Chapter 20

ABDOMINAL INJURIES

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INTRODUCTION

Abdominal trauma is a frequent indication for surgical exploration of the battlefield casualty. During one 16-month period (1966–1967) of the Vietnam War, 17,726 wounded American soldiers were admitted to U.S. Army hospitals in Vietnam. More than 70% of these injuries were due to small arms, mines, artillery, or mortar fire. Approximately 14% of these soldiers had abdominal wounds, which were frequently associated with wounds to the head, chest, or extremities. One authority[1] found that during the Vietnam War, hospital mortality was 4.5% in 2,454 casualties with abdominal wounds, which compares favorably with mortality rates of 21% in World War II and 12% in the Korean War. This reduction in mortality from abdominal wounds is due to many factors, but undoubtedly reflects the availability of rapid helicopter evacuation, improved understanding of the pathophysiology and treatment of hemorrhagic shock, improved antibiotic therapy, improved surgical technique, and the availability of trained anesthesia personnel.

ABDOMINAL TRAUMA AND WAR SURGERY

Battlefield casualties with abdominal trauma who reach the hospital level alive fall into two broad categories: (1) a smaller group, who have life-threatening, exsanguinating hemorrhage; and (2) a larger group, who are at risk of dying from sepsis due to intestinal spillage. The former group will frequently require urgent, if not emergent, surgery because of the high potential for death; medical personnel can take the time to perform thorough preoperative resuscitations and evaluations with the latter group. Israeli military surgeons made use of this distinction to treat abdominal casualties during the 1967 Yom Kippur War. Of 151 casualties who ultimately required a laparotomy, 30 who were in shock on arrival at the main field surgical hospital in the Sinai underwent immediate operation. The remaining 121 casualties, all of whom were hemodynamically stable, were given intravenous fluids and antibiotics and then evacuated by air to Israel for laparotomy. Mortality in the group who were operated on in the field was 20%, compared with 5% for those who were operated on in Israel.[2] By deploying far forward only enough medical assets to treat the nontransportable casualties, the Israeli army's medical commanders markedly simplified the logistics of medical support.

If they recognize that most casualties do not require immediate operation, medical officers can avoid hurried preoperative evaluations, which may overlook subtle findings indicative of serious internal injury. Thus, it is important to remember that apparent chest wounds may penetrate the abdominal cavity[3] and abdominal wounds may extend into the thoracic cavity (Figure 20-1). Close attention must be paid to unexplained hypotension in the apparently volume-resuscitated soldier undergoing thoracotomy, as it may reflect undiagnosed intraabdominal hemorrhage. Similarly, an exploratory laparotomy for an abdominal wound may be suddenly accompanied by wheezing, increased airway pressure, and arterial oxygen desaturation indicative of undiagnosed pneumothorax.

Myocardial laceration and cardiac tamponade may also be associated with abdominal wounds.

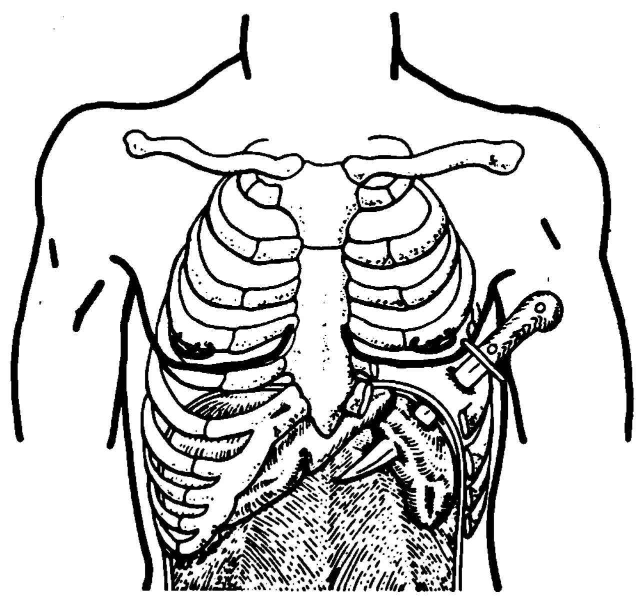


Fig. 20-1. Penetrating wounds to the chest may cause serious injury to organs below the diaphragm, resulting in a source of hemorrhagic shock not immediately apparent during thoracotomy. Penetrating abdominal wounds may similarly enter the thoracic cavity through small diaphragmatic perforations not readily seen during exploratory laparotomy.

The abdominal cavity is large and easily distended.[4] It may contain large quantities of blood with no readily apparent increase in circumference (Figure 20-2). A pelvic or retroperitoneal hematoma may also hold several liters of blood. Retroperitoneal and pelvic hemorrhage may not be immediately apparent during exploratory laparotomy, and should be considered when hypotension persists after volume resuscitation. Another potential cause of refractory hypotension is spinal shock: this diagnosis is suggested when hypotension is accompanied by bradycardia, strong pulses, and warm extremities in the presence of hemiplegia or quadriplegia.

Wound Ballistics

The intraabdominal organs can be injured by three mechanisms:

1. direct cutting and laceration, which are caused by a penetrating projectile;
2. radial stretching and displacement, which are caused by a penetrating projectile and are the result of cavitation within the organ; and
3. crushing, which is caused by blast or blunt trauma.

Most abdominal trauma in combat casualties is caused by penetrating projectiles. Penetrating injuries that enter the peritoneal cavity may require immediate exploration because of exsanguinating hemorrhage. The path followed by a projectile once it enters the abdomen generally follows a straight line, but injury involving multiple organs is common.

Projectiles with high kinetic energy can cause devastating injuries by the process of temporary cavitation (ie, stretch). Tissues around the wound tract are thrown aside with great force; the resultant radial stretching and displacement can cause gross disruption. Solid, friable organs such as the liver, kidney, and spleen are especially susceptible to injury by this mechanism (Figure 20-3).[5] Hollow organs such as the stomach, bowel, and bladder are resilient and resist temporary cavitation if empty but may be severely disrupted if distended with fluid at the time of injury. Muscle withstands temporary cavitation with little permanent effect. As might be expected, bone—markedly inelastic compared with muscle—may fracture when subjected

