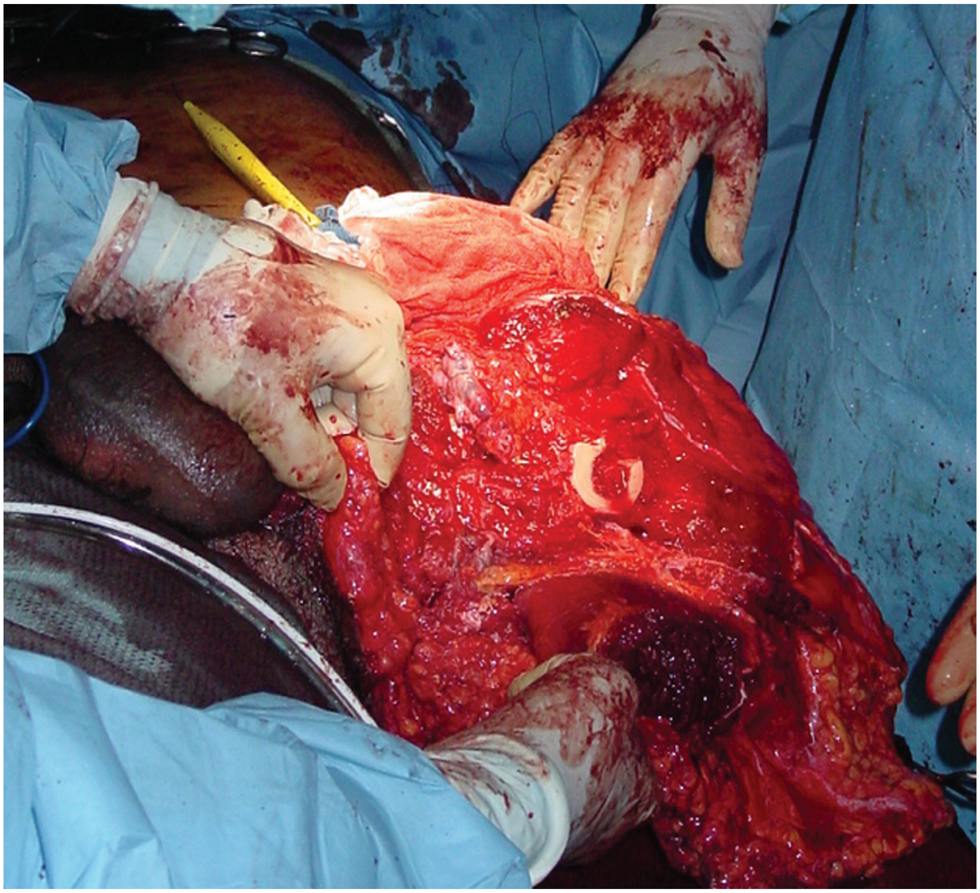
VIII.2 External Iliac Vein Injury, Exposure and Control

CASE PRESENTATION

This 23-year-old male soldier presented after an insurgent attack. He was traveling inside an armored vehicle when he was injured by a shoulder-fired, rocket-propelled–shaped charge missile that penetrated the vehicle but ultimately failed to explode. He arrived at the combat support hospital (CSH) hypotensive and actively bleeding from a large, left groin wound with an obvious femur fracture. Upon arrival in the emergency medical treatment area, direct pressure was applied to the wound, and pressure was applied to the left femoral pressure point. This decreased the bleeding and allowed visualization of the severed end of the superficial femoral artery (SFA) and the profunda femoris artery (PFA), which was clamped (Fig. 1). These maneuvers initially decreased the bleeding. Further resuscitation increased the blood pressure, resulting in diffuse bleeding from multiple locations. The patient was transported to the operating room and prepped from neck to feet of both extremities. No attempt at limb salvage was contemplated for this unstable patient with ongoing hemorrhage because of massive injury to the femoral artery, vein, and nerve associated with a large soft-tissue wound and femur fracture—an injury that essentially constituted a traumatic, near-complete amputation (Fig. 2). A high above-the-knee amputation was quickly performed. Ligation of the PFA was performed distal to its first branch in the hopes of preserving enough blood supply to avoid an eventual hip disarticulation. The superficial femoral vein (SFV) and branches were ligated as distal as possible to allow drainage (Fig. 3). With the amputation complete, bleeding from the ilioinguinal ligament region was noted. Despite retraction, the source of bleeding could not be identified. However, direct pressure over the ligament controlled visible bleeding, which was dark and consistent with a venous origin. It was determined that exposure of the external iliac vessels was necessary. Options for exposure included division of the inguinal ligament, laparotomy, or an iliac fossa (kidney transplant) incision. Division of the inguinal ligament was ruled out because pressure over the ligament was temporarily controlling the bleeding and exposure may have been inadequate. Similarly, it was felt that laparotomy may not allow adequate exposure of the distal external iliac artery and vein. Therefore, the transplant incision was used in this case because it provided the best exposure to the distal iliac vessels and would allow proximal control of the distal aorta, if necessary. This approach allowed proximal control of the iliac vein at the bifurcation and that stopped the bleeding. A 2-cm posterior laceration of the external iliac vein was identified and lateral

FIGURE 1. *Large proximal left lower extremity injury. Vascular clamps are in place.*

FIGURE 2. *Extensive tissue injury.*



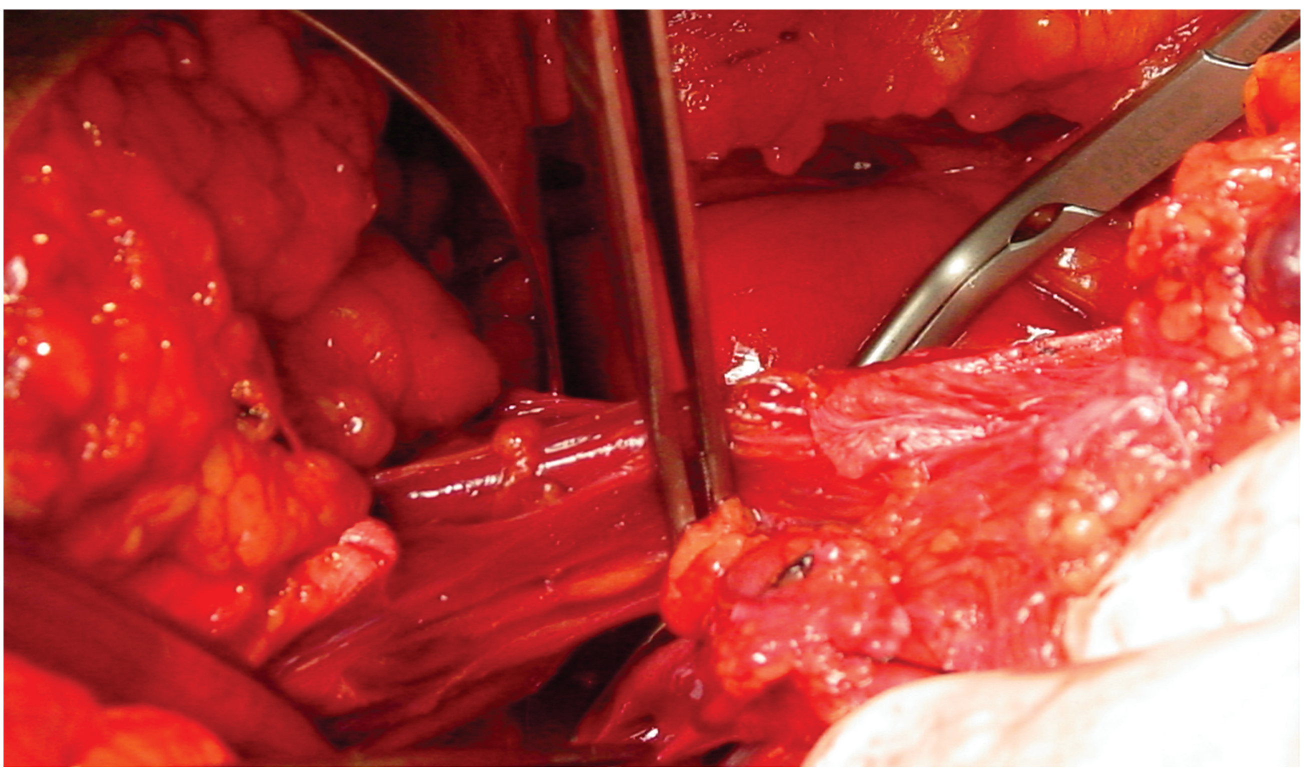


FIGURE 3. (Top) *Initial amputation has been performed.*

FIGURE 4. (Bottom) *The external iliac vein is dissected, and an injury is repaired.*

venorraphy performed (Fig. 4). With hemorrhage finally controlled, the wound was debrided with preservation of as much tissue as possible. The patient was evacuated to a level IV medical treatment facility. There, he underwent proctoscopy and an exploratory laparotomy for a rectal contusion and underwent diversion colostomy. The patient ultimately required a hip disarticulation. He progressed well with aggressive physical therapy and was able to ambulate with assistance upon discharge from Walter Reed Army Medical Center.

TEACHING POINTS

1. Nothing stops bleeding like direct pressure. In this case, direct pressure allowed enough control of the bleeding that direct clamping of the visualized vessels could be performed. The dictum not to use blind clamping is correct. However, if a vessel can be visualized, a clamp can provide excellent hemostasis.
2. Proctoscopy is warranted for injuries in this location due to the proximity of the wound to the rectum. Because of the urgency of bleeding, this step was correctly omitted at the patient's initial evaluation to address the life-threatening injury at hand. Once life-threatening injuries have been stabilized, it is important that the patient be completely reevaluated for other injuries that may have been initially missed or ignored and that may result in subsequent deterioration. Similarly, it is important that, at each level along the evacuation chain, the patient is completely reevaluated.
3. Use of the transplant incision (Fig. 5) gives excellent exposure of the iliac and hypogastric vessels and aorta. In this case, the transplant incision allowed for isolation and repair of this injury and examination of the proximal vessels to rule out injury.

CLINICAL IMPLICATIONS

1. Early control of external bleeding is critical. A patient with compressible hemorrhage can be temporized with direct pressure until surgical control of hemorrhage is possible.
2. The surgeon must balance the realistic likelihood of ultimate functional reconstruction against the risk of death associated with attempts to preserve a limb.

DAMAGE CONTROL

It is critical to recognize the need to institute damage control techniques at initial presentation. This case demonstrates the immediate recognition of the need for amputation as opposed to prolonged attempts at limb salvage. It is likely that this soldier survives today because of this initial decision.

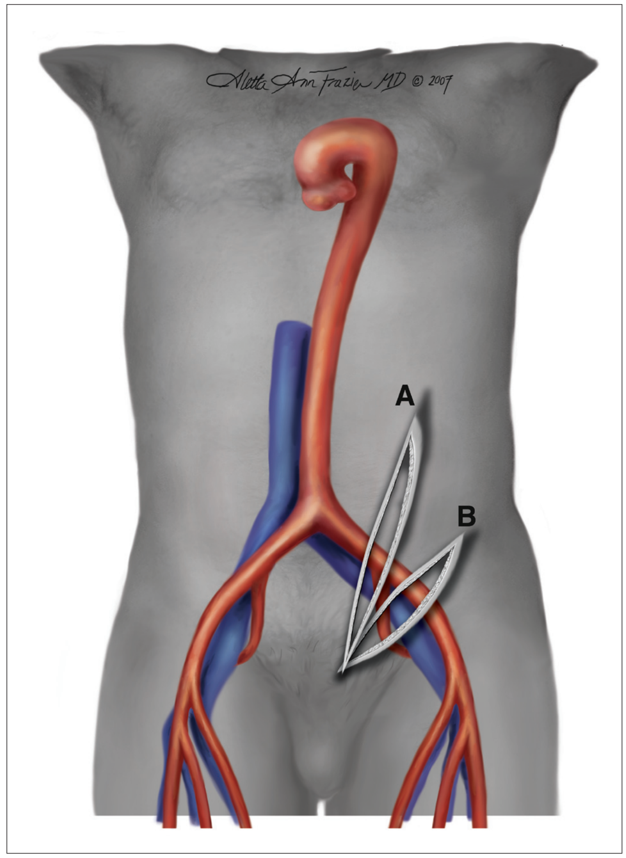


FIGURE 5. *Illustration of iliac vessel (transplant) incisions.*

SUMMARY

This is a case in which traumatic near amputation is completed operatively. Persistent hemorrhage was identified from above the inguinal ligament and required exposure of the external iliac vessels. The transplant incision was used with good results.

Note: See discussion of this case on page 359.

SUGGESTED READING

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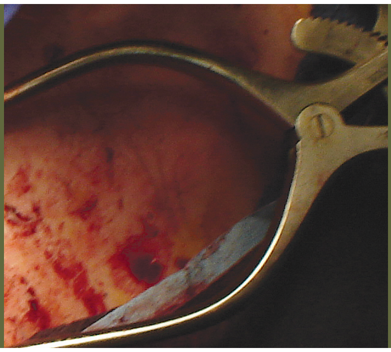
Chapter 27: Vascular injuries. In: *Emergency War Surgery, Third United States Revision*. Washington, DC: Department of the Army, Office of The Surgeon General, Borden Institute; 2004.



VIII.3 Penetrating Subclavian Artery Injury

CASE PRESENTATION

While on guard duty, this male patient was injured by a blast from a vehicle-borne, improvised explosive device (IED). On hospital admission, he was neurologically and hemodynamically uncompromised. His wounds were multiple, superficial fragment injuries. One such injury was in the right supraclavicular fossa. The wound was approximately 3 mm in length, but no evidence of distal neurovascular compromise was evident. A plain chest X-ray revealed a widened mediastinum, and a fragment could be seen superior to the right clavicle. CT scan revealed a hematoma around the subclavian vessels. The fragment was located along the posterior-superior margin of the subclavian artery. Consideration was given to evacuating the patient to a vascular surgeon at a level IV medical treatment facility. However, the risk of rebleeding during the 6-hour evacuation process was deemed to be significant. In the operating room, he was placed in the supine position. His chest was prepared and draped. Both lower extremities were prepped to provide an autologous vein, if needed. An incision was made superior and parallel to the clavicle. Proximal and distal control of the subclavian artery was obtained. The injury was in the most superior aspect of the subclavian artery. Proximal control was obtained distal to the origin of the vertebral artery. Distal control was obtained after transecting the anterior scalene muscle. The fragment had produced a tangential injury along the superior-posterior aspect of the artery. The vessel injury was only about 2 mm in length. The fragment destroyed only a very small portion of the vessel wall. The 3-mm fragment was removed from the surgical field, and primary repair was performed using polytetrafluoroethylene (PTFE) pledgets as bolsters for the fine Prolene suture. Hemostatic closure of the injury was achieved, and excellent distal pulses were present to palpation after repair. The Doppler signal of the radial artery was normal. The wound was closed after a small drain was placed in the area of dissection.

