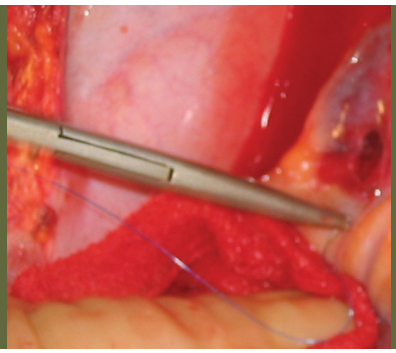
Chapter IV
THORACIC TRAUMA



IV.1 Penetrating Thoraco-Abdominal Trauma, I

CASE PRESENTATION

This 20-year-old host nation male was riding his donkey and got caught in a mortar barrage. He presented with hypotension and multiple fragment entry wounds to his chest and abdomen (Fig. 1). A FAST exam revealed a pericardial effusion (Fig. 2). At laparotomy, a large liver laceration was discovered (Fig. 3). This was rapidly packed to control bleeding. A median sternotomy was performed. A penetrating injury near the right atrial appendage, in the groove of the right coronary artery, was identified (Fig. 4). This was repaired using 3-0 Prolene suture with pledgets fashioned from the patient's pericardium. A horizontal mattress suture was used to avoid occluding the right coronary artery (Fig. 5 [also see Fig. 8]). Continued bleeding from the right chest necessitated a right thoracotomy where several lung lacerations were controlled. Further abdominal exploration revealed several small bowel lacerations that were repaired. A temporary abdominal closure was performed (Fig. 6). After 36 hours, the patient was returned to the operating room for reexploration. The liver laceration was not bleeding, and bowel edema had resolved. The patient's abdomen was closed, and his recovery was uneventful (Fig. 7).

TEACHING POINTS

1. This case demonstrates the relatively common combat scenario in which a patient presents with multiple truncal wounds and hypotension, posing the dilemma of which body cavity to open first. In this case, although the FAST exam revealed a pericardial effusion, the patient's relative stability allowed exploratory laparotomy with control of bleeding prior to sternotomy.
2. It is important to be aware of the coronary arteries when repairing cardiac injuries. In this case, a horizontal mattress suture was used to avoid occlusion of the coronary artery.
3. It is critical for the surgeon faced with a multiply wounded patient to approach each injury systematically. The importance of a well-trained team able to keep the patient stable and warm during this process cannot be overstated. Ongoing resuscitation and patient warming are fundamental.

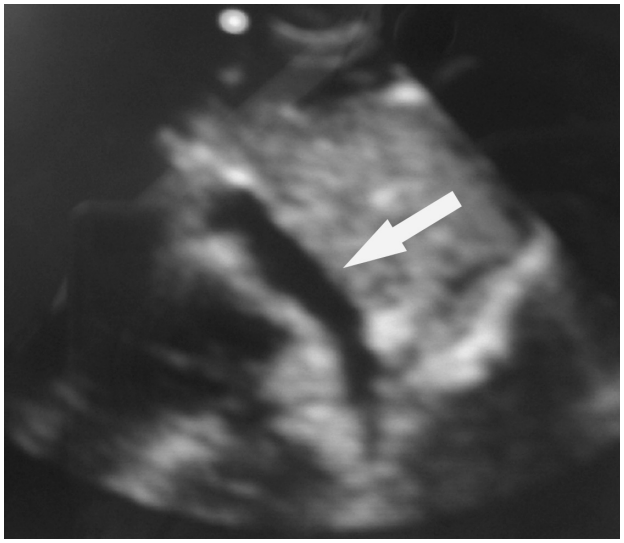
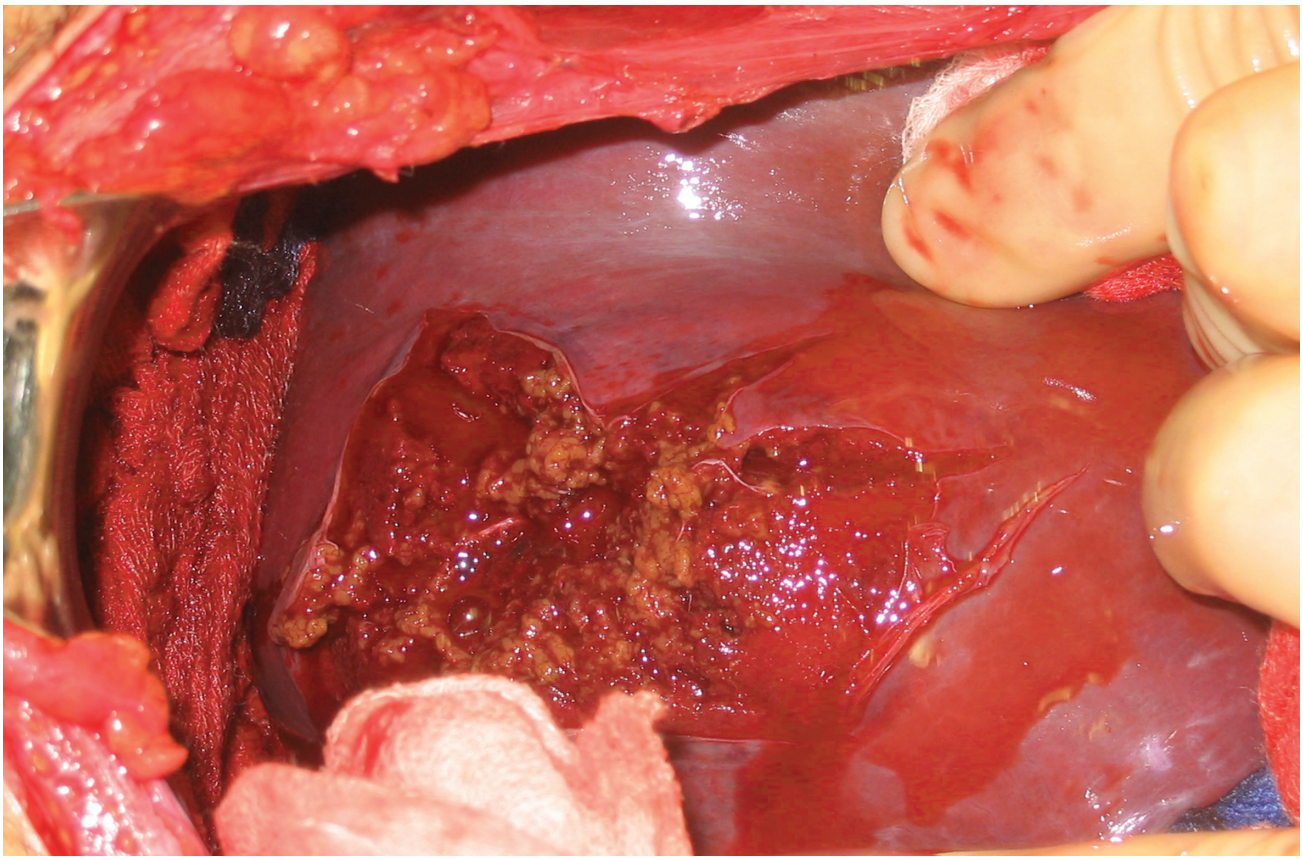


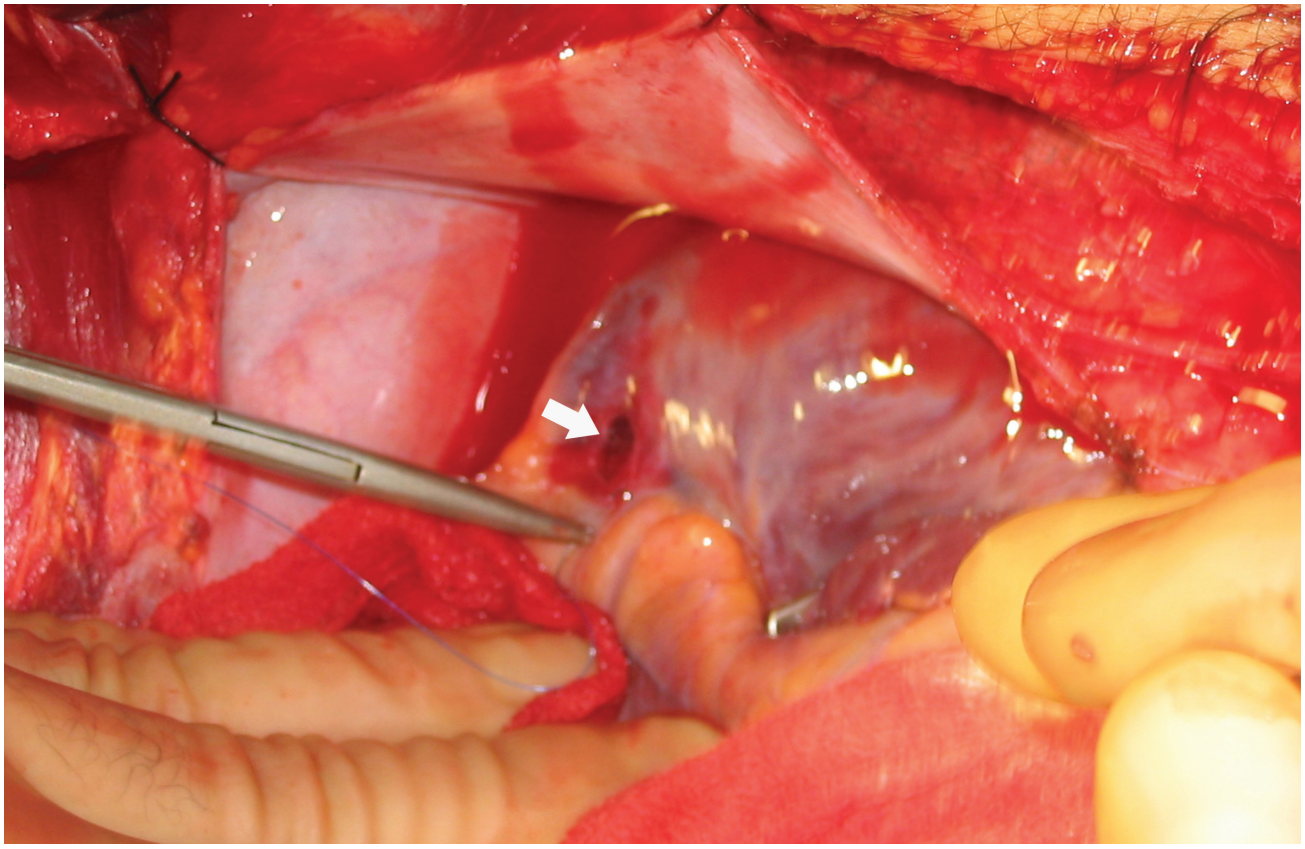
FIGURE 1. (Top, page 120) *Patient on admission to the CSH. Note penetrating wounds of the chest and abdomen.*

FIGURE 2. (Bottom, page 120) *Ultrasound (FAST) shows pericardial effusion* (arrow).

FIGURE 3. (Top, page 121) *Laparotomy revealing large liver laceration.*

FIGURE 4. (Bottom, page 121) *Median sternotomy exposure. Note right atrial penetrating wound* (arrow).





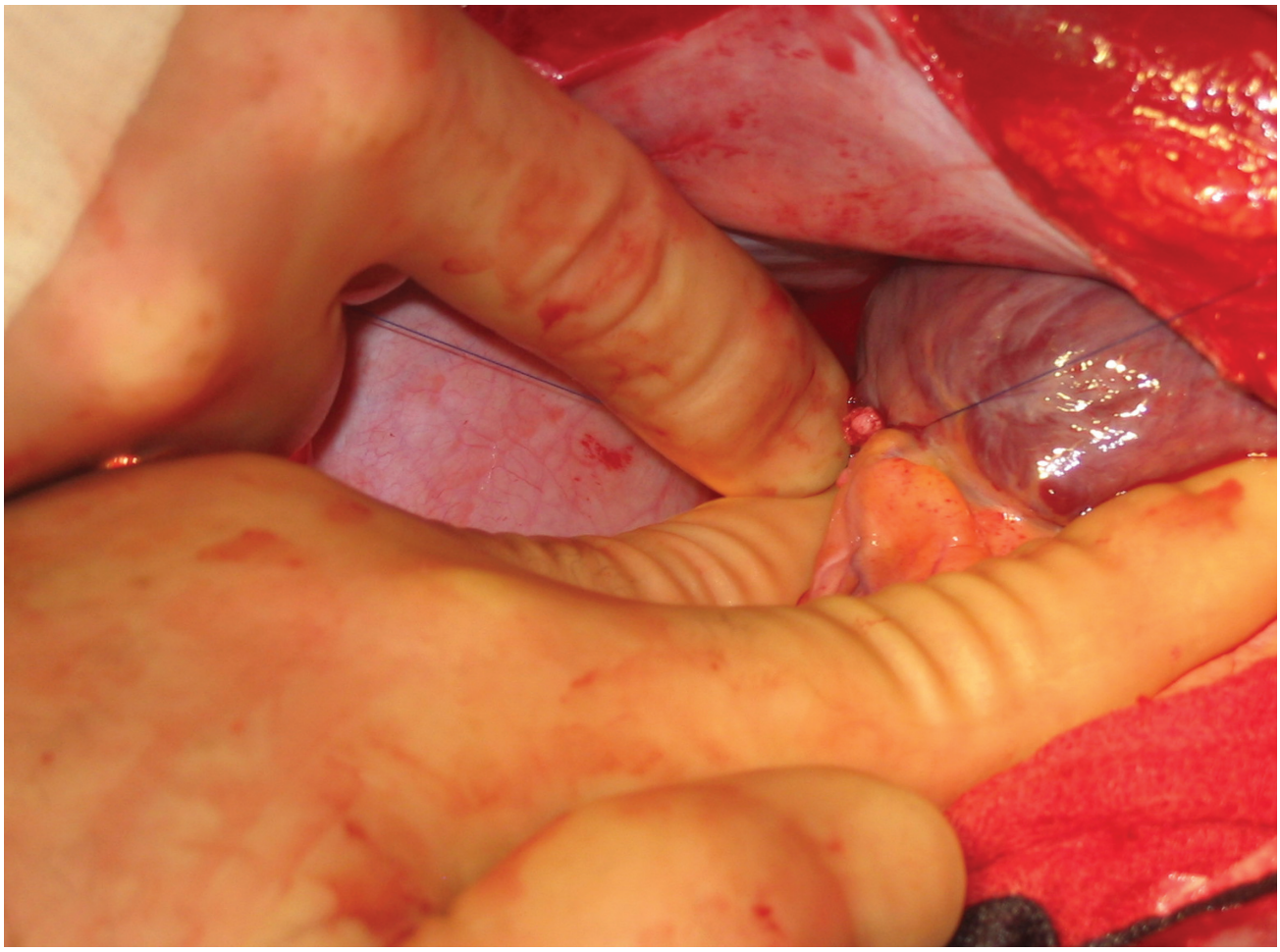


FIGURE 5. *The cardiac injury has been repaired.*

CLINICAL IMPLICATIONS

1. Isolated punctures of the heart should be exposed by opening the pericardium and occluding the injury with finger pressure. Other methods include the use of a Foley catheter or skin staples.
2. Use pledgeted horizontal mattress sutures (2-0 or 3-0 Prolene) on a tapered needle for definitive repair. Care must be taken to avoid injury to the coronary artery and muscle (Fig. 8). Simple figure-of-eight suture repair may be used if there is no risk of coronary artery occlusion.
3. Atrial repairs may include simple ligature, stapled repair, or running suture closure.

DAMAGE CONTROL

This case represents classic damage control. Bleeding from the heart, lung, and liver was controlled. Contamination was controlled by closing enterotomies, and the abdomen was temporarily closed with planned reoperation.

FIGURE 6. *Temporary abdominal closure.*

FIGURE 7. *Patient on post-op day 7.*

FIGURE 8. *Repair of penetrating cardiac injury.*

SUMMARY

This case demonstrates an appropriate approach to a patient with multiple penetrating injuries to the thorax and abdomen. Using damage control techniques and a systematic approach with ongoing appropriate resuscitation, the patient made a full recovery.

