13 Damage Control Cardiothoracic Surgery

J. Shaw, Bradley J. Phillips, and Juan A. Asensio

13.1 Introduction

Although damage control as a surgical concept and/or technique has become part of the trauma surgeon's armamentarium for the past 25 years, it is meritorious to review its origins and indications. The concept, as described, takes its origin from Stone's [1] hallmark work describing the "bailout" approach in honor of World War II paratroopers. In his 1986 seminal paper [1], he recognized a physiological "cluster" of intraoperative signs, i.e., coagulopathy, prompting interruption of trauma surgical procedures after institution of hemorrhage containing measures and packing of the abdominal cavity. He then proposed returning patients to a critical care setting and correcting the coagulopathy of trauma to return to the operating room later for definitive surgery.

This "bailout" approach ushered the area of staged surgical procedures for trauma. With this approach Stone [1] reported a 65% versus 7% survival rate in favor of patients packed versus those undergoing definitive surgical procedures.

Subsequently Burch [2] in 1992 described the abbreviated laparotomy with planned reoperation for critically ill patients, later to be described as "damage control" by Rotondo [3] in 1993. In Rotondo's [3] study consisting of 46 patients, the authors identified a maximum injury subset of 22 patients, of which 9 underwent definitive laparotomy (DL) and 13 damage control laparotomy (DL). In this group of patients, survival rate for the damage control group was 77% versus an 11% survival rate for the definitive laparotomy (DL) group. This paper [3], based on a small number of patients, provided no statistical analysis; however, it did outline a methodology for the management of critically injured trauma patients.

In reality, damage control as a methodology emerged to deal with exsanguination, an ill-defined, easily recognized, feared entity, but not foreign to trauma surgeons. Initial attempts by Anderson [4] to define this syndrome: "Patients losing their entire blood volume" and Trunkey

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[5] who described it within the context of flow, defining outcomes for patients with severe hemorrhage and rates of blood loss exceeding 250 mL per minute launched the initial attempts at rethinking and redefining this syndrome by Asensio and Ierardi [6–8] whom described it as: "Exsanguination is the most extreme form of hemorrhage. It is usually caused by injuries to major components of the cardiovascular system, injuries to parenchymatous organs or both. It is a hemorrhage in which there is an initial loss of 40% of the patient's blood volume with an ongoing rate of blood loss, exceeding 150 mls per minute. If this hemorrhage is not controlled, the patient may lose over half of his or her entire blood volume within 10 minutes." Subsequently, Moore [9] described the "bloody vicious cycle" of acidosis hypothermia and coagulopathy, while Cosgriff [10] postulated that the ability to predict the onset of coagulopathy, perhaps the most important of the components of the "bloody vicious cycle," would impact significantly decision-making with regard to the institution of "damage control."

Asensio and colleagues [11] based on 548 patients classified as sustaining exsanguination described and statically validated by univariate and logistic regression reliable variables indicating damage control and predicting outcomes in a patient population, with very low revised trauma scores (RTS) and very high injury severity scores (ISS) consisting of thoracic, abdominal, and multiple injuries admitted in profound shock with a mean pH of 7.15 and a mean estimated blood loss of 7.3 L. Subsequently, dysthymias were added to the bloody vicious cycle and described as the "lethal tetrad" [11–14]. Although the variables and indications described by Asensio and colleagues [11] for the institution of "bailout/damage control" have been adopted and validated, yet no specific study has applied them solely for the management of cardiothoracic injuries.

Application of "bailout [1]/damage control [3]" is now considered routine for severe abdominal trauma. It is recently that this strategy has begun to find its place in the management of cardiothoracic trauma. The general principles and goals of damage control are similar to those employed for the management of abdominal trauma. Expeditious operative management of unstable patients remains the primary focus.

Severe thoracic injuries are frequently and rapidly lethal; however, there is considerably less room for the institution of staged procedures for the management of cardiac, pulmonary, or thoracic vascular injuries which demand definitive repair if the patient is to survive. Although there is limited data available on the use of damage control in cardiothoracic injuries, patients with severe thoracic trauma and subsequent physiological derangement can benefit from its implementation [15].

Several factors have limited the use of damage control in cardiothoracic surgery. First, there are valid concerns that thoracic packing may compromise cardiac filling and, thus, right and left ventricular ejection fractions, as well as restricting pulmonary expansion. It should be noted that there is a paucity of literature on this topic and most of the available literature is limited to the opinions of individual trauma surgeons. Second, a clear definition of damage control as it applies to thoracic surgery is unfortunately lacking. Abbreviated thoracotomy as a damage control technique entails rapid hemorrhage control requiring a planned return to the operating room. Additionally, some authors [15–18] include emergency department thoracotomy (EDT) as a damage control procedure, while others excluded it. Finally, the available literature describes the treatment of anatomic injuries in sufficient detail but lacks crucial physiological data and outcomes [15–18].

There are both differences and similarities in the application of "damage control" to abdominal and cardiothoracic surgeries. However, the decision to perform damage control is the same regardless of anatomic location [11, 15]. In both instances, acidosis, hypothermia, and coagulopathy are individual and valid predictors of mortality. Therefore, the severely injured patient presenting with the "lethal tetrad" should prompt the trauma surgeon to rapidly institute damage control techniques. Exsanguinating hemorrhage and physiological derangements are considered the most important selection criteria. Finally, postoperative management of the abnormal patient's physiology in the intensive care unit (ICU) is approached in a similar fashion [11, 12].

For the most part, divergence of their similarities lies in the inherent anatomic differences between cardiothoracic and abdominal surgeries. One of the most important concerns during the institution in abdominal damage control is contamination from the gastrointestinal (GI) tract due to the original injury and/or the procedures required to manage these injuries. This complication is of lesser concern in cardiothoracic damage control given that thoracic esophageal injuries are rare, thus decreasing the risk of cavitary contamination. Another important difference, meritorious to note, is that virtually all abdominal and retroperitoneal injuries are accessed via a single incision laparotomy, whereas there is a broader armamentarium of incisions required to manage cardiothoracic injuries; as the thoracic cavity is compartmentalized, thus damage control largely depends on the anatomic location of injury.

