Chapter 9
Lung Injury: Techniques

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Introduction of the Problem

A majority of patients with chest trauma, from either penetrating or blunt injury, can be managed nonoperatively with either observation or a chest tube [1–3]. When surgery is indicated, the purpose of pulmonary resection is to either control lung bleeding or excise injured tissue [4]. Patients who require thoracotomy following blunt trauma often have more severe injuries requiring a more complex operation and are associated with higher mortality [1–5].

Indication for urgent or emergent thoracic surgical exploration includes shock with a penetrating thoracic injury, chest tube output in excess of 1000–1500 cc after chest tube placement, continued chest tube output or ongoing bleeding greater than 200–300 cc/h, massive air leak, and cardiac tamponade [2, 6]. High chest tube output is indicative of continued bleeding that requires surgical control, while large air leak is concerning for a major tracheobronchial injury.

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T. M. Scalea (ed.), *The Shock Trauma Manual of Operative Techniques*, https://doi.org/10.1007/978-3-030-27596-9_9

Bronchoscopy is often necessary to thoroughly evaluate a major airway injury in order to help plan the appropriate operation and incision while patients also require a stable and secure airway to maintain oxygenation and ventilation. Once the patient's airway is established and secured, in the presence of concomitant life-threatening hemorrhage, surgical repair of many airway injuries is deferred until bleeding is controlled. Up to a third of patients who require thoracotomy for traumatic hemorrhage will also require a pulmonary resection [1]. Managing patients with severe chest trauma requires an understanding of thoracic surgical procedures, which can be effectively employed in unstable actively bleeding patients. The first issue is to determine what incision or approach should be utilized, and the second consideration is to determine what procedure should be performed.

Incision

There are various options available for surgical exposure, and it is important to be familiar with the advantages and limitations associated with each approach. The thoracic incision that is ultimately utilized should be versatile enough to address potential injuries in adjacent locations including the neck and abdomen [7]. While covered elsewhere, a few comments may be helpful.

Anterolateral Thoracotomy

This incision is rapid, avoids the time-consuming positioning associated with the traditional posterolateral thoracotomy, and does not require a sternal saw. It provides excellent exposure to the anterior hilum. This incision is the most common approach to the patient in extremis undergoing a salvage resuscitative procedure. It is also utilized in patients undergoing an exploratory laparotomy who decompensate and necessitate an emergent thoracic exploration. Finally, this incision

permits an extension into the contralateral hemithorax providing wide exposure of both hemithoraces and the anterior mediastinum (clamshell thoracotomy). Limitations include limited exposure of the posterior mediastinum especially the esophagus, aorta, and posterior aspect of the lung.

The inframammary crease is the landmark for the incision. The pectoralis muscle is divided followed by the intercostal muscles within the desired interspace, often the fourth or fifth. The internal mammary artery and vein are in close proximity to the sternum, and they should be preserved if possible.

Bilateral Anterior Thoracotomies

Also known as a clamshell thoracotomy, it is performed by starting with an anterolateral incision and extending it across the midline. It provides wide exposure of the anterior mediastinum, bilateral lungs, and pleural cavities. It does require either a Lebsche knife, sternal saw, or Gigli saw to divide the sternum horizontally. Retractors are placed to enhance exposure. This incision requires the identification and ligation of both internal mammary vessels.

Posterolateral Thoracotomy

This is the classic incision utilized for thoracic surgery and provides the best exposure of the thorax, especially the entirety of the lung. It does require more extensive preparation. It should only be utilized if the patient is hemodynamically stable and the injury is confined to a single hemithorax [8]. Correct positioning of the patient is essential and includes lateral positioning with the iliac crest at the level of the table break and rolls or an inflated bean bag to assist in stabilization. An axillary roll should be placed while bending the lower leg to about a 90° angle, keeping the upper leg straight with a pillow in between. The upper arm is placed up toward

the head, flexed at the elbow, and secured to an armrest. Often, one lung isolation is required and achieved with either a double-lumen endotracheal tube or bronchial blocker placed by anesthesia. The bed is flexed to help expand the intercostal spaces.

The incision extends from the level of the mid-scapula in between its edge and the spinous processes, swinging down and anterior through a point about 2–3 cm below the tip of the scapula and then anteriorly to the anterior axillary line and into the inframammary fold as needed. The latissimus dorsi muscle is then divided. The serratus anterior muscle is identified, and the adjacent fascia divided in an attempt to preserve this muscle. A scapular retractor is utilized to elevate the scapula and help identify the desired interspace by counting the ribs. The thorax is entered in the desired interspace by dividing the intercostal muscles with the electrocautery in a posterior to anterior direction along the superior edge of the inferior rib. A Finochietto retractor is then inserted and carefully opened.