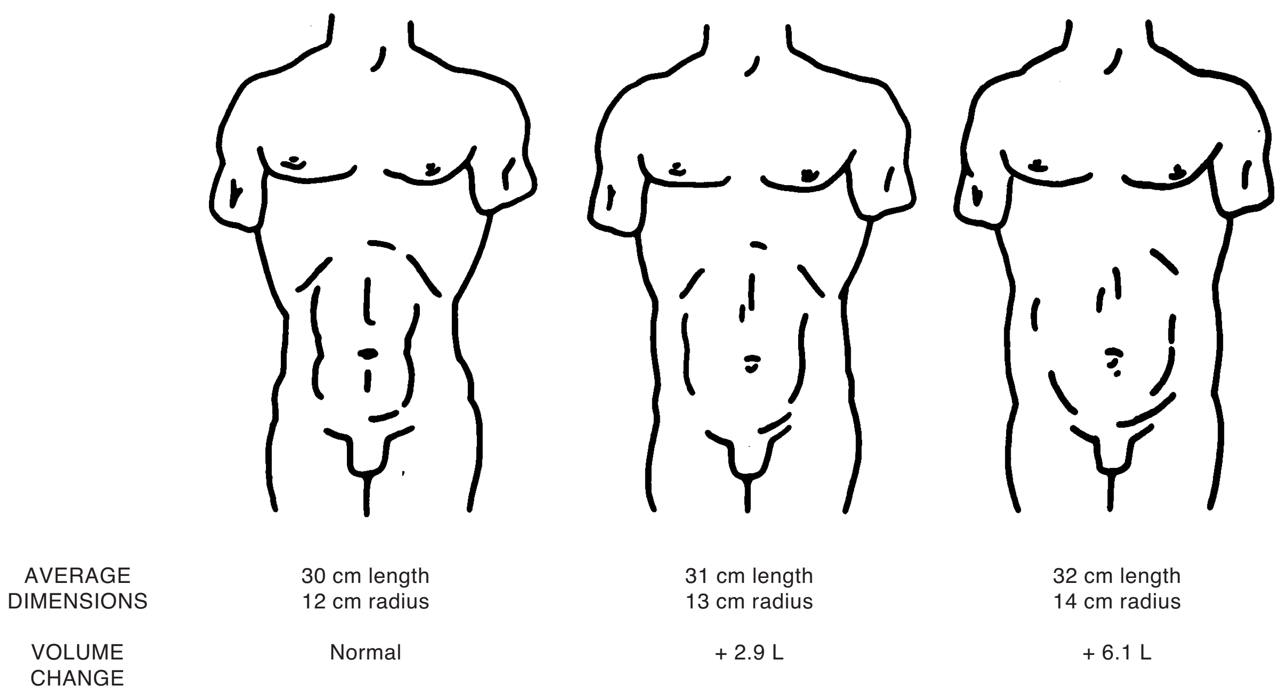


Fig. 20-2. The readily distensible abdominal cavity may hold large quantities of blood with minimal enlargement. Adapted from Trunkey DD, Sheldon PF, Collins JA. The treatment of shock. In: Zuidemia PD, Rutherford RB, Ballinger WF, eds. *The Management of Trauma*. 4th ed. Philadelphia, Pa: WB Saunders; 1985: 107.

Fig. 20-3. An anesthetized swine was shot in the upper abdomen from a distance of 3 m with a Russian AK74 (5.45 mm). Massive disruption and laceration of the liver can be seen. The recovered, fired bullet was placed in the center of the disrupted liver for comparison. Reprinted from Fackler ML, Surinchak JS, Malinowski JA, Bowen RE. Wounding potential of the Russian AK-74 assault rifle. *J Trauma*. 1984;24(3):265.

to cavitation. (Weapons, the mechanisms of injury to bone and soft tissue, the behavior of projectiles in tissue, and cavitation phenomena are discussed in *Conventional Warfare: Ballistic, Blast, and Burn Injuries*, a volume in the *Textbook of Military Medicine* series.)[6]

The magnitude of temporary cavitation is greatly increased by certain features of bullet construction: fragmentation, as exemplified by rounds that are fired by the M16 series of assault rifles; deformation, as is common with soft-point or hollow-nose bullets; and the bullet's *yaw* and *tumbling*, which are related to the location of the bullet's center of mass and the rate of spin imparted by the rifling.[7]

Small, low-velocity fragments, in contrast to bullets fired by military small arms, do not produce damage by cavitation. The clinical corollary of this difference in behavior is that damage at a distance from the wound path is to be expected with cavitating bullets but not with certain fragments or knives. This is one of the reasons that some intraabdominal knife wounds do not require surgical intervention.[8,9]

Diagnosis

The diagnosis of penetrating abdominal trauma in combat casualties is quite straightforward, being made by the presence of one or more holes in the trunk. One of the principles of military surgery is that a laparotomy be performed whenever a penetrating projectile wound of the abdomen is found. However, a hole in the abdominal wall is not necessarily synonymous with an intraabdominal injury, and this principle—*always* operate—leads to the occasional laparotomy that finds no evidence of intraabdominal injury. The expected incidence is approximately 20%.[1]

Because solid organs such as the liver, spleen, and kidney are less able to dissipate kinetic energy (ie, they are displaced and distorted) and maintain their structural integrity, it is therefore not surprising that these organs are primary targets of injury in blunt trauma.[10–12] The decision to operate following blunt trauma is frequently based on the results of diagnostic peritoneal lavage (DPL).[13] An infraumbilical incision is made after local anesthesia is obtained, and 1 L of saline is introduced into the abdominal cavity through a catheter. The saline is then siphoned off. The following are indications for exploratory laparotomy:

- gross blood or enteric contents in the effluent,
- a red blood cell count greater than 100,000/mm^3,
- a white blood cell count greater than 500/mm^3,
- alkaline phosphatase greater than 3 international units,
- amylase greater than 20 international units, or
- bile or bacteria in the effluent.

However, a computed tomography scan may be needed for the preoperative diagnosis of retroperitoneal hematoma secondary to traumatic rupture of the aorta or vena cava. In general, the sensitivity, specificity, and predictive value of DPL is high in both blunt and penetrating trauma.[14] Computerized tomography complements the examination when DPL is equivocal. Magnetic resonance imaging is highly accurate in defining tissue disruption but is very time consuming; thus, it is impractical in both the acute trauma setting[15] and in third-echelon surgical hospitals, as such equipment is not yet fieldable.

Intraoperative Blood Salvage

Blood loss in combat casualties with intraabdominal trauma may be substantial. Data collected during the Vietnam War indicate that approximately 37% of casualties with abdominal wounds required blood transfusion, and the average amount of blood administered was 8.9 units.[16] In view of the extensive logistical demands posed by the transfusion requirements, an approach using interoperative blood salvage is clearly desirable. Equipment for intraoperative blood salvage is now available in some field hospitals and should be a valuable means of reducing the need for homologous blood transfusion. A typical blood-salvaging device includes a double-lumen tube that permits heparin to be added to the blood as it is aspirated. The blood is then pumped into a bowl, where it is washed with saline and then centrifuged. The wash solution contains surgical debris, white blood cells, platelets, and clotting factors; it is discarded. Intact red blood cells are concentrated to approximately 70% for transfusion. A dedicated operator is required to assemble the apparatus, select cycling parameters, match the rate of heparin flow to the rate of blood aspiration, and change solutions and waste collection bags. It is unlikely that a single anesthetist involved in the resuscitation of a hemorrhaging soldier will have the freedom from direct patient care needed to fulfill this role; therefore, someone other than an anesthesia provider will have to perform this procedure in field hospitals.

