Wound Care Management, Non-penetrating Injuries, and Wounds Penetrating into Body Cavities

13

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13.1 Penetrating Trauma

Penetrating wounds are injuries that result from tissue penetration by a foreign material. Most commonly these injuries are caused by weapons that can be further classified into low-energy (knifes and hand-energized missiles); medium-energy (handguns, pistols, and revolvers), and high-energy weapons (military or hunting rifles). Injuries by projectiles propelled by the energy of a blast explosion (also called secondary blast injuries) will be covered in a different chapter, but according to the size of the projectile, the energy of the blast and the distance traveled, they usually fall under the medium- or high-energy categories.

13.1.1 Stab Wounds

Stab wounds to the chest and abdomen often cause life-threatening injuries as both cavities contain vital organs and major blood vessels that can be disrupted. Life or limb-threatening injuries can also result from stab wounds to other anatomical locations if neuro-vascular structures are affected. Because the energy transfer is done along a tract, the size and shape of the blade, as well as the exact anatomical location, play an important role in the outcome of these wounds. As a rule of thumb, damage is only inflicted to local tissues along the path, or paths, of the blade. Surrounding tissues that do not directly contact the blade are usually unaffected. This being said, one should not assume that blades always produce straight paths, as movements of the victim and the perpetrator may create multiple injuries in the cavities despite the existence of one single entry point.

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13.1.2 Gunshot Wounds (GSW)

Gunshot wounds are becoming increasingly common all around the world. Conflict, violence, and criminality coupled with flexible legislation that allows easy access to military rifles in some countries have been producing some of the most devastating injuries seen in civilian settings.

The original size of the entry and exit wounds per se do not give enough information on the path of the bullet or the damage produced, as this is dependent on many other factors. Entry wounds can be larger than the exit wounds and small-entry/small-exit wounds may conceal damage caused by the large temporary cavity that was formed in between.

Small Arms

Small arms are hand-held small caliber firearms with less than 20 mm bore size. Under the tag "Small Arms," we mainly find revolvers, pistols, rifles, carbines, assault rifles, submachine guns, and light machine guns.

Ammunition Terms

A typical cartridge contains a case (with a primer and different amounts of gunpowder) and a bullet (the projectile). Most bullets used nowadays have a lead or steel core. This core is then either fully jacketed with a harder material like a copper alloy (FMJ bullets) or semi-jacketed (SJ), leaving the tip of the core exposed (soft point/hollow point bullets).

Energy Transfer

When gunpowder ignites, expanding gas is generated. The more gunpowder, the more gas is generated. Bigger cartridges like the ones used in assault rifles have much more gunpowder than smaller cartridges used in revolvers and pistols (handguns). The extreme pressure generated by the expanding gas propels the bullet out of the case and through the weapon's barrel into the air at a certain speed. On impact, all the energy left on the bullet is transferred to the human body causing the injury.

Kinetic energy (E_k) of the bullet (muzzle energy) is calculated (in J) using the formula

$$E_k = \frac{1}{2}mv^2$$

where m is the mass of the bullet (in Kg) and v is velocity of the bullet (in m/s). The bullet of a typical 9 mm Luger cartridge used by many police forces has an average of 470 J. An AK47 Kalashnikov rifle's bullet has an average of 3000 J.
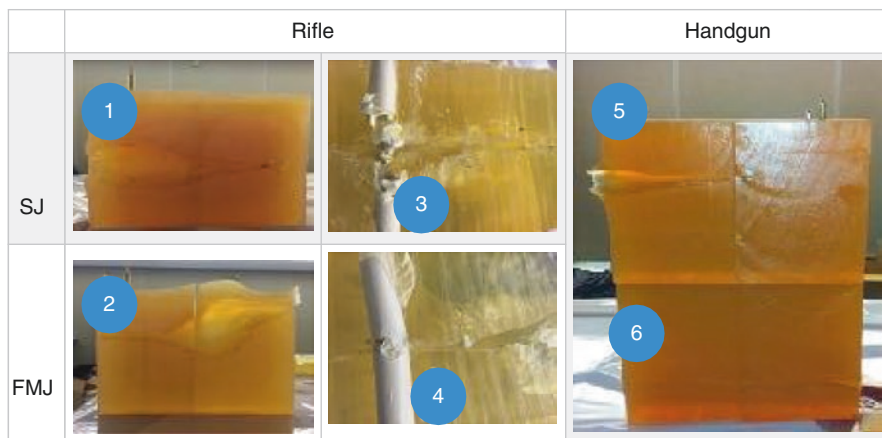
	Rifle		Handgun
SJ			
FMJ			