TEACHING POINTS

1. Subclavian artery injuries are treacherous because vascular control can be difficult to obtain. Injuries to the origin of the right subclavian artery require a median sternotomy to obtain proximal vascular control. A median sternotomy, with a trapdoor along the fourth left intercostal space, might be necessary to access the proximal left subclavian artery.

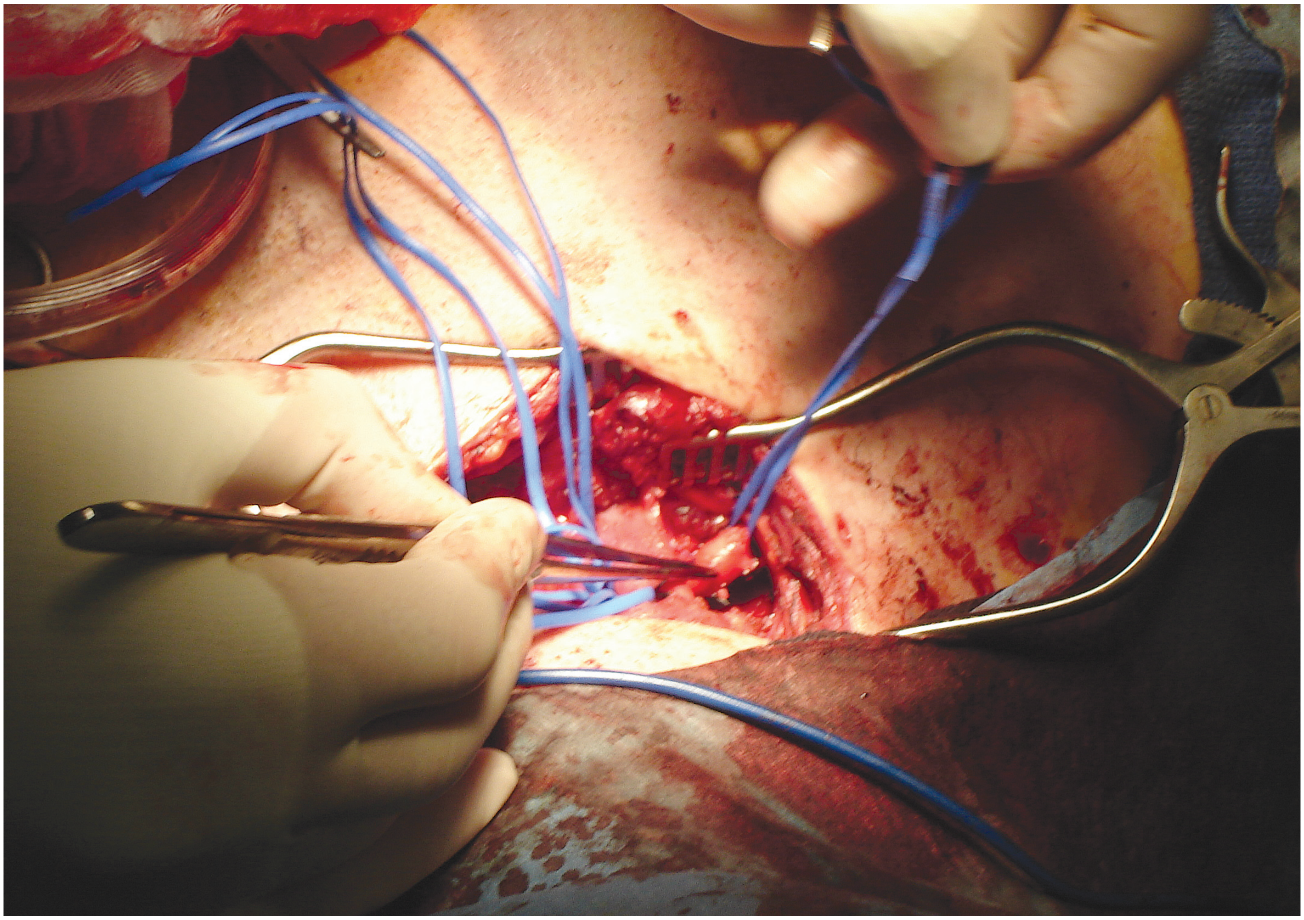


Figure 1. *The surgeon is grasping the right subclavian artery just proximal to the site of injury. Injury is not visible because it is on the dorsal aspect of the artery.*

2. In this case, the injury was near the middle of the right subclavian artery. Proximal and distal control were readily obtained using the supraclavicular approach. The chest had been prepared. A sternotomy set was available if more proximal control had been required.
3. A good working knowledge of the thoracic inlet is necessary to make sound decisions for the optimal surgical approach. The hemodynamically compromised patient, with injury to the thoracic inlet, requires immediate vascular control. A median sternotomy would be the most expeditious route to control hemorrhage.
4. The only evidence of significant hemorrhage on presentation may be radiographic findings that include extrapleural densities, pleural effusion, or mediastinal widening.
5. Autologous vein grafts are preferred for traumatic vascular repairs. In cases where an autologous vein is either inadequate or not available, prosthetic graft should be used for an expeditious repair or if a significant size discrepancy exists. In this case, PTFE was not used as an interposition graft, but as a pledget. Minimizing foreign material is an objective in combat wounds. However, in this patient, the injury was from a 3-mm fragment that was removed from the surgical site. Also, adjacent tissue destruction was minimal. Because the subclavian artery has a fragile texture, a buttressed repair was required.

CLINICAL IMPLICATIONS

Surgeons must be prepared to provide vascular exposure in areas not frequently approached. Under certain circumstances, prosthetic material is acceptable in vascular repairs. Basic vascular principles always apply and include the following:

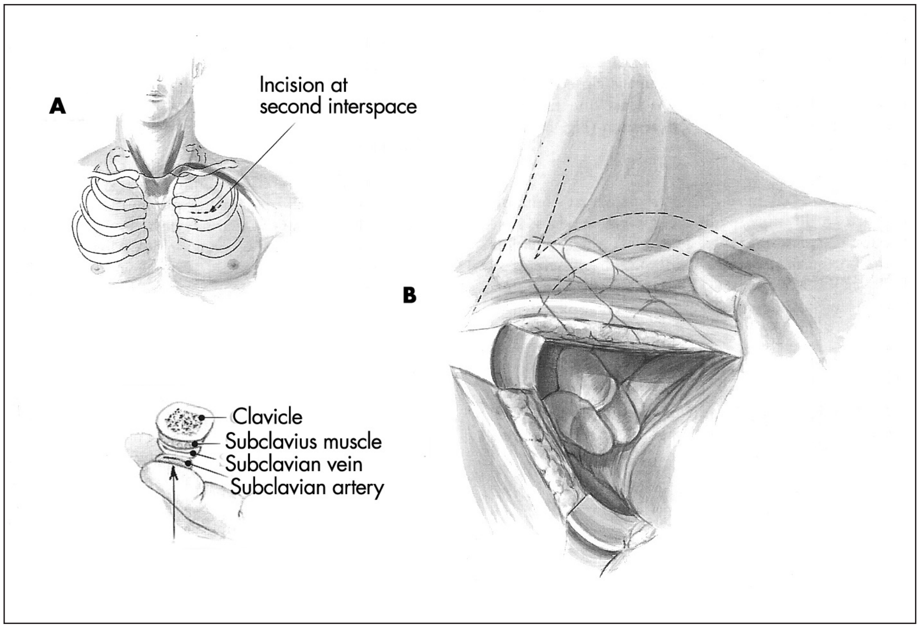


FIGURE 2. (A) *Temporary control of subclavian artery injury may be obtained through a second intercostal space incision.* (B) *Digital pressure is applied to the subclavian artery and vein.* Reprinted with permission from Thal ER, Weigelt JA, Carrico J. *Operative Trauma Management: An Atlas*. 2nd ed. New York, NY: McGraw-Hill Professional; 2002. Copyright © 2002 The McGraw-Hill Companies, Inc.

1. Hard signs of vascular injury may not be present (as in this case), but surgeons should remain alert to subtle injury changes. A missed subclavian artery injury has a high mortality rate.
2. Soft signs of arterial injury that require additional diagnostic evaluation—eg, proximity of wounds to major vessels, shock, diminished pulse, or nerve injury—should prompt further evaluation or exploration.

DAMAGE CONTROL

The key to controlling hemorrhage from a subclavian artery injury is adequate exposure. This may require a median sternotomy, a supraclavicular approach, or an infraclavicular approach to the vessel. The proximal clavicle can be resected if needed. A trapdoor incision can be used, if necessary. Once exposure is obtained, placement of a shunt is appropriate until definitive repair can be achieved.

SUMMARY

This is a case in which clinical vigilance led to the diagnosis and repair of a subclavian artery injury. This case demonstrates the importance of maintaining appropriate clinical concern and identifying subtle vascular injuries. Evacuation of this patient from theater without identifying his particular injury could have easily resulted in loss of an extremity or a fatal outcome.

Note: See discussion of this case on page 359.

SUGGESTED READING

Chapter 27: Vascular injuries. In: *Emergency War Surgery, Third United States Revision*. Washington, DC: Department of the Army, Office of The Surgeon General, Borden Institute; 2004.

VIII.4
Shunts in Vascular Injuries

CASE PRESENTATION

This 16-year-old female presented to a Forward Surgical Team (FST) after a gunshot wound to the right groin. The groin area was examined. Several centimeters of the common femoral artery were destroyed. A no. 10 French Argyle shunt was placed in the proximal and distal lumens of the injured artery and secured in position with 0 silk ties. The wound was approximated in a single layer, and the dressing was clearly marked to indicate the shunt. The patient was then intubated, sedated, and transferred (via helicopter) to the combat support hospital (CSH; Fig. 1). Distal pulses were intact. Resuscitation was continued, and the patient was taken to the operating room for reexploration (Fig. 2). The shunt was patent. The contralateral greater saphenous vein was harvested, and an interposition graft was performed (Figs. 3 and 4). The patient was not anticoagulated because of her ongoing coagulopathy from relative hypothermia and blood loss. She was admitted postoperatively to the intensive care unit, where the graft remained patent. Her recovery was prolonged, but she was eventually returned home.

Courtesy David Leeson, *The Dallas Morning News*

TEACHING POINTS

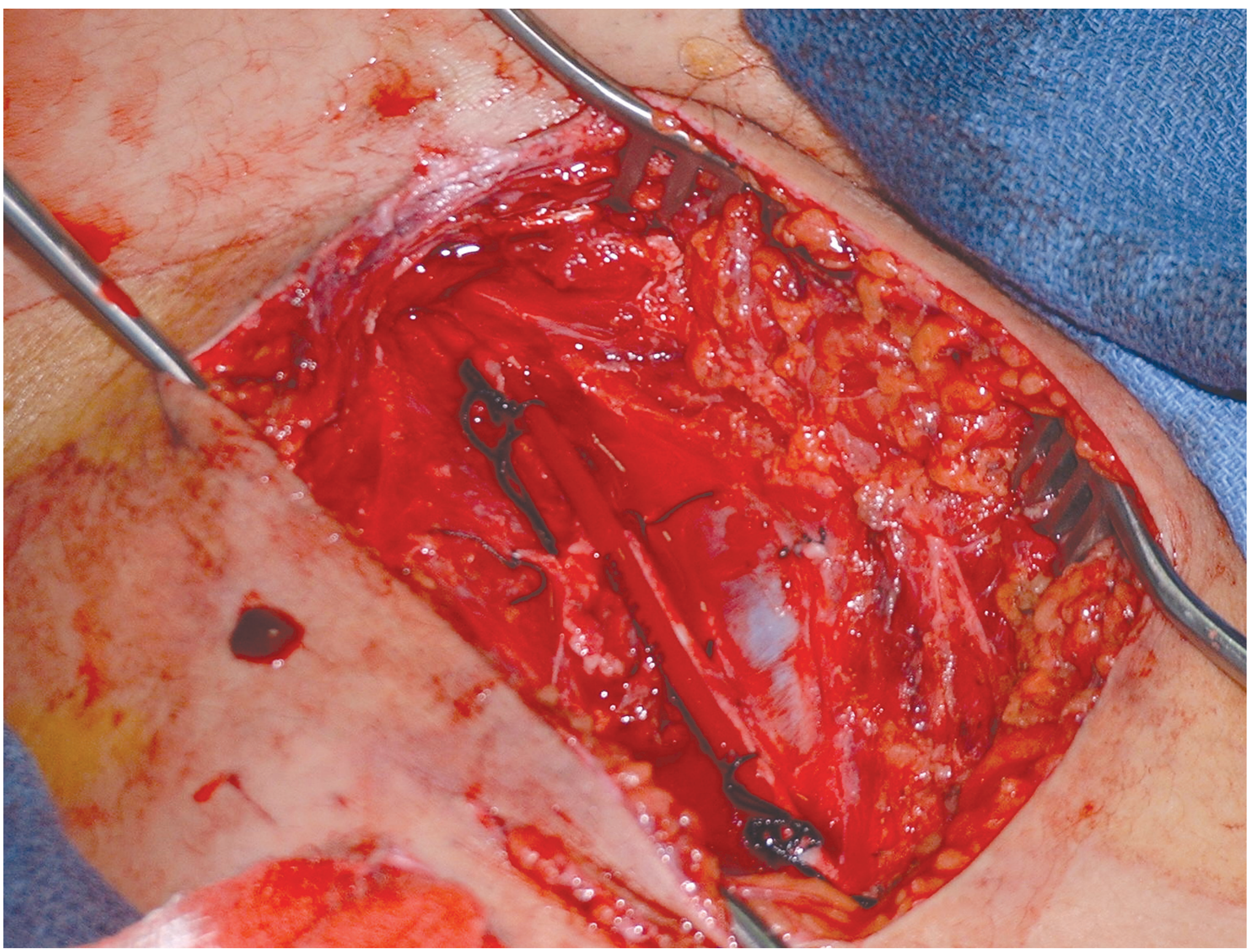
1. Well-positioned arterial shunts can be lifesaving and limbsaving. A functional shunt allows perfusion, while resuscitation is ongoing. The patient can then be evacuated to a higher echelon of care without compromising the extremity.
2. Dressings should be marked clearly to indicate a shunt is in place.
3. Systemic anticoagulation is not recommended for cases of arterial trauma unless the injury is isolated, there is no ongoing hemorrhage, and the patient does not have a coagulopathy.