Intraoperative autotransfusion has been used effectively in open heart, vascular, orthopedic, and transplantation surgery.[17] Its use in trauma surgery has been limited.[18] The potential for intestinal soilage of free intraabdominal blood is the particular concern in abdominal surgery. Although the wash cycle removes many bacteria, significant numbers of anaerobes remain.[19] Nevertheless, in the presence of life-threatening hemorrhage, blood that was contaminated with intestinal contents, urine, and bile has been reinfused.[20] In deciding whether to reinfuse contaminated blood, trauma anesthesiologists must consider the source of the blood (small intestine vs. colon), the quantity of contamination, and the urgency of transfusion. Similar concerns arise when the wound has been irrigated with Betadine Solution (povidone-iodine, manufactured by Purdue Frederick, Norwalk, Conn.), antibiotics, or any other substance not appropriate for intravenous use.

PERIOPERATIVE CONSIDERATIONS

Once the decision is made to perform a laparotomy, the most important consideration regarding the casualty is whether there are injuries to other body parts that will be treated simultaneously by multiple operating teams. After this determination has been made, the following interventions must be considered.

Antibiotics

The military trauma anesthesiologist must ensure that the combat casualty with a penetrating intraabdominal injury receives antibiotics as soon as possible. In the past, appropriate therapy consisted of an aminoglycoside for Gram-negative coverage and one or two additional drugs to combat Gram-positive and anaerobic organisms. However, because of potential nephrotoxicity from aminoglycoside, interest has been shown in developing single-drug regimens, usually employing a semisynthetic penicillin or cephalosporin, to be administered to patients with penetrating abdominal trauma. No difference in the rate of infectious complications was found in one study in which a conventional regimen (clindamycin 600 mg, administered every 6 h, and gentamicin 80 mg, administered every 8 h, adjusted for body size and renal function) was compared to single-drug treatment using the semisynthetic penicillin mezlocillin (Mezlin, manufactured by Miles Pharmaceutical, West Haven, Conn.), given intravenously at a dose of 4 g every 6 hours.[21] Likewise, a meta-analysis in which aminoglycoside combinations were compared with single β-lactam antimicrobials showed no difference between the two therapies.[22] Military trauma anesthesiologists who are assigned to deployable hospitals should ascertain which available antibiotics are usable as single-drug prophylaxis in casualties who have penetrating abdominal trauma.

Intravenous Access

Perioperative considerations for the soldier with abdominal trauma are similar to those for any other type of trauma. Foremost is the need for adequate intravenous access. Multiunit transfusions are common; replacement of two to three blood volumes during the initial resuscitation is expected in 2% to 3% of patients.[1,23] Adequate intravenous access is thus imperative. During the Vietnam War, saphenous cutdowns were performed and intravenous tubing was sutured directly into the vein, permitting very high rates of flow.[24] Subclavian and internal jugular venous access has also found recent utility.[25] With these options available, little time should be spent searching for peripheral access in a patient with extreme vasoconstriction secondary to hemorrhagic shock.

Coexisting Disease and Monitoring

Unlike their civilian counterparts, the victims of battlefield trauma usually have no underlying disease. Although it is beneficial in hemorrhagic shock, invasive monitoring of arterial and central venous pressure contributes little to the eventual outcome of soldiers undergoing resuscitation and massive transfusion. Clinical signs of capillary perfusion, jugular distension, the quality of the pulse, urinary output, and the requirement for anesthetics are excellent indices of the adequacy of volume resuscitation of young, healthy soldiers.[26] If sufficient personnel and equipment are available, invasive monitoring is not contraindicated if it does not delay control of hemorrhage.

Induction of Anesthesia

Wounded soldiers with abdominal trauma may be intubated awake or with a rapid-sequence induction. In wartime, the rapid sequence is frequently performed—not because it is superior but because of the high demand for rapid turnover of the operating room. Either ketamine or sodium thiopental may be used for induction, but *using a dosage appropriate to the patient's condition* is of more importance than the particular anesthetic selected. A moribund patient requires no anesthetic, just succinylcholine to ensure muscle relaxation prior to intubation. An alert patient with a profound volume deficit requires correspondingly less anesthetic than an volume-replete patient. As little as 0.25 mg of ketamine or sodium thiopental per kilogram of body weight may be all that is necessary to produce unconsciousness in the hypovolemic patient. There are two reasons for this:

1. The anesthetic is diluted in a smaller total blood volume.
2. In the hypovolemic state, a much larger proportion of the cardiac output is delivered to the brain and heart.

Both these factors produce a higher content of anesthetic in these organs than might be expected from the reduced cardiac output characteristic of shock. The key to the successful anesthetic management of the trauma patient is the use of *reduced and fractionated dosages* of any medication given.

Maintenance of Anesthesia

Maintenance of anesthesia may consist of (*a*) continued incremental dosages of ketamine, (*b*) small dosages of narcotics, and (*c*) benzodiazepines or potent inhalational agents, as tolerated. The requirement for potent inhalational agents for nontraumatized euvolemic patients is usually described in terms of the minimal alveolar concentration (MAC), which prevents purposeful movement in response to a surgical stimulus in 50% of the patient population tested.[27] Several factors that reduce MAC may be present in the trauma patient, including hypothermia, hypoxia, severe anemia, and hypotension.[28] Hemorrhage ultimately produces all four of these conditions, so it is not surprising that the hemorrhaging patient will require less inhalational agent. The reason for this includes the previously discussed fact that with hemorrhage, a larger proportion of the cardiac output is delivered to the brain and the heart, and so the anesthetic partial pressures in these organs rise quickly. Additionally, blunting of sympathetic tone by anesthetics rapidly manifests as life-threatening hypotension. The trauma anesthesiologist can compensate for these responses by using fractional values of MAC as tolerated by the patient's blood pressure.

However, the tenuous balance between preserving an adequate blood pressure and ensuring anesthesia is difficult to maintain, as fluid and anesthetic requirements fluctuate widely during surgery. Lower partial pressures of anesthetic do not ensure lack of awareness; recall of intraoperative events is not uncommon in the trauma patient.[29]

The anesthetic partial pressure that prevents patient movement is not necessarily the same partial pressure that prevents intraoperative awareness or postoperative recall. For example, in a normovolemic patient, hypnosis is produced by fractions of MAC. The alveolar concentration of anesthetic at the time patients first open their eyes in response to verbal command during recovery from anesthesia is known as *MAC-awake*. For isoflurane, MAC-awake has been reported to be 0.19%, or 15% of MAC.[30] MAC-awake for other inhaled anesthetics has been reported to be 33% to 50% of MAC.[31] Most patients who are maintained on end-tidal concentrations of potent, inhaled anesthetics in this range do not recall intraoperative events. Conversely, there are case reports describing recall with apparent (but not measured) end-tidal concentrations exceeding these values.[32,33] The extent to which hemorrhage reduces MAC-awake has not been determined, but anesthesiologists can take some comfort from knowing that low concentrations of potent inhaled anesthetics produce amnesia in the normovolemic patient.