Fig. 13.1 FMJ bullets (2, 4, 6) vs SJ bullets (1, 3, 5)

13.1.3 Patterns of Injury

The pattern of injury is mainly determined by the type of bullet (FMJ vs SJ) and by the energy still left upon impact (handgun vs rifle). The bullets on image 1 (SJ) and 2 (FMJ) had exactly the same energy, but the energy was deposited at different depths (Fig. 13.1):

- Rifle FMJ bullets penetrate deeper (2,4) before they start tumbling to create a temporary cavity.
- Handgun FMJ bullets (6) do not create temporary cavities.
- SJ bullets (1,3,5) deform or expand on impact, depositing most of the energy in the first centimeters after penetration. SJ bullets are used for hunting and by some police departments, but are prohibited for use in war by the 1899 Hague Convention.

13.2 Hemorrhage

Noncompressible hemorrhage is the immediate major concern following penetrating trauma to the chest or abdomen, even in the absence of obvious external exsanguination. Some injuries will inevitably lead to death almost instantly. If we consider that on an average 70 kg man, an estimated 5000 ml of blood flows through the aorta every minute, and that volume amounts for the whole blood volume, then we can easily infer that a complete disruption of the aorta will lead to death in less than a minute. Complete disruptions of other smaller arteries would imply different timings as, for example, the 600 ml/min flow rate of the superior mesenteric artery or

the 450 ml/min flow rate of a renal artery. Fortunately, not every penetrating injury disrupts a major blood conduct but rather a series of smaller arterial and venous vessels, and numerous capillaries.

During hemorrhage, the natural physiological response will focus on preserving blood pressure as the circulating volume is progressively lost, and this is mainly achieved through peripheral vasoconstriction. However, the buffering capacity of the system is limited and the potential for inadequate cardiac output leading to inadequate organ perfusion is high even if the blood pressure remains within the normal range. This is particularly true when we are facing a massive hemorrhage, defined by one or more of the following criteria:

- Loss of more than total blood volume within 24 h (around 70 ml/kg, >5000 ml in a 70 kg adult)
- 50% of total blood volume loss in less than 3 h
- Bleeding in excess of 150 ml/min
- Bleeding which leads to a systolic blood pressure of less than 90 mmHg or a heart rate of more than 110 beats per minute

13.2.1 Shock

Hypoxia due to inadequate tissue perfusion is called shock, and until otherwise proven, in patients with penetrating injuries to the chest or abdomen this is due to hypovolemia secondary to hemorrhage.

Shock can also be classified into different classes according to the volume of blood loss and the resulting abnormalities identified in some physiological parameters (i.e., pulse rate, blood pressure, and mental status) (Table 13.1).

Patients presenting with tachycardia, hypotension, and visible blood loss are easily identified as being in shock, however, trauma patients may be shocked even if presenting with normal blood pressure and pulse rate. Thus, in trauma patients with penetrating injures, adequate cardiac output cannot be inferred from blood pressure. A relationship between the two only happens when blood loss is critical or rapid.

Table 13.1 Shock classifications

	Class I	Class II	Class III	Class IV
Blood loss (ml)	Up to 750	750–1500	1500–2000	>2000
Blood loss (% of volume)	Up to 15%	15–30%	30–40%	>40%
Pulse rate	<100	>100	>120	>140
Blood pressure	Normal	Normal	Decreased	Decreased
Mental status	Normal to slightly anxious	Slightly anxious, restless	Anxious, confused	Confused, lethargic

13.2.2 The Trauma Triad of Death

Massive and ongoing blood loss inevitably leads to tissue hypoperfusion. This means that there is less oxygen being delivered to the cells. Less oxygen delivery makes the individual cells shift into anaerobic metabolism. The problem with anaerobic metabolism is that it produces lactic acid as an end product (leading to lactic acidosis), and is less efficient in terms of ATP production. Less ATP being produced, means less ATP is available for heat production, thus further contributing to hypothermia (temperature ≤35 °C) (Fig. 13.2).