CLINICAL IMPLICATIONS

1. Arterial injuries are common on the battlefield.
2. Usually, patients have suffered significant hemorrhage before arriving at the first echelon of care.
3. Shunt placement allows perfusion of the injured extremity while the patient is being resuscitated or transferred. The Argyle shunt, Javid shunt, and Sundt shunt are all acceptable. The proximal end of the shunt is placed first, then the distal end. The shunt is secured in position with 0 silk ties. Once flow has been confirmed by the

Figure 1. (Top) *Transfer of patients between military treatment facilities can result in confusion because of the lack of communication. In this case, the dressing has been marked (as "shunt"* [white circle]) *so the receiving team knows that further surgery is required.*

Figure 2. (Bottom) *Shunt bridging the arterial injury.*



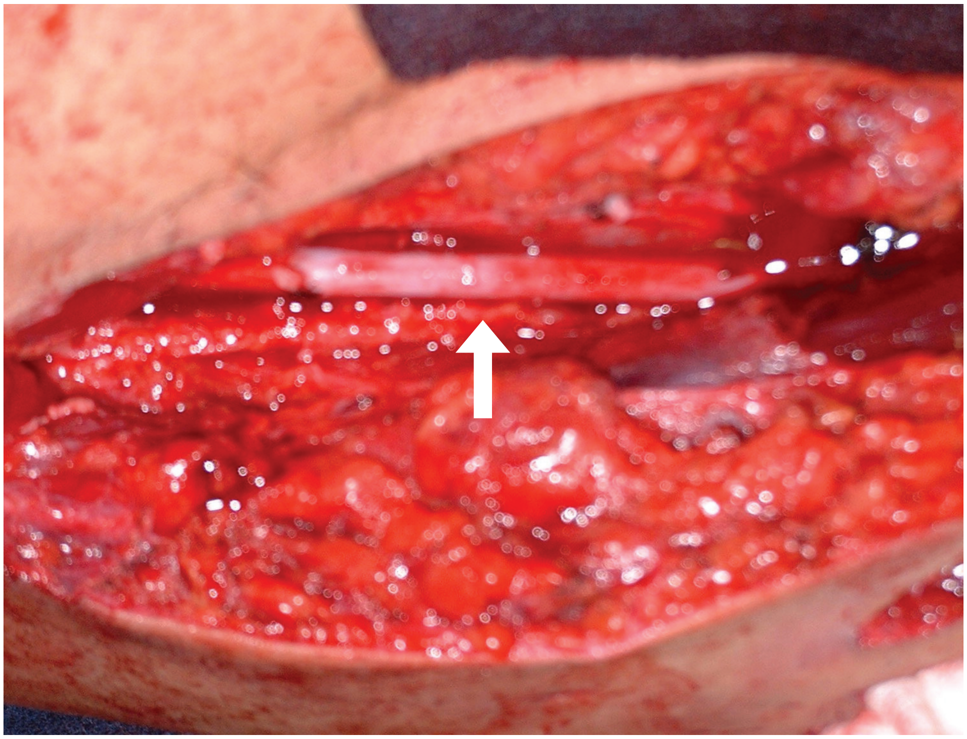
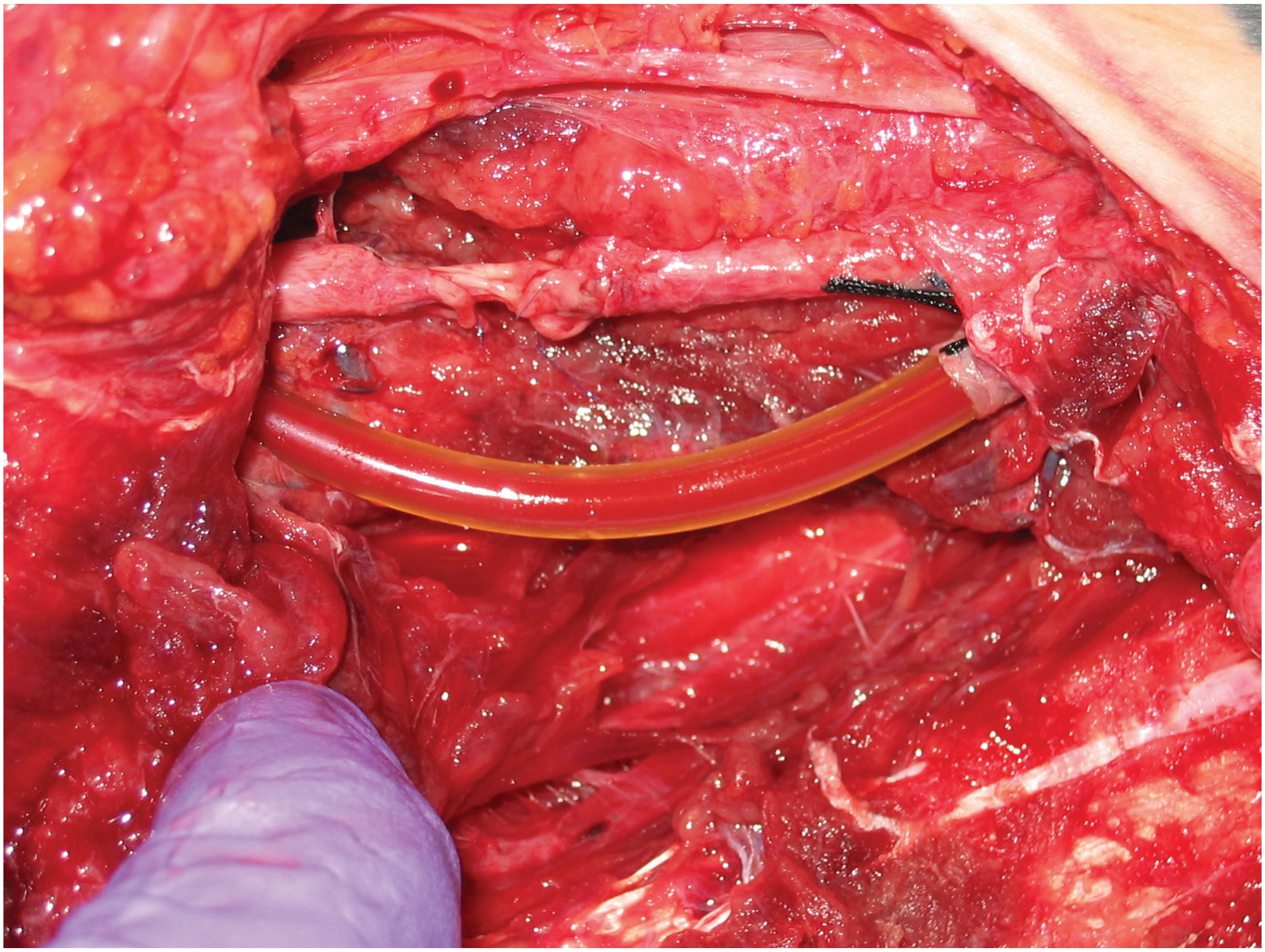
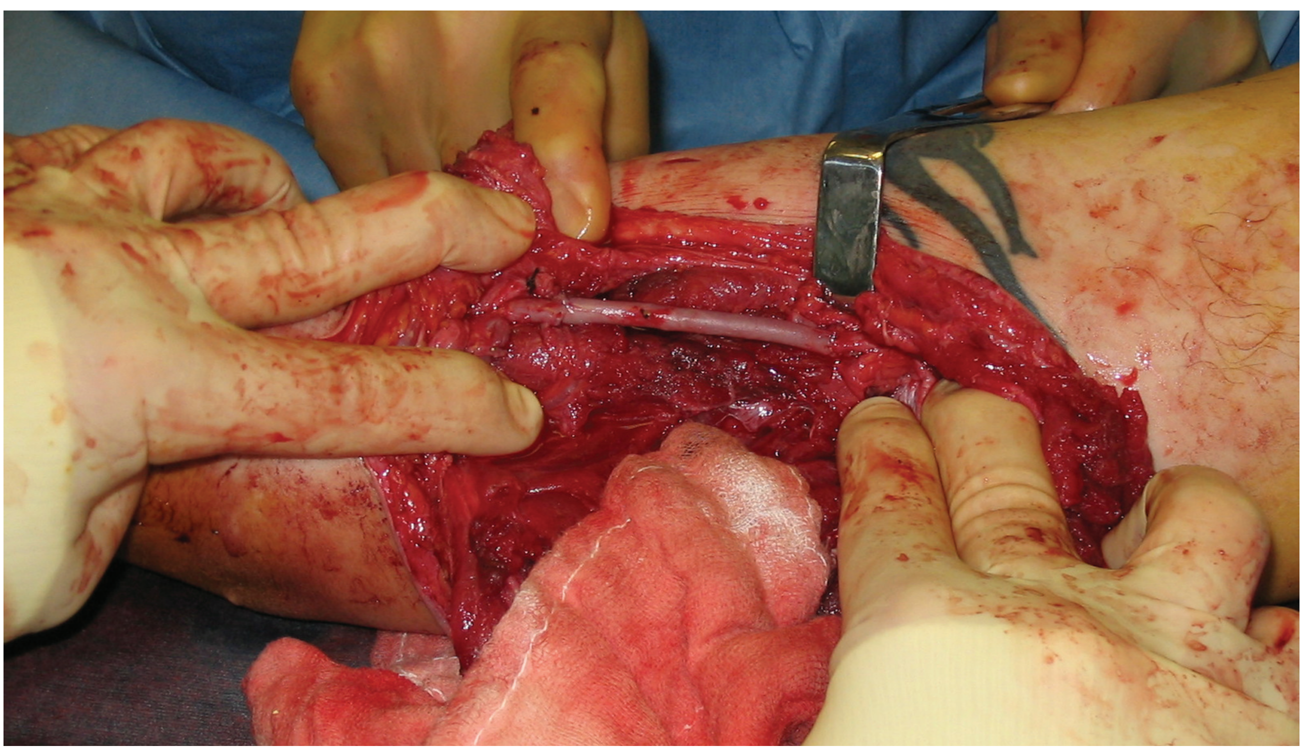


Figure 3. (Top Left) *Saphenous interposition graft in place.*

Figure 4. *Vascular shunt in another patient.* (Bottom Left) *Patient presenting to CSH with shunt in left brachial artery.* (Top Right) *Shunt in place.* (Bottom Right) *Saphenous interposition graft in place.*





SHUNTS

A shunt diverts or permits flow of a body fluid from one pathway or region to another by surgical means. There are various types of shunts, but they usually have two similar elements: a catheter (the tubing) and the shunt (which regulates pressure/flow). Usually for the shunt being used, the surgeon selects a range of pressure and bases that decision on the patient's needs. Note: Interestingly, the various parts of the shunt system are named according to where they are placed in the body. In addition, these parts are normally made from materials that are well-tolerated by the human body.

Javid Shunt

A Javid or Argyle shunt is frequently used for shunting cerebral blood flow.
Javid shunts:

- — are soft, kink-resistant, and tapered
- — have extra length that allows looping
- — have smooth, polished tips for easy insertion

Sundt Shunt

This shunt is also known as the Sundt carotid endarterectomy shunt. During carotid endarterectomy procedures, the shunt provides temporary carotid bypass for cerebral circulation. Dr Thoralf M. Sundt (1930–1992) developed the Sundt shunt for carotid surgery.

presence of distal pulses or Doppler signal, the shunt is covered with viable tissue, dressed, and marked.

DAMAGE CONTROL

Placement of an arterial shunt is a damage control technique. The use of prosthetic grafts can hasten the completion of a procedure in unstable patients where expeditious surgery is required. Prosthetics can also be used in areas of extensive soft-tissue debridement as a "prolonged shunt," where planned revision days to weeks later, out of theater, will be undertaken.

SUMMARY

This case is a common scenario in which a patient with an arterial injury is first seen at an FST facility that has minimal capability to provide massive resuscitation and definitive repair. The shunt allowed the patient to be evacuated safely to a higher level of care without compromise of the extremity.

Note: See discussion of this case on pages 359–360.

SUGGESTED READING

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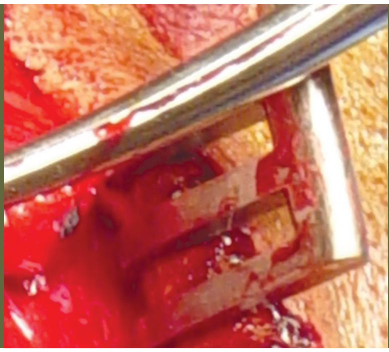


VIII.5 Arteriovenous Fistula, Delayed Effect of Blast

CASE PRESENTATION

This 26-year-old male presented with complaints of swelling in the right temple, buzzing in his right ear, and a feeling of fullness on his face. Two months previously, he sustained minor injuries to his right side, the result of a blast from an improvised explosive device (IED). On physical examination, he had a 6 x 4 cm soft mass anterior to his right ear, with engorgement of the superficial veins (Fig. 1). There was a bruit over the mass. Plain radiographs showed multiple, small radiopaque foreign bodies in the soft tissues on the right side of the head and neck. An ultrasound scan confirmed an arteriovenous fistula between the superficial temporal artery and an overlying vein (Fig. 2). In the operating room, the fistula was exposed, and the vein branches were ligated (Fig. 3). Once the superficial artery was exposed, the arteriotomy was closed with a single 6-0 Prolene suture. The patient made a full recovery.