Nitrous Oxide

The use of nitrous oxide in the battlefield casualty with abdominal trauma deserves special mention. Since World War I, nitrous oxide has been an extremely valuable adjunct to the anesthetic care of the battlefield casualty.[23,25,34,35] Although nitrous oxide is not able to provide a complete anesthetic for the normovolemic patient undergoing elective surgery, it is excellent in preserving cardiovascular stability in many trauma patients. However, even nitrous oxide is not always tolerated by the most seriously wounded.[35]

Nitrous oxide is notorious for producing gaseous distention of the gut in the absence of bowel obstruction, and is therefore clearly contraindicated in the presence of a closed air space (eg, pneumothorax, pneumocephalus, bowel obstruction). That nitrous oxide diffuses into closed spaces more rapidly than relatively insoluble gases (eg, methane, hydrogen, nitrogen) diffuse out is unquestioned. Rather, the argument has been made that these gases are present in the gastrointestinal tract in small volumes and are thus insignificant even if their volume is increased 2- or 3-fold.[36] However, recent studies have demonstrated significant differences in qualitatively assessed gas content of the small and large bowel, and operating conditions of patients given nitrous oxide, compared with air, as part of their anesthetic for bowel surgery (Figure 20-4).[37] Additionally, return of bowel function and duration of hospital stay were shorter for patients not given nitrous oxide. Although not all patients given nitrous oxide had bothersome distention of the bowel by the end of surgery (the average duration of anesthesia was 282 ± 53 min), the evidence clearly favors the use of air rather than

Fig. 20-4. A casualty's small bowel during a laparotomy for a fragment wound of the abdomen. The anesthetist ascribed the distension of the small bowel to the presence of nitrous oxide. Photograph: Swan Vietnam Surgical Slide Collection.

nitrous oxide during bowel surgery of this duration. When considered with the logistical demands of supplying compressed gases in the field environment, it may be that nitrous oxide is best avoided in the battlefield casualty undergoing abdominal surgery. For reasons such as these, nitrous oxide has been deleted from the U.S. Department of Defense's Deployable Medical Systems (DEPMEDS) list.

Positioning for Operation

Because a midline incision is the standard for a laparotomy on combat casualties, the supine position will be needed. Casualties in refractory shock may first be subjected to a thoracotomy, but this will usually be done through an anterolateral incision with the casualty in the supine position. Debridement should be performed prior to laparotomy in hemodynamically stable casualties who have multiple wounds, some of which involve the dorsum of the trunk, or a large wound of exit or entrance posteriorly. Thus, these casualties should initially be placed in either the prone or the lateral decubitus position.

SPECIFIC SITES OF ABDOMINAL INJURY

Data from the Wound Data and Munitions Effectiveness Team (WDMET) database, which was compiled during the Vietnam War, indicate that about 50% of casualties with an abdominal wound who survived long enough to reach a hospital had an injury to a single intraabdominal organ. The most commonly injured organs were large bowel including the rectum in 23% of these casualties, small bowel also in 23%, and liver in 14%. In casualties with injuries to multiple intraabdominal organs, 30% had an injury to two organs, 13% to three, 4% to four, and 3% to five or more organs.[38] The most common combinations in casualties with injuries to multiple organs were small bowel and colon; small bowel and liver; and small bowel, colon, and stomach.

Because casualties with injuries to multiple organs are common, a systematic approach is essential to avoid missing an important site. A wide range of severity will be encountered and the severity influences how the injury is managed. To bring clarity to discussions of abdominal trauma, the severity of injury has been scaled for each organ.[39,40] Although this system of injury severity classification has not yet been applied to combat casualties, military anesthesiologists need to know how to use it. In general, for any given organ, two broad classes of injuries are recognized: *hematoma* (more often than not indicating blunt trauma) and *laceration* (usually indicating penetrating trauma). For each type of injury, five or six grades of severity are recognized and in turn are correlated with the International Classification of Disease (ICD-9) and the Abbreviated Injury Scale (AIS). As an example, the scheme as it applies to the liver is reproduced in Table 20-1. Figure 20-5 shows a casualty from the Vietnam War with a grade III laceration caused by fragments from a Claymore mine.

Retroperitoneal Injuries

The retroperitoneum contains major blood vessels (aorta, inferior vena cava) as well as the kidneys, ureters, pancreas, and duodenum. Any of these sites may be involved in penetrating or blunt trauma if the vector of injury is of significant mag-

TABLE 20-1

CLASSIFICATION OF SEVERITY OF HEPATIC INJURY

Grade*		Injury Description†	ICD-9	AIS 90
I	Hematoma	Subcapsular, nonexpanding, < 10% surface area	864.01 864.11	2
	Laceration	Capsular tear, nonbleeding, < 1 cm parenchymal depth	864.02 864.12	2
II	Hematoma	Subcapsular, nonexpanding; 10%–50% surface area Intraparenchymal, nonexpanding; < 2 cm in diameter	864.01 864.11	2
	Laceration	Capsular tear, active bleeding; 1–3 cm parenchymal depth, < 10 cm in length	864.03 864.13	2
III	Hematoma	Subcapsular, < 50% surface area or expanding Ruptured subcapsular hematoma with active bleeding; Intraparenchymal hematoma > 2 cm or expanding		3
	Laceration	> 3 cm parenchymal depth	864.04 864.14	3
IV	Hematoma	Ruptured intraparenchymal hematoma with active bleeding	864.04	4
	Laceration	Parenchymal disruption involving 25%–50% of hepatic lobe	864.14	4
V	Laceration	Parenchymal disruption involving > 50% of hepatic lobe		5
	Vascular	Juxtahepatic venous injury (ie, retrocaval vena cava/major hepatic vein)		5
VI	Vascular	Hepatic avulsion		6

* Advance one grade for multiple injuries to the same organ
† Based on most accurate assessment at autopsy, laparotomy, or radiological study
ICD-9: International Classification of Disease, 9th revision; AIS 90: Abbreviated Injury Scale, 1990 revision
Adapted with permission from Moore EE, Shackford SR, Pachter HL, et al. Organ injury scaling: Spleen, liver, and kidney. *J Trauma*. 1989;29:1665.

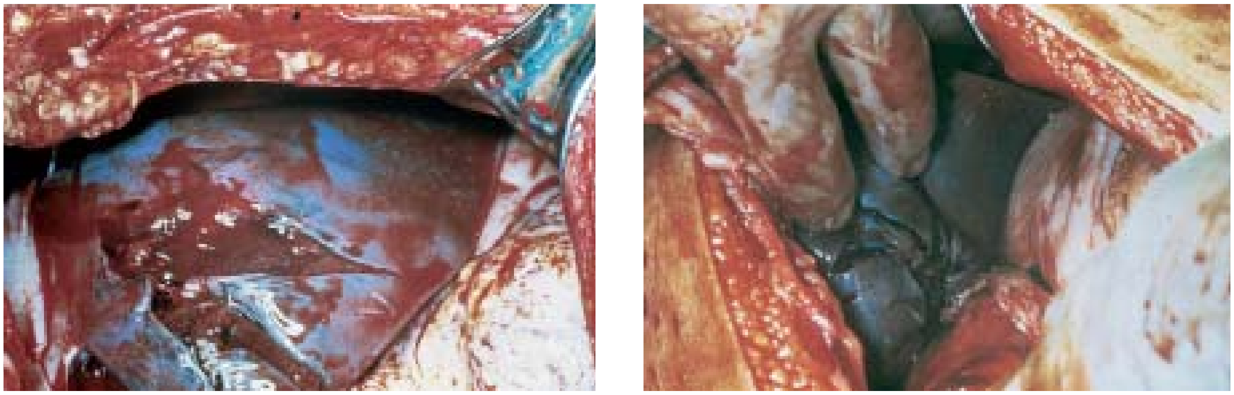
a  b

Fig. 20-5. This injury was caused by a fragment from an exploding munition. (**a**) The wound of entrance is in the dome of the lateral segment of the right lobe of the liver. This is a grade III laceration of the liver. (**b**) The wound of exit is in the *undersurface* of the right lobe of the liver. Photographs: Swan Vietnam Surgical Slide Collection.

nitude and direction. Isolated retroperitoneal injuries from penetrating missiles are unusual, because the missile usually passes from the retroperitoneal space into the abdominal cavity.