Lactic acidosis will further impair myocardial contractility, contributing to reduced tissue perfusion. Hypothermia, on the other hand, is further aggravated by the adrenergic stimulation vasoconstriction that attempts to keep the blood pressure within acceptable values.

The clotting cascade enzymes and platelets only operate within a narrow temperature range; thus, hypothermia together with the vigorous immunologic response (cytokines) both contribute to the establishment of a trauma-induced coagulophaty. Furthermore, hypoperfusion together with tissue injury results in hyperfibrinolysis and activation of the protein C pathway, leading to fibrinogen depletion and systemic anticoagulation also called trauma-induced coagulophaty (TIC) by some authors.

Hypothermia is one of the most important physiological predictors for early and late mortality in trauma patients, and coagulopathy, independent of hypothermia but strongly correlated with acidosis and ISS, is also associated with increased mortality in trauma patients. Some studies suggest an overall in hospital mortality rate of 47.8% for those patients arriving at the emergency department presenting with the
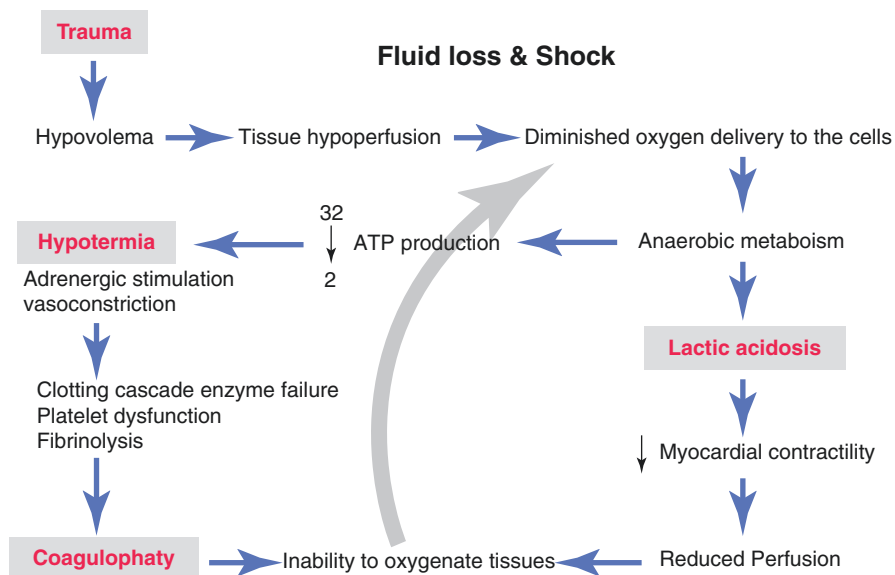
Fig. 13.2 Fluid loss and shock scheme

full triad: coagulopathy (international normalized ratio (INR) >1.5), hypothermia (temperature <35 °C), and acidosis (pH <7.2).

13.3 Damage Control Concepts

Damage control can be seen as a principle, a concept, and a philosophy. The founding pillars of damage control have been imported from naval military experience, where in the aftermath of a battle-damaged ship, all internal resources are mobilized in order to limit the extension of the damages and keep the ship afloat with a functional steer. In practical terms, all the actions taken during this emergency situation aim at: temporarily stop the flooding, extinguish the fires, and keep the propellers running.

The extrapolation of these naval damage control principles into penetrating trauma thus requires a set of measures aiming to stop the bleeding, limit contamination and soilage, and preserve blood flow to vital organs. The most important goal is to keep the patient alive at all costs, and ideally this process should begin at the point of injury.

13.3.1 Damage Control Resuscitation

Although the initial management of every single trauma patient starts with the traditional "ABCDE" or "(C)ABCDE" approach (which prioritizes catastrophic blleding), the modern approach to trauma management includes a series of clinical interventions known as damage control resuscitation which also target the complications of major hemorrhage (coagulophaty, hypothermia, and acidosis).