TEACHING POINTS

1. Arteriovenous fistulae and pseudoaneurysms are the result of arterial injury that can manifest in a delayed manner days, months, or even years after injury.
2. An arteriovenous fistula develops when an artery and vein in close proximity are both injured. The higher pressure in the artery keeps the connection between the two vessels open.
3. Many smaller arteriovenous fistulae are asymptomatic, but tend to enlarge over time, thus increasing flow through the fistula. Larger fistulae can cause symptomatic venous insufficiency or congestive heart failure. As the fistula enlarges, the artery becomes tortuous and is at risk for thrombosis.

CLINICAL IMPLICATIONS

1. Consequences of arterial injury may present long after other wounds have healed and can be the result of a seemingly innocuous injury.
2. Arterial injuries should be repaired when diagnosed to prevent complications of arteriovenous fistulae.

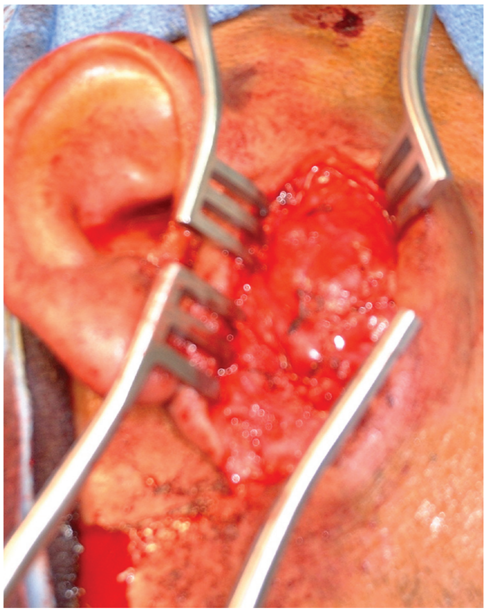
SUMMARY

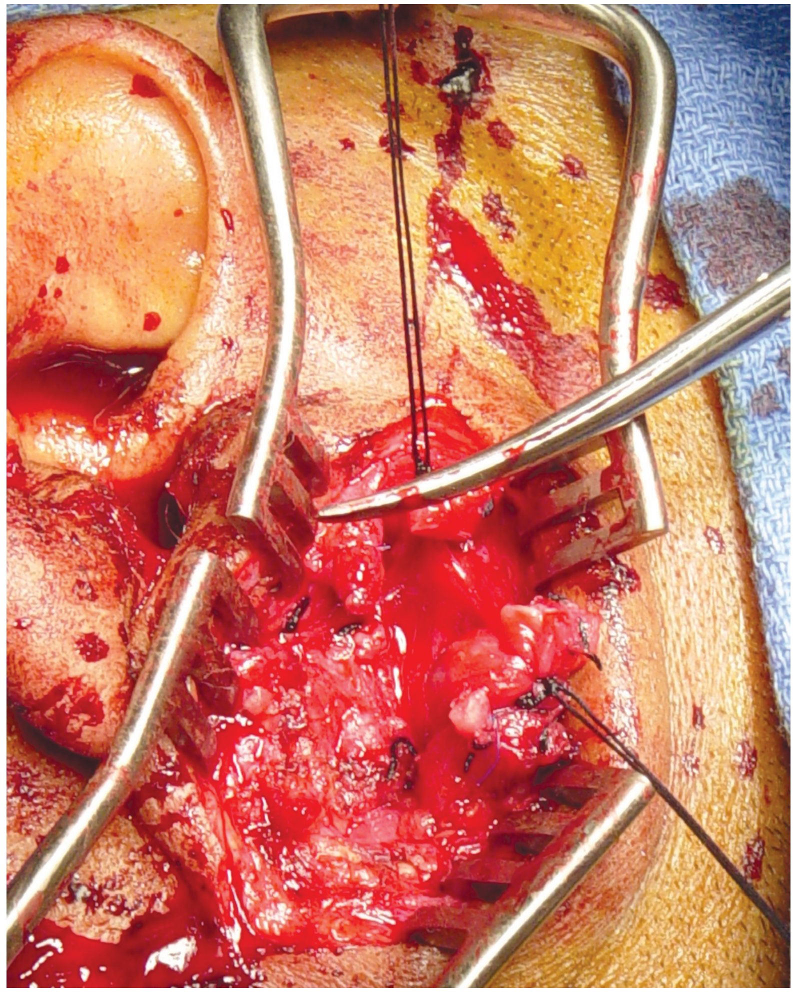
Arteriovenous fistulae and pseudoaneurysms most often present in a delayed manner, well after the initial injury. Generally, these conditions

FIGURE 1. *Note the mass anterior to the right ear. A bruit was present, as well as dilated superficial veins.*

FIGURE 2. (Right) *Exposure of the arteriovenous fistula.*

FIGURE 3. (Left) *Fistula treated with vein ligation and closure of the arterial injury.*





become apparent after the patient has been evacuated home. In this case, the arteriovenous fistula was repaired to alleviate the patient's symptoms and to prevent further complications.

Note: See discussion of this case on page 360.

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VIII.6

Brachial Artery Injury, Transection

CASE PRESENTATION

This 24-year-old male was injured by a blast from an improvised explosive device (IED). On presentation, he had a compressive dressing around his right arm and had no pulses in the extremity. The dressing was removed in the operating room and the wound explored. The brachial artery, basilic vein, and portions of the brachial plexus were transected (Fig. 1). Control of the proximal and distal ends of the brachial artery was obtained with vascular clamps. The patient was given 5,000 units of heparin, and the basilic vein was ligated. The right groin and thigh were prepped, and the greater saphenous vein harvested and inserted as a reversed interposition graft. Once flow was restored, the brachial plexus was explored, and the transected ends were tagged with Prolene suture. Viable muscle tissue was closed over the brachial artery repair and the wound dressed open. Within 48 hours, the patient was evacuated with pulses intact.

TEACHING POINTS

1. Even in the event of major nerve injury, upper extremity arterial injuries should be repaired. Tagging the injured nerves if primary repair is not possible allows easier identification for future repair or grafting. Systemic anticoagulation should only be given if there is an isolated injury.
2. In any battlefield vascular injury, autologous vein is the conduit of choice. The incidence of infected grafts following use of synthetic material mandates replacement of these type grafts at the earliest possible time.

CLINICAL IMPLICATIONS

1. Typically, surgical training in vascular procedures is based on the treatment of atherosclerotic disease. As such, the upper extremity is poorly represented during a surgeon's residency and in garrison practice. On the battlefield, the upper extremity is often wounded, and the surgeon needs to know how to care for such injuries. When proximal control is not easily obtained through the wound, the axillary artery should be exposed and clamped through an infraclavicular incision.

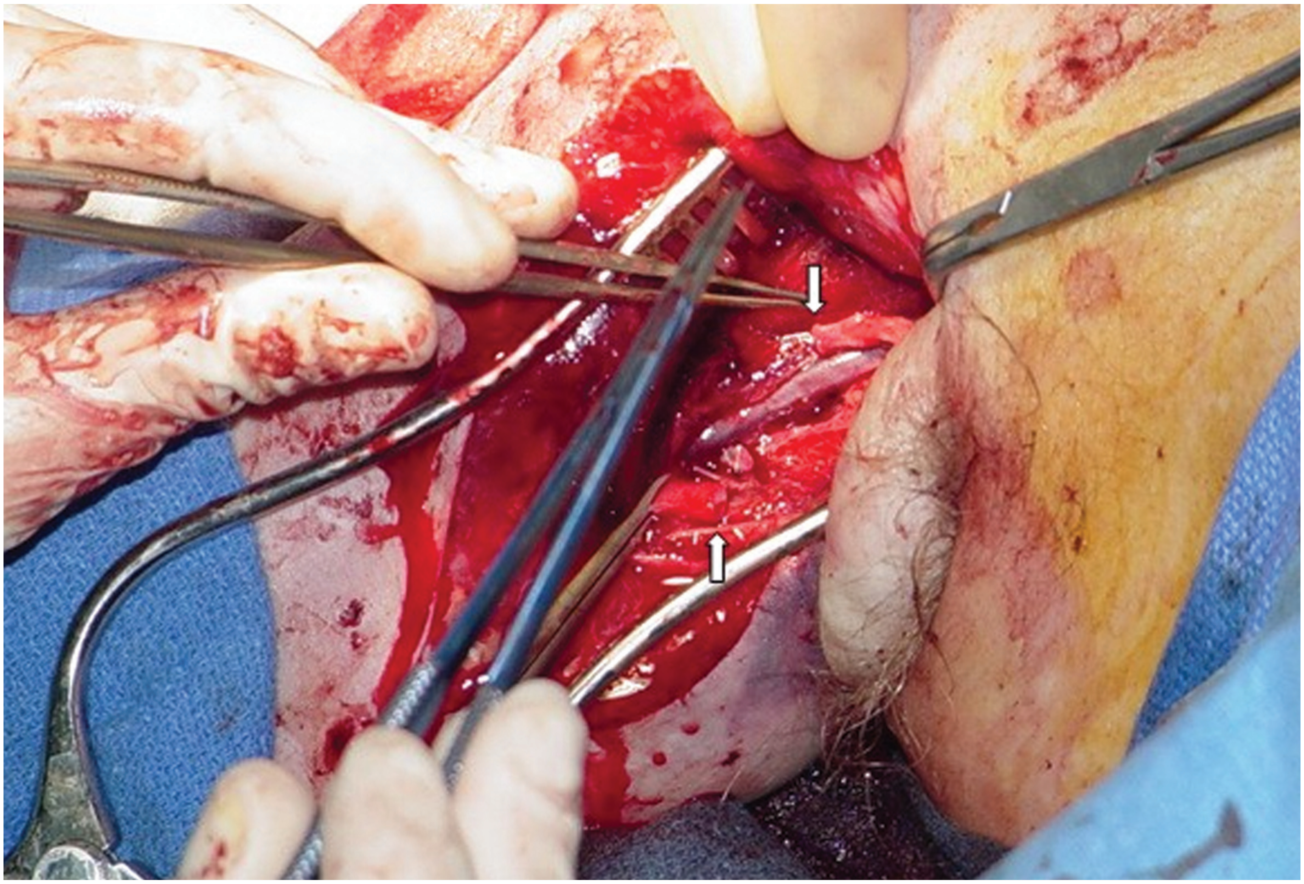

FIGURE 1. *Arrows indicate transected ends of the brachial artery.*

2. Proximal and distal control of extremity injuries can be obtained through the primary wound or an extension of that wound. When that is not possible, it may be necessary to obtain proximal control through a separate incision.
3. Exposed vein grafts will dessicate, leading to graft blowout and potential exsanguination. They must be covered by soft tissue or muscle. Superficial muscles, such as the sartorious or gracilis in the thigh, may be mobilized to cover a graft.

DAMAGE CONTROL

If a definitive repair cannot be performed, a shunt may be placed in the brachial artery to perfuse the limb during evacuation, resuscitation, or for conversion of an emergent case to a less urgent one while other cases are being attended. If the brachial artery is injured distal to the profunda brachii, the artery can be ligated, and perfusion to the hand can be maintained.

SUMMARY

This case presents a typical battlefield wound. The patient had injuries to his brachial artery, basilic vein, and brachial plexus. Using basic vascular techniques, the brachial artery was repaired with a saphenous vein interposition graft.

Note: See discussion of this case on page 360.

SUGGESTED READING

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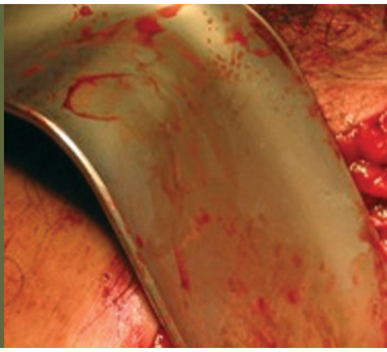

VIII.7
Femoral Vein Injury

CASE PRESENTATION

A 27-year-old male sustained a gunshot wound to the right buttock that exited the right groin just below the inguinal ligament. He presented with severe hemorrhaging from the exit wound. His initial blood pressure was 65/42 mm Hg, and his heart rate was 88 beats per minute. The patient's Glasgow Coma Scale score was 15, but the patient was somnolent. Significantly, his pH was 7.11, and his base deficit was 14. Resuscitation was started in the trauma bay, and the patient was taken immediately to the operating room. After the patient was prepped—from the nipples to the ankles circumferentially—a lower abdominal incision was made, and control of the right external iliac artery and vein was obtained with vessel loops. Vascular control of the femoral artery and vein distal to the injury was obtained (Fig. 1). Constant pressure had been maintained on the wound during this time. Despite this maneuver, some bleeding continued, but decreased when the patient was given recombinant factor VII. With bleeding controlled, a large medial wound to the femoral vein without complete transection was identified. Significant back bleeding through the venous tributaries continued, and this bleeding was controlled with ligation. Vascular clamps were then placed proximal and distal to the wound, and arterial flow was reestablished. Lateral venorrhaphy was then performed. Back bleeding was excellent, with no clotting noted. All clamps were removed, with good flow noted in the vein. Exploration of the abdomen revealed no further injuries, and all surgical wounds were closed. Throughout treatment, the patient received 7,500 mL of crystalloid fluid, 11 units of packed red blood cells, 2 units of fresh frozen plasma, and 100 mL of albumin. During the operation, the patient's pH improved to 7.29, and his base deficit decreased to 6. Postoperatively, the patient's foot remained well perfused, with no evidence of neurological injury. He was evacuated awake and alert to a level III medical treatment facility.