To assist in deciding on the optimal intraoperative intervention, it has become customary to divide the retroperitoneum into three zones[41]:

- Zone 1: midline to midclavicular lines (includes the great vessels and most of the duodenum and pancreas);
- Zone 2: from midclavicular lines laterally to the flanks (includes the kidneys); and
- Zone 3: below the iliac crests (includes the iliac vessels).

At the hospital level, Zone 3 injuries are encountered most commonly. Zone 1 injuries are least common, probably because injuries to Zone 1 frequently result in rapid exsanguination. Penetrating injuries are explored regardless of the zone. Blunt trauma involving Zone 1 is always explored, as is an enlarging hematoma in Zone 2. Exploration of a hematoma in Zone 3 should be avoided.

Great Vessels

Analysis of the WDMET database reveals that isolated injuries to the great vessels (the aorta, iliac arteries, and inferior vena cava) account for about one half of all deaths of combat casualties who were killed in action or died of intraabdominal injuries (see Chapter 1, Combat Trauma Overview, for a discussion of the WDMET database).[38] Intraabdominal injuries to the great vessels are very uncommon in combat casualties who survive; for example, there are only eight survivors of intraabdominal aortic injuries in the Vietnam Vascular Registry.[42] Nevertheless, the military anesthesiologist should be prepared for such a contingency. A midline retroperitoneal hematoma may reflect injury to the aorta or vena cava and should be explored. Although arterial injury is associated with more-rapid blood loss, venous injury, which is characterized by low-pressure but high-volume hemorrhage, frequently proves more difficult to control. Furthermore, attempts to define the anatomy of vena caval injury by occlusion may precipitate cardiac arrest in the hypovolemic patient. Atrial–caval or femoral–caval shunts have been suggested (but in fact are rarely employed) to maintain circulation while vascular clamps are applied to isolate the site of hemorrhage, but these techniques have not been demonstrated to improve survival. Injuries to the retroperitoneal vasculature carry a high mortality,[43,44] and lacerations of the retrohepatic vena cava are particularly lethal.[45]

Kidneys, Ureters, and Bladder

The kidneys, ureters, and bladder may be injured directly by projectiles or indirectly by blunt trauma. Blunt trauma, or the cavitary damage accompanying high-energy-transfer projectiles, may produce avulsion of the renal vascular pedicle, fracture of the renal parenchyma, or avulsion or disruption or both of the ureters. The elasticity of the bladder renders it less susceptible to disruption[46] and, more commonly, the injury results from direct cutting by the missile. These injuries may be revealed preoperatively by computed tomography scan, intravenous pyelogram, retrograde pyelogram, ultrasound, or, as is common in combat casualties, may be discovered incidentally during laparotomy.[47] In the latter situation, it is essential that an effort be made to demonstrate the presence of a functioning contralateral kidney before ablative renal surgery is undertaken. One way to do this is to clamp the ureter on the injured side and watch the Foley catheter for 5 minutes to see if urine continues to be formed. Ureteral injuries are difficult to diagnose except by direct visualization at the time of laparotomy.

Relatively minor degrees of renal trauma resulting from blunt trauma are managed nonsurgically. The diagnosis of renal injury associated with penetrating missiles is usually made at the time of laparotomy. Knowing exactly what to do about grade II (< 1-cm parenchymal depth of renal cortex without urinary extravasation) or grade III (> 1-cm parenchymal depth of renal cortex without collecting-system rupture or urinary extravasation) injuries is difficult and controversial. Treatment options are partial nephrectomy, debridement, and suture. Grade IV injuries (laceration extending through the cortex, medulla, and collecting system; or a major renal vessel injury) or grade V injuries (completely shattered kidney) are treated in combat zone hospitals by nephrectomy (Figure 20-6). Renal function declines more in patients who are managed operatively; whether this is due to the effects of surgery itself or the presence of more -underlying tissue destruction is unknown.[48,49]

Injuries to the dome of the bladder are often easy to repair because the remaining wall is usually sufficiently redundant to be closed primarily. Care must be taken to ensure that the ureteral orifices are not compromised during closure of the defect. The bladder is closed over a Foley catheter; ureteral injuries are closed over a ureteral catheter splint. Injuries to the trigone of the bladder that require reconstruction may require reconstruction of both the urethra and the ureteral orifices.

Pancreas and Duodenum

Blunt pancreatic injuries are difficult to detect with peritoneal lavage and may be missed by computed tomography scan. Elevated amylase in the lavage fluid from DPL raises suspicion but is neither sensitive nor specific: the absence of amylase does not exclude significant pancreatic injury, and its presence may only reflect small bowel or urinary tract injury.[50] Serum amylase should be measured serially if the site of injury leads to a suspicion of pancreatic damage. Severe pancreatitis will result if pancreatic enzymes are not contained within the pancreatic ducts, so careful, regular consideration must be given to this diagnosis when the physical examination and test results are equivocal.

Grades I or II pancreatic injuries (laceration without duct injury or tissue loss) resulting from penetrating trauma require only closed-suction drainage. More-severe pancreatic injuries such as a disrupted tail or distal ductal laceration (grade III) may be treated by distal pancreatectomy. Injuries of the head of the pancreas, especially when the ampulla or duodenum are involved (grades IV or V) may be treated with the Whipple procedure (pancreaticoduodenectomy with gastrojejunostomy and Roux-en-Y cholecystojejunostomy and Roux-en-Y pancreaticojejunostomy). Mortality is 30% to 40%.[51] The difficulty, complexity, and time-consuming nature of the Whipple procedure makes it unsuitable for performance in the combat zone except in unusual circumstances.

Isolated duodenal injuries are treated by closure of the defect, sometimes in conjunction with temporary defunctionalization of the duodenum brought about by closure of the pylorus with absorbable suture material. A gastrojejunostomy is constructed to reestablish gastrointestinal continuity. The pyloric suture can be expected to remain intact until the duodenal defect is securely healed. Severe injuries, especially when they involve the head of the pancreas, may require a Whipple procedure; however, an operation of such magnitude may severely disrupt the function of a forward surgical facility and should be performed only as a last resort. Dependent drainage is a necessary part of any duodenal or pancreatic operation.[52] Repeated surgeries are often required for treatment of pancreatic fistulas, abscesses, secondary hemorrhage, and pseudocysts. Catastrophic shock occurs in those few who develop hemorrhagic pancreatitis.