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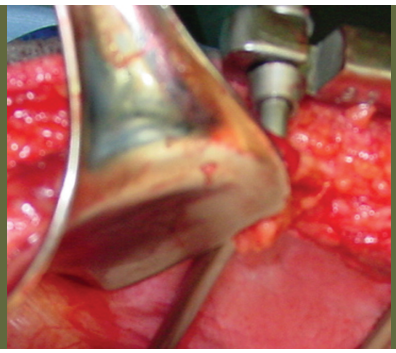

IV.2 Penetrating Thoraco-Abdominal Trauma, II

CASE PRESENTATION

A 40-year-old host nation male arrived at the Forward Surgical Team (FST) 30 minutes after sustaining multiple gunshot wounds from an AK-47. He was conscious. There were multiple entry and exit wounds to the left upper extremity, as well as two entry wounds to the left thorax, which entered lateral to the nipple at the nipple line. Vital signs showed a blood pressure of 100/60 mm Hg and a heart rate of 120 beats per minute. A chest tube was placed in the left hemithorax with a return of 250 cc of blood. A FAST scan was negative for intraabdominal blood and negative for pericardial blood. Abdominal examination was negative for signs of peritonitis, and the abdomen was flat without distention. An initial chest X-ray, taken after chest tube placement, showed a moderate-sized left hemothorax and adequate chest tube placement. There were two bullet fragments that were apparently in the lower ipsilateral thorax. No abdominal films were taken, and resuscitation was performed according to Advanced Trauma Life Support (ATLS) protocol. The patient was taken to the operating room (OR) to address the extremity wounds after initial resuscitation with crystalloid and 2 units of packed red blood cells (PRBCs). He required washout of the multiple gunshot wounds and open reduction of a forearm fracture. Total time in the OR was 90 minutes. During this time, chest tube output was followed closely. Drainage for the next hour was 200 cc. He continued to receive resuscitation in the OR with crystalloid, and his blood pressure remained stable. The patient was then transferred to the intensive care unit (ICU), where chest tube output continued to be monitored. He became hypotensive and responded to boluses of crystalloid and packed RBCs. Chest tube output increased to 300 cc for the next hour. A repeat chest X-ray showed adequate drainage of the hemothorax. Abdominal examination revealed a distended abdomen. Repeat FAST scan was positive for intraperitoneal fluid. He was returned to the OR for urgent laparotomy. The patient was placed supine with a bump under the left hemithorax in preparation for a left thoracotomy. On entering the abdomen, a large amount of blood was evacuated immediately. A splenic laceration (Fig. 1) and a left colon perforation at the splenic flexure were encountered. There was gross fecal soilage of the peritoneal cavity, with an approximately 2-cm diaphragm defect. Splenectomy was performed and damage control principles followed. The left hemithorax was inspected through the

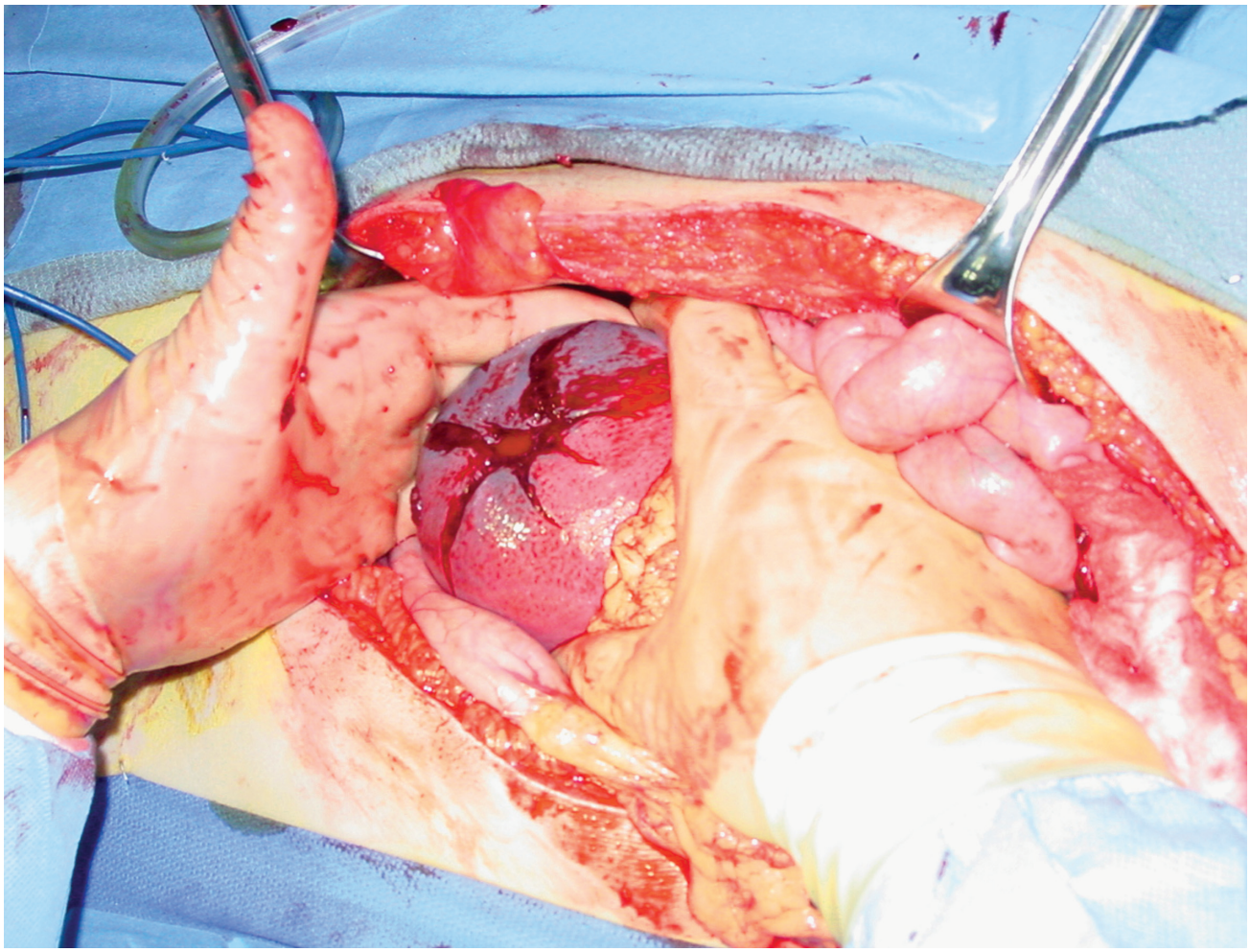

FIGURE 1. *Splenic laceration.*

diaphragmatic defect (Fig. 2), and there was no active hemorrhage from the left hemithorax. Postoperatively, there was no further significant hemorrhage from the chest tube. The patient was urgently evacuated to a level III medical treatment facility, where definitive surgery was performed.

TEACHING POINTS

1. Thoracoabdominal injuries, especially at the level of the nipple line or below, carry a high incidence of intraperitoneal injury. As demonstrated in this case, a high index of suspicion must accompany such injuries and immediate laparotomy considered, even without definitive evidence of intraperitoneal injury.
2. After placing the chest tube on the affected side, this patient's condition stabilized, allowing further studies to fully evaluate his injury. Lacking sensitivity, a FAST scan performed early after penetrating trauma may be negative. If plain X-rays (chest X-rays, KUB [kidneys, ureters, and bladder]) with radiopaque markers for the entry and exit wounds reveal that the trajectory of the fragment likely passed through the peritoneal cavity, then laparotomy should be performed.
3. When it is unclear to the surgeon which body cavity is likely the source of bleeding, position the patient supine with the affected hemithorax "bumped up" to a 30- to 45-degree angle. This will allow access to both the abdomen and the chest. By rotating the OR table up to 30 degrees, the chest will essentially be in the lateral decubitus position, easily allowing a thoracotomy incision to be made (Fig. 3).

CLINICAL IMPLICATIONS

1. When the patient presents with a penetrating truncal injury, proceed with ATLS protocol. If the patient does not have an indication for an emergency

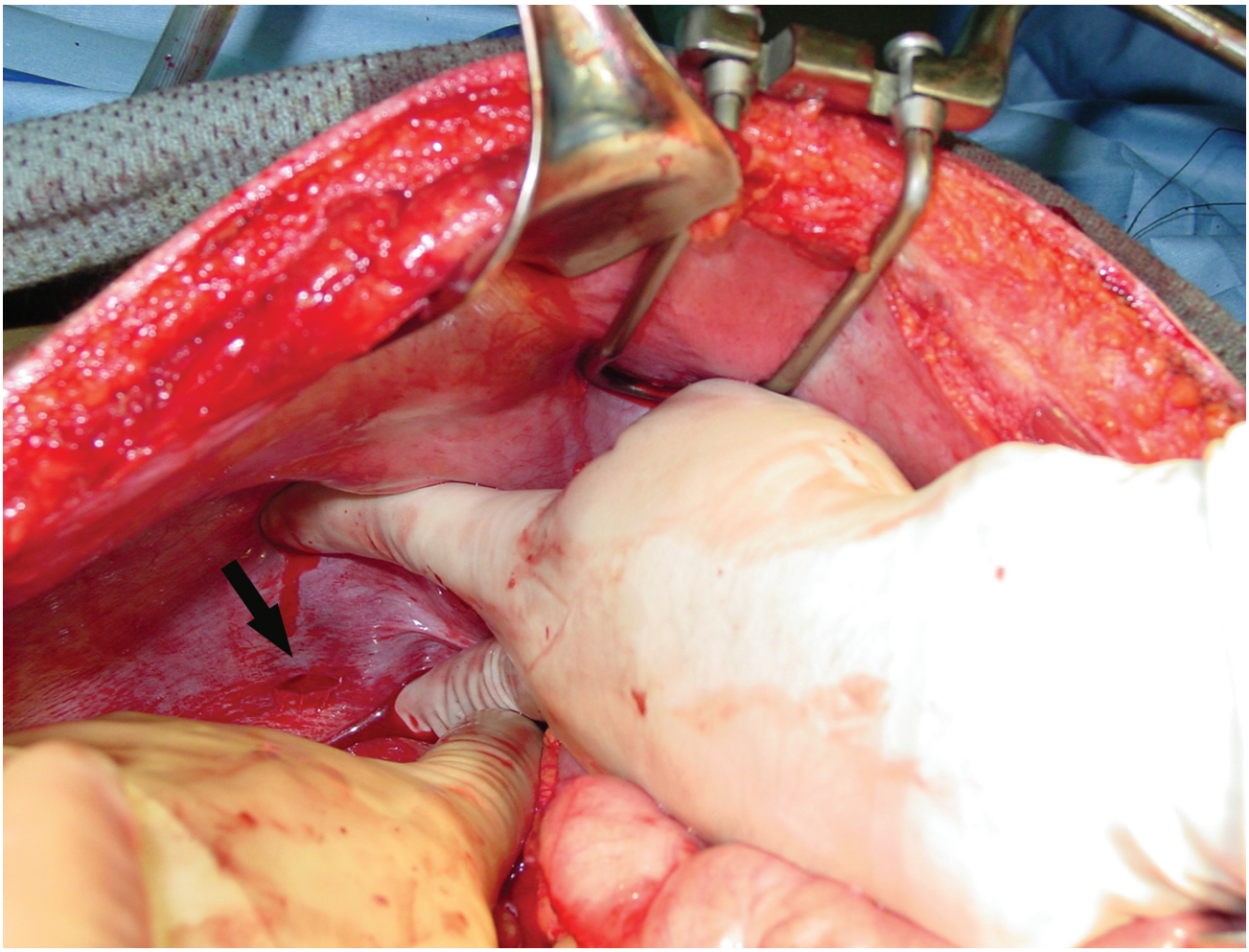

FIGURE 2. *Small diaphragmatic injury.*

department (ED) thoracotomy (ie, loss of vital signs or refractory hypotension with a penetrating thoracic wound), then proceed with a plain chest X-ray and abdominal films. Mark the entry and exit wounds with a radiopaque marker. This can help determine the trajectory of the missile (ie, does it cross the diaphragm?; Fig. 4). Obvious signs—such as free air under the diaphragm or a hemopneumothorax—will help guide the surgeon to the next step. **If the patient loses vital signs in the ED, he will require an immediate thoracotomy for resuscitation.**

2. Patients hypotensive with penetrating chest injuries should undergo immediate tube thoracostomy with airway control. Rapid evaluation with chest X-ray and a FAST scan will help guide the surgeon as to which body cavity should be entered first, but neither study should overrule clinical judgment. Should the patient remain unstable, the amount of chest tube output may mandate immediate thoracotomy. Specifically, if greater than 1,500 cc of blood are recovered immediately, then immediate thoracotomy is indicated. With lesser amounts of initial chest tube output (less than 1,500 cc), urgent operation may be necessary based on the time elapsed after injury, the patient's clinical condition, or the surgeon's judgment.
3. The pitfalls and limited sensitivity of chest X-ray, FAST scan, chest tube output, and diagnostic peritoneal lavage (DPL) are many and well known.[1–5] Nonetheless, initial evaluation of a stable patient with a gunshot wound to the chest should include a chest X-ray with entry and exit markers, as well as a FAST scan. The FAST scan can be helpful in determining priorities. If a patient with a gunshot wound to the chest is hypotensive and an initial chest X-ray reveals no significant hemothorax or pneumothorax, a nega-

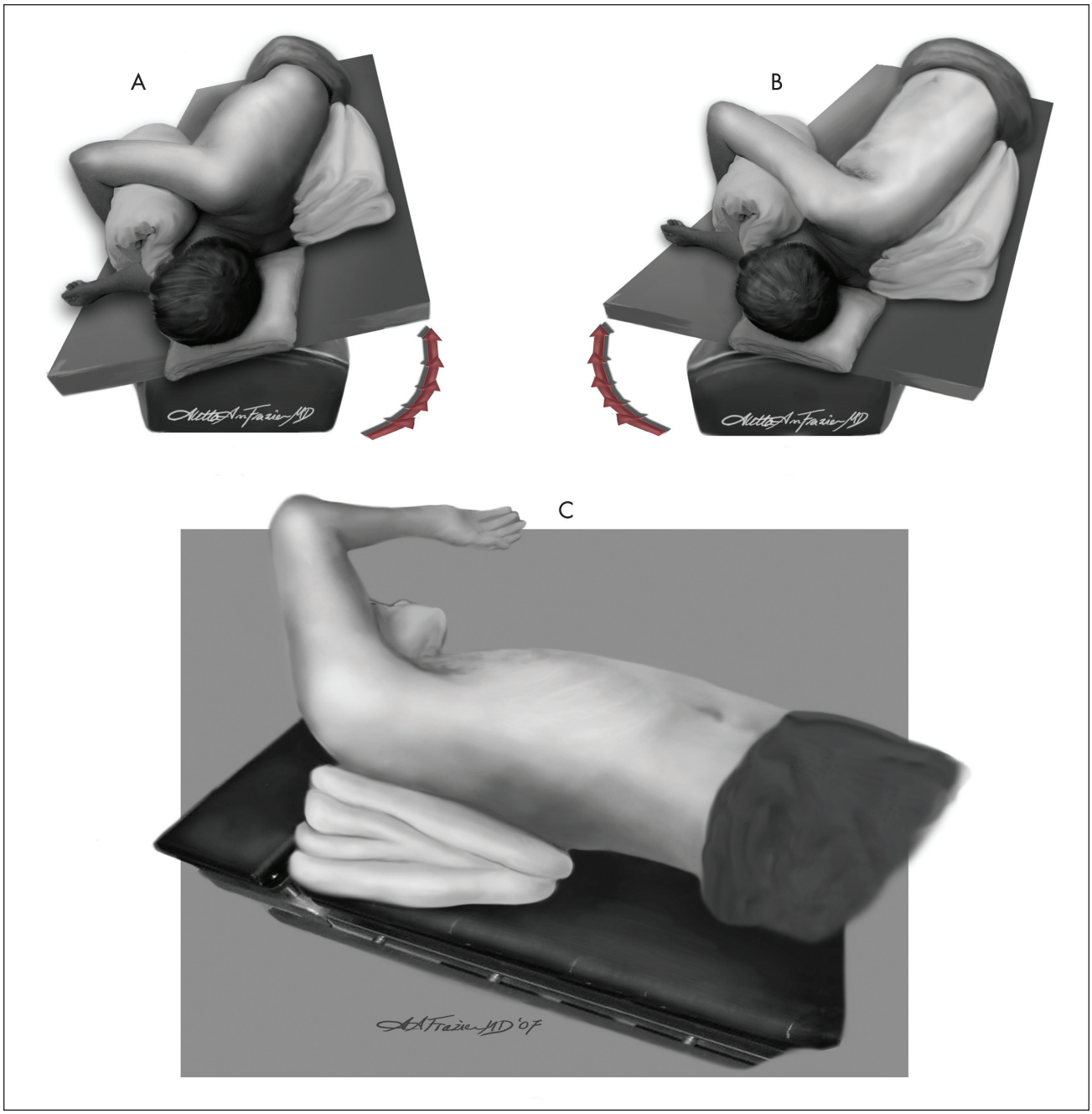

FIGURE 3. *Bent table.*

tive FAST scan for pericardial blood will guide the surgeon toward performing a laparotomy as the initial procedure. The chest wound can be managed with a simple tube thoracostomy.