TEACHING POINTS

1. Vascular control of proximal lower extremity injuries can be extremely difficult to obtain, especially when associated with large wounds. In this case, proximal control was obtained first in the abdomen, and distal control was obtained below the wound.
2. Patients in combat environments frequently present acidotic and coagulopathic. They require a multidisciplined approach that ad-

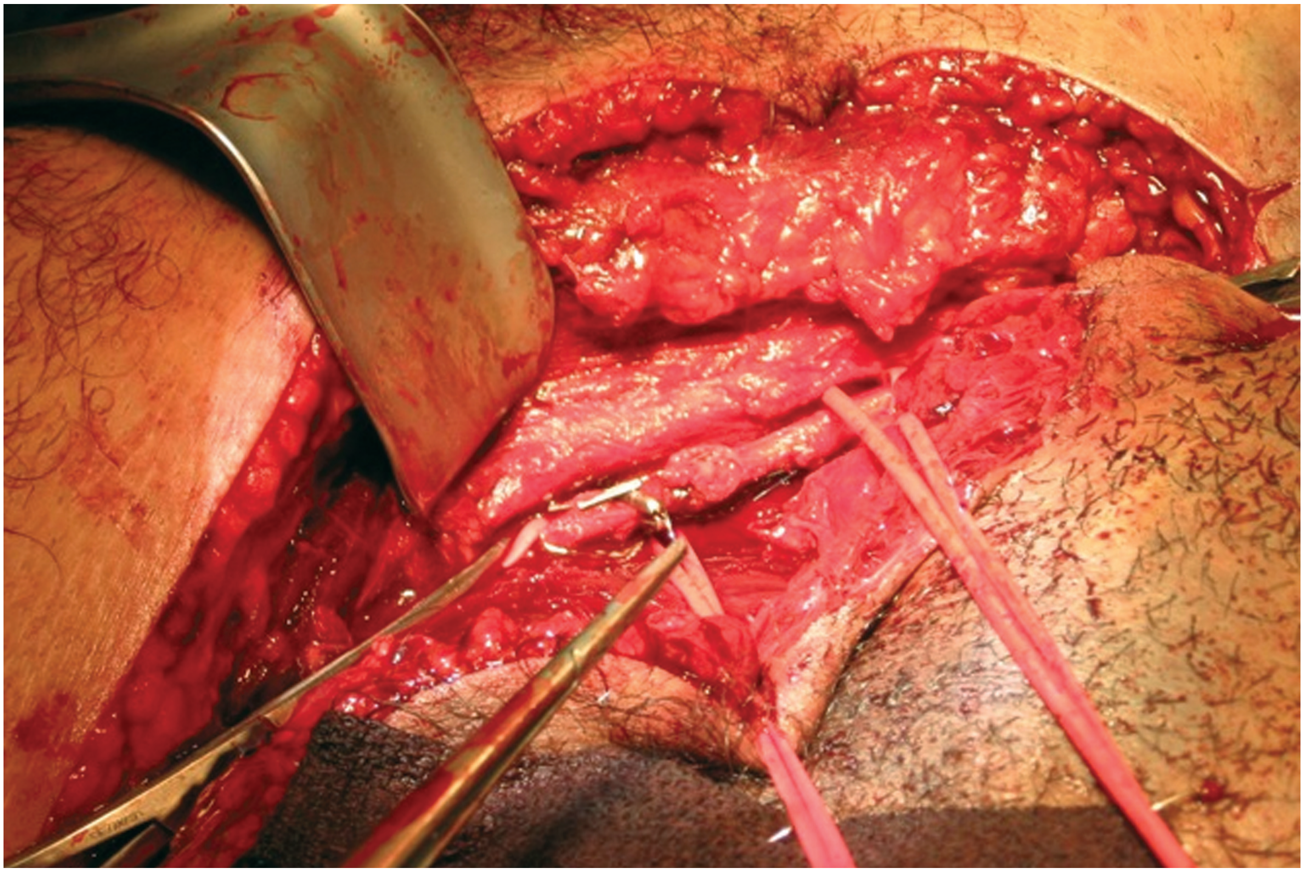

Figure 1. *Common femoral vein injury after control has been obtained.*

dresses control of hemorrhage and resuscitation simultaneously. Also, patients must be kept warm during the evacuation and resuscitation processes.

3. Patients can exsanguinate from isolated, major venous injury, especially proximal extremity injuries. It is difficult to place tourniquets on these wounds. Usually, the bleeding can be initially controlled with direct pressure (Fig. 2).
4. Forward Surgical Teams (FSTs) must be able to expertly administer packed red blood cells, whole blood, recombinant factor VII, and fresh frozen plasma.

CLINICAL IMPLICATIONS

Patients with vascular injuries present in a variety of ways. Once the diagnosis of vascular injury is made or suspected, some basic tenets apply:

1. Control external bleeding by direct pressure, if possible. Avoid blind clamping with vascular clamps. If possible, applying a temporary tourniquet proximal to the wound is often helpful.
2. Administer intravenous antibiotics, tetanus toxoid, and analgesia.
3. Note that reduction of long bone fractures may reestablish blood flow.
4. Prepare and drape both the injured and contralateral extremities in case vein grafting is required.
5. Debride the injured vessel (once control is obtained) to normal-appearing tissue, pass balloon catheters proximally and distally to remove thrombus, and flush with heparinized saline.
6. Repair the artery first to decrease ischemia time, if both artery and vein are injured, and no shunt is used.
7. Note that major veins should be repaired in stable patients, but may be ligated in life-threatening situations. Limb arteries can also be ligated in life-threatening situations, but limb loss will be likely.
8. Consider fasciotomy after all vascular repairs.
9. Document a neurological examination before and after surgery.
10. Monitor distal pulses hourly.

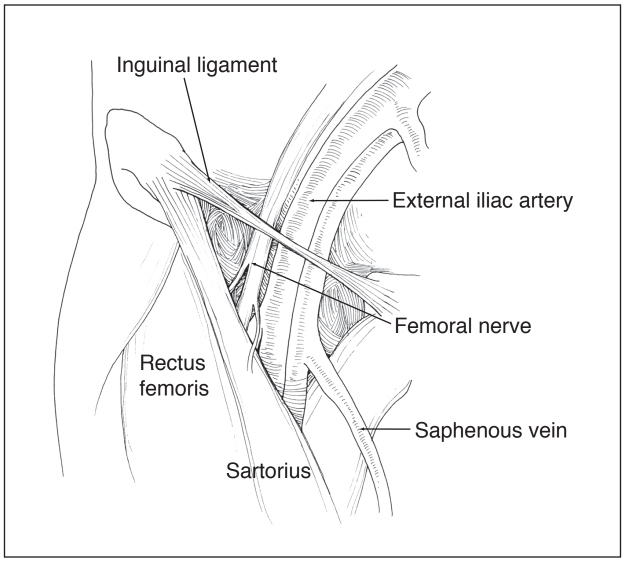

FIGURE 2. *Inguinal anatomy.*

DAMAGE CONTROL

Major veins should be repaired in stable patients, but may be ligated in life-threatening situations. Consider shunting injured vessels, especially if both artery and vein are injured, extensive debridement is required, there is concurrent long bone fracture, or the patient is not stable and requires ongoing resuscitation. Vascular shunts can be placed in unstable patients for up to 72 hours. Shunts should be secured firmly with silk sutures. Heparin is not required. Make sure that the receiving facility knows that the shunts are in place, if the patient is evacuated for definitive repair.

SUMMARY

This patient presented with a major venous injury that required large-volume resuscitation. Initial control was obtained using direct pressure. Surgical control was also obtained. With the patient stabilized, lateral venorrhaphy was performed with good results.

Note: See discussion of this case on page 360.

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RECOMBINANT FACTOR VIIa

Recombinant factor VIIa (rFVIIa) is currently only FDA approved for the prevention of bleeding during surgery or episodes of severe hemorrhage in patients with congenital FVIIa deficiency and hemophilia A or B with inhibitors. Since its FDA approval, rFVIIa has been proposed as a potential intervention to limit bleeding in surgery and trauma. The first case report of rFVIIa use in trauma was in 1999 and was soon followed by a series of controlled experimental animal studies published using swine models of liver trauma, many of which showed decreased blood loss. These initial studies coincided with a number of subsequent case reports and case series of rFVIIa in trauma and uncontrolled hemorrhage. The majority of publications suggested decreased blood loss and/or decreased transfusion requirements for patients, although some offered cautionary notes and limitations of rFVIIa—especially in acidosis and refractory coagulopathy. The only randomized controlled trial (RCT) to date on the use of rFVIIa in the setting of trauma was published in 2005. This study randomized patients suffering both blunt and penetrating injuries with rFVIIa administered after the 8th unit of blood. This trial showed no survival benefit, although it did show a reduction of 2.6 red blood cell (RBC) transfusions for the blunt trauma subgroup, and a similar—though nonsignificant—trend in the penetrating injury subgroup.

Thromboembolic complications associated with rFVIIa have been a serious concern given the valid biological plausibility for such events. A metaanalysis of RCTs published in 2006, however, suggested that there is no overall increase in adverse events. Retrospective military studies have shown that early administration of rFVIIa reduced transfusion requirements when compared with late administration. Severely injured patients requiring massive transfusion who received rFVIIa had a lower mortality at 12 and 24 hours and at 30 days without a significant increase in adverse events, including deep venous thrombosis. Ongoing clinical trials of the use of rFVIIa in trauma will help to clarify risk:benefit ratios.

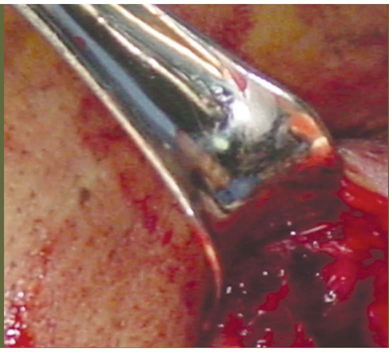
In a recent prospective, randomized human trauma study, rFVIIa was shown to be effective in decreasing transfusion requirements, to include those patients requiring massive transfusion (RBCs ≥ 10 units/24 hours), in humans with life-threatening hemorrhage, including patients with hypothermia (30°–33°C; pH > 7.1). However, rFVIIa is 90% inactivated in patients with profound acidosis (pH < 7.1), based on in vitro data.

A retrospective review of combat casualty patients with severe trauma (ISS > 15) and massive transfusion (RBCs ≥ 10 units/24 hours) admitted to one Combat Support Hospital in Baghdad, Iraq, was conducted. Admission vital signs and laboratory data, blood products, ISS, 24-hour and 30-day mortality, and severe thrombotic events were compared between patients who received rFVIIa and those who did not receive rFVIIa. Of 124 patients who received massive transfusion, 49 patients received rFVIIa and 75 patients did not. ISS scores and vital signs did not differ between the two groups. A statistically significant decrease in mortality was demonstrated in the group who received rFVIIa at 12 hours, 24 hours, and 30 days. When rFVIIa was given at a median of 2 hours from admission, an association with decreased mortality was seen. There was no statistical difference in the incidence of severe thrombotic events (DVT, PE, stroke) between the study groups. There is currently an ongoing Phase III trauma trial of rFVIIa that addresses the question of whether earlier administration of rFVIIa improves the outcome of severely injured patients.

Guidelines for administration in the deployed surgical setting: rFVIIa should be considered for administration to trauma patients or patients in shock who have the following signs associated with hemorrhage:

a. Hypotensive from blood loss.
b. Base deficit > 6.
c. Difficult to control bleeding associated with hypothermia (T < 96°F).
d. Coagulopathic bleeding (clinically or an INR > 1.5).
e. Require damage control maneuvers.
f. Require fresh whole blood.
g. Anticipated or actual transfusion of > 4 units of PRBCs.
h. Anticipated significant operative hemorrhage.

Adapted, in part, from JTTS, CPG for Recombinant Factor VIIa, October 2007. See CPG for references and dosing.



VIII.8 Brachial Artery Injury, Blunt Trauma

CASE PRESENTATION

This 30-year-old male patient was involved in a motor vehicle accident (Fig. 1). The vehicle he was traveling in was struck by a dump truck, and he was the only person in the vehicle to survive the accident. He presented with a fractured scapula, a proximal humerus fracture (Fig. 2), and a left pneumothorax. Tube thoracostomy was performed, and the patient was taken to the operating room. Exploration revealed the bicep and triceps muscles were avulsed from the bone, resulting in an internal amputation. The patient's distal upper extremity pulses were absent. Arteriogram using a C-arm showed cutoff of arterial flow near the humerus fracture. Exploration of the artery showed clear cutoff at the injury (Fig. 3). The artery containing the intimal flap was resected, and a shunt was placed (Fig. 4). Internal fixation was then performed by the orthopaedic surgeons. A successful end-to-end anastomosis was performed to repair the artery (Fig. 5).

TEACHING POINTS

1. Although penetrating injury is a more common mechanism of arterial injury in combat zones, blunt arterial injury does occur. Blunt arterial injury parallels civilian trauma experiences and is usually associated with concurrent long bone fracture, as in this case.
2. Diagnosis can be difficult, and arteriography may not be available. However, it is reasonable to assume that the arterial injury will be near the fracture. In this case, the injury was apparent. Penetrating injuries to arteries do not usually represent a diagnostic challenge.
3. A common approach in concurrent arterial and long bone fracture is to reestablish perfusion by placing a shunt and completing the repair after fixation of the fracture, as in this case.

CLINICAL IMPLICATIONS

Hard signs of vascular injury that suggest the need for immediate exploration include the following:

1. Pulsatile external bleeding.
2. Enlarging hematoma.
3. Absent distal pulses.
4. Thrill or bruit.
5. Ischemia.

FIGURE 1. *Patient as he appeared at the time of presentation.*

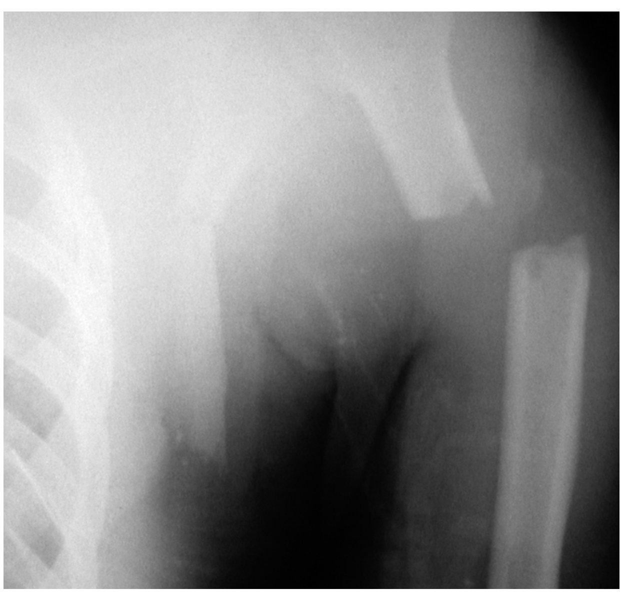


FIGURE 2. *Humerus fracture and scapula fracture are seen in this radiograph.*

Signs of ischemia include the following:

1. Pain.
2. Pallor.
3. Pulselessness.
4. Poikilothermia.
5. Paresthesia.
6. Paralysis.

DAMAGE CONTROL

Vascular shunts can be placed in unstable patients for up to 72 hours. Shunts should be secured firmly with silk sutures. Heparin is not required. Distal pulses should be monitored hourly. If the patient is evacuated for definitive repair, the receiving facility should know that the shunt is in place.