Intraperitoneal Injuries

For military anesthesia providers, the major treatment problems of casualties with abdominal injuries involve the intraabdominal organs, which contaminate the abdomen and give rise to peritonitis. To a lesser extent, hemorrhage is a threat; regrettably, however, most casualties who have significant intraabdominal vascular injuries will have exsanguinated before they reach the hospital. Two

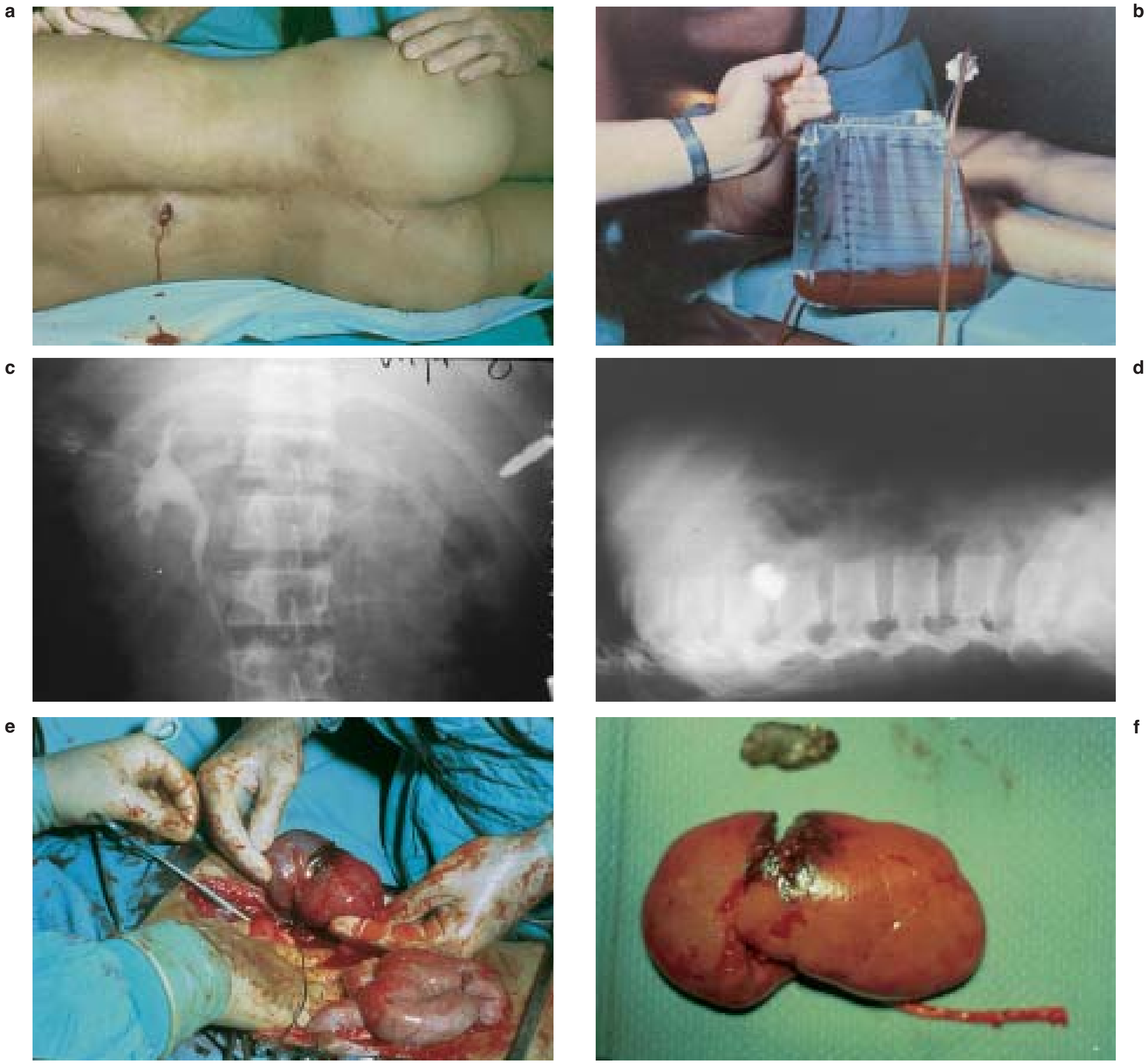


Fig. 20-6. (**a**) This grade IV kidney injury to a casualty during the Vietnam War was caused by a large mortar fragment and was treated by a nephrectomy. The wound of entrance is in the casualty's back. (**b**) Grossly bloody urine was found in the casualty's bladder, indicating a significant injury somewhere in the urinary tract. (**c**) Anteroposterior and (**d**) lateral radiographs taken during an intravenous pyelogram. A large metal fragment is seen in the left upper quadrant of the abdomen. There is no evidence of function by the left kidney. (**e**) The upper pole of the kidney appears cyanotic, a finding indicating a vascular injury. This was the indication for a nephrectomy, which is shown in progress. (**f**) The excised kidney and the fragment that caused the injury. Photographs: Swan Vietnam Surgical Slide Collection.

casualties of the Vietnam War who were seen at the hospital level of care illustrate the ramifications of penetrating abdominal trauma (Figures 20-7 and 20-8). Note that in both casualties, the retroperitoneal component of the injury is the less serious.

Stomach, Small Bowel, and Colon

Injuries to the stomach, small bowel, and colon are accompanied by hemorrhage and peritoneal contamination. Bacterial peritonitis may result from spillage of the stomach contents into the peritoneal