Hemodinamically unstable patients should be simultaneously assessed and resuscitated. The goal is to have normal perfusion restored, thus recovering from shock. However, it has been demonstrated that in trauma patients with penetrating injuries presenting with active bleeding, attempts to restore perfusion, before adequate hemostasis is achieved, are counterproductive. Damage control resuscitation thus relies on three basic principles:

- Hemorrhage control (preserving circulating volume and minimizing blood loss)
- Permissive hypotension/hypovolemia (keeping systolic blood pressure around 80–90 mmHg in order to avoid "popping the clots")
- Early empiric use of red blood cells and clotting products (thus limiting fluids that may dilute coagulation proteins) and consequently preventing and treating trauma induced coagulopaty

The single most important step in the management of the severely injured patient is to arrest bleeding and restore blood volume. Still, fluids should be judiciously used and prioritized according to their availability, knowing that the most effective resuscitation fluid is the patient's own blood. In order of preference, the following should be used:

- Fresh warm whole blood (better than stored whole blood)
- Plasma (1) + red blood cells (1) + platelets (1)
- Plasma (1) + red blood cells (1)
- Plasma or red blood cells
- Warm colloids (HES)
- Warm crystalloids (Plasmalyte A; better than Ringer lactate, better than normal saline)

When homeostasis has been achieved, definitive resuscitation to restore organ perfusion is initiated, and although this strategy clearly sacrifices perfusion for homeostasis (prioritizing TIC), several studies have demonstrated that it is associated with a decrease in mortality and reduced duration of stay in intensive care and hospital.

Certain procedures like tourniquets and splints, as well as some adjuncts like tranexamic acid or topical hemostatic agents (combat gauze), or some interventions such as resuscitative endovascular balloon occlusion of the aorta, may all play a role until definitive surgical or radiological hemorrhage control is achieved.

Having this in consideration, during the initial "ABCDE" or "(C)ABCDE" approach, the initial resuscitation end points are:

- Radial pulse present.
- Systolic blood pressure around 80–90 mmHg.
- Improved mental status.

13.3.2 Damage Control Surgery

Damage control surgery (DCS) is part of the damage control resuscitation (DCR) philosophy and sacrifices the completeness of the immediate surgical repair and restoration of anatomy in order to adequately address the combined physiological insult of trauma and subsequent surgery.

In practical terms, damage control surgery is done to treat the physiology and not the anatomy. Historically, the first time the term was used was in 1993 by Rotondo and colleagues. The initial description was of an abbreviated laparotomy followed by intensive resuscitation and later return to the operating theater for definitive repair, thus defining three damage control stages:

- DCS Stage 1
  - Hemorrhage control
  - Limit peritoneal contamination
  - Temporary abdominal closure
- DCS Stage 2
  - Hypothermia prevention and treatment
  - Correction of coagulopathy
  - Correction of acidosis

- DCS Stage 3 (no longer than 72 h from Stage 1)
  - Definitive surgery
  - Creation of ostomies, feeding access, fascial closure

Since then and in the past 25 years, the DCS concept has been broadly applied in different surgical fields including, orthopedic surgery, vascular surgery, neurosurgery, and plastic surgery. Additionally and more recently, two new stages were added in order to cover for the prehospital and early resuscitation phase (DCS Stage 0) and reconstructive surgery (DCS Stage 4).

Important to note that most trauma patients who present to an emergency department, even those with penetrating wounds, do not require a damage control approach. Only a few who are seriously injured, in shock, should require damage control resuscitation and damage control surgery, and these should be identified as early as possible.

13.4   Penetrating Abdominal Wounds

All patients should be initially managed using the traditional ABCDE/(C)ABCDE approach, and it is important to early identify patients who have an immediate indication for laparotomy. This patient population shall not undergo axial imaging, but rather be immediately transferred to the operating theatre.

Gunshot and stab wounds are always contaminated. All patients undergoing surgery should receive tetanus prophylaxis and antibiotic prophylaxis to deal with the eventual bacteremia produced by the manipulation of contaminated tissues.