4. However, if the patient has a significant hemothorax and the chest tube is placed first, this may not actually reflect an intrathoracic injury. Even if such an injury is present, a transthoracic intraabdominal injury cannot be excluded. If there is a diaphragmatic injury, the chest tube output may actually reflect intraabdominal bleeding. In this situation, a DPL could be helpful, using 15,000 RBCs/mm^3 as the threshold for a positive result. With a negative DPL, the initial procedure should be a thoracotomy.
5. A CT image of the chest and abdomen may also provide clues as to the location of the injury. A CT

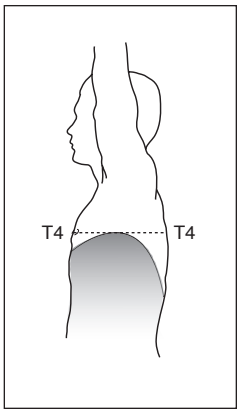

FIGURE 4. *Penetrating thoracic injuries below the T4 level (nipple line) have a high probability of involving abdominal structures.*

image is more sensitive and specific for diagnosing intraabdominal and intrathoracic hemorrhage. In the field environment, CT imaging may not be available. With an unstable patient, CT imaging is not an option.

6. A helpful maneuver when performing a laparotomy is to look for significant hemorrhage through the diaphragm into the hemithorax. If there is a diaphragmatic defect with gross fecal soilage, it is also prudent to do a lavage through the defect to reduce the risk of postoperative empyema. Enlarge the defect as necessary and close with a running Prolene suture. In addition, the best clues will come from the anesthesiologist. Elevated peak airway pressures, persistent hypotension, or hypoxia suggest that there is a problem in the thorax rather than in the abdomen.

DAMAGE CONTROL

With massive intraperitoneal and thoracic injuries, the priority is hemorrhage control. This may be accomplished with packing of the abdomen after bleeding has been controlled. The thoracic cavity can also be packed once hemorrhage control has been achieved. Temporary closure of both cavities can be used and the patient returned to the ICU for further resuscitation and warming prior to return to the OR for definitive repair.

SUMMARY

Managing thoracoabdominal injuries requires a high index of suspicion for injuries in both the thorax and abdomen. In the unstable patient, tube thoracostomy and X-rays with radiopaque markers will assist the surgeon in determining where to intervene. Adjunctive studies that include the FAST scan and CT imaging may prove helpful in the appropriate clinical situation. Despite all the best efforts at diagnosis, the wrong cavity is entered about 23% to 44% of the time.[4,5] The best course of action is to maintain intraoperative flexibility and be prepared to change course rapidly and enter another body cavity. The best position for these cases is supine, arms extended, with a bump under the relevant thorax. Prep the patient widely, from neck to knees. A Foley catheter should be in place. This positioning allows the surgeon to perform a laparotomy, thoracotomy, or a median sternotomy without the need to reposition the patient.

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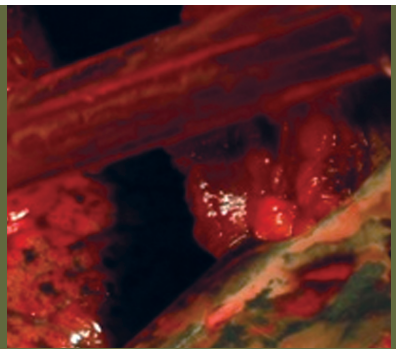

IV.3 Thoracotomy for Massive Hemothorax

CASE PRESENTATION

This 27-year-old male presented about 90 minutes after sustaining penetrating injuries to the right chest and left thigh. The patient was hypotensive. Immediate right tube thoracostomy resulted in 1,700 cc of blood output. He was hypothermic, with a temperature of 93.9°F and a pH of 7.09. The international normalized ratio was 1.7. A whole blood drive was initiated. Transfusion in combination with recombinant Factor VIIa corrected his coagulopathy. Right anterolateral thoracotomy was performed. The right internal mammary artery was transected and ligated immediately. The inferior pulmonary ligament was divided, and the entire lung was mobilized. The bullet tract was in the vicinity of the pulmonary hilum. The pulmonary hilum was dissected enough to allow vascular control. The bullet tract included all three lobes, and bleeding from this wound was heavy. The lung was consequently twisted around the hilum, resulting in some hemorrhage control and allowed assessment of the wounds (Fig. 1). Injuries to the inferior and middle lobes were more peripheral and were stapled across with a gastrointestinal anastomosis (GIA) stapler using a few reloads. This controlled the bleeding. Injury to the upper lobe was more central and bleeding continued. A tractotomy with a GIA stapler was performed, with oversewing of the bleeders and air leak that produced excellent results. The hemithorax was washed out, the lung was returned to its correct anatomical position, and the chest was closed with two large thoracostomy tubes in place. The femur fracture and wound were addressed with washout and external fixation as the patient was warmed and resuscitated at the end of the thoracotomy.

TEACHING POINTS

1. Patients presenting in hypovolemic shock with the triad of hypothermia, coagulopathy, and acidosis have a mortality rate as high as 90%.[1] They must be warmed and resuscitated rapidly. The patient in this case was given whole blood, packed red blood cells, recombinant Factor VIIa, and fresh frozen plasma, in addition to crystalloid. Military medical personnel must be expert in the use of all of these products to save patients in extremis.
2. Thoracotomy is indicated for massive hemothorax usually defined as 1,500 cc of output with initial tube thoracostomy or 200 cc of output per hour for 4 hours.

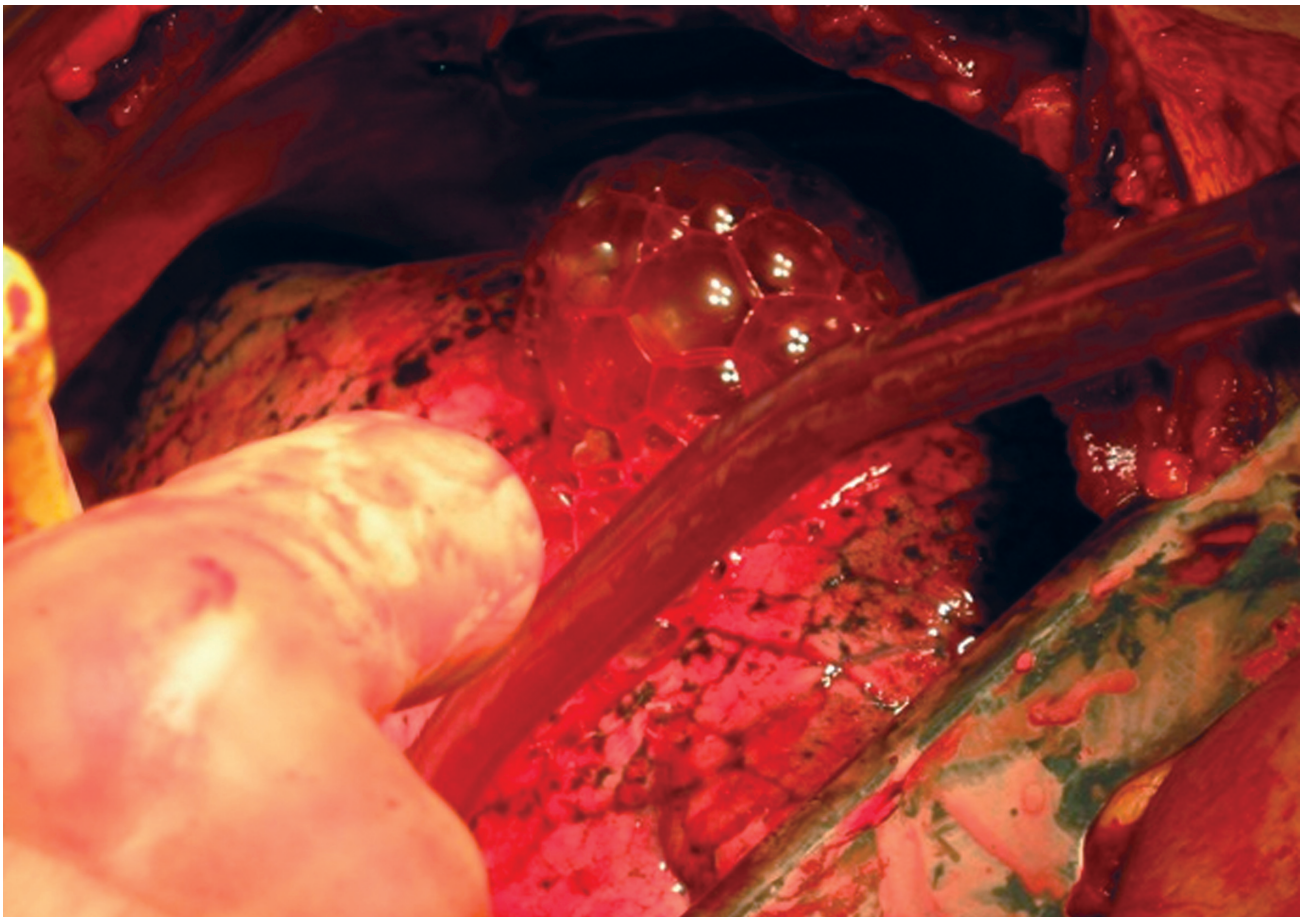

FIGURE 1. *The lung after it has been mobilized and twisted around the hilum to slow the bleeding.*

CLINICAL IMPLICATIONS

1. Tube thoracostomy alone is adequate treatment for most simple lung parenchymal injuries.
2. Large air leaks not responding to thoracostomy will require open repair.
3. Simple bleeding should be controlled with absorbable sutures on a tapered needle or with staples (eg, TA-90 staples).
4. Bleeding tracts should be opened with a GIA stapler, and bleeding points should be ligated. To avoid an air embolism produced by positive pressure ventilation, simple closure of the entrance and exit wounds of the lung parenchyma is contraindicated. Remember: The more central the injury, the higher the risk of air embolism.
5. Resection of the bleeding area of the lung may be necessary. Avoid anatomical resection in favor of a simple wedge resection.
6. Uncontrolled parenchymal or hilar bleeding, or complex hilar injuries with massive air leaks, should be controlled with hilar clamping (or a "hilar twist"; Fig. 2) and attempted repair. Pneumonectomy should be performed as a last resort because it is associated with a 90% mortality rate.[1]

DAMAGE CONTROL

In patients with exsanguinating hemorrhage from thoracic injury, the goal is to stop the bleeding and restore a stable physiological status. The following principles apply:

1. Large lung staplers should be used to perform nonanatomical wedge resections to achieve hemostasis and control of air leaks rapidly.
2. In pulmonary tractotomy (Fig. 3), the lung bridging the wound tract is opened between long clamps or with a stapler, the wound is inspected, bleeding points are ligated, and air leaks are controlled.
3. If the patient continues to bleed despite the above measures, packing and temporary chest closure may be necessary to allow further resuscitation.