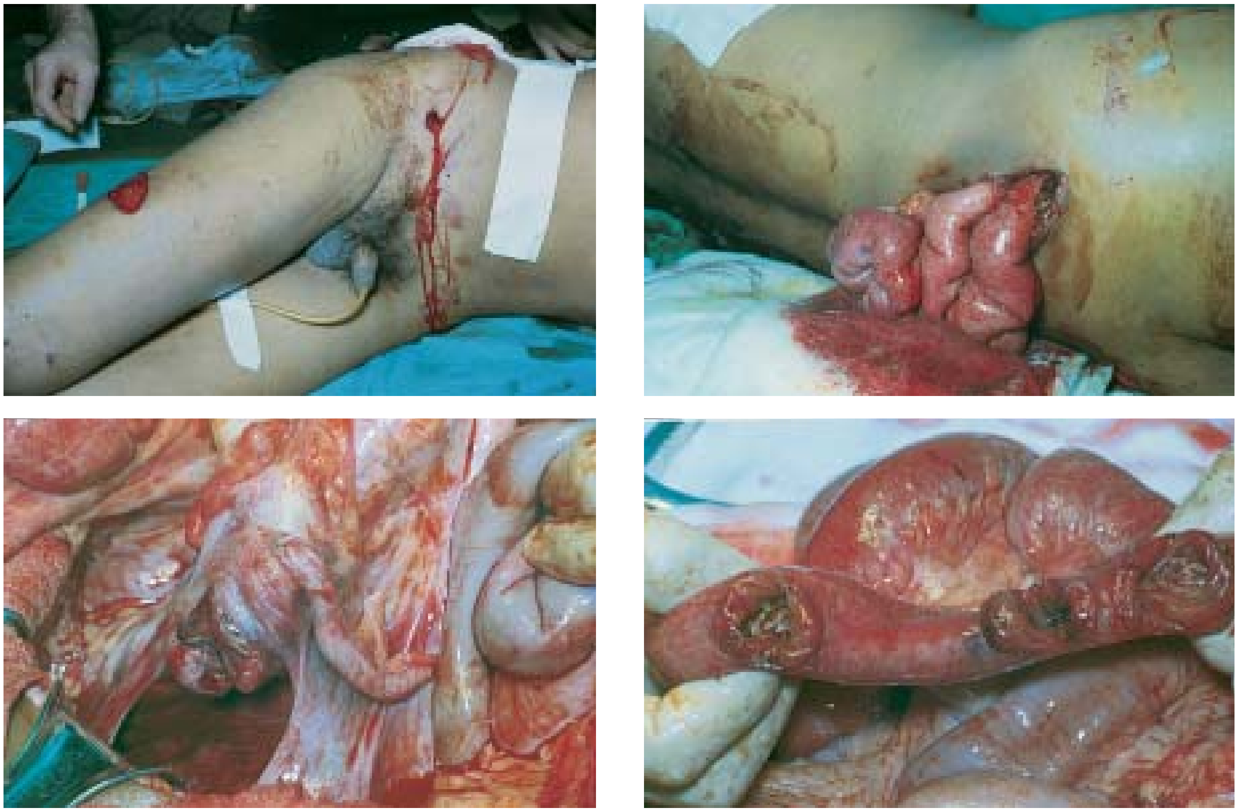


Fig. 20-7. (**a**) This soldier sustained a perforating AK47 (7.62-mm) bullet wound of the inferior portion of the right lower quadrant of his abdomen. The wound of entrance is shown. A second bullet wound in the thigh involved only soft tissue. (**b**) The bullet exited from the flank, causing an evisceration. (**c**) At laparotomy, the tip of the cecum was found to be perforated. The casualty underwent a cecostomy in lieu of an ileotransverse colostomy. (**d**) The casualty's multiple small bowel perforations were treated by small bowel resection and anastomosis. Photographs: Swan Vietnam Surgical Slide Collection.

cavity if a meal has recently been ingested, or, as is common in battle casualties, if stomach emptying is delayed. Salivary flora are ingested during a meal and bacterial counts rise rapidly as stomach acidity is neutralized. As the stomach empties, the hydrogen ion concentration again falls to bactericidal levels, rendering the stomach sterile.[53] Penetrating injury to the stomach is usually managed easily by primary suture. The stomach's good blood supply assures primary healing. With any wound of the

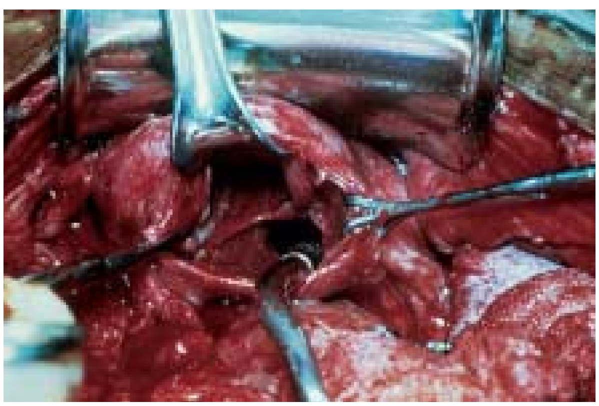
Fig. 20-8. This soldier sustained a perforating AK47 (7.62-mm) bullet wound of the lower abdomen. (**a**) The wound of entrance is seen in the right buttock. Proctoscopy demonstrated blood in the rectum, indicating an injury to the distal large intestine. (**b**) The wound of exit is in the left lower quadrant of the abdomen. The bullet apparently passed posterior to the right iliac vessels and anterior to the left iliac vessels, thereby sparing the casualty from death due to exsanguination. (**c**) The massive small bowel damage can be seen at laparotomy. (**d**) The shredded appearance of this resected specimen of small bowel is probably caused by temporary cavitation, which occurred as the bullet passed through the fluid- and gas-filled viscera. (**e**) The bladder was totally disrupted by the bullet. (**f**) Because of the proximity of the damage to the trigone of the bladder, safe reconstruction of the bladder required catheterization of both ureters and the urethra. The balloon of the urinary catheter is seen in the depth of the wound. (**g**) The rectosigmoid colon has been perforated by the bullet. A totally diverting end colostomy and a mucus fistula are being constructed. (**h**) The casualty is now in the prone position. The perirectal space is exposed for purposes of drainage. Photographs: Swan Vietnam Surgical Slide Collection.

a


b


c


d


e


f


g


h


stomach, it is important to determine whether the projectile continued through the posterior wall into the lesser sac and the retroperitoneum.

The small bowel has a very low bacterial count, but peritonitis will eventually occur as the bacteria proliferate. Grades I and II injuries (partial-thickness and full-thickness wounds involving less than one half the bowel circumference) are managed by primary suture repair of the defect. Grade III injuries (defects of > 50%) and grade IV injuries (transection) are managed by resection and primary anastomosis. Multiple, contiguous grade II injuries are best managed by resection and anastomosis.

Colon wounds are difficult to manage: primary healing of a sutured colon wound, in contrast to a wound of the small bowel, has a disturbingly high rate of failure. The peritoneal cavity is capable of tolerating one episode of exposure to the vast bacterial population that resides in the colon, but continued contamination, as will occur with a suture-line breakdown, is rapidly lethal. The following scenario is much feared by military surgeons: a casualty's colonic wound is primarily repaired in a forward surgical hospital; the wound then dehisces during evacuation; and by the time the casualty reaches the next hospital, he is dying from fulminating peritonitis. To prevent this occurrence, military surgical doctrine dictates that a proximally diverting colostomy be constructed on all casualties with large bowel injuries. This practice is at variance with civilian trauma management, in which primary repair is frequently possible.

In grades I, II, or III colonic injuries, primary repair of the colonic wound may prove possible, but the colostomy will assure that the segment is defunctionalized so that leakage of colonic contents, if it occurs, will be inconsequential. Resection is indicated when the projectile transects the bowel (grade IV) or destroys a segment (grade V). The colon distal to the site of resection is mobilized so that it can be pulled through the abdominal wall as a mucous fistula.

Injuries to the rectum create special problems because of the need to both evacuate all feces from the retained bowel and drain the perirectal space in the perineum. Therefore, the casualty with a rectal wound will have a proximally diverting colostomy, a distal mucous fistula (or a closed intraabdominal segment known as a Hartmann's pouch), and an excised coccyx through which drainage of the perirectal space is established. To accomplish this sequence of procedures, the anesthesiologist must be prepared to turn the casualty from supine to prone.