Violation of the peritoneum occurs in between 20% and 80% of patients with penetrating trauma, and the peritoneum can accommodate nearly all of a patient's circulating blood volume.

Unlike blunt trauma, injuries to the stomach, duodenum, small intestine, and colon are common in penetrating trauma. The small intestine is actually the most common site of injury in both blunt and penetrating trauma.

Evisceration of bowel or omentum and bleeding from the wound are indications for surgical exploration, regardless of the patient hemodynamic status. All abdominal gunshot wounds require exploration but anterior abdominal stab wounds are best managed following the "Western Trauma Association algorithm for local wound exploration and abdominal stab wounds" (Fig. 13.3).

13.4.1 Damage Control Laparotomy

For the selected subset of unstable patients requiring immediate laparotomy, the whole team should be aware of the surgical goals (and resist the temptation to embark into definitive repairs):

- Hemorrhage control
- Limiting peritoneal contamination
- Temporary abdominal closure

Fig. 13.3 D/C—discharge;
Cbc—complete blood count

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                        ┌─────────────────────┐
                        │ Anterior Abdominal  │
                        │     Stab Wound      │
                        └──────────┬──────────┘
                                   │
                         YES       ▼
        ┌────┐  ◄───────────┌──────────────┐
        │ OR │              │ Shock        │
        └────┘              │ Peritonitis  │
                            │ Evisceration │
                            └──────┬───────┘
                                   │ NO
                 Negative          ▼
      ┌─────┐  ◄─────────┌──────────────────────────┐
      │ D/C │            │ Local Wound Exploration*  │
      └─────┘            └────────────┬─────────────┘
                                      │ Positive / Equivocal
                                      ▼
                          ┌──────────────────────┐
                          │ 23-Hour Observation: │
                          │ Serial Physical Exam,│
                          │ CBC q8 h             │
                          └──────────┬───────────┘
                                     │
                         YES         ▼
        ┌────┐  ◄───────────┌──────────────────────┐
        │ OR │              │ Peritonitis          │
        └────┘              │ Hemodynamic Instability│
                            └──────────┬───────────┘
                                       │ NO
             YES                       ▼
   ┌──────────┐  ◄───────────┌────────────────────────────┐
   │ CT, DPL  │              │ Significant Drop in Hemoglobin│
   │ or OR    │              │ (>3 g/dL) Leukocytosis       │
   └──────────┘              └─────────────┬──────────────┘
                                           │ NO
                                           ▼
                                       ┌──────┐
                                       │ Feed │
                                       │ D/C  │
                                       └──────┘
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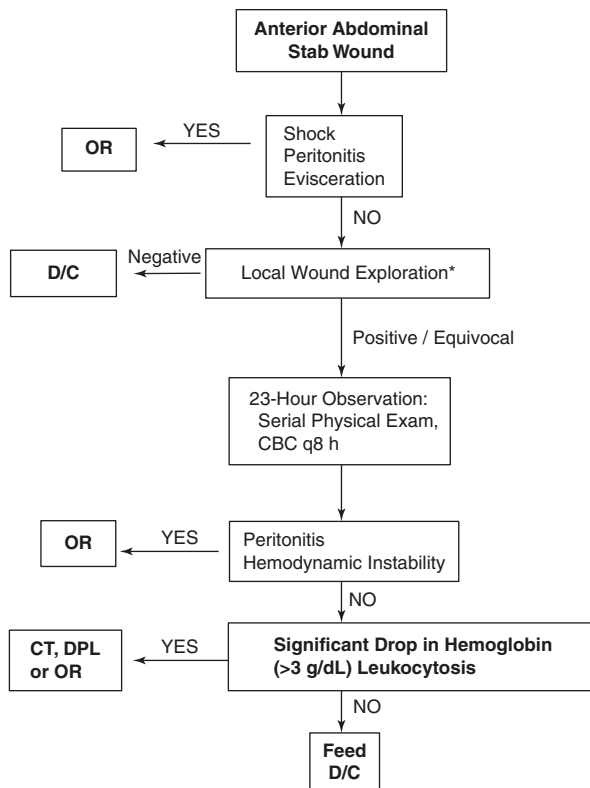
Hemorrhage control: As soon as entering the abdomen, vascular control of the abdominal hemorrhage should be paired with packing of all four quadrants. Vascular control can be achieved either by direct digital pressure applied to the abdominal aorta or through performing an initial left anterior lateral thoracotomy for proximal aortic control before the laparotomy. The later technique is currently subject to debate as some authors suggest that the physiologic cost of this thoracotomy is greater than direct control or endovascular occlusion techniques. Whatever the choice of technique, this initial maneuvers usually improve cardiac and cerebral perfusion, thus contributing to the overall resuscitation process.