Left anterolateral thoracotomy allows rapid access to the left hemithoracic, pericardium, heart, and thoracic aorta, whereas median sternotomy provides optimal exposure to the heart and mediastinum. Extension of this incision as bilateral anterolateral thoracotomies or "clamshell thoracotomy" has also been used. Regardless of the approach, it cannot be overemphasized that the incision must provide adequate exposure of all injuries [19].

The patient most likely to require damage control for thoracic injury is the unstable patient with penetrating thoracic injuries [20]. The most common mechanisms of penetrating injury are gunshot wounds (GSWs), stab wounds (SWs), and uncommonly shotgun wounds (STWs), while motor vehicle collisions comprise the majority of blunt thoracic trauma, very rarely warranting damage control. Additional patient characteristics that predict the need to institute damage control are not unique to thoracic trauma.

13.2 Cardiothoracic Damage Control in the Trauma Center

All damage control for trauma patients begins in the trauma center. Addressing the "ABCs" of cardiothoracic trauma differs slightly from nonthoracic trauma in that both resuscitative and diagnostic techniques are performed simultaneously. Following Advanced Trauma Life Support (ATLS) principles, a definitive airway and large bore IV access for resuscitative fluids should be established. Emergency release blood should be readily available, and a blood sample should be sent promptly for typing. Activation of the massive transfusion protocol (MPT) is often required. Thoracostomy tubes can be placed for both therapeutic and diagnostic purposes along the midaxillary line at the level of the fifth intercostal space. An initial assessment of the wound should be attempted by either physical examination or radiographic imaging. Thoracostomy tube output, FAST in both pericardial and pleural views, as well as chest radiographs (CXR) should be sufficient to establish the diagnosis of injuries requiring immediate surgical intervention.

Emergency department thoracotomy (EDT) is performed under strict indications to both resuscitate and control hemorrhage as well as to repair cardiac injuries until they can be transported to the operating room. EDT also functions as a triage instrument, by ensuring that patients with lethal injuries are not routinely transported to the OR. The indications for EDT have long been a subject of intense debate. In general, the decision to perform this procedure is dictated by the presence or absence of signs of life and mechanism of injury. Survival rates following EDT in thoracic trauma are highest for patients sustaining penetrating injuries and presence signs of life either in the field or upon arrival at the trauma center.

Patients requiring EDT for blunt thoracic trauma have extremely low survival rates. Therefore, EDT in these patients is generally not indicated unless very specific criteria are met [19, 21].

The primary goals of EDT are the same in damage control: release of pericardial tamponade, control of intrathoracic hemorrhage and sources of air embolism, as well as to perform open cardiopulmonary resuscitation and cross-clamping of the descending aorta. This maneuver redistributes the remaining blood volume to perfuse both carotid and coronary arteries [19, 21, 22].

The procedure begins with a left anterolateral thoracotomy (see Figs. 13.1 and 13.2). An incision is made below the nipple in the fifth intercostal space starting at the left fifth costochondral junction in a slightly curved fashion and extends to the anterior border of the latissimus dorsi. In females, the left breast is displaced cephalad. The skin, subcutaneous tissues, and chest wall musculature are rapidly transected with a scalpel. A small incision is made through the intercostal muscles, followed by complete transection of the three layers of the intercostal musculature with Metzenbaum thoracic scissors. If extension is required for better visualization, the sternum can be divided with Bethune shears or a Lebsche knife. A Finochietto rib retractor is then placed and positioned with the handle toward the table. Upon entrance into the thoracic cavity, the trauma surgeon should note whether the blood is arterial or venous. Clots must be rapidly removed, and the pericardium must be assessed for the presence of tamponade. The lung is retracted anteromedially by placing the left hand posterior and lateral to the lung with the palm against the parenchyma. If the inflated lung significantly impairs visualization, the lung can be momentarily deflated by temporarily holding ventilation. Using Metzenbaum scissors, the mediastinal pleura is then divided immediately anterior to the aorta, avoiding injury to the esophagus. Prior placement of a nasogastric tube provides a useful landmark. The trauma surgeon then digitally develops a space between the esophagus and aorta. Subsequently, a Crafoord-DeBakey aortic clamp is placed (see Figs. 13.3, 13.4, and 13.5). If present, pericardial tamponade is released by opening the pericardium anterior to the phrenic nerve initially with a scalpel followed by complete incision with Metzenbaum scissors. Extension from the root of the aorta to the apex of the heart allows for complete delivery of the heart. Injury to the phrenic nerves, which course anterior to the pericardium, should be avoided [19–23]. The presence of an air embolus is an ominous finding and a negative predictor of outcome (see Fig. 13.6).

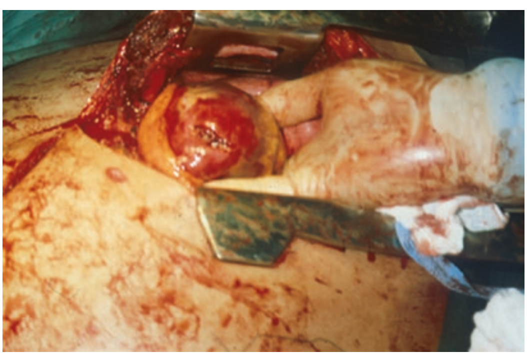

Fig. 13.1 Left anterolateral thoracotomy for gunshot wound in the left ventricle

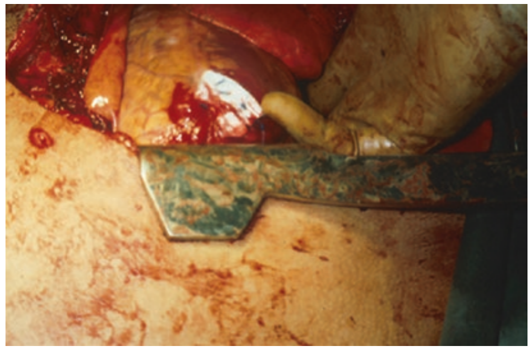

Fig. 13.2 The same patient who begun to bleed. Complex left ventricular cardiorrhaphy requiring Teflon pledgets