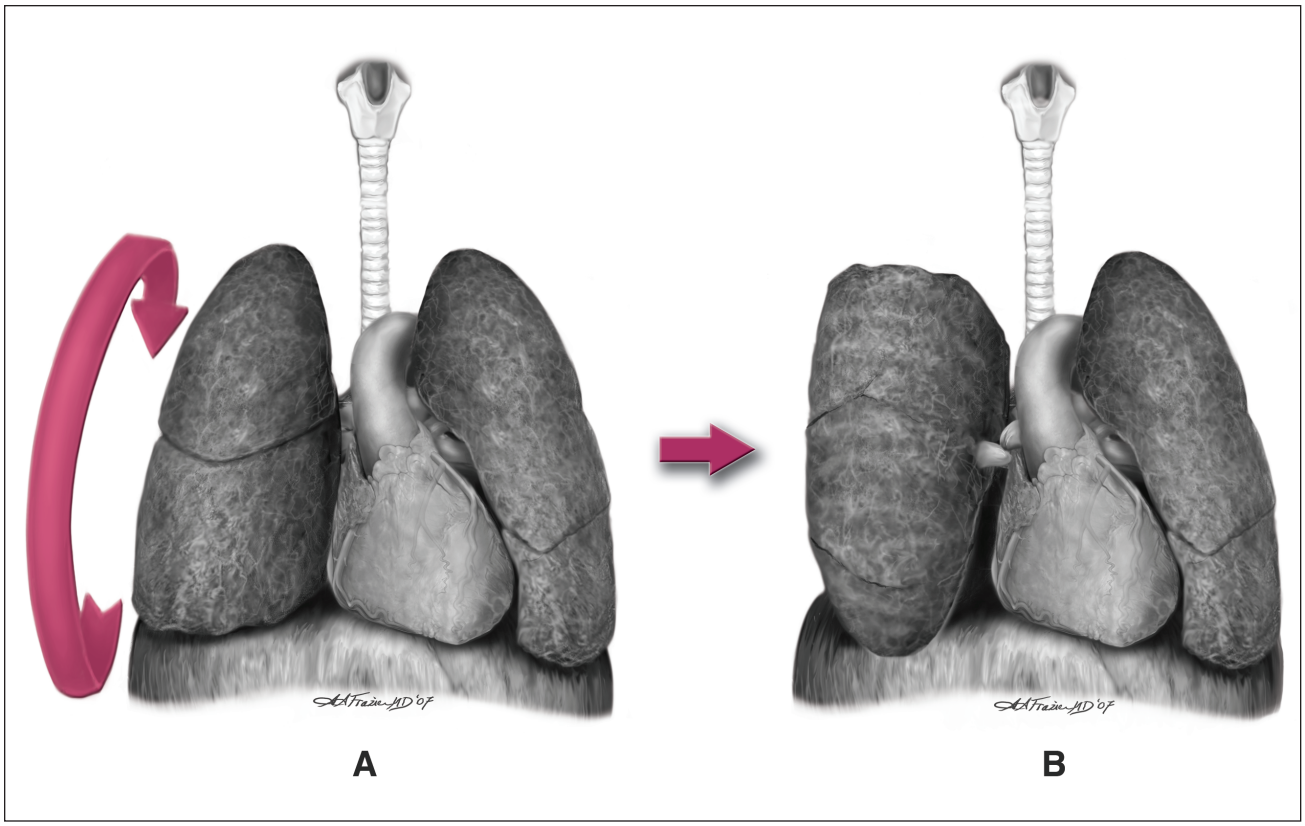

FIGURE 2. *Hilar clamping or "hilar twist."*

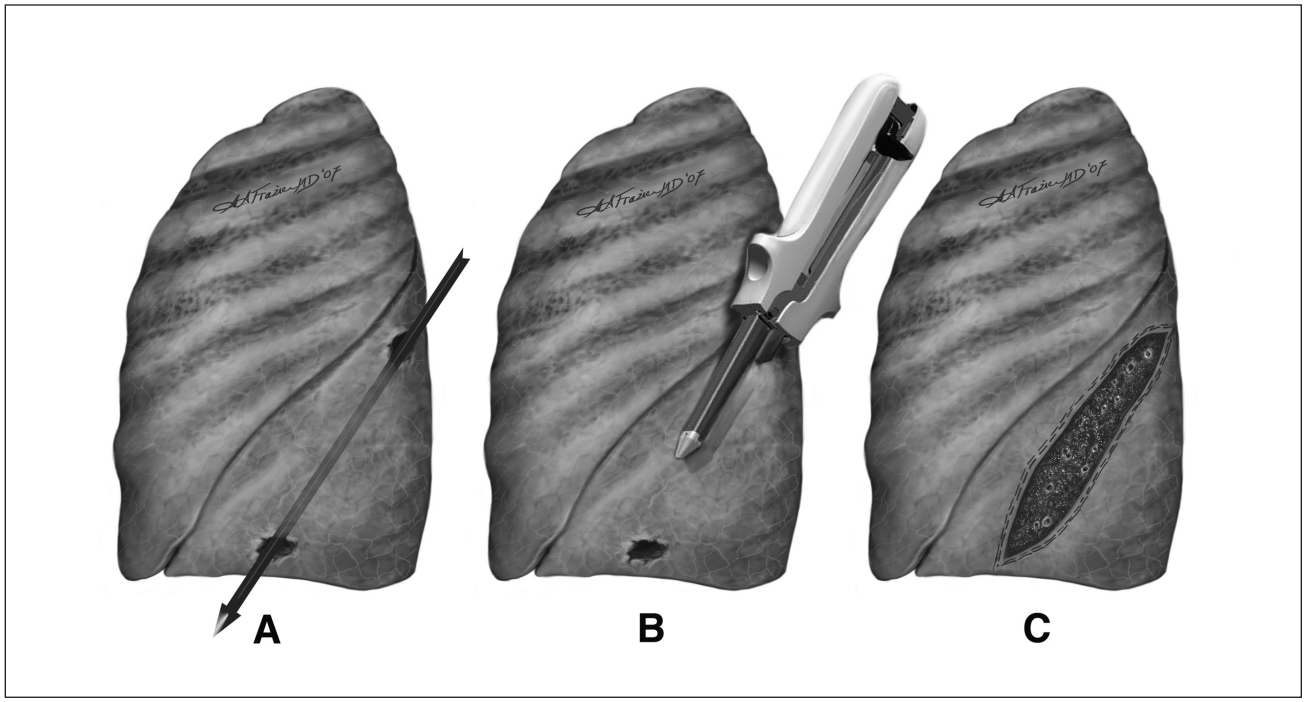

FIGURE 3. *Illustration of pulmonary tractotomy.*

SUMMARY

This case demonstrates a successful approach to massive hemothorax in a hypotensive, coagulopathic, and cold patient. The combination of expert resuscitation with damage control thoracotomy resulted in this patient's survival.

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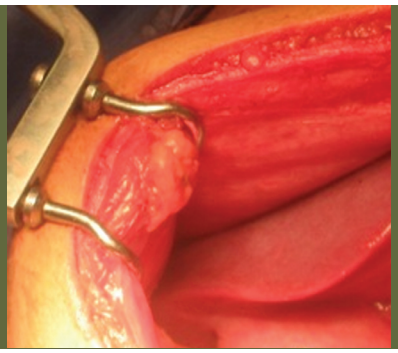

IV.4
Spinal Injury With Penetrating Thoracoabdominal Injuries

CASE PRESENTATION

A 25-year-old male presented with a single gunshot wound that entered through the back and traversed the midthoracic spine. The patient was paraplegic with no sensation or motor function below a midthoracic level (T5). He complained of mild abdominal pain. The initial chest radiograph was unremarkable, as was the FAST exam. The patient was taken to the operating room (OR) for abdominal exploration. Shortly after intubation, he developed symptoms consistent with a tension pneumothorax, and a right chest tube was placed with resolution of symptoms. Intraoperatively, the patient was found to have a large injury of the anterior duodenum that extended from the first portion of the duodenum to the body of the stomach and a smaller posterior injury of the second portion of the duodenum (Fig. 1). The anterior duodenum was repaired using a Heineke-Mikulicz repair, opening it horizontally and closing it vertically to ensure that the lumen was not narrowed. A right medial visceral rotation was performed to ensure that there was no injury to the inferior vena cava. Injury to the pancreas, ampulla, porta hepatitis, and diaphragm were specifically ruled out, as well as small bowel and colon injuries. A small injury to the liver was packed. Bowel edema precluded closure of the abdomen, and a sterile bag was sewn to the skin (Fig. 2).

TEACHING POINTS

This case demonstrates the destructive power of a high-velocity missile entering the back and traversing the abdomen and chest with injury to multiple organs. The following points deserve emphasis:

1. Penetrating injuries to the back—especially gunshot wounds—should undergo exploratory laparotomy, particularly when CT imaging is not available.
2. Duodenal repairs should be liberally drained.
3. To prevent abdominal compartment syndrome, the abdomen should not be closed under tension.
4. When thoracic injury is suspected, tube thoracostomy should be performed, especially if the patient cannot be observed continuously.
5. Spine immobilization should be maintained in patients with spinal cord injury until they have been evaluated by a neurosurgeon, if one is available.

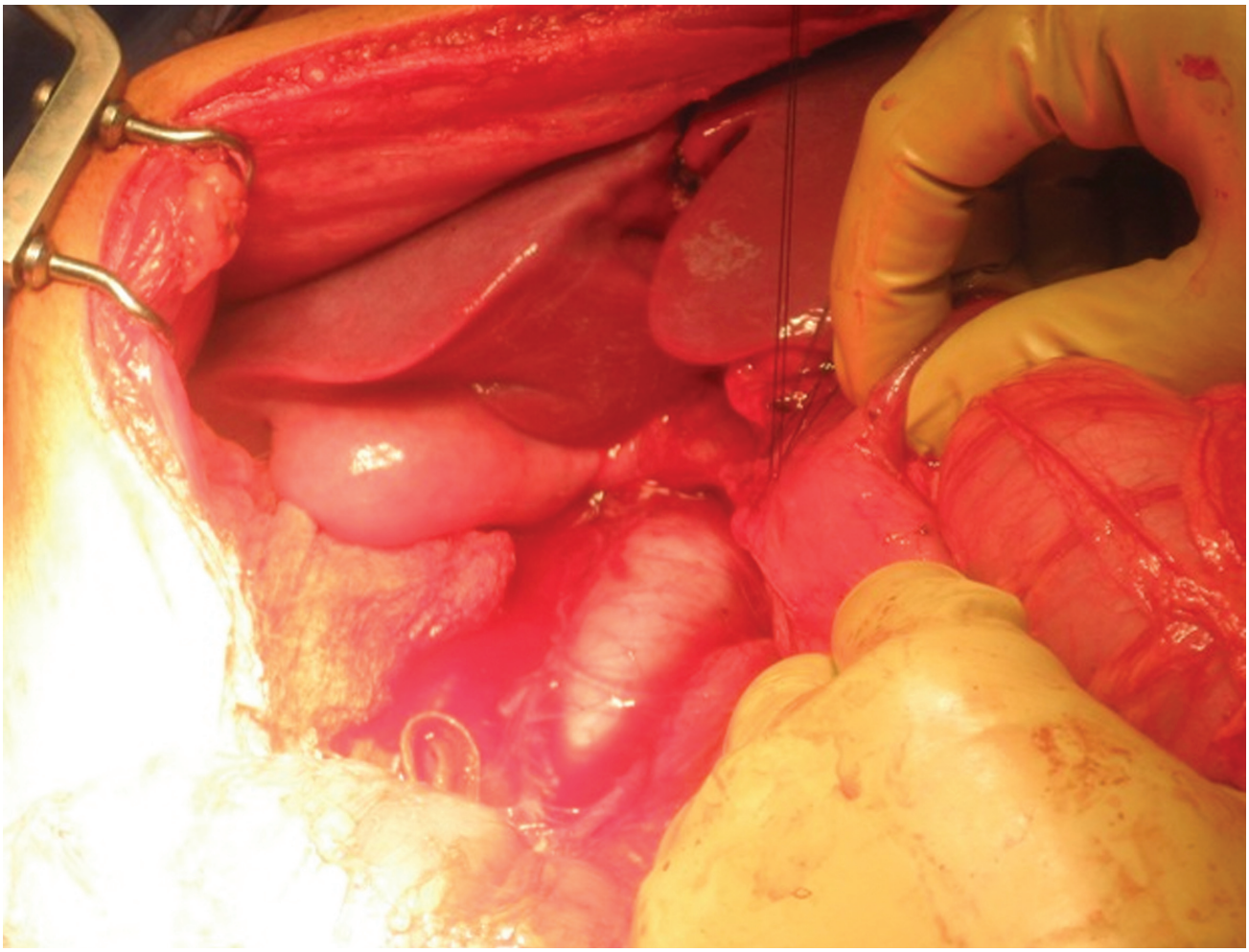

FIGURE 1. *Intraoperative view of duodenal injury.*

FIGURE 2. *Temporary abdominal closure with sterile bag.*

CLINICAL IMPLICATIONS

1. Posterior truncal penetrating injuries from the tip of the scapula to the sacrum (Figs. 3 and 4) may have caused retroperitoneal and intraabdominal injuries. A low threshold for exploratory laparotomy is warranted in these patients.
2. Injuries to the duodenum are frequently associated with injury to other organs. Damage control techniques should be considered early. Do not close the abdominal fascia under tension. Leave the skin open.
3. Minor injuries of the duodenum can be repaired primarily, and large injuries should be repaired if the lumen will not be narrowed by more than 50%.[1] If the lumen will be narrowed by more than 50%, consider the following options:

FIGURE 3. (Top) *Trajectory of missiles may include both chest and abdomen.*

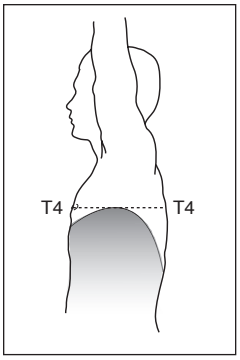

FIGURE 4. (Bottom Left) *Penetrating thoracic injuries below the T4 level (nipple line) have a high probability of involving abdominal structures.*

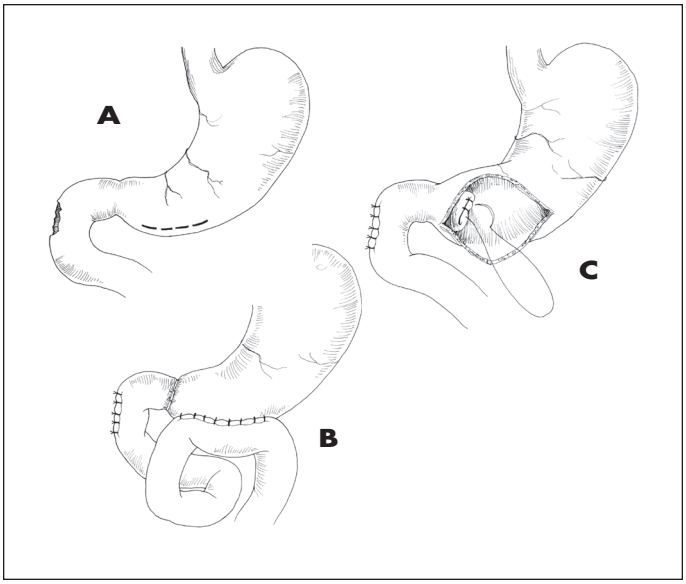

FIGURE 5. (Bottom Right) (A) *Duodenal injury.* (B) *Gastrojejunostomy.* (C) *Ligation of the pylorus. Alternate method of closing the pylorus is stapling across it with a TA stapler.*

a. For major injuries, close the pylorus temporarily and divert the gastric stream with a gastrojejunostomy (Fig. 5).
b. Use a Heineke-Mikulicz repair (as in this case) for the first portion of the duodenum extending to the stomach.
c. Create an anastomosis between the injury and a Roux-en-Y limb.
d. Consider draining the injured area and transferring the patient to a facility equipped for large procedures, if pancreaticoduodenectomy is required.
e. Close the injury around a tube duodenostomy using 2-0 VICRYL suture with a Malecot catheter, if available.

DAMAGE CONTROL

Injuries of the duodenum are frequently associated with injuries to other organ systems and hemorrhage. When repair of duodenal injuries cannot be performed using relatively simple techniques, damage control should be considered, specifically:

1. Control hemorrhage and contamination.
2. Pack and close the patient temporarily.
3. Resuscitate the patient to normal physiology.
4. Plan for future reoperation and definitive repair.
5. Note that emergent spine surgery for penetrating injuries of the spinal cord is indicated only in the presence of neurological deterioration.

SUMMARY

Penetrating spine injuries associated with hollow viscus injuries should undergo appropriate treatment of the viscus trauma without extensive debridement of the spinal injury, followed by appropriate broad-spectrum antibiotics. This patient presented with a penetrating back injury and paraplegia. Exploratory laparotomy revealed injuries to multiple organs. The patient's abdomen was temporarily closed to prevent abdominal compartment syndrome, as is often necessary with these types of injuries.

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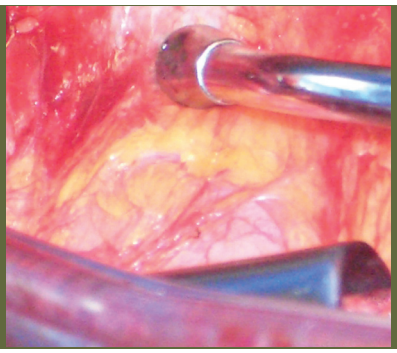

IV.5 Traumatic Pericardial Tamponade

CASE PRESENTATION

A 40-year-old civilian contractor was wounded when a mortar struck in the vicinity of his sleep trailer. The patient was brought to the Emergency Medical Treatment (EMT) section of the combat support hospital (CSH) where he was alert, oriented, and complaining of a little pain in the right groin and left chest. His vital signs on arrival were a heart rate of 110 beats per minute and a blood pressure of 80/60 mm Hg. The initial survey revealed a superficial wound below the left nipple, a penetrating wound of the right groin, and what appeared to be a penetrating wound of the chest above the left nipple (Fig. 1). His abdomen was soft without tenderness. A left chest tube was placed with minimal recovery of intrathoracic blood. FAST examination was negative for intraperitoneal and pericardial fluids. A chest X-ray (CXR) revealed a metallic fragment in the left chest (Fig. 2). Despite fluid resuscitation and no obvious bleeding source, the patient's blood pressure remained below 100 mm Hg systolic. A CT scan of the chest revealed pericardial blood (Fig. 3), and the patient was taken to the operating room where he underwent an urgent median sternotomy (Fig. 4). The pericardium was open with immediate extrusion of clotted blood (Fig. 5). The patient's vital signs normalized after pericardial tamponade was relieved. The pericardium was fully opened, and a penetrating injury to the apex of the heart was found (Fig. 6). This was repaired with a single horizontal mattress suture using pericardium for pledgets (Figs. 7 and 8). The patient's chest was closed, and he was evacuated from theater the following day. He had an uneventful recovery.