All incisions are closed after placing chest tubes, which are taken out through separate stab incisions and secured to the skin. The ribs are reapproximated with interrupted intercostal sutures. The muscles are sutured to the adjacent fascia, followed by a subdermal and skin layer.

Sternotomy

This incision provides excellent exposure to the anterior mediastinum for quick access to the heart, great vessels, pericardium, and thymus. Thus, it is not a primary incision for pulmonary injuries. Injury to the lung may occur with an injury best repaired via a sternotomy. It does provide adequate exposure for many pulmonary procedures except for access to the left lower lobe.

The standard incision is from the jugular notch down to the xiphoid process. The ligamentous tissue just superior to the jugular notch should be divided with electrocautery, and

the retrosternal space bluntly mobilized digitally. The midline of the sternum is identified, scored, and then divided with a sternal saw while respirations are temporarily held. After inspecting the sternal edges and controlling the sternal bleeding, a sternal retractor is placed. After placing chest tubes, the incision is often closed with sternal wires to reapproximate the sternum and Vicryl suture in layers for the soft tissue.

Operative Technique with Personal Tips

Emergent thoracic trauma cases present challenges to achieving the isolated lung ventilation routinely employed in elective thoracic surgery. However, in patients who can be temporarily stabilized, placing a double-lumen tube can be very helpful. Having an experienced anesthesia team helps keep time to a minimum. However, most operations in the trauma setting are performed with a single-lumen endotracheal tube in patients with tenuous respiratory function. Temporary holding of ventilation and manual compression of lung parenchyma are some techniques that may facilitate the surgeon in overcoming this challenge of the lack of isolated lung ventilation [7].

Once the chest is entered, accumulated blood should be cleared and the injury assessed. The inferior pulmonary ligament should be divided to give maximal mobility to the lung (Fig. 9.1). Associated chest wall and/or vascular injuries should be identified before a definitive plan is made. One should assess the adequacy of exposure. If exposure is not adequate, the incision should be widened and/or a counter incision made to facilitate adequate exposure. If a sternotomy has been used, anterolateral thoracotomy should be considered. If an anterolateral thoracotomy has been used, converting to a clamshell should be considered. One should avoid struggling through an inadequate incision.

Formal pulmonary resections for trauma such as lobectomy and pneumonectomy are associated with high mortality rates. Other less morbid “lung-sparing” techniques have

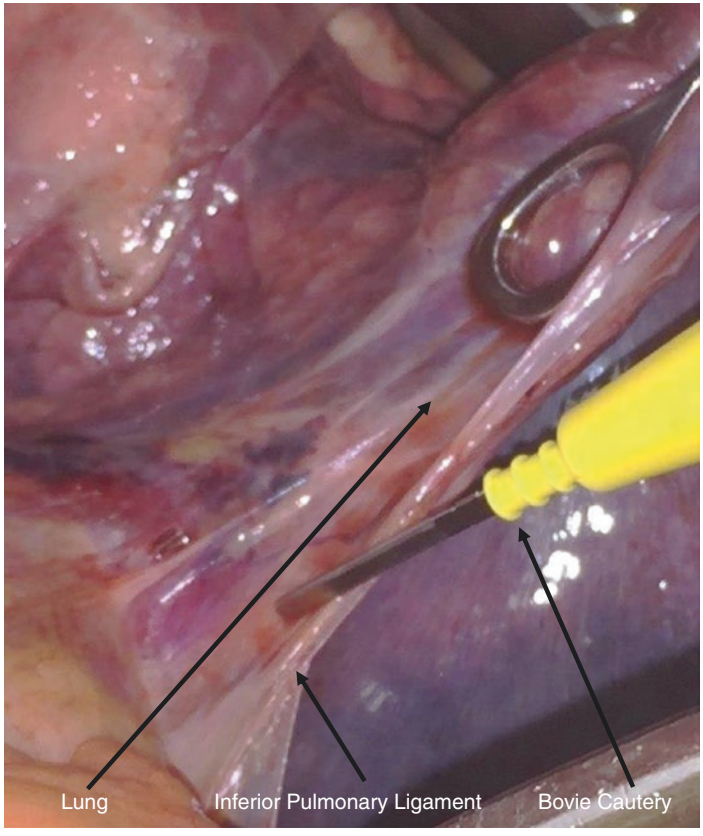

FIGURE 9.1 Dividing the inferior pulmonary ligament

evolved and include pneumonorrhaphy, tractotomy, and nonanatomic pulmonary resections. These less extensive procedures often utilize staplers and have shorter operative times, decreased blood loss, and less parenchymal loss, all of which may contribute to improved outcomes [9, 10]. One should still be familiar with all the possible surgical options but be prepared to perform a more extensive resection if lung-sparing attempts fail [11]. When performing any type of lung procedure, adequate exposure is essential. This is