Once these general techniques have been implemented, additional procedures can be used based on the injury and physiological status of the patient. Hemorrhage from cardiac injuries is controlled with digital occlusion prior to performing either atrial or ventricular cardiorrhaphy with 2-0 polypropylene sutures on an MH needle [19, 23–25]. Initial management of pulmonary

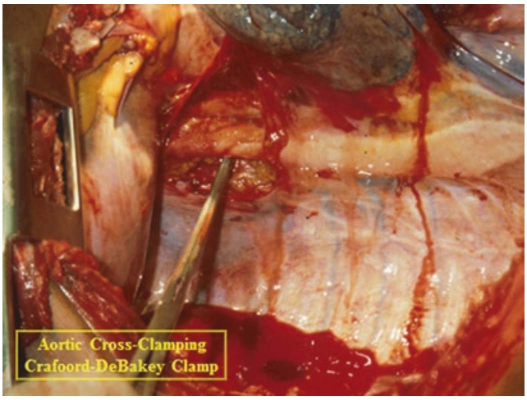

Fig. 13.3 Resuscitative thoracotomy on a patient that succumbed. Notice the left hemithoracic cavity which can harbor the entire blood volume. Thoracic aorta is dissected. Esophagus is above

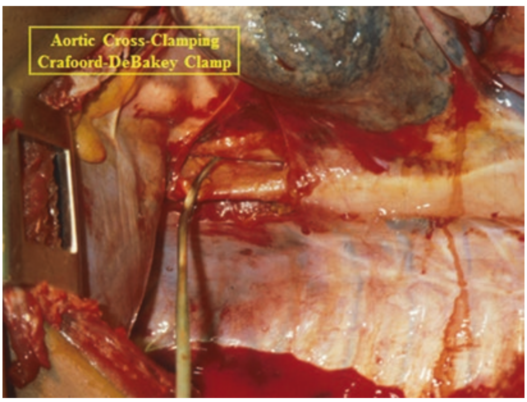

Fig. 13.4 Resuscitative thoracotomy on a patient that succumbed. Descending thoracic aorta has been clamped

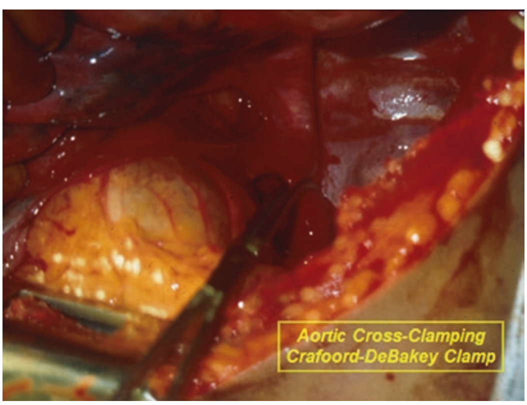

Fig. 13.5 Descending thoracic aorta cross-clamped on a live patient. Notice the decrease in size even in the largest blood vessel in the body in the presence of profound shock

Fig. 13.6 This is an ominous finding

injuries begins with mobilization of the lung by sharply transecting and mobilizing the inferior pulmonary ligament, with the knowledge that proximity of the inferior pulmonary vein may place it at risk for iatrogenic injuries. Hemorrhage control and prevention of air embolism can be achieved by applying Duval clamps to the injured pulmonary parenchyma. Cross-clamping of the pulmonary hilum is indicated if there is an actively bleeding pulmonary hilum or if there is an expanding hilar or central hematoma. A Crafoord-DeBakey aortic clamp is also utilized [19, 23–25].

EDT is an indispensable first step in the institution of cardiothoracic damage control. Although this complex procedure is lifesaving, EDT is not without its risks or pitfalls. Overall survival rates remain low despite years of debate about the procedure and its indications. Asensio [19, 23–29] and Wall and colleagues [30] described the practice management guidelines of the American College of Surgeons Committee on Trauma (ACS-COT). In their study, a large volume of literature was reviewed, scrutinized, and stratified according to the levels of evidence. The authors reported survival rate of 7.83%. Stratified to mechanism of injury, survival rates for penetrating and blunt trauma were 11.16% and 1.6%, respectively.

EDT can also pose serious risks to the healthcare team. Rapidity of the procedure, use of sharp instruments, and suboptimal visualization make exposure to blood-borne pathogens an unequivocal risk. This risk is substantiated by reported HIV seropositivities as high as 4% in some urban trauma centers.

13.3 Cardiothoracic Damage Control in the Operating Room

13.3.1 Overall Considerations

If the patient has an organized perfusing rhythm following EDT, they are promptly transported to the operating room (OR). Upon arrival, speed is paramount and sterility a secondary concern. The patient should be placed in the supine position with both upper extremities abducted. A splash prep and draping from neck to midthighs are advisable in the event that access to the saphenous vein for an interposition reverse autogenous vein graft is required. Once the patient is properly positioned, the trauma surgeon should gown and glove immediately. Ongoing intravascular volume replacement with crystalloid, blood, and blood products should continue for the duration of the operation [23–29]. Appropriate thoracic instruments should be available (see Fig. 13.7).