Bleeding from solid organs should be controlled by either direct compression or removal of the organ. In the case of splenic bleeding, the damage control approach favors immediate splenectomy instead of time-consuming splenorrhapies. For a massive liver hemorrhage, the initial approach can follow the sequence "Push, Pringle, Pack," thus buying some time for further decisions to be taken.

Lateral expanding hematomas of the retroperitoneum are best approached laterally to medially through a Mattox maneuver (left-medial visceral rotation) or through a Cattel–Braasch maneuver (right-medial visceral rotation). In both cases if the kidney is identified as the source of injury, a quick palpation of a normal kidney on the contra-lateral renal fossa will give you the peace of mind to proceed with the nephrectomy.

Shunting is probably one of the best options when leading with a major vascular injury, but even major truncal arteries and veins may have to be ligated if no other option is available on the table. Vascular repair at DCS Stage 1, should only be attempted if time permits and in agreement with the anesthetist.

Limiting peritoneal contamination: Although hollow viscus injuries do not often contribute to hemodynamic instability, they are associated with significant morbidity and mortality.

Stool and other enteric content should be washed out. Ongoing leakage from non-circumferential holes in the bowel can be easily and quickly repaired with 3-0 or 2-0 silk sutures, whether major leaks should not undergo any attempt for anastomosis and should be addressed with linear stapling devices, umbilical tapes, skin staplers, or abdominal clamps that will remain in place until DCS Stage 3.

Injuries to the pancreas and duodenum are particularly challenging. Duodenal injuries should be simply debrided and closed. In the damage control situation, the addition of nasogastric decompression will be enough, and considerations of pyloric exclusion can be taken at DCS Stage 3. Pancreatic injuries in this setting are better managed by closed suction drainage or a combination of closed suction drainage and resection, which is the case of distal injuries with ductal involvement who will benefit from a distal pancreatectomy with splenectomy plus close suction drainage. Attempting a pancreaticoduodenectomy in a damage control setting defies the whole concept of Damage Control surgery.

Temporary abdominal closure: Primary fascial closure is not an option under damage control mode and it is important to recognize that the role for an open abdomen (OA) is not exclusive to the damage control population. OA has been an effective treatment for abdominal catastrophes in traumatic and general surgery. Damage control surgery, severe abdominal infection, planned second look operation, and prevention of abdominal compartment syndrome are all indications for temporary closures. Intra-abdominal hypertension (IAH) and abdominal compartment syndrome (ACS) have been increasingly recognized as contributing factors for mortality.

Historically, abdominal packing, Bogota bags, and towel clip skin closure have been used as temporary means to achieve temporary closures. Currently the most commonly used techniques derive from the initial vacuum pack technique described by Barker et al. In summary, a perforated polyethylene sheet is placed over the intraperitoneal viscera and beneath the peritoneum of the anterior and lateral abdominal wall. Then, a layer consisting of compressible material, such as sterile surgical gauzes, applied over the polyethylene sheet. Two silicone drains positioned between the gauzes and connected to an aspiration source at -20 cm H_2O. A plastic polyester drape to cover the skin surrounding the wound.

Today, different and more efficient, pre-assembled commercial systems are available to provide negative pressure therapy, sub-atmospheric pressure or vacuum sealing techniques. The underlying principle is the same as the Barker system, and availability of resources will probably dictate the method of choice.

13.5   Penetrating Chest Wounds

Penetrating chest injuries account for 12% of all trauma-penetrating injuries, yet thoracic injuries account for up to 25% of early trauma related deaths, second only to head and neck injuries.