accomplished by choosing the most appropriate incision as described earlier and by complete mobilization of the lung after entering the thoracic cavity. This includes lysing any pulmonary adhesions [7].

Pneumonorrhaphy

This is a common technique in which hemostasis is achieved and air leak sealed by direct suturing of the actively bleeding pulmonary injury (Fig. 9.2). A running locked suture technique can be employed to help achieve hemostasis [12]. This should only be utilized on peripheral superficial pulmonary injuries. Entry and exit injuries from penetrating wounds should usually not be oversewn since hemostasis may not actually be achieved. The risk is that only visible bleeding may be controlled while active hemorrhage may remain hidden, with continued, uncontrolled bleeding into the underlying pulmonary parenchyma risking the formation of an intrapulmonary shunt, bronchopulmonary fistula, aspiration, pneumonia or infection, and ARDS respiratory failure [2, 9, 13, 14].

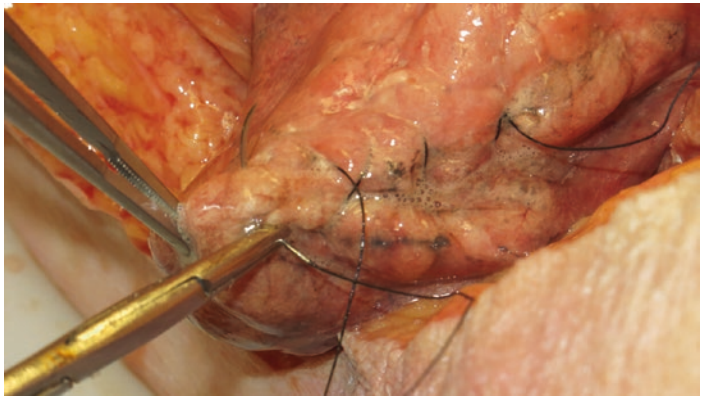

FIGURE 9.2 Pneumonorrhaphy

Tractotomy

This is a technique to rapidly control deep pulmonary parenchymal bleeding that does not involve the hilum or central bronchial vascular structures. It helps avoid a pulmonary resection, which was historically performed for such injuries, thus preserving lung tissue while preventing retention of a parenchymal hematoma [1, 11, 14, 15]. The sites of the entry and exit wounds are identified, and lung clamps are placed along the injury tract (Fig. 9.3). A GIA or TA stapler is placed through these openings and fired, which opens the injury tract. Bleeding vessels and injured airways are identified and ligated with absorbable suture. After controlling bleeding and air leaks, the pulmonary tissue can be closed with a running locked suture, or if feasible, the edges can be stapled [8, 12, 14, 15]. Once these techniques of air leak and bleeding control are completed, the stapled edges of lung tissue may also be sutured together to reapproximate divided parenchyma.

Patients treated with tractotomy often have shorter operative times and lower blood loss relative to formal lung resection. These patients also have less severe hypothermia and coagulopathy. If while performing a tractotomy it becomes evident that bleeding cannot be adequately controlled, often due to a more central injury location, conversion to a more extensive resection should be considered early [13].

Postoperative complications include bleeding and respiratory failure. Bleeding may either be by surgical or secondary to coagulopathy and should be carefully assessed by the surgical team. These patients also need aggressive postoperative pulmonary toilet due to the common occurrence of atelectasis and lobar collapse, which may also require repeated bronchoscopy for secretion clearance to maintain adequate parenchymal aeration [15]. An increased risk of infection has also been reported for those treated with tractotomy [10]; however, these data are limited.