Generally, the massive transfusion protocol (MPT) should be activated. Additional warming devices are used to minimize heat loss and facilitate rewarming in the hypothermic patient. Autotransfusers are viable options in thoracic injury given reduced risks of contamination. Continuous hemodynamic monitoring is achieved by placement of an arterial line. Switching to a dual-lumen endotracheal tube is usually not imperative, feasible, or recommended. If better

Fig. 13.7 Thoracic surgical instruments

visualization is required, the anesthesia staff may insert a bronchial blocker, or alternatively the endotracheal tube is advanced into one of the main stem bronchi to induce unilateral deflation.

13.3.2 Cardiac Injuries: Technical Aspects

For the majority of cardiac injuries, primary repair is the only option. Injuries addressed during the initial emergency department thoracotomy (EDT) should be inspected. Atrial injuries can be controlled by a Satinsky clamp and primarily repaired with 2-0 polypropylene monofilament sutures on a MH needle with horizontal mattress sutures of Halsted. Similarly, ventricular injuries are also primarily repaired in the same fashion. Occasionally, and mostly for gunshot wounds, the use of Teflon pledgets is warranted. The technical demands of suturing a functioning heart are obvious, and the difficulty of tying knots securely may be underestimated. Several techniques have been described that reduce the risk of lacerating the myocardium or exacerbating a concurrent injury [19, 23, 24, 25, 28].

Distal injuries comprise the majority of coronary vessel lacerations in those patients surviving long enough to be transported to the operating room. These injuries are often amenable to ligation with the knowledge that postoperative ischemia and intraoperative myocardial infarction are a very definite possibility. Proximal coronary artery injuries are usually fatal. Those that survive to reach the operating room will require aortocoronary artery bypass with a reverse autogenous saphenous vein graft (RSVG). In this setting, cardiopulmonary bypass is required [19, 23, 24, 25, 28]. However, one case has been described in which the LAD was repaired "off-pump" using a saphenous vein bypass graft [31]. Total inflow occlusion is indicated for injuries to the superior or inferior atriocaval junction and lateral most portion of the right atrium. This technique involves cross-clamping both the intrapericardial superior vena cava and the inferior vena cava (IVCs), resulting in complete inflow occlusion (Shumacker's maneuver) (see Fig. 13.8) [19, 23, 24, 25, 28]. Subsequent arrest ensues along with a brief window of time to perform repairs. However, as these authors have previously warned, the safety period of this maneuver likely ranges from 1 to 3 min. If this time frame is exceeded, reestablishment of a sinus rhythm is improbable [19, 24, 25, 28].

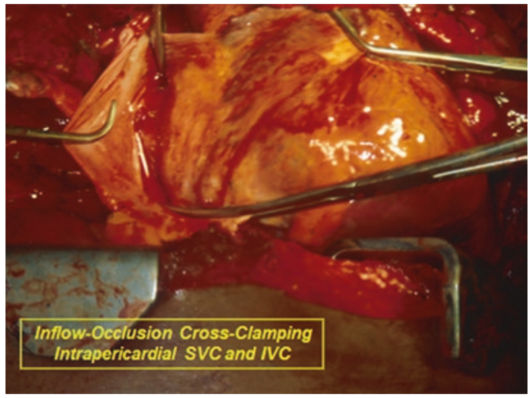

Fig. 13.8 Shumacker's maneuver

When the repair is complete, no attempt should be made to close the pericardium. Doing so can be harmful in the event of cardiac swelling following the "stunned myocardium syndrome" and reperfusion injury. In rare instances, this may carry an increased risk of damage to the anterior cardiac surface [32].

13.3.3 Pulmonary Injuries: Technical Aspects

Management of pulmonary injuries includes pneumorraphy, non-anatomic resections, tractotomy, lobectomy, and pneumonectomy. Small peripheral injuries can be successfully managed with stapled non-anatomic resections. Most through-and-through injuries without involvement of the hilum are most amenable to pulmonary tractotomy. Clamp tractotomy, described by Wall [33], utilized aortic clamps through the wound tract which were noted to crush the pulmonary parenchyma. Asensio [34] described

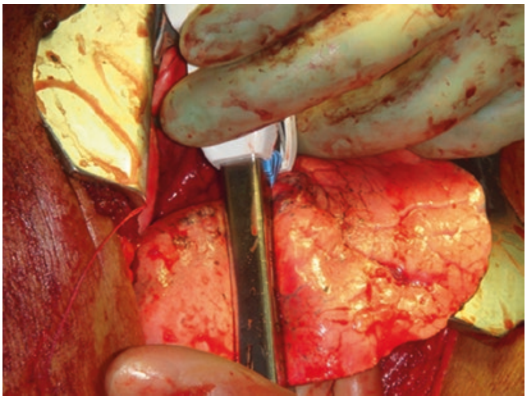

Fig. 13.9 Stapled pulmonary tractotomy

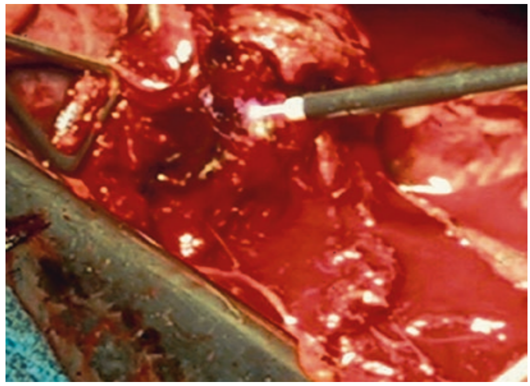

Fig. 13.11 Argon beam coagulator being utilized as an adjunct to stapled pulmonary tractotomy to control diffuse pulmonary parenchymal bleeding