TEACHING POINTS

1. Patients presenting with penetrating chest trauma and hypotension require rapid evaluation and treatment of their injuries. Immediate needle chest decompression or rapid insertion of a chest tube on the affected side will either treat or rule out tension pneumothorax or massive intrathoracic bleeding as the cause of hypotension. FAST scan should also rule out massive intraperitoneal blood, as well as pericardial blood or tamponade. Other sources of significant blood loss (retroperitoneal, pelvic or long bone fractures, or external bleeding from large, soft tissue or scalp wounds) should be sought to explain hypotension. A high index of suspicion for

FIGURE 1. *Patient undergoing resuscitation. Note penetrating injuries to left chest.*

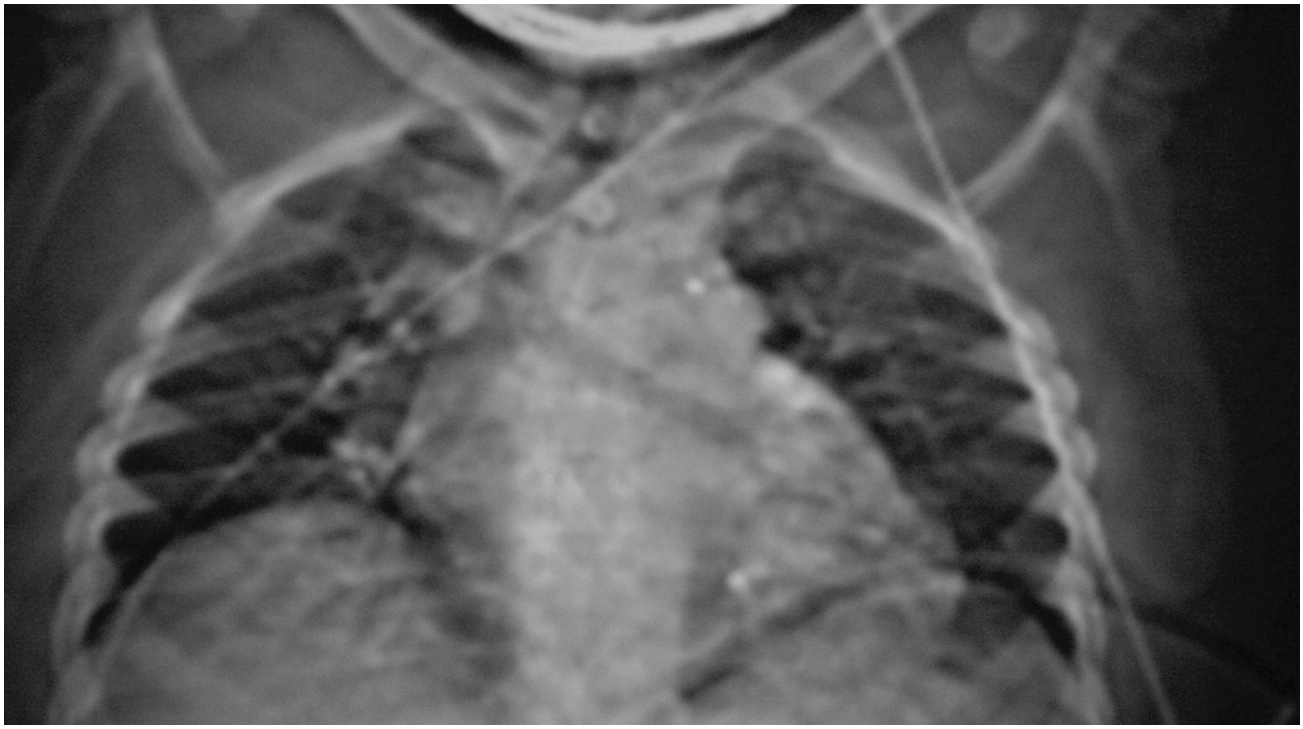

FIGURE 2. *Chest radiograph. Note multiple metal fragments in left chest.*

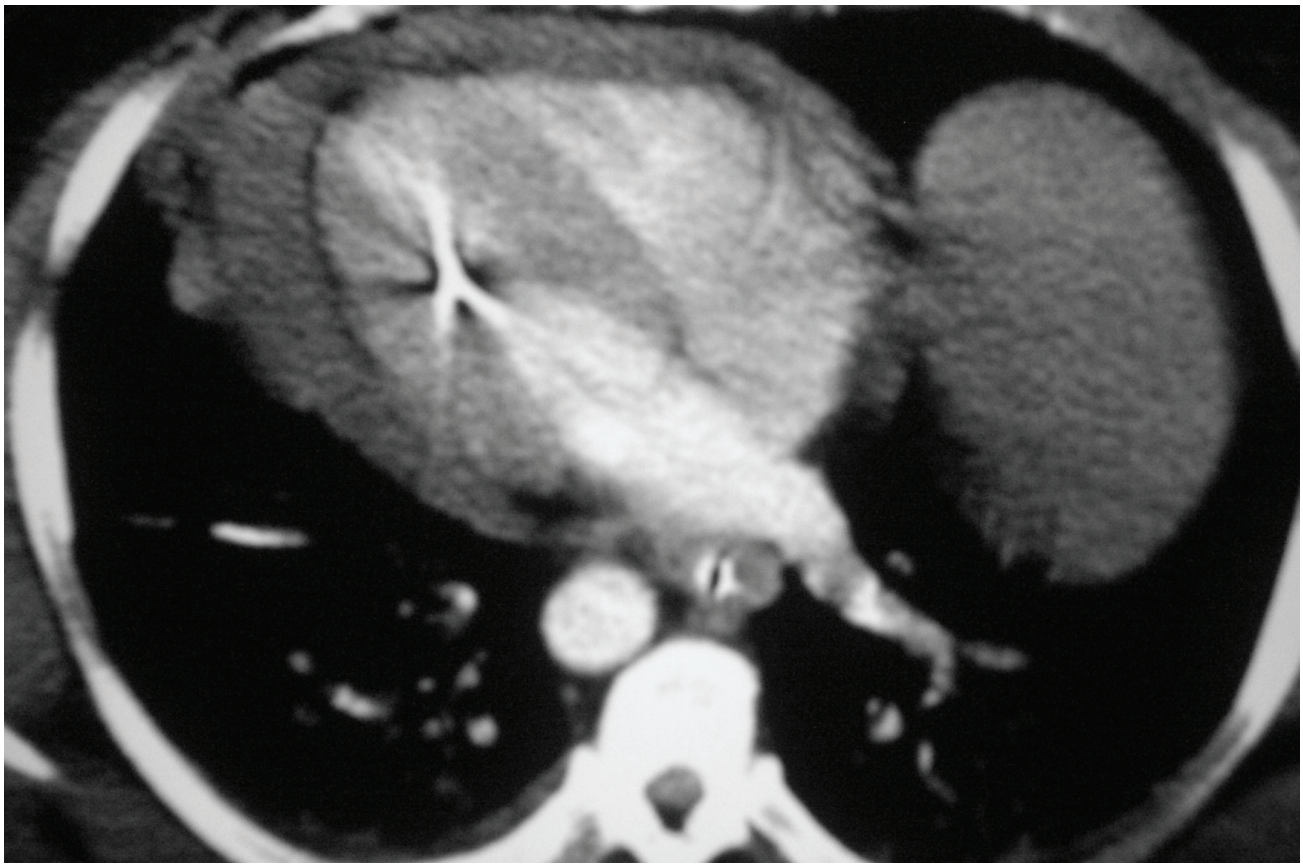

FIGURE 3. *Chest CT image* (mediastinal window) *showing metallic fragment in the heart with surrounding pericardial effusion.*

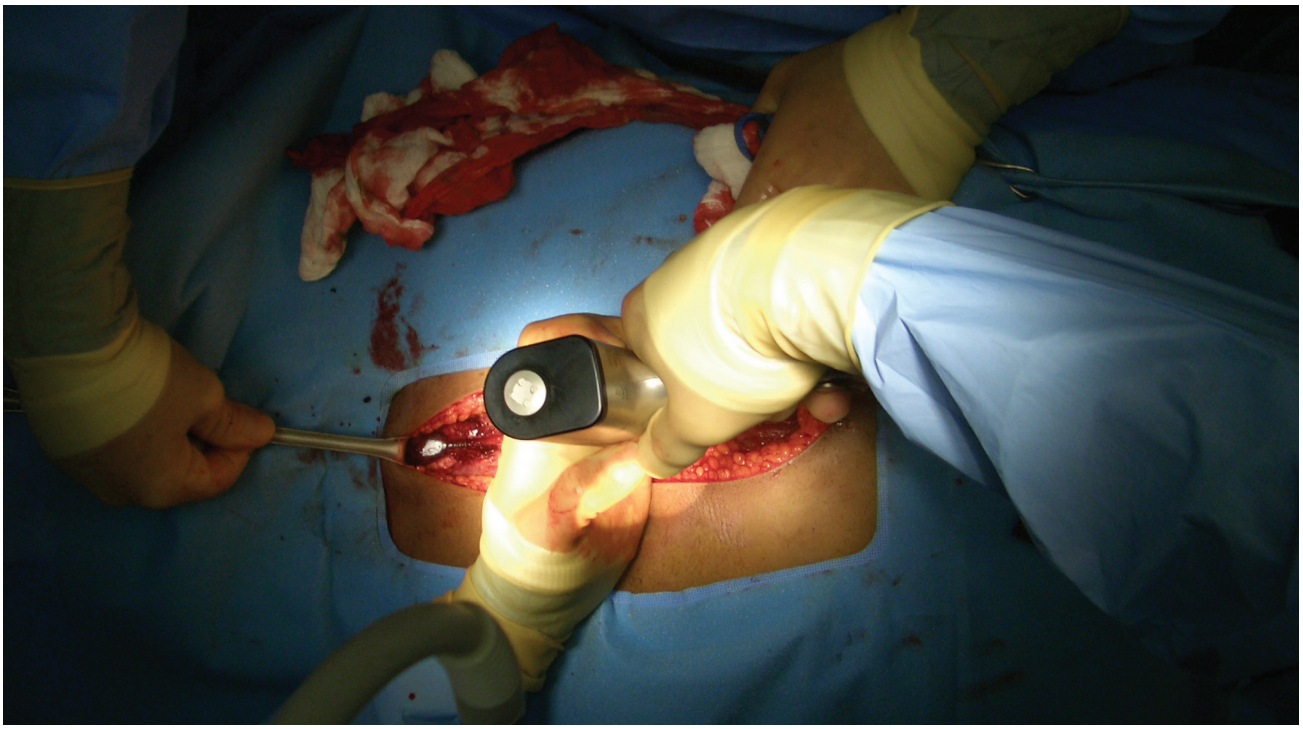

FIGURE 4. *Median sternotomy.*

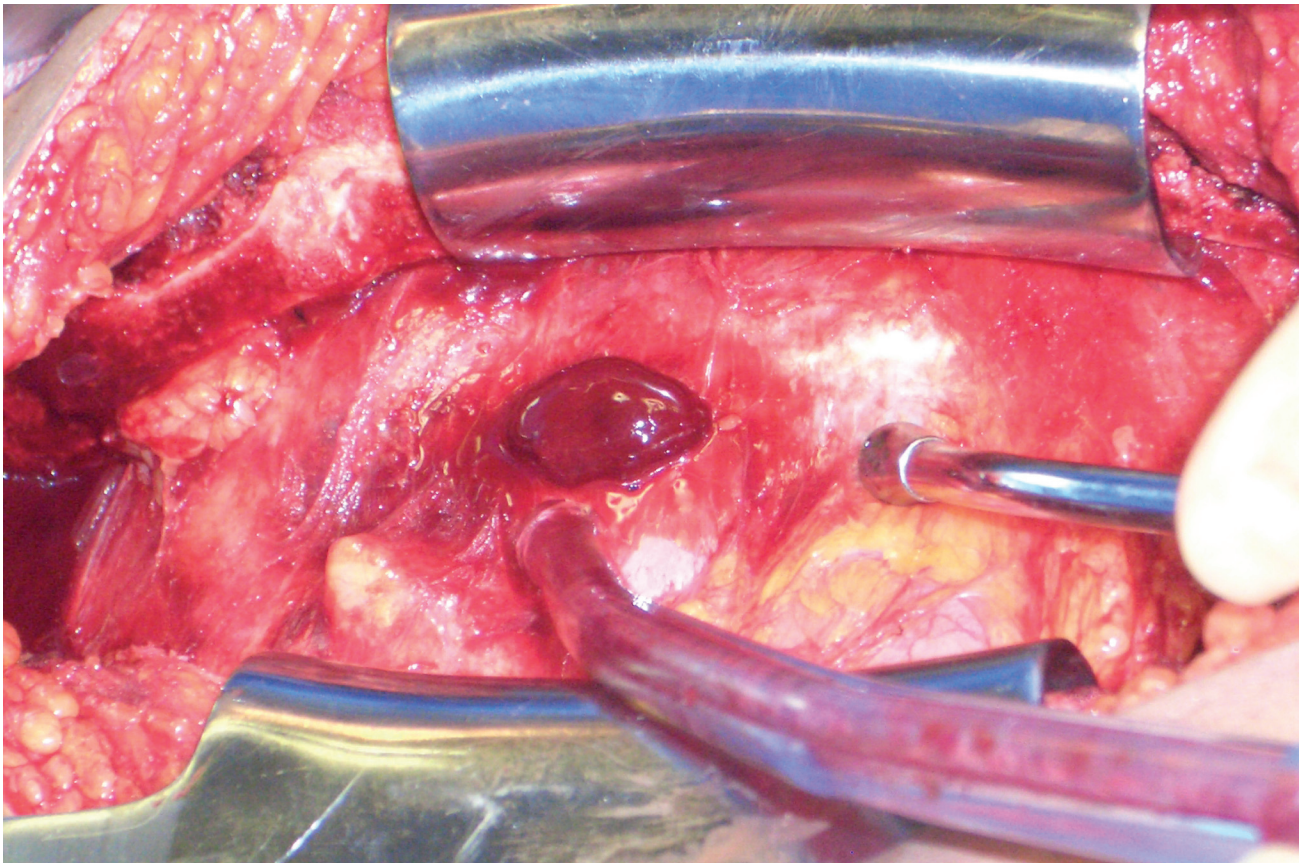

FIGURE 5. *Exposed pericardium with blood clot from initial pericardiotomy.*

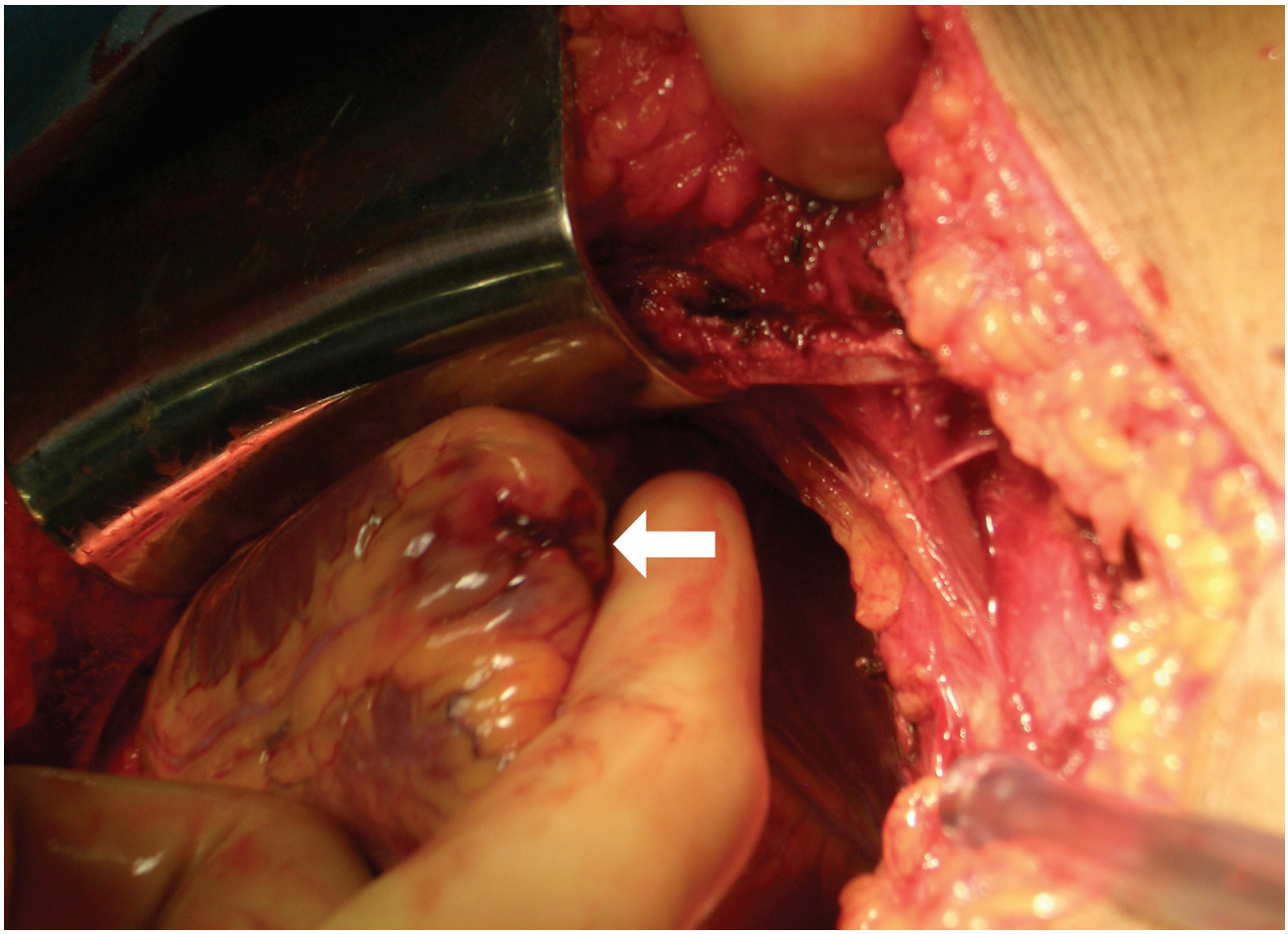

FIGURE 6. *Penetrating injury to the apex of the heart* (arrow).

pericardial tamponade should be maintained for patients with penetrating chest injuries and no other source of blood loss. This patient's large size may have decreased the sensitivity of our FAST examination. With a CT available, a chest scan readily revealed pericardial blood. If CT is unavailable and the FAST is negative, a subxiphoid pericardial window is indicated with penetrating chest trauma and ongoing hypotension with no obvious source of bleeding. A trial of pericardiocentesis may be diagnostic (as well as therapeutic), but aspiration may be falsely negative in the presence of an organized clot.