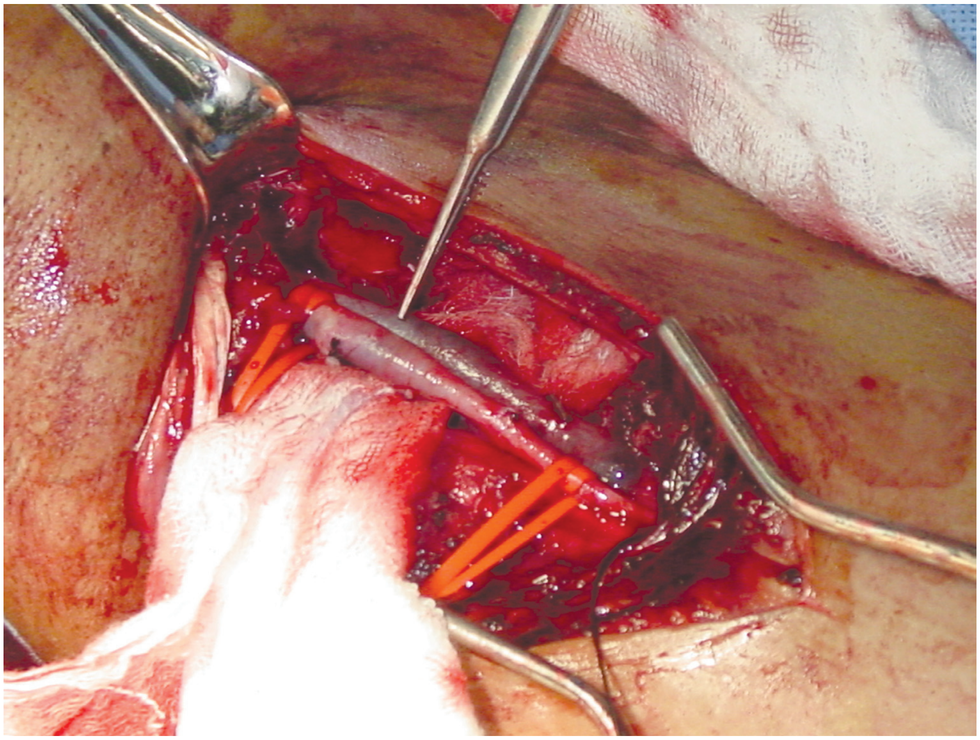


FIGURE 3. (Top) *Area of arterial injury.*

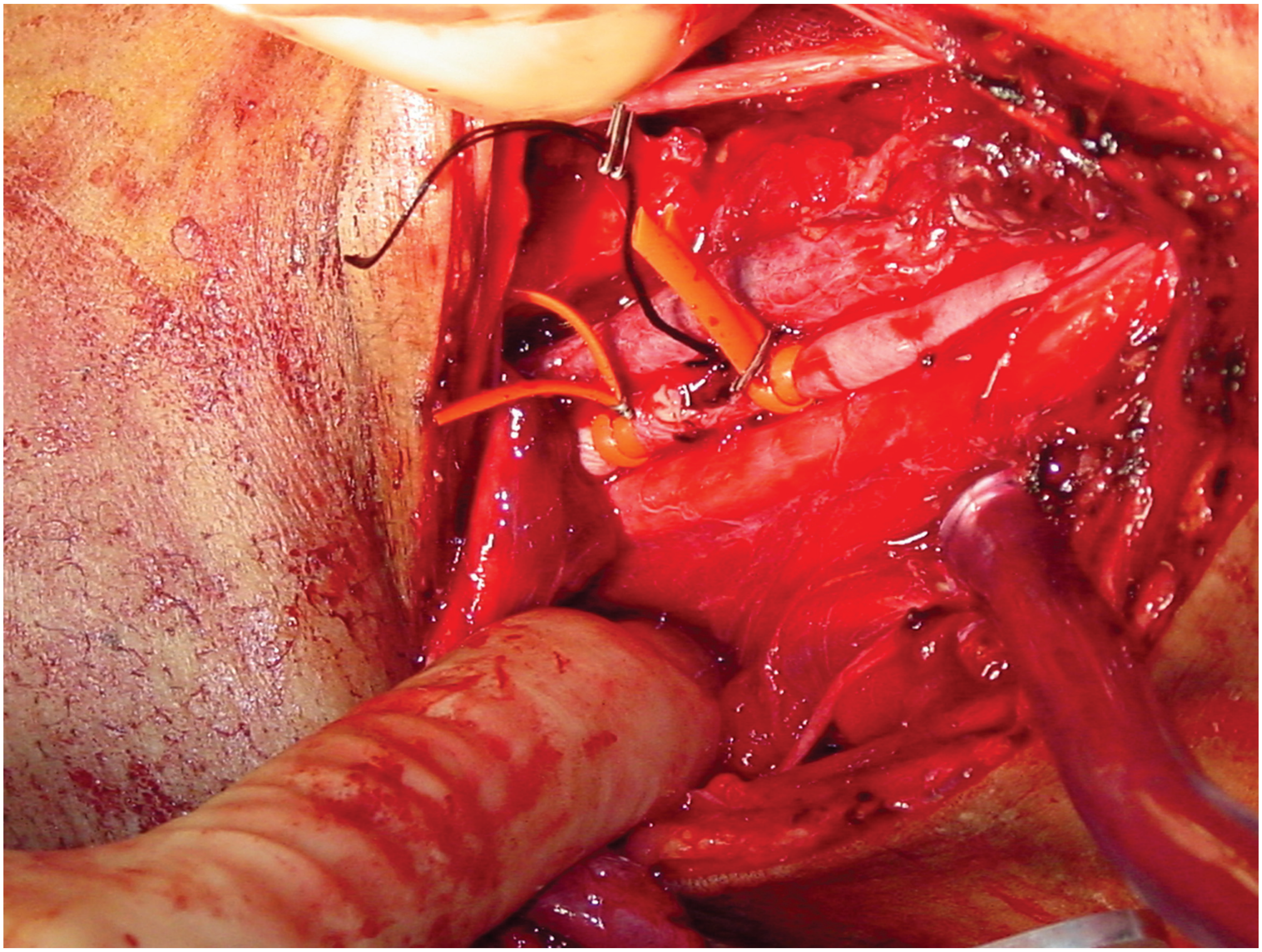


FIGURE 4. (Bottom) *A shunt has been placed to reestablish flow while the humerus is stabilized.*

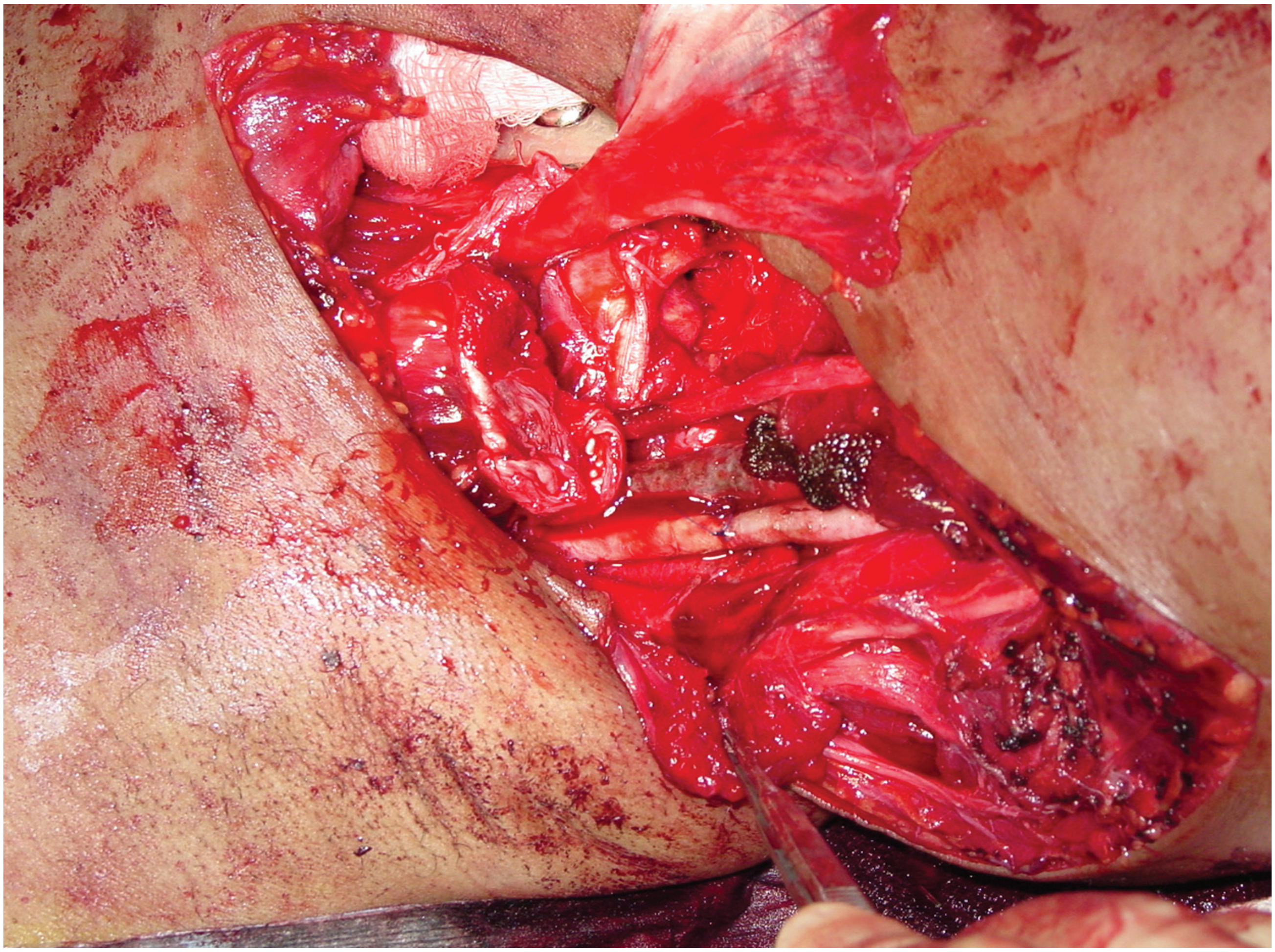


Figure 5. *The artery has been repaired by resecting the intimal flap and performing an end-to-end anastomosis.*

SUMMARY

This patient presented with a pulseless upper extremity after blunt trauma resulted in a proximal humerus fracture. Initial placement of a shunt allowed reperfusion of the extremity while the fracture was fixated. Vascular repair was completed with good result.

Note: See discussion of this case on page 360.

SUGGESTED READING

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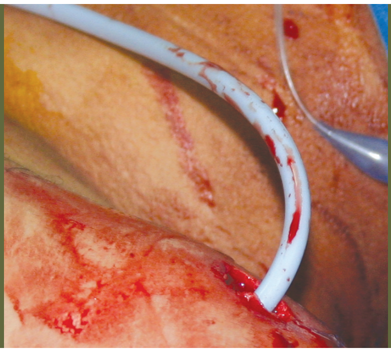

VIII.9
Left Subclavian Artery Gunshot Wound

CASE PRESENTATION

This 23-year-old host nation male presented to the combat support hospital (CSH) after sustaining a single gunshot wound to the upper anterior chest, medial to the left shoulder. On arrival, the patient was in extremis with minimal bleeding from the wound. He was intubated immediately without difficulty, and a left-sided chest tube was placed with drainage of approximately 600 mL of blood. After intravenous access was gained via a right subclavian vein central line and a fluid bolus was started, new profuse bleeding from the left chest wound was noted. Attempts at direct pressure on the wound were unsuccessful. To obtain control of this bleeding, a large urinary catheter was placed in the wound, and the balloon was inflated with water (Fig. 1). The proximal end of the urinary catheter was also clamped to prevent bleeding from the lumen of the catheter. With bleeding controlled and the patient responding to fluid infusion, the remainder of the primary and secondary surveys was completed. No other injuries were identified. The patient was then transported directly to the operating room, where the chest and left groin were prepped and draped. A left anterolateral thoracotomy was performed. This classic incision was also extended fairly far posteriorly. Bleeding from the subclavian artery was first controlled by compression with a sponge stick. Next, proximal and distal control were obtained using vascular clamps. Injury to the subclavian artery involved approximately 50% to 75% of the vessel circumference. The vessel was mobilized, and the area of injury was resected to include the surrounding blast-affected areas. The subclavian artery was repaired primarily using end-to-end anastomosis. Following this repair, there was excellent capillary refill of the fingers and strong radial and ulnar pulses. The thorax was irrigated to remove any retained clots, a new chest tube was placed, and the incision was closed. The edges of the gunshot wound were debrided, and the entrance wound was left open and closed by secondary intension. This postoperative course was uneventful, and the patient was transferred to a host nation facility after removal of the chest tube.

TEACHING POINTS

1. Direct pressure should be the first method used to control hemorrhage. Unfortunately, there are regions of the body where this approach will not be successful (eg, subclavian and groin

Figure 1. *Left superior chest wound. A Foley catheter has been inserted directly into the wound and the distal balloon inflated with water to staunch uncontrolled hemorrhage.*

injuries). In these circumstances, insertion of a urinary catheter and inflation of the balloon with water will frequently tamponade bleeding under bony or ligamentous structures. It is important to clamp the proximal end of the catheter to prevent bleeding from the lumen.