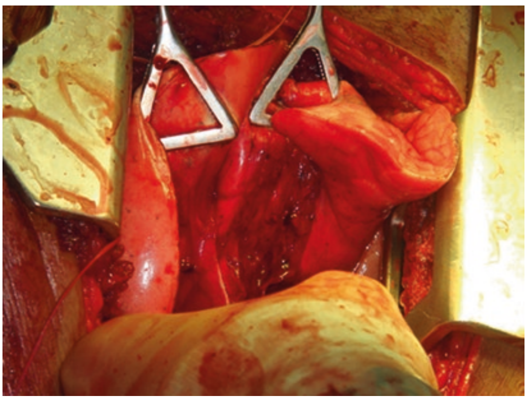

Fig. 13.10 Pulmonary parenchyma opens to identify injured blood vessels and bronchi for selective deep blood vessel ligation

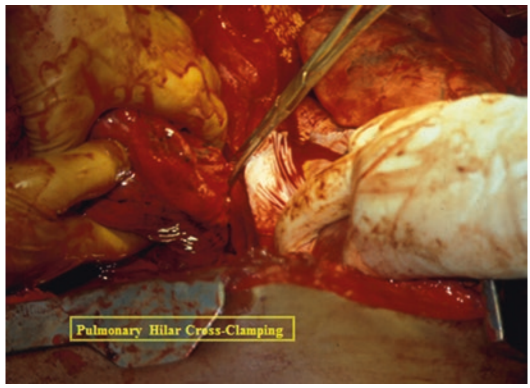

Fig. 13.12 Cross-clamping pulmonary hilum

stapled pulmonary tractotomy utilizing a GIA stapler as a tissue-sparing technique to identify and selectively ligate bleeding sources for control of hemorrhage. Once entrance and exit wounds have been identified, the stapler is placed through the wound and fired. This opens the tract, resulting in the exposure of bleeding vessels and transected bronchi [34] (see Figs. 13.9 and 13.10). Multiple studies have since shown this technique to be safe and effective [35, 36]. Similarly, Asensio and colleagues also described the use of the argon beam coagulator to control diffuse pulmonary parenchymal bleeding and as an adjunct to stapled pulmonary tractotomy [37] (see Fig. 13.11).

Pulmonary injuries that involve the hilum or hilar structures often require hilar cross-clamping and lobectomy or pneumonectomy (see Figs. 13.12 and 13.13). If time is adequate and patient physiology favorable, pulmonary vessel and bronchus isolation should be attempted (see Figs. 13.14 and 13.15). Thoracic damage control may not allow for either circumstance, in which case en bloc lobectomy or pneumonectomy using a large green load TA stapler may be required [34–36].

13.3.4 Intrathoracic Vascular Injuries: Technical Aspects

For the repair of thoracic vessels, diagnosis determines the type of incision required to gain proximal and distal control. The clear majority

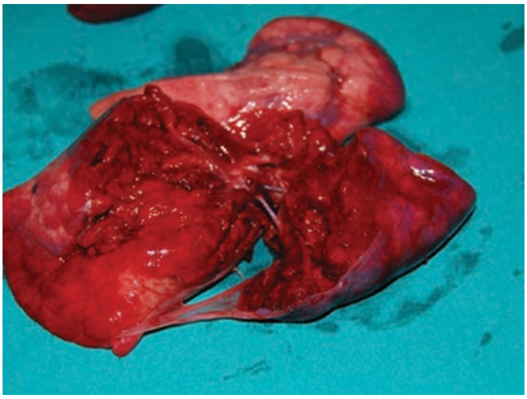

Fig. 13.13 Pneumonectomy for central hilar gunshot wound

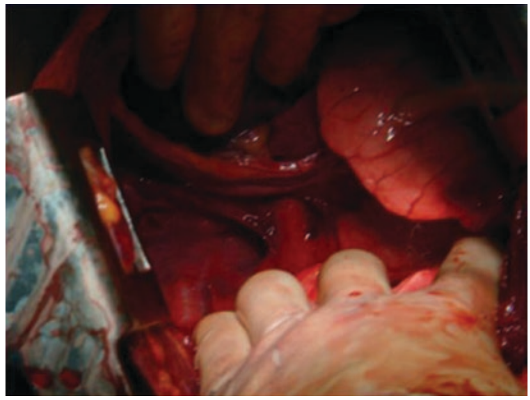

Fig. 13.15 Left main pulmonary artery

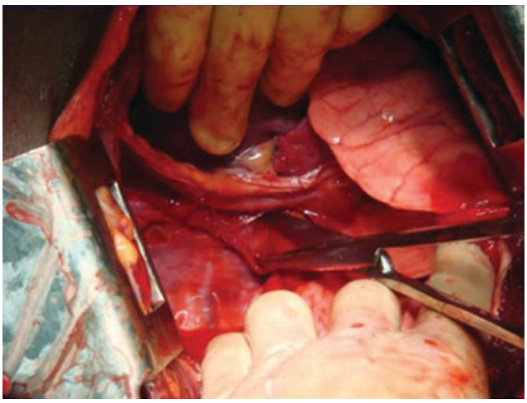

Fig. 13.14 Dissection of the extrapleural left pulmonary artery

Fig. 13.16 Temporary intraluminal shunt in the left carotid artery after shotgun wound

of patients requiring damage control would have most likely undergone previous left and possibly bilateral anterolateral thoracotomies. Control of the descending thoracic aorta and proximal left subclavian artery is accessible via this incision. While an anterolateral thoracotomy provides proximal access to most other vessels, it lacks sufficient access for distal control and exposure for definitive repair [19, 38] (see Figs. 13.16 and 13.17). Injuries of the aortic arch and proximal great vessels require median sternotomy, which can be extended into the neck via the standard incision anterior to the sternocleidomastoid or as a subclavicular incision (see Figs. 13.18 and 13.19).

Injuries to the subclavian vessels are most easily accessed via a subclavicular incision with clavicle removal with or without replacement of the clavicle post-repair (see Figs. 13.20 and 13.21). If digital compression of a vessel was required at the time of EDT, the person providing digital control should be prepped in the field and digital control not removed until adequate intraoperative control is achieved. Hemorrhage originating adjacent to the clavicles can be temporarily controlled via digital pressure [19, 38, 39].