2. When suturing cardiac injuries, pericardium for the pledgets is readily available and an excellent choice. Although figure-of-eight sutures may be used, avoid compressing or compromising coronary vessels by using horizontal mattress sutures if the vessel will be crossed by the repairing suture (Fig. 9).

CLINICAL IMPLICATIONS

1. Patients presenting with penetrating chest trauma and who are hypotensive require rapid evaluation. After ensuring the patient has an adequate airway and is breathing, hypotension mandates rapid chest decompression (needle or chest tube) to rule out tension pneumothorax. If discovered by needle decompression (as evidenced by a rush of air or improvement of the patient's hemodynamics), a chest tube should be immediately inserted. There is no time to wait for a CXR to confirm the diagnosis of tension pneumothorax.
2. With ongoing hypotension, despite chest decompression, massive hemothorax should be revealed by chest tube placement or CXR. If a large amount of blood is drained immediately at chest tube insertion, urgent thoracotomy should quickly follow. Although Advanced Trauma Life Support (ATLS) guidelines suggest 1,500 cc of blood as the initial amount drained that mandates immediate

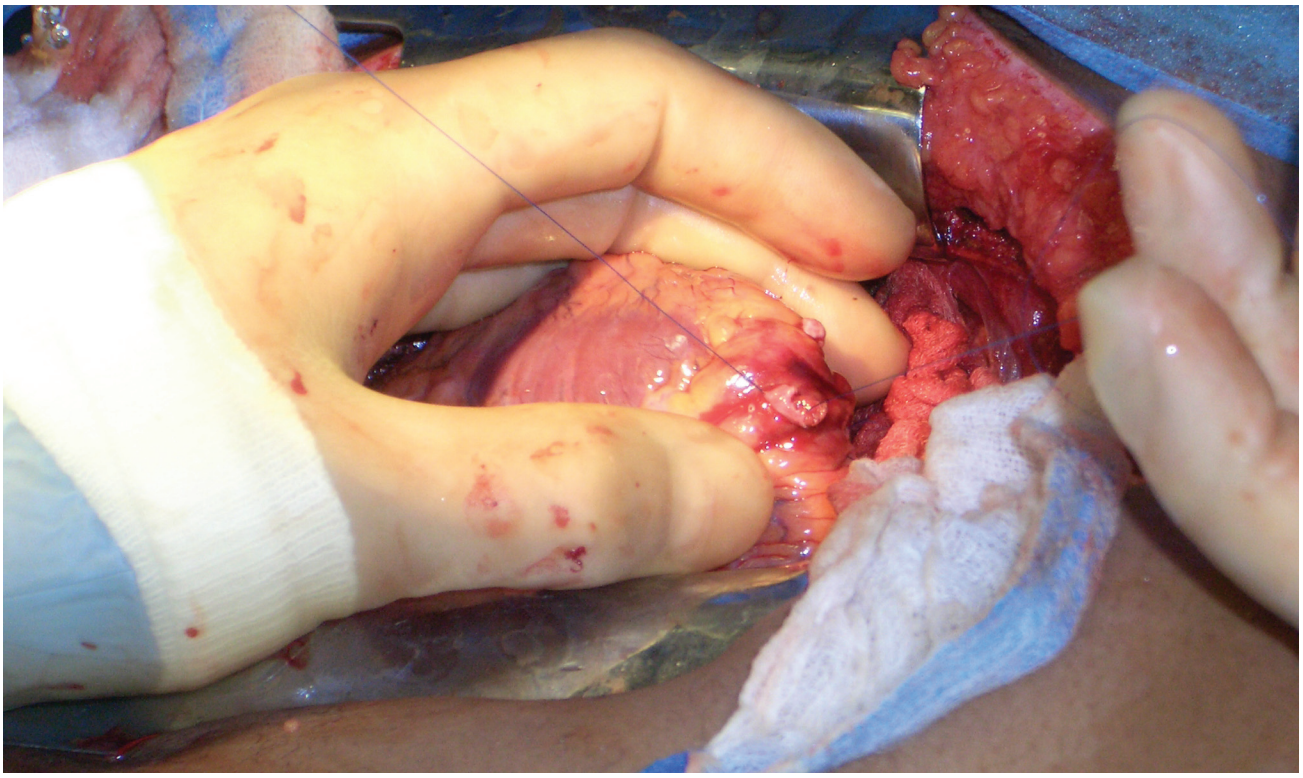

FIGURE 7. *Single horizontal mattress suture using pericardium for pledgets.*

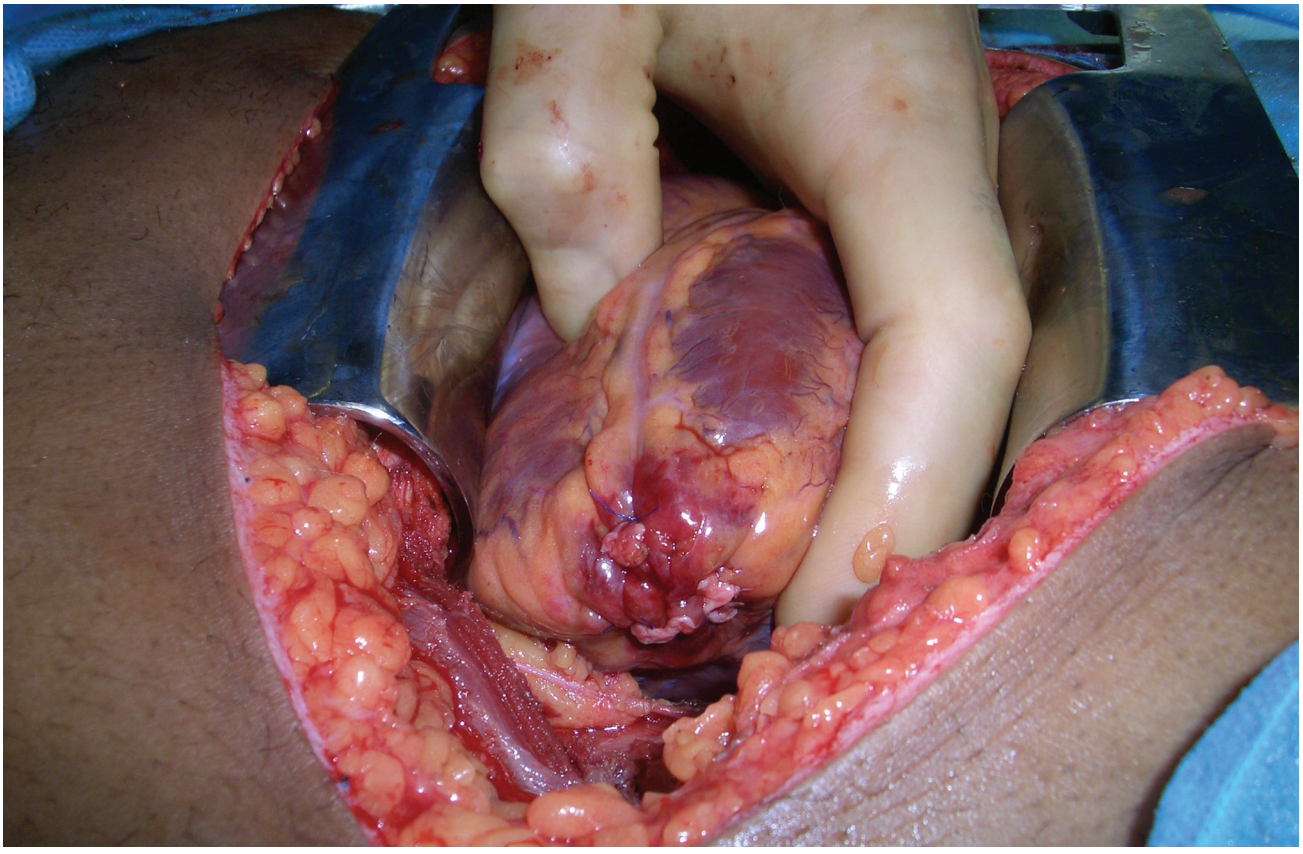

FIGURE 8. *Completed cardiac repair.*

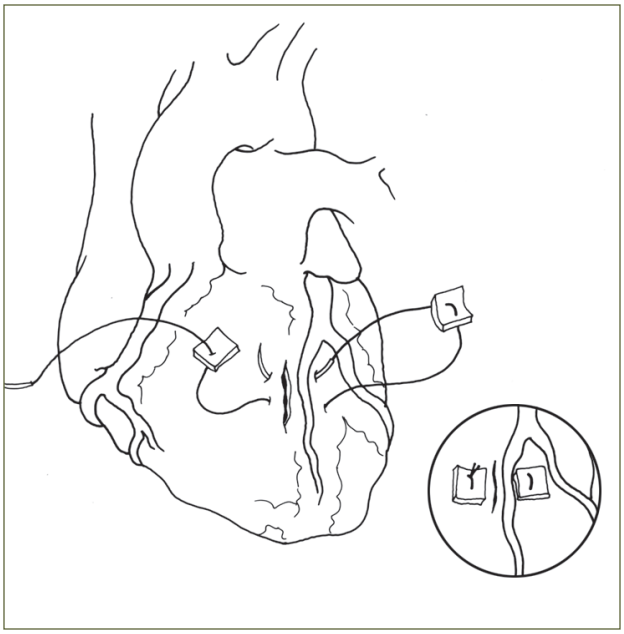

FIGURE 9. *Repair of penetrating cardiac injury.*

thoracotomy, this number should be mitigated by the type of injury (large penetrating fragment), the patient's clinical condition, as well as the length of time from injury to chest tube insertion. Patients may present to the CSH only minutes after injury. A patient in shock with 500 cc of blood in the chest within a few minutes of wounding who remains hypotensive despite initial resuscitative efforts may need urgent thoracotomy.

DAMAGE CONTROL

Although inserting a percutaneous pericardial catheter may temporarily alleviate tamponade for penetrating heart injuries, definitive repair cannot be delayed without a prohibitive risk of retamponade and cardiac arrest. Large cardiac injuries can be temporarily controlled after sternotomy with the insertion of a Foley or Fogarty catheter (depending on the size of the injury) and inflating the balloon to control bleeding. Skin staples may also be used to close a cardiac injury rapidly.

SUMMARY

Patients with penetrating chest injuries who present in shock require expeditious evaluation and management to locate the cause and quickly manage it. Tension pneumothorax, massive hemothorax, and pericardial tamponade should be rapidly investigated and treated. With ongoing hypotension and other sources of shock eliminated, a high index of suspicion for pericardial tamponade—despite a negative FAST—should be maintained and a subxiphoid pericardial window performed to definitively rule out this injury.

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IV.6 Penetrating Right Chest Injury

CASE PRESENTATION

This male soldier sustained a penetrating right chest injury from a mortar round. He was immediately transported to the combat support hospital (CSH). On arrival in the Emergency Medical Treatment (EMT) area, he was mildly tachycardic and hypotensive. During the patient's resuscitation, a right chest tube was placed yielding the immediate return of 800 cc of blood with continued output. He was rapidly moved to the operating room (OR) and an urgent right posterolateral thoracotomy performed (Fig. 1). Hilar bleeding and air leak were apparent, and a linear stapler was used to open the fragment tract. In conjunction with the injury, this maneuver essentially resulted in a right upper lobectomy. Once the right upper lobe was removed, continued bleeding was noted from the hilum of the middle lobe. The patient had a complete middle lobe fissure, and a linear stapler was placed at the middle lobe hilum and fired, completing a middle lobectomy (Figs. 2 and 3). This completely controlled the bleeding (Fig. 4). The chest was thoroughly irrigated with warm saline, the entrance wound debrided, and the chest closed with right angle and apical chest tubes in place. The patient was evacuated in stable condition to a level IV medical treatment facility the following day.

TEACHING POINTS

1. Although Advanced Trauma Life Support (ATLS) guidelines recommend urgent thoracotomy when either 1,500 cc of blood is recovered immediately on placing a chest tube or the rate of chest tube output is greater than 200 cc/hr for 4 hours, some clinical circumstances require more aggressive treatment. In this case, the close proximity of the wounded soldier to the resuscitation site resulted in a chest tube being placed within minutes of the penetrating injury. The immediate recovery of 800 cc of blood, with ongoing bleeding, indicated the likelihood of surgical bleeding. The patient also presented in shock. Taken together, urgent thoracotomy was the appropriate course of action.
2. Massive chest bleeding may make pinpointing the specific injury difficult. In this case, palpating the lung revealed the fragment tract, which allowed rapid exposure of the wound tract with a linear stapler. Once the tract is opened, locating the specific site of bleeding becomes possible (see Case IV.3, Fig. 3).

BEHIND ARMOR BLUNT TRAUMA (BABT)

All types of body armor and helmets are designed to prevent missiles from entering the part of the body protected by the armor, and, at the same time, to dissipate the kinetic energy created by the missile. However well the armor performs, some kinetic energy is still transferred to the individual. If penetration is prevented, the mechanism of injury is converted to "behind armor blunt trauma" (BABT).[1] The severity of the injury to the patient depends on:

- missile velocity
- energy transfer produced by the defeated missile
- energy dissipated by the armor
- area of the body that absorbs the remaining energy.