2. Use of a urinary catheter with a 30-mL balloon works best. If that is not immediately available, then several smaller urinary catheters may also be effective.
3. This technique is also useful in controlling hepatic bleeding, when there is bleeding from the tunnel created by a bullet.
4. The choice of operative incision for penetrating thoracic trauma may be difficult because the side of injury dictates the type of incision used. The surgeon should be prepared to make a second or even third incision in 25% to 30% of cases.
5. In this case (left-sided injury), an anterolateral thoracotomy incision with a posterior extension provided both proximal and distal control. Use of a median sternotomy would have been inappropriate because the left subclavian vessels are posterior and cannot be reached from this incision. In addition, a clavicular incision is ill-advised because it is frequently difficult to gain proximal control. Another approach combines all three of these incisions into a trapdoor incision, also known as a "book" thoracotomy. However, this incision is frequently associated with causalgia in the postoperative period.
6. When exposing a right-sided subclavian injury, a median sternotomy with cervical extension should be the incision of choice.

7. Great care must be taken to avoid injury to the brachial plexus during this operation.
8. Concurrent or isolated injury to the subclavian vein may be treated with either lateral venorrhaphy or ligation.

CLINICAL IMPLICATIONS

Unlike this case, most missile injuries of the subclavian artery will require interposition graft (vein or prosthetic) and will not be amenable to primary repair.

DAMAGE CONTROL

Insertion of a urinary catheter to staunch noncompressible subclavian vessel hemorrhage is an acute temporizing measure only. This may be used for intratheater transport prior to definitive repair. It is not recommended for prolonged treatment.

SUMMARY

Obtaining initial control of bleeding from a vessel under a bony or ligamentous structure can be difficult. Use of a urinary catheter is an effective method (as in this case). Incision choice after a subclavian wound may also be difficult, because the approach to a right-sided injury is different from a left-sided injury. Once the incision has been made, the surgeon needs to be prepared to extend the incision or make another incision, if required.

Note: See discussion of this case on pages 360–361.

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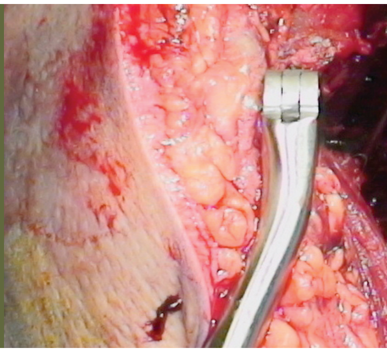


VIII.10 Gluteal Compartment Syndrome

CASE PRESENTATION

A 19-year-old US Marine Corps male vehicle driver was involved in a blast injury after driving over an improvised explosive device (IED). He presented with a Glasgow Coma Scale score of 15, but was hypotensive with a systolic blood pressure in the 80s and a pulse in the 120s. He reported pain in the right buttock and both legs, but denied any loss of consciousness or paresthesias. Physical examination showed a large area of ecchymosis and edema over the right buttock (Fig. 1), which was compressible. In addition, he had moderate tenderness over his right sacrum and buttock. The pelvis was evaluated and found to be stable. The leg compartments were soft, and there was no crepitus nor instability in his lower extremities. The neurovascular examination was normal. His hemoglobin was 8.0 g/dL. CT scan of the pelvis revealed a large right gluteal hematoma (Fig. 2). CT scan also revealed a right sacral fracture (Fig. 3) and right pubic rami fractures (Fig. 4). He was taken to the operating room where he underwent angiography and selective catheterization of the right inferior gluteal artery. There was active extravasation from several branches of the artery (Fig. 5). Coil embolization was performed using multiple microcoils (Fig. 6). Completion angiography was performed and showed no further extravasation (Fig. 7). After obtaining hemostasis, the right buttock was reexamined and found to be tense. Orthopaedic surgery confirmed the diagnosis of a gluteal compartment syndrome, and the patient underwent emergent fasciotomy through a posterior approach (Fig. 8). The gluteus maximus was incised and a large (1.5 L) hematoma was evacuated (Fig. 9). Further examination revealed healthy muscle in the buttock and hip with good hemostasis. The buttock and thigh were soft following the fasciotomy, and there was a positive wrinkle sign in the skin. The wound was therefore closed in layers over a drain, and the patient was taken to the intensive care unit for further monitoring and care. His neurovascular examination was unchanged after the surgery, and he was transferred to a higher echelon of care the following day.

TEACHING POINTS

1. Compartment syndrome is defined as increased pressure within an enclosed osteofascial space that reduces the capillary blood perfusion below a level necessary for tissue viability. It is a clinical diagnosis and usually manifests with pain out of proportion on physical examination

FIGURE 1. *Right buttock and thigh ecchymoses of hematoma.*

and pain that is not controlled with pain medication. In addition, patients can note paresthesias and will have pain on passive stretch of the affected extremity.

2. In patients without a reliable clinical examination (eg, an intubated or head-injured patient), compartment pressure measurements can be obtained. The diagnosis of compartment syndrome is made when either the absolute pressure is greater than 30 mm Hg or the pressure is within 30 mm Hg of the diastolic blood pressure (delta P < 30 mm Hg). Once the diagnosis is made, emergent fasciotomy is indicated. Clinical suspicion overrules pressure monitors, however, which are cumbersome and may not be available. If compartment syndrome is suspected, surgical intervention is warranted.
3. Isolated gluteal compartment syndromes are uncommon, and they are usually caused by pelvic and acetabular fractures or vascular injury. A high index of suspicion should be maintained for any patient who presents with the signs and symptoms of compartment syndrome and a plausible mechanism of injury.
4. All patients who present with pelvic fractures need a thorough physical examination of the spine, chest, pelvis, and extremities. The pelvis should be examined by applying anterior-posterior and lateral compressive forces across the iliac wings. If any instability is noted, a pelvic binder or sheet can be applied to stabilize the pelvis and prevent further bleeding.
5. Pelvic fractures are potentially complex injuries. In this instance, the pelvic fractures represented a lateral compression mechanism and were considered stable. In general, lateral compression pelvic fractures carry a high incidence of associated brain and visceral injuries; however, there is a lesser incidence of pelvic vascular injuries. Interestingly, this patient presented with a vascular injury, which may be attributed to the high-energy blast mechanism.
6. This type of lateral compression pelvic fracture is treated symptomatically with weight-bearing as tolerated using assistive devices.

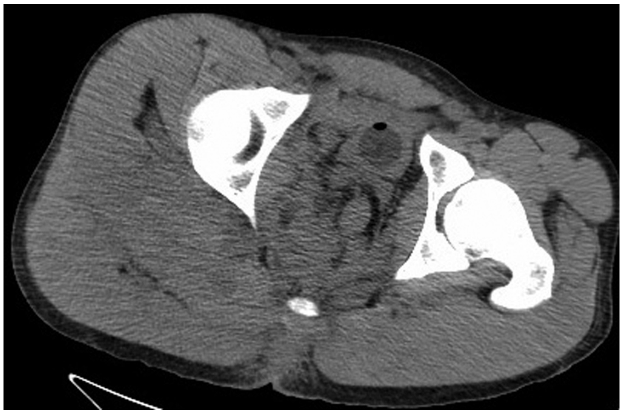


FIGURE 2. *Pelvis CT image. Note right gluteal hematoma.*

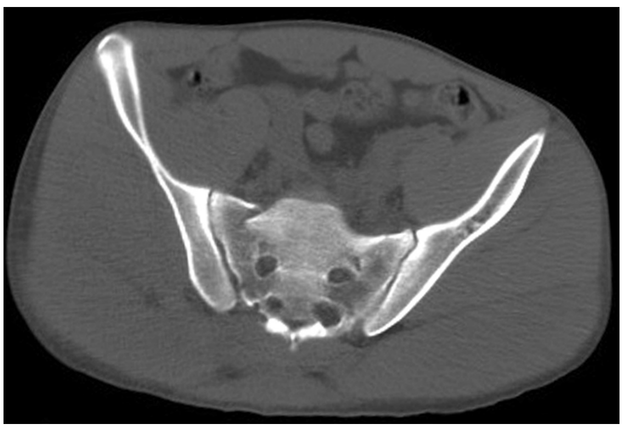


FIGURE 3. *Sacrum CT image. Note displaced fracture of the right sacrum.*

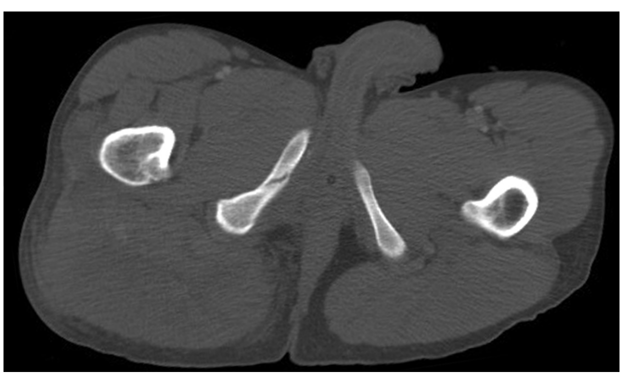


FIGURE 4. *Pelvis CT image. There is a nondisplaced fracture of the right pubic ramus. Note large right gluteal hematoma.*

CLINICAL IMPLICATIONS

Treatment of a hemodynamically unstable patient with a pelvic fracture requires a multidisciplinary approach and algorithm. Although this patient had a stable pelvic fracture, potentially life-threatening sources of hemorrhage need to be identified and controlled. Permanent muscle and nerve dysfunction can develop if a compartment syndrome is not released in a timely fashion, which makes compartment syndrome a true surgical emergency. The following treatment principles were applied in this case:

1. Control of hemorrhage can be obtained through open or endovascular techniques. Surgical ligation of the hypogastric artery can diminish pelvic blood flow and associated hemorrhage, but is nonselective and may result in ischemic complications. With this technique, persistent bleeding is also possible via collateral vascular pathways from the contralateral hypogastric artery or ipsilateral femoral artery. Direct surgical control of bleeding at the time of compartment release may also be effective, but this approach is often associated with poor exposure, and difficulties obtaining control of the artery of hemorrhage can result in significant blood loss. Finally, if the patient is stable enough to tolerate angiographic evaluation, pelvic angiography is highly sensitive and specific for determination of the source of bleeding. Embolization of the hemorrhagic artery can then be performed in a selective fashion with greater than 90% technical success in achieving thrombosis of the vessel.
2. Gluteal compartment syndromes should be released through a posterior approach to the hip, which utilizes the greater trochanter as the primary landmark. Once the greater trochanter is identified, a 15- to 20-cm incision is made that gently curves over the buttock. Because the gluteus maximus is innervated by both the superior and inferior gluteal nerves, it can be divided in line with its fibers. There are always vessels that cross the plane of dissection, so it is important to maintain good hemostasis.
3. Once the surgical plane is fully developed, the hematoma can be evacuated to relieve pressure on the surrounding tissues. After all sources of bleeding have been identified and controlled, the wound can be closed in layers over a drain.
4. It is important to monitor the patient postoperatively for improvement in symptoms and potential changes in neurovascular examination.

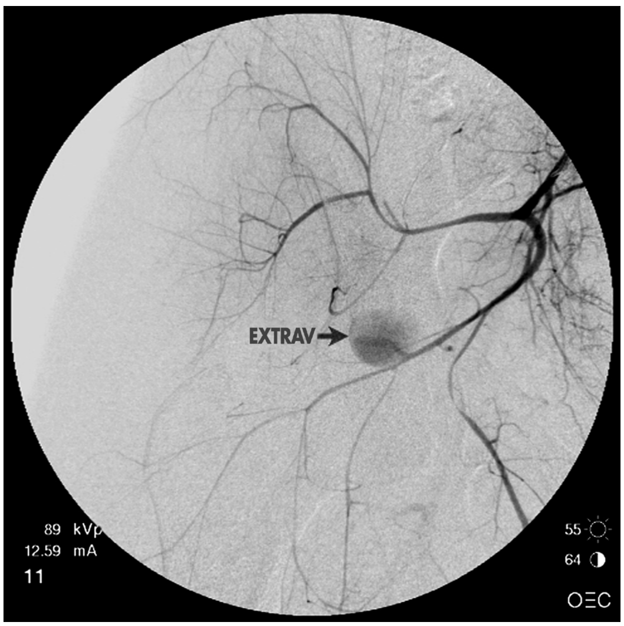
DAMAGE CONTROL

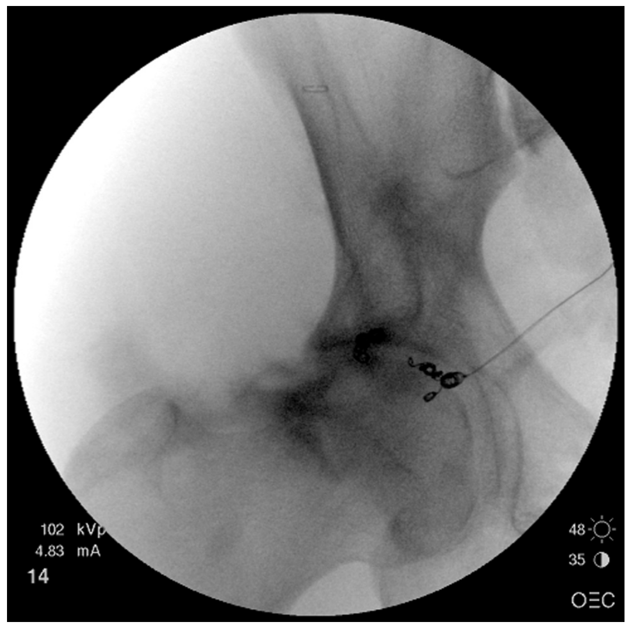
An unstable pelvic fracture can be temporarily stabilized with a pelvic binder or sheet. Once applied, it should not be removed until definitive stabilization can be performed. If a vascular surgeon or interventional radiologist is not available to embolize a pelvic vascular injury, emergent fasciotomy should still be performed in the face of a compartment syndrome. If the source of the bleeding cannot be identified at the time of surgery, it is prudent to pack the area in question and transport the patient to a facility with the appropriate personnel and equipment.

SUMMARY

This case demonstrates an uncommon type of compartment syndrome that was caused by high-energy blunt trauma. A team approach was used to address the vascular injury and resulting compartment syndrome. Once the inferior gluteal artery injury was embolized, the gluteal compartment was completely released to improve local tissue perfusion. Prompt diagnosis and treatment of gluteal compartment syndrome will help optimize patient recovery and long-term function.