Primary repair is the preferred option in cardiothoracic damage control after satisfactory exposure and control are obtained; however, this is usually not possible given the extent of vessel damage.

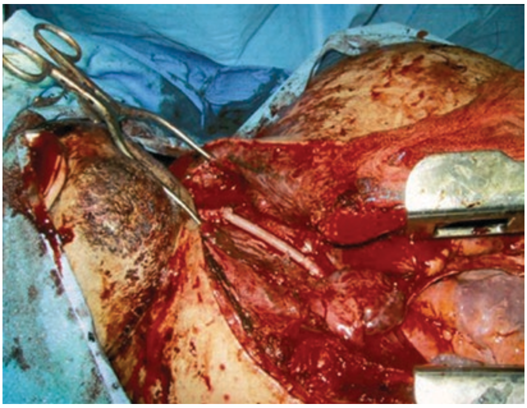

Fig. 13.17 The same patient after saphenous vein interposition graft between the proximal left carotid artery approximately 3 centimeters from its origin and the distal left common carotid artery

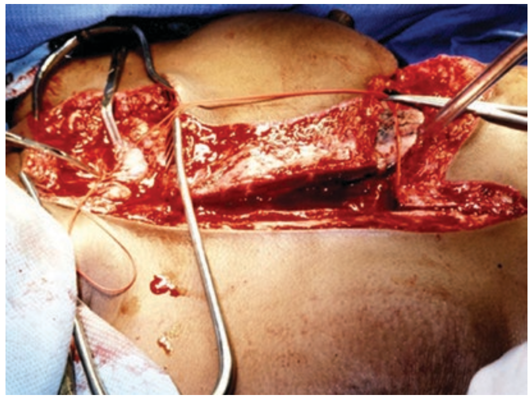

Fig. 13.20 Tangential gunshot wound. Left subclavian artery. Patient arrived in cardio pulmonary arrest. Required resuscitative thoracotomy. Transported to the OR for median sternotomy and left subclavicular incision

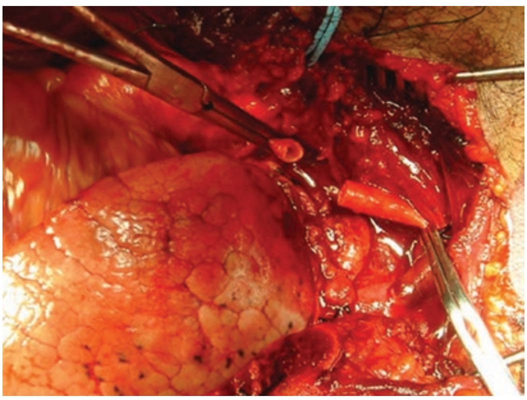

Fig. 13.18 Gunshot wound origin left common carotid artery. Proxmial and distal cross-clamping

Fig. 13.21 The same patient. Left subclavian artery clamped prior to resection and PTFE interposition graft

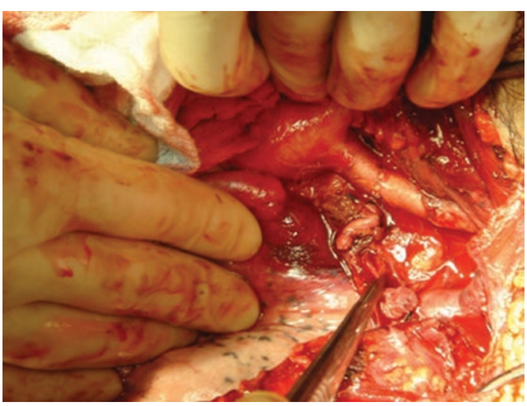

Fig. 13.19 After mobilization a primary end to and anastomosis was completed. Note arch of the aorta and transected phrenic nerve

Thus, synthetic grafts are most often used. Polytetrafluoroethylene (PTFE) or knitted Dacron grafts are the conduits of choice for vessels larger than 5 mm in diameter. Penetrating aortic injuries can usually be managed with primary repair but may require placement of a Dacron graft. In the past decade, intraluminal grafts have changed the entire spectrum of vascular injury management; however, most endografts are used for blunt thoracic aortic injuries [19, 38, 39].

Placement of intraluminal shunts to maintain blood flow in medium-sized vessels with the intention of delayed definitive repair has been rarely reported and used with some success. Shunt material and configuration are matters of personal preference, with Argyle shunts being the shunt's of choice. In areas of conflict, these authors have secured the shunts in place with 2-0 silk ties to ensure flow. Inaccessible vascular injuries can be temporized with a Fogarty catheter. In patients with rapidly deteriorating physiology, ligation is also an option. This is feasible for subclavian venous injuries but not for subclavian arterial injuries. Injuries to the subclavian, innominate, and jugular veins can be safely ligated [19, 38, 39].

13.3.5 Tracheobronchial Injuries: Technical Aspects

Penetrating injuries to the distal tracheobronchial tree are rare. In these cases, an airway should be secured prior to any specific interventions. Tracheal injuries, when suspected, can be initially managed via advancement of the endotracheal tube through the wound tract followed by wide surgical drainage. Penetrating tracheal wounds should be primarily repaired. Sutures should be applied either through or around the tracheal rings with external knot placement to reduce the risk of granuloma or stricture. These authors prefer to place sutures around the cartilaginous rings when possible and have found that to 2–3 cm defects can be approximated without tension. Bronchial injuries, although rare, should be primarily repaired if possible (see Figs. 13.22 and 13.23), or else a pneumonectomy is indicated. Postoperative suture line, dehiscence, leaks, and fistula formation are potential complications. Therefore, the intercostal muscle or other vascular pedicles can be used to buttress the repair [19, 34–36].