FIGURE 1. *Left-lateral chest wall injury from BABT.*

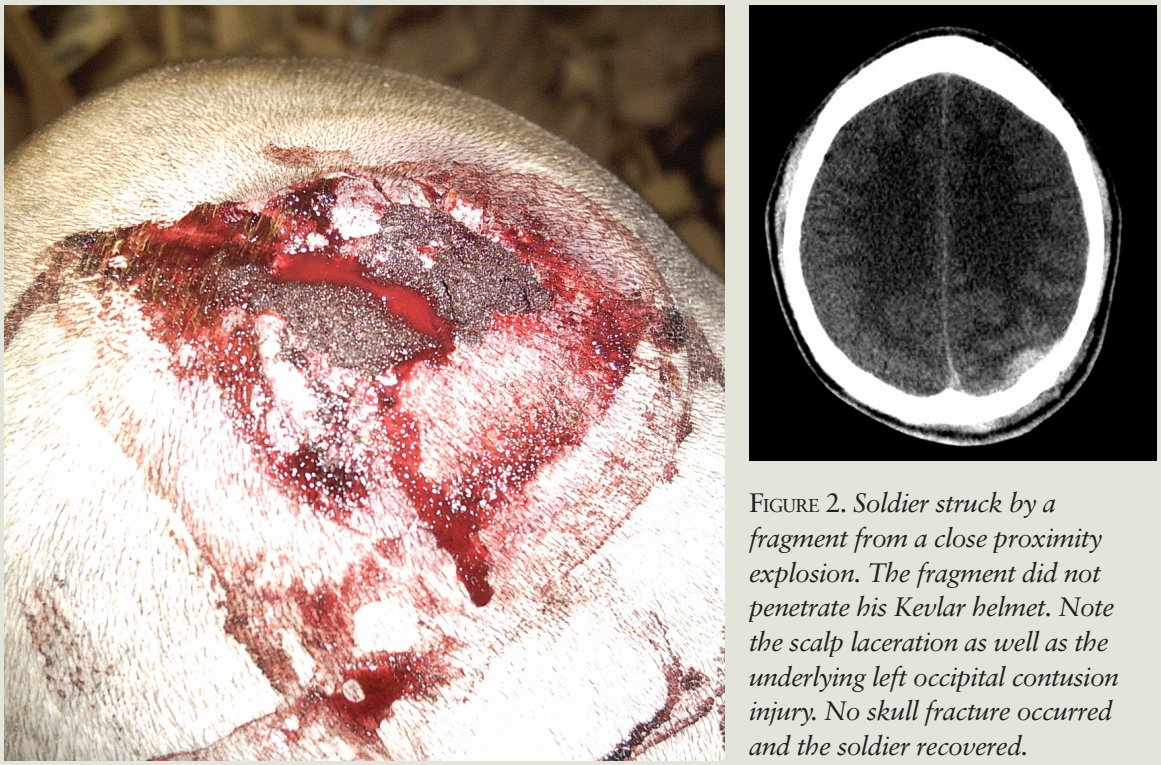

FIGURE 2. *Soldier struck by a fragment from a close proximity explosion. The fragment did not penetrate his Kevlar helmet. Note the scalp laceration as well as the underlying left occipital contusion injury. No skull fracture occurred and the soldier recovered.*

Energy transfer with resulting body wall deformation and visceral conduction can produce significant injury and death. BABT is a common mechanism of battlefield blunt trauma. Injuries produced by this mechanism include:

- fractures
- pneumothorax
- pulmonary contusion
- cardiac contusion and/or arrhythmia (commotio cordis)
- liver and spleen lacerations
- bowel injury
- traumatic brain injuries.

Invariably, skin abrasions and hematomas are evident at the point of impact (Figs. 1 and 2). Contralateral cutaneous injuries may also be present. Victims of blunt trauma mechanisms in combat must be systematically evaluated according to ATLS (Advanced Trauma Life Support) protocols. In the case of thoracic injuries, chest CT is sensitive and superior to standard chest X-ray in visualizing lung contusion, pneumothorax, and hemothorax.[2]

1. Cannon L. Behind armor blunt trauma—An emerging problem. *J R Army Med Corps*. 2001;147(1):87–96.
2. Trupka A, Waydhas C, et al. Value of thoracic computed tomography in the first assessment of severely injured patients with blunt chest trauma: Results of a prospective study. *J Trauma*. 1997;43(3):405–412.

FIGURE 1. (Top Left)
Patient in OR preoperatively.

FIGURE 2. (Top Right)
Separately resected lobes.

FIGURE 3. (Bottom Right)
Reconstructing the hilar injury with the lobes together.

3. Preserving viable lung tissue is certainly an important aspect of emergent thoracotomy for bleeding. Unfortunately, adequate exposure and control of massive bleeding may require resection of otherwise normal lung. Nonetheless, every effort to preserve undamaged lung should be made.

CLINICAL IMPLICATIONS

1. High-velocity penetrating lung injuries carry a high potential for life-threatening intrathoracic injuries (chest wall, lung, heart, and great vessels), as well as the possibility of peritoneal penetration. If the patient's clinical condition allows, radiological studies with radiopaque markers for the entrance and exit wounds—along with a FAST scan to evaluate for pericardial or intraperitoneal blood—should be performed.
2. If a patient presents without obtainable vital signs with recent signs of life, proceeding with an emergent (in the EMT area) thoracotomy in the combat zone should be considered only under the most favorable circumstances (minimal associated injuries, small penetrating chest injury, few or no other urgent patients, abundant resources, surgeons, and OR availability, to name just a few considerations). In general, such a patient should be triaged as expectant.
3. Patients presenting in shock should be rapidly transported to the OR for urgent thoracotomy. Simultaneous resuscitation while locating and controlling the source of bleeding should occur.

DAMAGE CONTROL

1. On entering the chest, if massive hemorrhage or air leak does not allow for rapid visualization and control of the specific injury, immediately freeing the inferior pulmonary ligament (may be accomplished bluntly) and twisting the lung around the hilum may achieve temporary control. During this time, the surgeon can catch up and

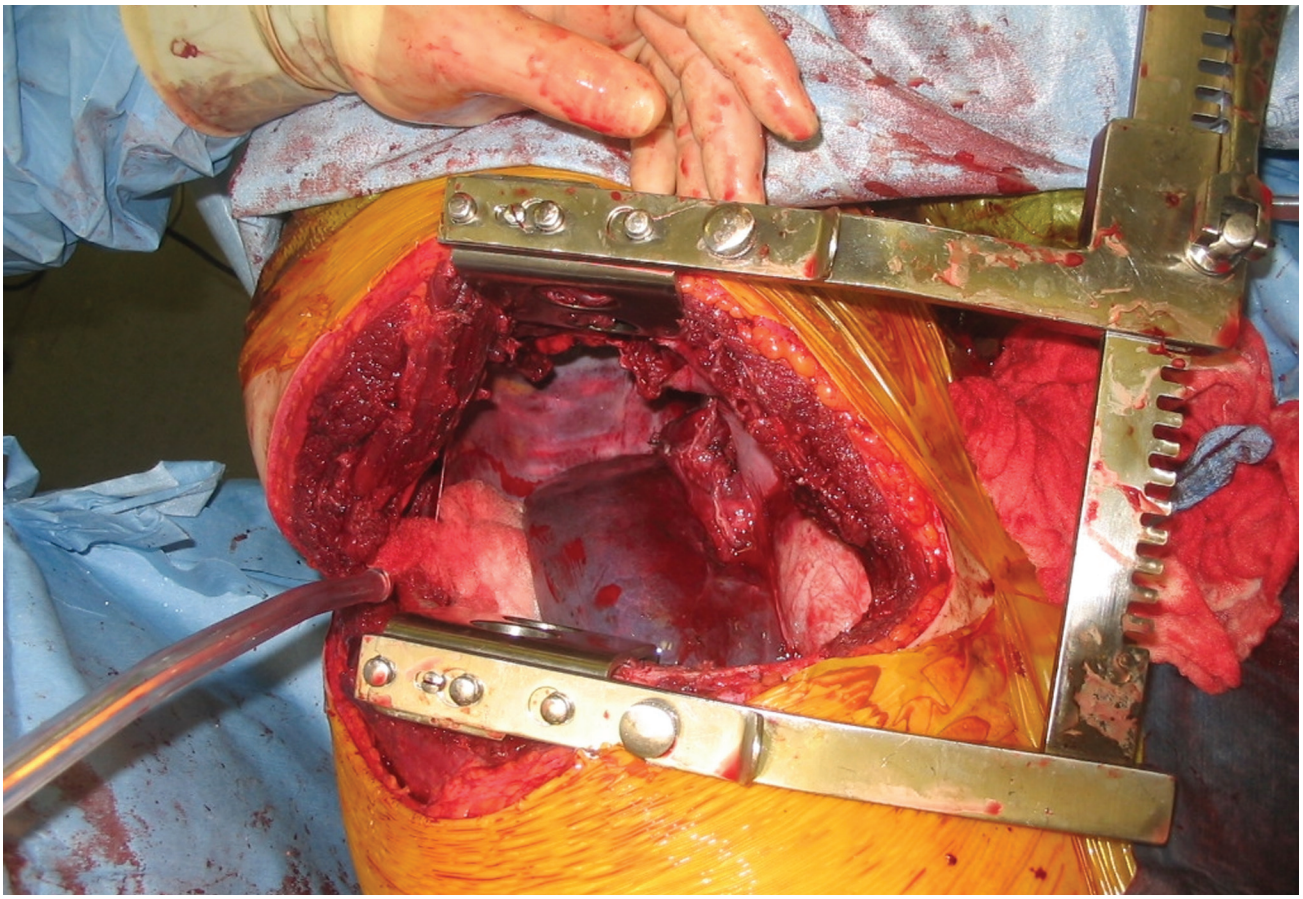

FIGURE 4. *Open right chest with intact lower lobe and stapled upper and middle lobe vessels.*

resuscitate the patient with fluid, blood, and other appropriate products. This may also allow adequate exposure for the surgeon to obtain control of the hilum with a large vascular clamp, ultimately permitting exposure of the injury and appropriate repair.

2. Pneumonectomy for lung injury (specifically for a large hilar injury) should be used only if hilar structures are irreparably damaged or as a procedure of last resort, given the high mortality of this operation.
3. If surgical bleeding is controlled, but the patient has multiple sites of oozing and is slipping toward the lethal triad (hypothermia, coagulopathy, and acidosis), packing the chest and temporary closure (similar to the temporary abdominal closure) should be used until the patient can be adequately resuscitated to allow a return to the OR for definitive repairs.

SUMMARY

High-velocity missiles (bullets and fragments) that pentrate the chest have a high potential for intrathoracic injury that may require urgent thoracotomy and/or laparotomy. Rapid evaluation and assessment of these injuries are essential so that patients will receive the appropriate initial treatment (thoracotomy, laparotomy, and chest tube), resulting in the best possible outcome.

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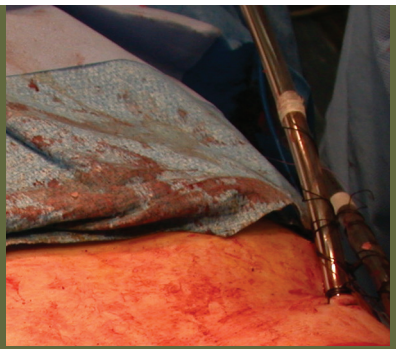

IV.7 Transmediastinal Gunshot Wound

CASE PRESENTATION

A 27-year-old male soldier on routine foot patrol encountered small arms fire. All members of his patrol were wearing torso ballistic protection. The soldier sustained a direct hit to the torso, entering the left chest along the anterior axillary line just above the nipple and eventually exiting the torso through the right midaxillary line at the nipple. The 7.62-mm round was recovered by the treating medic after it exited the right chest. It was not deformed (Fig. 1). Needle chest decompression was performed in the field. Rapid transport from the point of injury to the Forward Surgical Team (FST) was accomplished within 15 minutes. On arrival, the patient was hypotensive, hypoxic, and hypothermic. Bilateral tube thoracostomies were performed, and a large hemopneumothorax (1,500 cc) was evacuated from the left chest. Refractory hypotension continued. A left thoracotomy was performed through the fifth intercostal space revealing a large laceration of the left upper lobe with active hemorrhage from segmental pulmonary vessels that were controlled with tractotomy and ligation. The bullet had traversed the anterior mediastinum. An upper anterior mediastinal hematoma was noted, and extension of the left thoracotomy across the sternum was performed with the intent of exploring the hematoma for major vascular injury (Fig. 2). A proximal injury of the left internal mammary artery/vein and a fracture of the upper sternum were encountered from the round. The left internal mammary vessels were ligated and the sternum fracture packed. The patient was coagulopathic, and the mediastinum was gently packed and the chest covered with Ioban (antimicrobial incise drapes). A whole blood drive was instituted by the co-located battalion aid station personnel, as previously rehearsed. Blood was transfused and the coagulopathy quickly reversed. The patient was transferred to a level III intensive care unit, and further resuscitation was continued. He was reexplored the following morning, and the chest was definitively closed (Fig. 3). The patient remained hemodynamically stable and was evacuated to a combat support hospital (CSH) and eventually to Walter Reed Army Medical Center.

TEACHING POINTS

1. Contemporary management of transmediastinal gunshot wounds remains controversial. Many patients die from major vascular or cardiac injuries as a result of missiles. Those individuals who

Table 1. *Approaches to the Chest*

Exposure	Advantages	Disadvantages
Median sternotomy	Excellent exposure of heart Excellent exposure of great vessels Excellent exposure of pulmonary hilum	Posterior mediastinum difficult to expose May require separate thoracotomy for repair of tracheal or esophageal injuries
"Clamshell" thoracotomy	Excellent exposure of heart Excellent exposure of great vessels Wide exposure of pulmonary hilum, lung, and posterior mediastinum in both thoracic cavities	Exposure to heart and great vessels inferior to median sternotomy Incisional discomfort/morbidity

survive to definitive surgical care in the civilian world and remain hemodynamically stable may undergo a less invasive workup to evaluate these injuries, with definitive care planned based on the findings. Those patients who present hemodynamically unstable require prompt surgical exploration. Injuries to the mediastinum can be explored either via a median sternotomy or "clamshell" thoracotomy. Each procedure has its advantages and disadvantages, and is listed in Table 1. Regardless of the method of exploration, a thorough evaluation of all mediastinal structures (cardiac, vascular, pulmonary hilum, tracheal, and esophageal) is prudent, because any injury left undiscovered may result in death.

2. Detailed data from the US Department of Defense studies outline the basics of wound ballistics. Specific information regarding the particular missile has significant impact on the potential extent of the injury. Missiles with less deformation or yaw in tissue will characteristically produce less cavitation and smaller wound cavities independent of the tissue encountered, but with greater tissue penetration. However, specific tissues are more prone to the transfer of kinetic energy (eg, the heart and great vessels) relative to tissues less prone (eg, lung). In this case, the wound cavity was relatively small and required pulmonary tractotomy to control hemorrhage, but the resulting transgression across the mediastinum put the heart and great vessels at significant risk from both the primary and secondary ballistic cavities produced. Exploration was warranted to rule out injury despite the projected path of the bullet.
3. In this case, utilization of whole blood was critical in rapidly correcting the patient's coagulopathy. Prior instruction of and rehearsal by the co-located battalion aid station personnel allowed surgical personnel to dedicate themselves wholly