Liver

Hepatic trauma is commonly encountered in abdominal wounds. Grades I and II injuries are rarely the sole cause of death and require no surgical intervention at the time of laparotomy.[54] Grades III and IV injuries are more difficult to treat: suture ligation of vessels will be necessary to control bleeding. Grade V injuries can be treated by formal right or left hepatic lobectomy, but not only is the mortality of this intervention extremely high (not a single casualty subjected to a right hepatic lobectomy in the Vietnam War is thought to have survived), the demands for blood and blood products will likely exhaust all but the largest blood bank. As an alternative to lobectomy, the practice dating from World War II of tamponading the bleeding liver by packing with large laparotomy pads has been proposed. The pack must be removed within 2 to 4 days.[55] The goal is to remove the packs safely after the casualty has reached a higher-echelon medical treatment facility that is capable of providing care of the needed sophistication.

The overwhelming problems that will encountered by the anesthesiologist caring for a casualty with a grade IV or V liver injury will be massive hemorrhage and its complications (hypothermia, acidosis, hypocalcemia, coagulopathy, and the adult respiratory distress syndrome). Intraoperative hemorrhage in these patients may be controlled by the Pringle maneuver (ie, manual compression of the porta hepatis at the epiploic foramen). If this fails, occlusion of the thoracic aorta or the proximal abdominal aorta may be attempted. The most difficult bleeding to control is from a vascular injury at the junction of the hepatic veins with the inferior vena cava. The problem arises from the fact that exposure of the site of injury is possible only when the inferior vena cava is occluded, but the resulting cessation of venous return usually precipitates a cardiac arrest in the already hypovolemic casualty. In rare circumstances, surgeons have been able to shunt blood from the infrahepatic vena cava to the heart, using a plastic tube with a large tangential port (an endotracheal tube can be so modified) inserted through the right atrial appendix and from there guided into the vena cava below the liver. Tourniquets are then tightened around the supradiaphragmatic and infrahepatic venae cava.[56] By isolating the liver and its blood supply, exposure is facilitated and transfusion requirements are reduced. An extension of the shunt may be passed to the anesthesiologist, who then uses it for transfusion. Blood glucose should be closely monitored, as hypoglycemia is not uncommon. Casualties with grades IV or V liver injuries will frequently need secondary operations for removal of a hepatic pack, further debridement, and drainage of hematomas or abscesses or both.[57]

Spleen

For many years, the spleen was considered to be a vestigial organ of no significance and was treated as such in abdominal trauma. Since the 1950s, however, the spleen has come to be recognized as a key component of the immune system. The risk of early or delayed infection is increased in asplenia. Overwhelming postsplenectomy infection occurs in about 0.6% of children and 0.3% of adults.[58] As a result, in civilian practice, the options for managing splenic injury emphasize conservation whenever possible. The options are (*a*) application of a topical hemostatic agent, (*b*) debridement and suturing, and (*c*) splenectomy, which is reserved as a last resort. Wrapping the spleen with an absorbable mesh bag has proven valuable in treatment of extensive capsular avulsion.[59] Grades I, II, and III injuries (ranging from slight capsular tear to parenchymal laceration not involving the hilum) in blunt trauma have been managed nonoperatively when hemodynamic instability and other organ involvement are absent (in the field, however, this can be established with certainty only at the time of laparotomy).[60]

Although splenic conservation is desirable, such an approach has little merit in the management of combat casualties: the essential condition for its application is time to observe the casualty, and this is precisely what cannot be guaranteed in a combat zone hospital. Furthermore, the specter of delayed hemorrhage during evacuation is too frightening to ignore. Accordingly, splenectomy remains the accepted treatment for combat casualties with all but grade I injuries. As is standard with civilian postoperative management of patients who have had splenectomy, antipneumococcal vaccine should be given, and the casualty should be warned of the possible implications of high fever in association with an infection.

Diaphragm

The diaphragm may be ruptured in blunt trauma or perforated in penetrating trauma. In either case, intraabdominal organs may herniate through the diaphragm and produce respiratory embarrassment or organ strangulation. Unless the diaphragm is carefully inspected at the time of laparotomy, a perforation can be missed until clinical symptoms or an abnormal chest radiograph provoke further study.[61–63] Even a small perforation needs to be closed because the defect will gradually enlarge and become the site of a potentialy fatal herniation. Holes in the diaphragm can also create problems for the anesthesiologist during the operation because air can pass from the open abdomen into the chest, creating a pneumothorax. A chest tube placed preoperatively will prevent this condition; however, the surgical team must remember that a missile wound in the area of the costal margin may first have passed through the pleural space and diaphragm before entering the abdomen.

The advent of endoscopic laparotomy is certainly the most significant development in modern gastrointestinal surgery, but the practicality of laparoscopy as a therapeutic modality for treating typical combat injuries in deployed hospitals is unclear. Both endoscopic thoracoscopy and laparoscopy in a diagnostic mode have been used to demonstrate penetrating diaphragmatic injury.[64] A thoracic endoscopic approach to diagnosing diaphragmatic injury (and by implication, a possible intraabdominal injury) following a missile wound to the lower thorax would appear to be a reasonable alternative to observation or an exploratory laparotomy. If a hole in the diaphragm is seen, a laparotomy is indicated both to close the hole and to treat any coexisting intraabdominal injuries.

Damage Control

The concept of staging the operative interventions in the severely injured to allow for optimizing the casualty's physiological status is known by a variety of names: "abbreviated laparotomy and planned reoperation,"[65] "staged celiotomy,"[66] and "delayed gastrointestinal reconstruction,"[67] among others. What these terms describe is the following sequence:

1. emergency laparotomy performed to stop exsanguinating hemorrhage and to prevent further peritoneal contamination;
2. a nonoperative resuscitative phase during which hypovolemia, hypothermia, acidosis, and coagulation defects are corrected; and
3. repeat laparotomy to definitively correct the injuries.

The essential feature of this regimen is the "damage control" of the life-threatening injuries that are found during the initial laparotomy: enteric injuries are ligated to prevent further peritoneal contamination, and exsanguinating hemorrhage is controlled by clamping or packing. Because of its staged nature, this regimen would appear to have much to offer military surgery, which is, after all, characterized by the provision of care by stages, or echelons. We can imagine a forward surgical team performing the initial laparotomy, and then the casualty's being immediately evacuated to a third-echelon hospital for resuscitation and definitive surgery. However, this regimen should be considered for use *only if rapid and reliable evacuation can be guaranteed*.

SUMMARY

Abdominal injuries are the most common life-threatening injuries that military anesthesia providers are likely to encounter. Casualties with abdominal injuries may present with exsanguinating hemorrhage, but more commonly, a stable patient will present with intraabdominal contamination as the major threat to life. with intraabdominal contamination. In the former circumstance, military anesthesia providers will strive for adequate oxygenation, with fluid resuscitation ongoing during surgical control of hemorrhage. In the latter circumstance, a more measured and thorough approach to preoperative preparation is usually possible. In the ideal circumstance, the casualty will receive adequate fluid resuscitation, intravenous antibiotics, and instrumentation for monitoring. Although operations have been done using regional anesthetic techniques, the overwhelming majority are best managed using endotracheal anesthesia.

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