13.3.6 Esophageal Injuries: Technical Aspects

The primary goal in the management of esophageal injuries is to achieve primary repair with an excellent and functional closure without stenosis. Meticulous surgical technique will prevent suture line, dehiscence, or anastomotic failures thus avoiding risks of mediastinitis, mediastinal abscess, or empyema. Accordingly, these injuries are managed by wide drainage with two thoracostomy tubes in the setting of cardiothoracic damage control. Primary repair should be utilized and reinforced with a Grillo pleural flap or intercostal muscle [40, 41] (see Figs. 13.24 and 13.25). Non-reconstructible injuries can be temporarily managed by ligation and placement of a nasogastric tube above the level of injury with chest tubes draining the area. For complex injuries, reconstruction over a T-tube (Kehr tube) has been successfully reported [40, 41].

Fig. 13.22 Self-inflicted gunshot wound left chest. Massive air leak requiring multiple chest tubes. Bronchoscopy detected a left main stem bronchial laceration

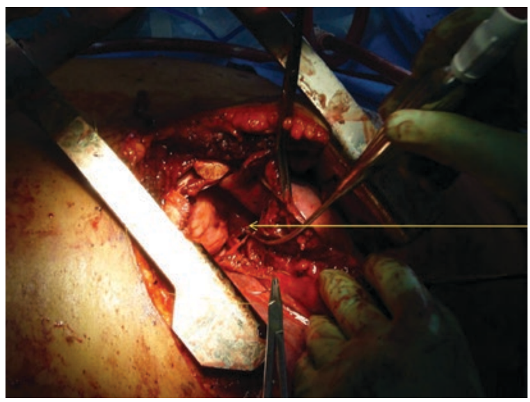

Fig. 13.23 Left mainstem bronchial laceration located after central stapled pulmonary tractotomy and primary repaired with simple interrupted 2-0 vicryl sutures

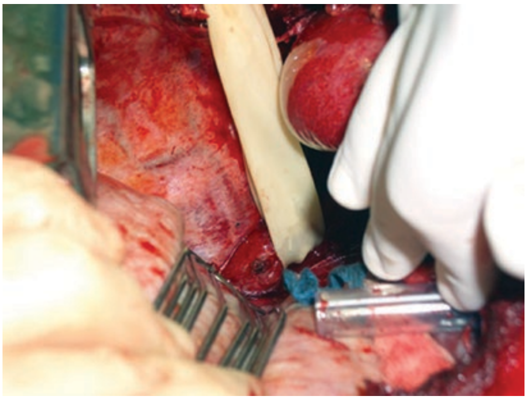

Fig. 13.24 Gunshot wound thoracic esophagus approached via right posterolateral thoracotomy esophagus mobilizes and isolated prior to double layer repair with 3-0 vicryl and 3-0 silk sutures

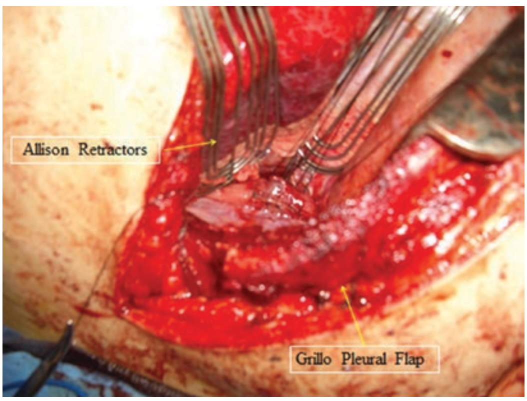

Fig. 13.25 Gunshot wound thoracic esophagus primary repaired and buttressed with grillo pleural flap

Diversion via cervical esophagostomy is a second option but adds significant time to the damage control phase and has been used infrequently. These authors prefer to wait on diversion until the second look procedure. Gastrostomy tube placement is also recommended but should be delayed until definitive repair [40, 41].

13.3.7 Thoracic Packing

Packing has long been an accepted practice for controlling hemorrhage in trauma surgery. It continues to be a useful damage control adjunct. Thoracic packing has been described as a means of controlling bleeding after cardiac surgical procedures and occasionally pulmonary resections. However, the use of packing in thoracic trauma has been less often used and at times discouraged, mainly because of concerns regarding its effects on intrathoracic pressure.

The physical space occupied by packing material combined could theoretically restrict venous return, cardiac filling, and lung expansion. This may increase the risk for the development of cardiac tamponade or inadequate ventilation [22, 38]. Specific reports substantiating these concerns are generally lacking and limited to personal experiences of trauma surgeons. Reports by Caceres [42] and Lang [43] described the application of this technique in thoracic damage control with some success. The data from these experiences seem to indicate that aforementioned concerns about possible sequelae may be unfounded. However, larger studies are needed to draw any meaningful conclusions.

Temporary packing of the chest, like the abdomen, carries an inherent risk of infection. In thoracic damage control, packing of the chest cavity is primarily used as a means of controlling bleeding, especially in the case of a massively injured chest wall. These injuries, such as those seen following close-range gunshot or shotgun wounds, often exhibit bleeding that lacks a rapid, definitive surgical solution [22]. Wall suggested the employment of chest packing as a last resort in the hypothermic, coagulopathic patient with multiple chest wall injuries and diffuse bleeding [17]. The use of gauze rolls or laparotomy pads as packing material in conjunction with the use of topical hemostatic agents may be effective in these patients. The argon beam coagulator may also be useful in this setting. Tissue debridement should only be performed if it significantly facilitates hemostasis. Otherwise, it can be delayed until the definitive operation [17, 37].