Figure 1. *A 7.62-mm round that caused the injury in this case.*

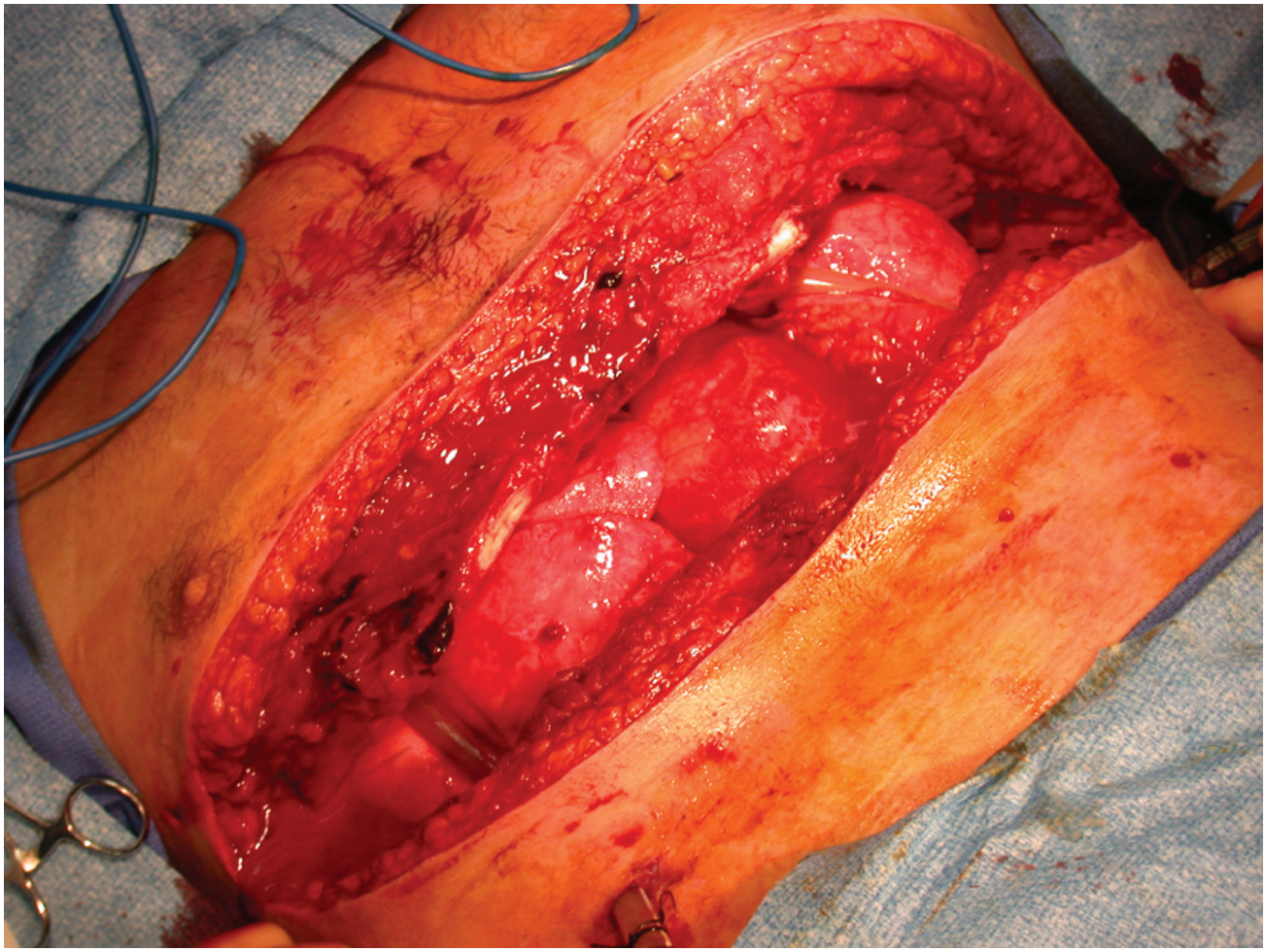

FIGURE 2. (Top) *Mediastinum exposed after transfer incision and sternotomy.*

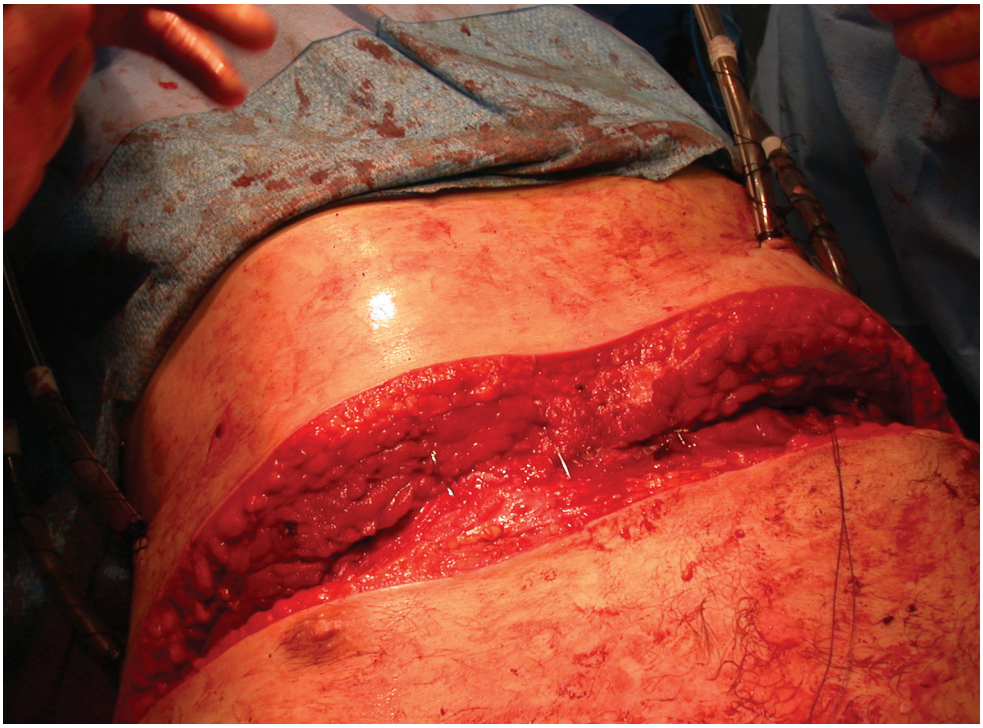

FIGURE 3. (Bottom) *Definitive closure of the chest.*

to the care of the patient, allowing the blood drive to function independently of the surgical staff.

CLINICAL IMPLICATIONS

1. Transthoracic missile injuries are often catastrophic. Acute intervention and management of penetrating thoracic trauma require the surgeon to anticipate a spectrum of injuries that includes the following:

    a. Thoracic vascular injuries.
    b. Pulmonary tractotomy and control of pulmonary hemorrhage.
    c. Pulmonary hilar injuries.
    d. Thoracic aerodigestive injuries.
    e. Penetrating cardiac injuries.

2. Exposure of these injuries necessarily defers to surgeon preference, but should incorporate some knowledge of the ballistics, as well as the potential injuries caused by these missiles.

DAMAGE CONTROL

Damage control procedures are less well tolerated in the thoracic cavity because of restrictions on pulmonary and vascular dynamics. Chest wall bleeding can be managed with packing and expected reexploration, but careful awareness of the effects of packing on hemodynamics, pulmonary compliance, and ventilation must be weighed carefully.

SUMMARY

Survival of transmediastinal ballistic injuries to a surgical facility is rare, and survival following exploration has high mortality and high morbidity rates. Battlefield environments do not allow complex diagnostic workups prior to exploration. In this case, the patient underwent acute aggressive intervention with a successful outcome.

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COMMENTARY

Approaches to the Chest Cavity

by MAJ Charles R. Mulligan, MD

The key to managing chest trauma is knowing when, and when not, to operate. An incorrect decision can lead to increased morbidity and/or mortality. Unlike civilian chest trauma, military chest trauma tends to involve more penetrating injuries. The principles of management are quite similar. A properly placed chest tube is sufficient to treat the majority of chest wounds encountered (70%–80%). Indications for early thoracotomy include chest tube output greater than 1,500 cc at initial placement, or more than 200 cc/hr for four consecutive hours, open sucking chest wound, and retained hemothorax. Other indications for thoracotomy include postcontusion infection, empyema, and bronchopleural fistula. Indications for emergency room thoracotomy include penetrating chest injuries with hemodynamic instability or collapse and nonthoracic penetrating trauma with witnessed cardiovascular collapse (resuscitative thoracotomy).

The military surgeon should be familiar with a variety of approaches to the chest cavity. The key to success is using the incision that best gets you quickly to the problem. Adequate exposure is critical, and wider tends to be better ("high, wide, and handsome"). A thorough knowledge of thoracic anatomy is critical to success.

The quickest access into the chest is through an anterolateral thoracotomy. This can be accomplished in seconds with just a scalpel. The left anterior approach provides access to the pericardium, descending aorta, proximal left subclavian artery, and the left pulmonary hilum. The right anterior approach provides access to the right pulmonary hilum and the pericardium (not as well as the left-side approach). The pitfall of this method is that it provides a less-than-ideal approach to medial-posterior parenchyma lung injuries.

A clamshell incision (bilateral anterior lateral thoracotomies with a transverse sternotomy) improves exposure to the entire pericardium and heart, as well as the thoracic inlet. It also provides quick access to the right atrial appendage following pericardiotomy for vascular access if needed during emergency resuscitations. It can be used for transmediastinal wounds that require bilateral chest cavity exploration. The disadvantage is poor access to the esophagus and posterior trachea.

Median sternotomy also provides access to the pericardium, heart, thoracic inlet, and both lungs. In skilled hands, using a sternal saw, it can be done rapidly. However, most Forward Surgical Teams (FSTs) do not have power saws, and median sternotomy using a Lebsche knife is slower. Sternotomy provides limited access to the left lower lobe, which is obscured by the heart. Left lower lobe exposure can be improved if the sternotomy is extended into the left anterior lateral chest along the submammary crease (hemiclamshell or sternothoracotomy). This also improves access to the proximal left subclavian artery and the descending aorta. Additional versatility of the incision can be obtained by extending the incision along the anterior border of the sternocleidomastoid or via a supraclavicular extension, thus providing more exposure to the subclavian and carotid vessels. The trapdoor incision (sternothoracotomy with supraclavicular extension) provides excellent exposure to the thoracic inlet. However, it limits simultaneous access to the axillary artery.

The posterolateral thoracotomy is the standard access recommended for unilateral isolated chest trauma requiring surgery. It provides the best view of the entire lung and chest wall, as well as the intrathoracic esophagus and the carina from the right. The patient is placed in the lateral decubitus position with the down leg flexed and

the upper leg extended with pillows between the legs. For maximum exposure, one lung ventilation (lung isolation) is preferred, but it is not always practical in trauma. Lung isolation gives the surgeon a quiescent lung to work on; but, more importantly, it protects the uninjured lung from soilage. The incision should be as large as required to see the injuries. Entering the chest through the fifth intercostal space centers the surgeon on the major fissure, but entry can and should be tailored to the wounds/injuries expected. Widely open the interspace to provide optimum exposure. If parenchyma bleeding is the major issue or if there is a large contusion, isolate the hilum as quickly as possible to prevent soilage and air embolus and to provide hemorrhage control so that the injury can be completely evaluated and addressed. This can be done easily by placing a hand around the hilum and guiding an aortic cross-clamp or large DeBakey vascular clamp around all the structures. A hilar twist is an alternative method of control. The pulmonary vasculature is a low-pressure system and can be easily controlled with direct pressure, which is done ideally with a broad-based sponge stick with just enough pressure to stop the bleeding.

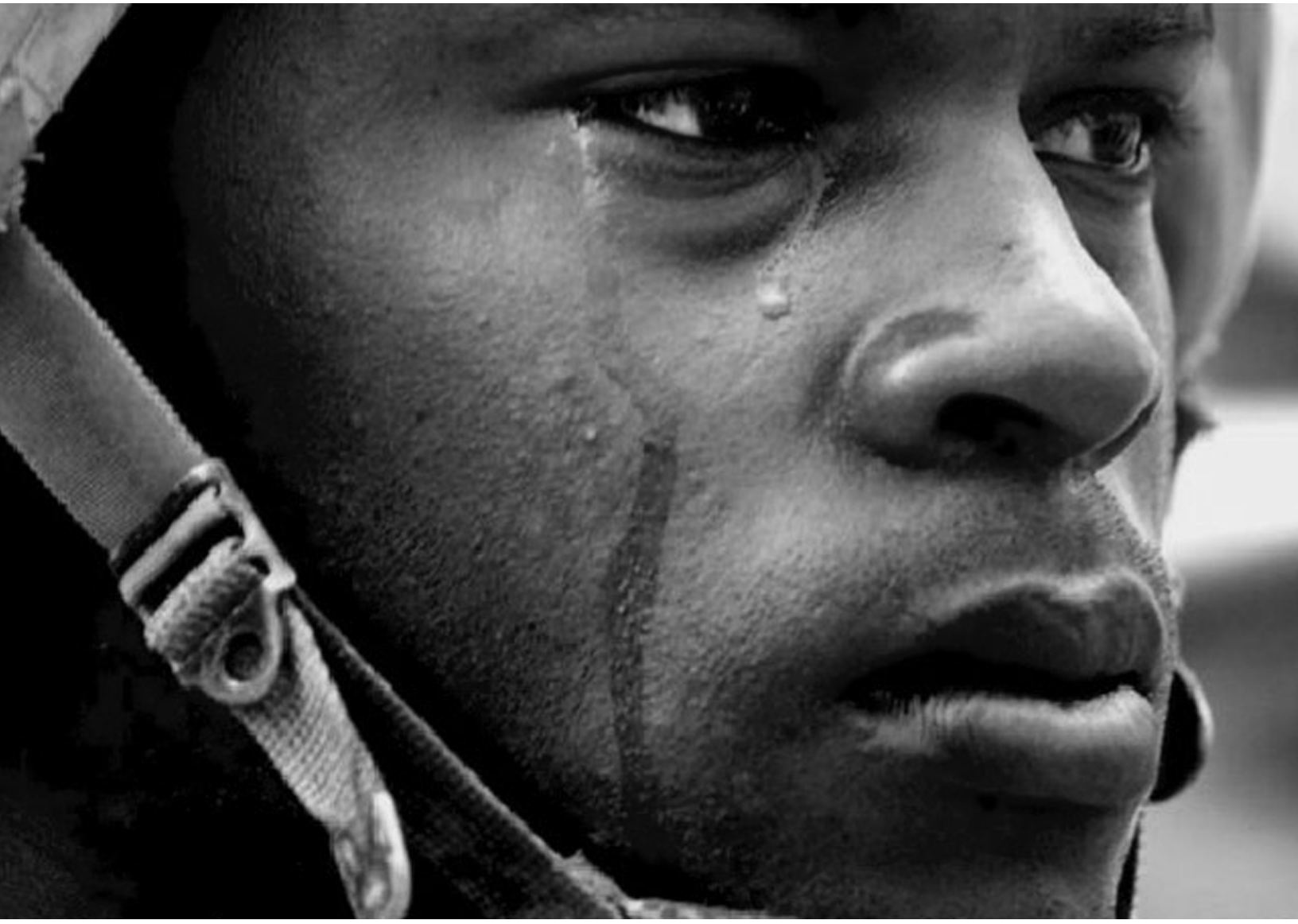
In managing parenchyma lung injury, the goal is to limit removal of viable lung and control bleeding. The injury is either bleeding or not. Within the lung parenchyma, expanding hematomas do not occur because the pleura prevents expansion with a resultant contusion. Pulmonary contusions are not acutely managed operatively.

Most penetrating lung parenchymal injuries can be managed by tractotomy or wedge resection of a peripheral tract. However, if the tract traverses the fissure, the surgeon should suspect a pulmonary artery injury, and a lobar or greater resection may be required to control the hemorrhage.

Once bleeding is controlled, the surgeon must next control the postoperative pleural space. Placement of both apical straight anterior and posterior tubes is recommended. This provides more pleural coverage than a single apical and basilar right-angle tube. It also provides better pneumostasis. A poorly controlled pleural space leads to increased morbidity.

Thoracoabdominal wounds provide a greater quandary to the military surgeon. Projectile tract and potential organs injured should dictate operative incisions. Midline laparotomy incision is usually satisfactory for most of these wounds; but, if primary liver and upper abdominal injuries are suspected, a chevron incision may be considered. The chest component of most of these wounds can be generally attended with well-placed tubes. However, if necessary, either of these incisions can be extended with a sternotomy or an anterolateral thoracotomy, which provides optimum exposure. Do not fear going across the costochondral junction or extending it down through the diaphragm. The military surgeon should be familiar with the location of the phrenic nerve and what are safe incisions to prevent its injury. The costochondral juncture is easily repaired with no. 2 VICRYL in U-stitch fashion after diaphragm closure.

The proper approach to thoracic injury varies, depending on the structure injured. Under the best of circumstances, preoperative determination of thoracic injuries is difficult. In the combat environment, the surgeon will be required often to enter the chest using clinical judgment alone. The usual indication for entering the chest will be massive hemorrhage. There is no cookbook answer to what is the right incision in this circumstance, and the surgeon should not hesitate to make a second or even third incision if required to expose the damaged structure quickly, allowing control of hemorrhage. Knowledge of three-dimensional anatomy of the thorax will serve the combat surgeon well under these circumstances.



Courtesy David Leeson, *The Dallas Morning News*