Note: See discussion of this case on page 361.





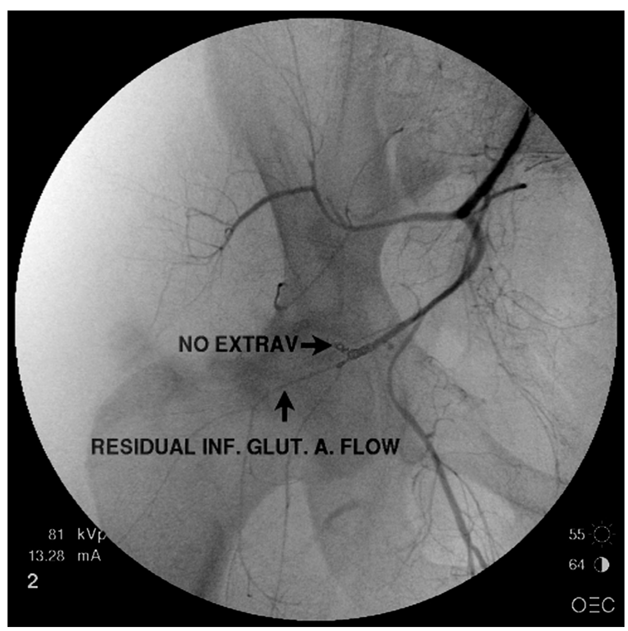


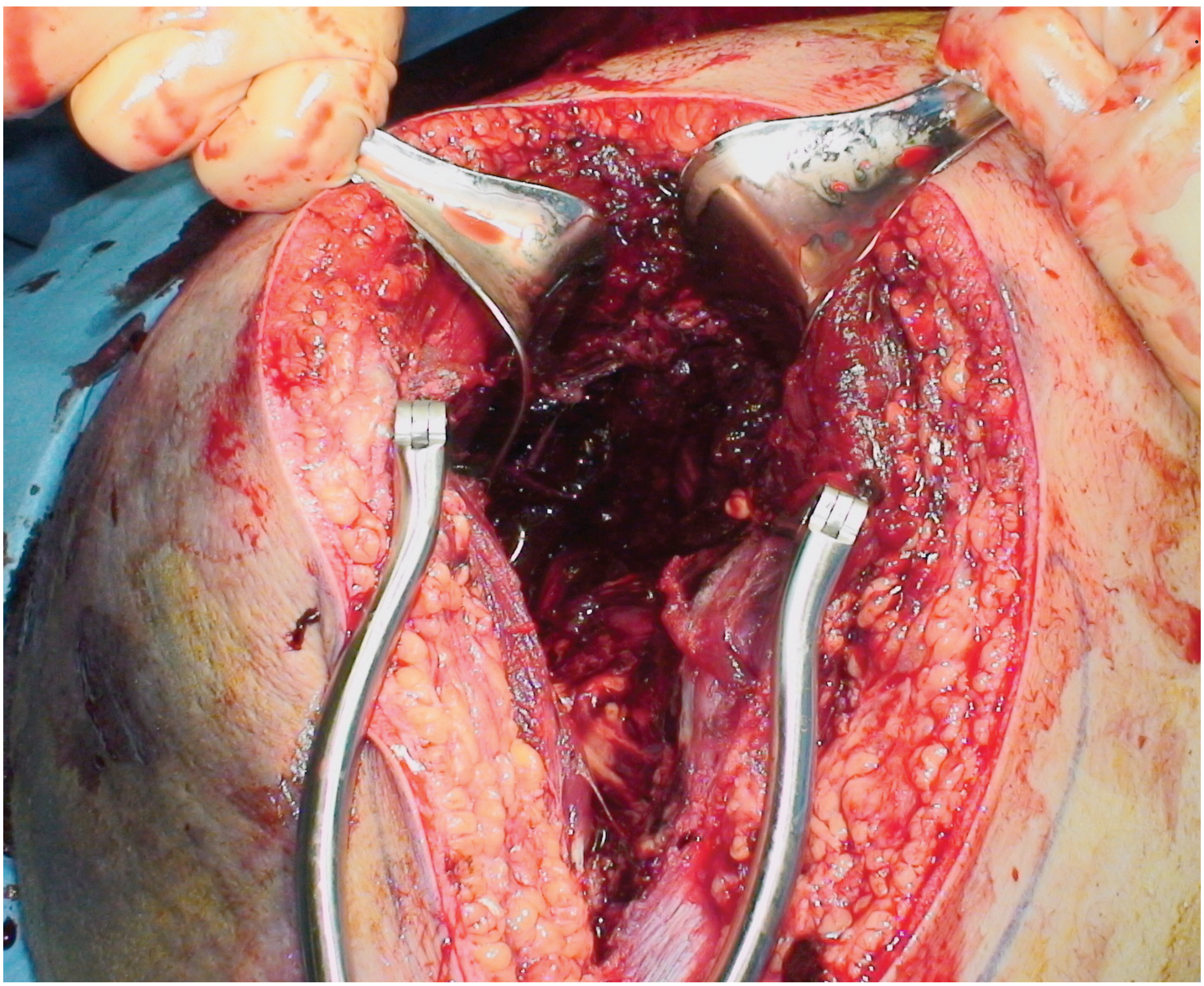
Figure 5. (Left) *Selective angiography of the right inferior gluteal artery. Note extravasation (EXTRAV).*

Figure 6. (Top Right) *Microcoil embolization of right inferior gluteal artery.*

Figure 7. (Bottom Right) *Completion angiogram after branch artery embolizations. No extravasation of contrast is noted. EXTRAV: extravasation; INF. GLUT. A.: inferior gluteal artery.*

Figure 8. (Top) *Markings for incision to relieve right gluteal compartment syndrome* (A) *and to identify right greater trochanter* (B).

Figure 9. (Bottom) *Large gluteus hematoma exposed.*



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Browner BD, Jupiter JB, et al. *Skeletal Trauma*. 3rd ed. Philadelphia, Pa: Saunders; 2003.

Chapter 8: Vascular access. In: *Emergency War Surgery, Third United States Revision*. Washington, DC: Department of the Army, Office of The Surgeon General, Borden Institute; 2004.

Chapter 12: Damage control surgery. In: *Emergency War Surgery, Third United States Revision*. Washington, DC: Department of the Army, Office of The Surgeon General, Borden Institute; 2004.

Chapter 17: Abdominal injuries. In: *Emergency War Surgery, Third United States Revision*. Washington, DC: Department of the Army, Office of The Surgeon General, Borden Institute; 2004.

Chapter 21: Pelvic injuries. In: *Emergency War Surgery, Third United States Revision*. Washington, DC: Department of the Army, Office of The Surgeon General, Borden Institute; 2004.

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COMMENTARY

Vascular Trauma; Cases Review

by MAJ Niten N. Singh, MD

Numerous topics were covered in the vascular section and relevant scenarios were presented that the deploying surgeon will encounter. As a surgeon who has deployed both as a general and vascular surgeon, these collected cases can constitute a typical week in a deployed combat support hospital (CSH). The main urgency of any surgeon in theater is to transport the patient with a penetrating injury to the operating room (OR) as soon as feasible. As opposed to civilian trauma—in which blunt injury is the rule rather than the exception—the majority of combat trauma patients present after penetrating injury. Penetrating vascular injuries need to be controlled quickly. In the emergency room (ER), if a patient is found to have hard signs of arterial injury (ie, pulseless extremity, expanding hematoma, etc), then that patient should be transported to the OR for operative intervention. If the patient is hemodynamically unstable, placing a clamp or ligature on the bleeding vessel and continuing resuscitation in the OR, not the ER, is the course that should be pursued. Prolonged resuscitation should not occur in a setting where the surgeon does not have the ability to intervene surgically.

CASE VIII.1 (Innominate Vein Injury) emphasizes the importance of neck exploration in zone II injuries of the neck. There are proponents of exploration, as well as those that tout the use of endoscopy, arteriography, and bronchoscopy. I believe that, in the case of combat trauma, all zone II injuries should be explored. Resection of the clavicle to allow exposure of the subclavian vessels is a useful technique, but extending the neck incision into a median sternotomy can be the next step for venous injuries in zone I on the left. If injury of the proximal subclavian artery is suspected, a median sternotomy—along with a supraclavicular incision and fourth intercostal space anterior thoracotomy (trapdoor)—provides excellent exposure. When dealing with innominate vein injury, the surgeon may choose between repair versus ligation. Adequate control and flushing are extremely important to avoid potential air embolism.

CASE VIII.2 (External Iliac Vein Injury, Exposure and Control) provides a good example of how knowledge of various vascular exposures can be lifesaving. In this case, the patient had venous bleeding above the inguinal ligament. Using a retroperitoneal approach, they were able to identify and repair the injury. I would stress that, in these types of cases, if digital pressure is controlling the hemorrhage, the patient should be transported directly to the OR. The handholding pressure can be prepped into the field and the injury subsequently repaired or ligated. Any time spent resuscitating or attempting to clamp vessels in the ER without adequate equipment/lighting can lead to unnecessary delay in treatment.

CASE VIII.3 (Penetrating Subclavian Artery Injury) is an example of a lifesaving operation that must be performed prior to evacuation. In this case, a simple supraclavicular exposure allowed the surgeons to repair a potentially lethal injury. Given the fact that it was a minor arterial injury, debridement and repair were appropriate. If the injury were larger, proximal greater saphenous vein grafting should be used. Small size discrepancies are tolerated; otherwise, a Dacron graft soaked in rifampin is not ideal, but is a capable substitute (soak the graft in 1,200 mg of rifampin for 20 minutes).

In **CASE VIII.4** (Shunts in Vascular Injuries), the use of shunts shows the importance of shunts in level II settings. These should be removed and the artery and vein repaired expeditiously at the CSH, prior to evacuation out of theater. Remember that the proximal and distal aspects of the vessels need to be inspected because the

shunt and suture can injure that portion of the vessel. Up to 0.5 to 1.0 cm will need to be debrided before placing an interposition graft. If possible, which was not the case with this patient, systemic heparin should be given to all patients during vessel repair. There is no need to pass Fogarty catheters if there is good back bleeding and heparin saline flushes easily.

CASE VIII.5 (Arteriovenous Fistula)—Although not readily apparent, arteriovenous fistula and pseudo-aneurysms are fairly common in the follow-up of patients with proximity injuries. Treatment is straightforward as described. However, in difficult-to-reach areas, endovascular repair with covered stents is becoming more common practice, but is not always an option at the CSH.

CASE VIII.6 (Brachial Artery Injury, Transection) is a common one in theater. If the injury is distal to the profunda brachii and the patient is in extremis, ligation can be performed and the extremity should remain viable. Remember that the brachial artery is extremely reactive and will go into vasospasm easily. Therefore, systemic heparin, when possible, is advised. The additional use of papaverine may be necessary. The latter can be placed in heparin saline solution (5,000 units of heparin, 500 cc of normal saline, and 2 cc [60 mg] of papaverine) and injected subadventially around the artery and vein graft.

CASE VIII.7 (Femoral Vein Injury) depicts the massive blood loss that can ensue with a venous injury. With soft-tissue damage, bleeding can be worse unless the vein is repaired and venous outflow restored. If the patient is in extremis, ligation is the procedure of choice, as indicated in this case. It is unlikely that the use of activated Factor VII assisted in this case and should be avoided with vascular injuries. Once these injuries are repaired, bleeding will usually cease, and there is no need to promote potential thrombus formation in an injured vessel.

CASE VIII.8 (Brachial Artery Injury, Blunt Trauma) is another example of a brachial artery injury. It is also an example of the use of a temporizing shunt while orthopaedic procedures are performed, then performing a vein graft repair. In general, this is a good technique in the setting of major orthopaedic trauma. The greater saphenous vein can be harvested during the orthopaedic repair.

In **CASE VIII.9** (Left Subclavian Artery Gunshot Wound)—controlling hemorrhage from a penetrating thoracic wound—a Foley catheter was used to compress the bullet tract, which allowed the surgeon time to perform a thoracotomy and repair the subclavian artery. Penetrating thoracic trauma is common in theater. Wounds in proximity to the great vessels should raise a high index of suspicion for coincident injury. If the patient loses vital signs in the emergency medical treatment area, an anterolateral thoracotomy provides good exposure to the proximal subclavian artery. Combined with a median sternotomy and supraclavicular extension (trapdoor), excellent exposure to this area is obtained (see Case VIII.1). At this point, the goal is to save a life. Concern for causalgia is not warranted; many thoracotomy patients may suffer from postthoracotomy pain as well. If the patient is in extremis, the proximal subclavian artery can be ligated, as long as it is proximal to the vertebral artery. In most patients, the left vertebral artery is dominant, and flow reversal will allow for perfusion of that extremity. Reconstruction can be performed later.

In **CASE VIII.10** (Gluteal Compartment Syndrome), the use of endovascular techniques for the embolization of a gluteal compartment syndrome reveals the options available to the deployed endovascular-trained surgeon. Bleeding can be controlled in this manner if the patient is stable. However, in the face of a large gluteal hematoma, direct ligation is effective for those not trained to perform endovascular procedures and is likely more expeditious. As stated previously, large hematomas tend to make the dissection easier. The inferior gluteal vessels are below the gluteus maximus and can be ligated relatively easily.

These cases are representative of the variety of vascular cases a surgeon will see while deployed. It might be nice to be able to perform therapeutic endovascular procedures, but a surgeon should proceed with what methods he is most comfortable performing. All of these cases call on the operating surgeon's knowledge of anatomy and exposures, which are the most important preparations I can recommend prior to deployment. Once proper exposure is obtained, repair becomes the simple part of the operation. I would highly recommend a reference text on common vascular exposures (see below) for the deploying surgeon to take along in his personal kit, because these injuries are commonly seen.

SUGGESTED READING

Rutherford RB. *Atlas of Vascular Surgery: Basic Techniques and Exposures*. Philadelphia, Pa: WB Saunders Company; 1993.

Wind GG, Valentine RJ. *Anatomic Exposure in Vascular Surgery*. 2nd ed. Baltimore, Md: Williams & Wilkins; 1991.


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