13.3.8 Temporary Chest Wall Closure

Proper closure of a thoracotomy incision requires each layer to be anatomically re-approximated. Therefore, temporary closure is a more feasible option in thoracic damage control. It allows rapid closure of the chest cavity so that the patient can be transported to the ICU where resuscitation may continue under more optimal conditions. In the setting of damage control, the thoracic cavity can be temporarily closed with towel clips, a running en masse suture, a Bogota bag, or a negative atmospheric pressure device (Wound Vac™) [24–28, 35]. For the patient in extremis, towel clips can be used as an expedient form of wound closure. However, this technique comes at the cost of reduced hemostasis and suboptimal visualization if angiography is later required. En masse closure with a single running locked suture is a second, more hemostatic option. If closure of the chest wall by either of these methods results in pulmonary or cardiac compromise, a Bogota bag can be used as a temporary closure. These authors have also used large adhesive dressings (Ioban™) to temporarily close one or both chest cavities in areas of conflict.

13.4 Cardiothoracic Damage Control in the Intensive Care Unit

The next step in the damage control sequence is continued resuscitation in the intensive care unit (ICU). Postoperative care can be just as challenging as the initial operation. Angiography, if required for vascular injuries, should be accomplished prior to arrival in the ICU [12, 16, 17, 22, 27]. Diagnostic and therapeutic bronchoscopy should also be used in patients with pulmonary injuries.

The speed with which hypothermia, acidosis, and coagulopathy are corrected is directly proportional to the likelihood of a good outcome. Hypoperfusion is the cause of acidosis in these patients. Therefore, its correction is focused on volume resuscitation and optimization of oxygen delivery. Care should be taken to address these issues while avoiding fluid overload. Many of these patients have decreased pulmonary reserve due to intraparenchymal hemorrhage, pulmonary contusions, and/or air leaks resulting from the initial injury. Excessive fluid administration can exacerbate these injuries and impair ventilation. Large intravascular volume requirements may put these patients at risk for edema. Subsequent increases in intraabdominal pressure can quickly progress to abdominal compartment syndrome, which may require decompressive laparotomy [12, 16, 17, 22, 27].

Trends in thoracostomy tube output should be monitored closely. Bleeding from thoracostomy tube drainage should decrease over the course of a few hours, as coagulopathy is addressed with blood products. Abrupt cessation of thoracostomy output should prompt suspicions of malfunction or clotting either within the drained hemithoracic cavity or the tube. If thoracostomy output remains high despite efforts to correct coagulopathy, this usually indicates that hemostasis has not been completely achieved. However, it may be difficult to know whether the cause of bleeding is surgical or because of uncorrected coagulopathy. This has long been acknowledged as one of the most difficult scenarios a trauma surgeon can encounter. The decision to return the patient to the operating room is based on clinical judgment. Unfortunately, judging incorrectly often leads to death or poor outcomes. Martin [20] advocates a threshold of six units of packed red cells transfused in 6 h without a change in hematocrit as an indication to return to the operating room. However, strict guidelines have yet to be published. These authors rely on the use of thromboelastography (TEG) and focused use of blood products to try to address the balance between a re-exploration versus continued critical care resuscitation [12, 16, 17, 22, 27].

13.5 Return to the Operating Room

Patients who have had temporizing procedures should be returned to the operating room once normal physiology and end points of resuscitation have been restored and met. The goals of reoperation are definitive organ repair and complete closure of the chest wall. At least two thoracostomy tubes should be placed at that time. These authors routinely place a 32 FR right-angled tube in the costophrenic sulcus and a 36 FR straight tube near the apex of the lung to ensure full expansion [12, 16, 17, 22, 27]. Additional tubes may be used as needed and placed in accordance with existing injuries. The thoracic cavity and incision are vigorously irrigated and hemostasis obtained prior to closing the chest wall in layers.

13.6 Complications

Complications arising from cardiothoracic damage control are common, severe, and often multiple. Those unique to this patient population are cardiac tamponade and air leak. The classical presentation of pericardial tamponade of distended neck veins, distant heart sounds, and hypotension—Beck's triad—is infrequent, even in patients presenting with cardiac injuries. In these patients findings of pericardial tamponade are often subtle, if not absent. It often presents with inadequate cardiac output and cessation of mediastinal chest tube output. Therefore, the use of noninvasive hemodynamic monitoring with a pulse wave analyzer, echocardiography, and even TEE may aid in the diagnosis [19, 23–25].

Definitive management of pericardial tamponade includes reopening of the chest and accessing the pericardium to release the tamponade. Air leaks are common following pulmonary procedures [19, 23–25]. Conservative management via thoracostomy tube drainage can initially be attempted. This often requires full expansion of the lung with adequate ventilation to be successful and avoidance if possible of high levels of positive pressure ventilation (PEEP). Persistent leaks may require reoperation to repair or resect the portion of lung parenchyma involved.

Given the condition of the patient requiring thoracic damage control, it is not surprising that mortality is very high. Mortality rates reported in the literature range from 23 to 69 %. The lowest mortality rate was reported by O'Connor [29] in the largest series to date. Variation has been attributed to differences in patient age, damage control techniques employed, and severity and mechanism of injury. In the same study, mortality rates were highest in patients requiring pneumonectomy [22].

Conclusions

Patients with severe chest trauma and marked physiological decline may benefit from cardiothoracic damage. Damage control in the chest, like in the abdomen, begins with initial management in the trauma center, followed by an abbreviated operation focused on hemorrhage and source control and temporary stabilization. This is followed by goal-directed critical care including appropriate intravascular volume replacement, normalization of end points of resuscitation, and a planned second look via reexploration once the physiological derangements have been corrected. Cardiothoracic damage control has emphasized simple and rapid definitive procedures since there is little room for error in the management of patients "in extremis." These authors have found that the use of TTE during the initial procedure is helpful/beneficial as well as the role of TTE in the critical care unit and final chest closure. Therefore, it is imperative that the trauma surgeon be familiar with these techniques and be willing to adopt an aggressive mind-set to ensure the best opportunities for a favorable outcome. If all else fails, stop the bleeding, place thoracostomy tubes, and temporarily close the chest. Needless to say, rapid and meticulous surgical technique will influence the outcomes of these critically injured patients.

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