Paradoxically, however, thoracic trauma can uniquely benefit from bedside procedures like tube thoracotomy, emergency airway creation and emergency department thoracotomy, to alleviate the immediate threat of mortality and allow further definitive treatment.

All patients should be initially managed using the traditional ABCDE/(C)ABCDE approach, and, as in abdominal trauma, it is important to early identify patients who have an immediate indication for thoracotomy.

13.5.1 Damage Control Thoracotomy

The principles of thoracic damage control are the same as abdominal damage control: DCS Step 1 to stop the hemorrhage and limit contamination, DSC Step 2 at the ICU unit in an effort to restore physiologic condition, and DSC Step 3 for definitive repair.

For an abbreviated thoracic operation, the patient should be positioned in the supine position with the arms extended out at 90° with a slight elevation under the left chest to increase exposure. In the event of a nonanticipated emergency laparotomy, this is the more convenient position.

For patients who present in extremis, an anterolateral incision is simpler and quicker than a midline sternotomy.

Once inside, three main actions can be taken: release of cardiac tamponade, compression of the supradiaphragmatic aorta, and packing of the chest for hemorrhage control.

If a pericardial tamponade is found and released (pericardium incision parallel to the frenic nerve), then one should focus on the control of the cardiac/great vessel bleeding. Digital pressure followed by a quick staple closure or simple suture will often work. For bigger defects, a bladder catheter can be inserted an inflated into the bleeding cavity to buy some time.

Vascular injuries should also be approached in a damage control manner: either lateral repair, shunt placement, or ligation.

Lung injuries are traditionally easier to solve from a technical perspective. In cases where the source of a significant hemorrhage is the lung, releasing of the inferior pulmonary ligament, followed by a twisting maneuver of the lung around its hilum will compress both the pulmonary veins and arteries. Alternatively, a pulmonary hilar clamp can be placed, with similar results.

Hemorrhage from through and through pulmonary parenchymal injuries are best managed by a technique called tractotomy, by which, using a surgical stapler or between clamps the "roof" of the tract/channel is opened, exposing the underlying bleeding vessels that can now be individually addressed.

Esophageal injuries are usually very challenging. In a damage control setting the best options to deal with esophageal injuries are: primary closure (reinforced with pericardium) with wide drainage, or wide drainage alone with two chest tubes together with a nasogastric tube placed at the level of injury.

Most upper airway injuries can be managed by passing an endotracheal tube past the site of injury.

A subset of patients presenting with penetrating chest trauma with witnessed previous cardiac activity which as seen been lost, or patients deteriorating rapidly prior to arrest of cardiac activity, are strong candidates for a bedside left anterolateral resuscitative thoracotomy. The primary aim is to release a cardiac tamponade, apply digital pressure to the descending aorta, or allow for internal cardiac massage. Additionally, this approach also allows for a quick lung twist (180° rotation of the lung) or a lung tractotomy with a surgical stapler, in order to temporary control pulmonary sources of bleeding. If needed the incision can be extended to the contralateral side over the fifth intercostal space, creating a clamshell thoracotomy and allowing for a total chest exposure. Even knowing that the survival rates in these cases are quite low (18–33%), these patients are almost always candidates for a subsequent thoracic damage control procedure.

It is debatable whether the chest can be definitively closed after a damage control operation. Some authors favor the vacuum sealing techniques, while others prefer the immediate traditional closure leaving the chest tubes in place. Whatever technique is used, it is important to remember that the goal is to achieve adequate perfusion and oxygenation while monitoring for any ongoing hemorrhage.

13.6   Wound Care

Entry and exit wounds, whether caused by bullets or knifes, require proper debridement. Unless strictly unavoidable, these wounds should not be part of the main surgical incision (laparotomy or thoracotomy) and should not be used to pass drains (abdominal or chest). Proper debridement of these wounds may however require a combination of incision (to extend the wound and expose deeper layers of subcutaneous fat, fascia and muscle) plus excision (the removal of all contaminated and necrotic tissue). As a rule of thumb, with very few exceptions, all wounds should be left open (covered by a dressing) for a period of 2–5 days, when safe delayed primary closure of the clean wound can then be achieved.