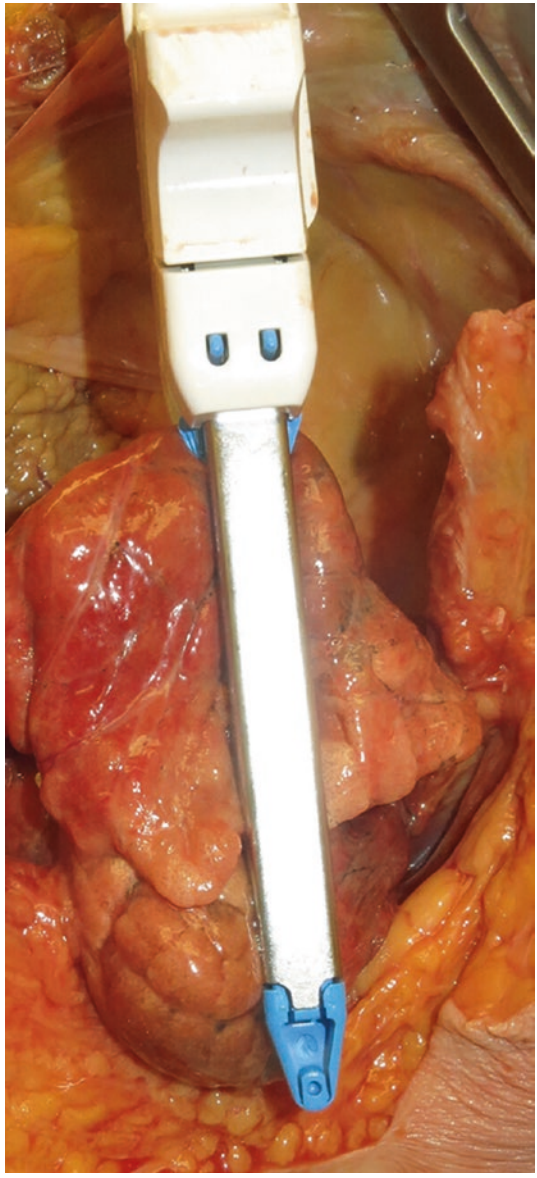

FIGURE 9.3 Tractotomy: a GIA stapler placed through the entry and exit wound sites

Wedge Resection

These are small nonanatomic lung resections of peripheral injuries with surgical staplers [1] with the goal of minimizing the amount of resected normal lung parenchyma. These less extensive nonanatomic resections should be utilized when possible to help avoid the associated morbidities of a formal anatomic lobectomy in a trauma setting [9, 10].

The procedure is often straightforward and is performed by firing a linear cutting stapler across the lung tissue, just under the damaged parenchyma requiring resection which is stabilized with a lung clamp (Fig. 9.4). The staple lines should then be inspected to ensure no air leak and with adequate hemostasis [16]. If necessary, the staple line can be reinforced with an additional firing or be oversewn.

Anatomic Resection: Lobectomy and Pneumonectomy

This procedure is usually reserved for central injuries or extensive lobar involvement involving a complex injury that cannot be managed via limited resection [4, 13]. Most anatomic resections are for hemorrhage control, major bronchial injury, a hilar injury, or significantly damaged lung

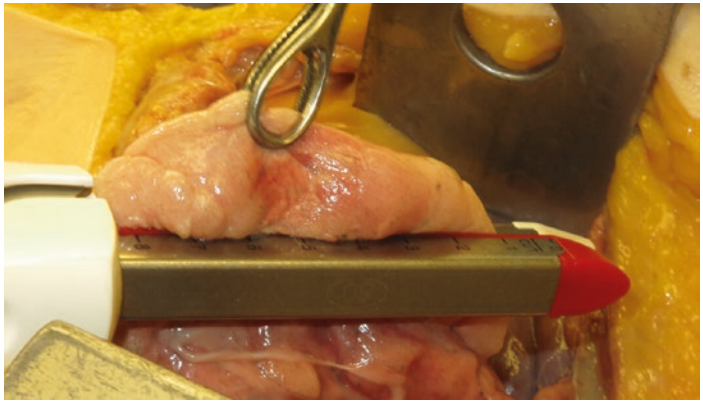

FIGURE 9.4 Right lower lobe wedge resection with GIA stapler

parenchyma in which lung salvage is not feasible. In a case of extensive parenchymal injury isolated to one lobe, it may be managed with a formal lobectomy. This may be performed in a standard anatomic approach or in a more expedited stapled fashion. Anatomic resections have been utilized more often for injuries in proximity to the main pulmonary artery or when stapling was not considered a viable safe option, while stapled lobectomies were often performed in patients who were more unstable and following blunt trauma [10]. A major hilar injury with resulting hemorrhagic shock may require a pneumonectomy. Control of hilar bleeding is challenging, and some techniques that have been utilized include manual compression of the hilum, clamping the hilum en masse, and lung twisting (Figs. 9.5 and 9.6). Proximal hilar

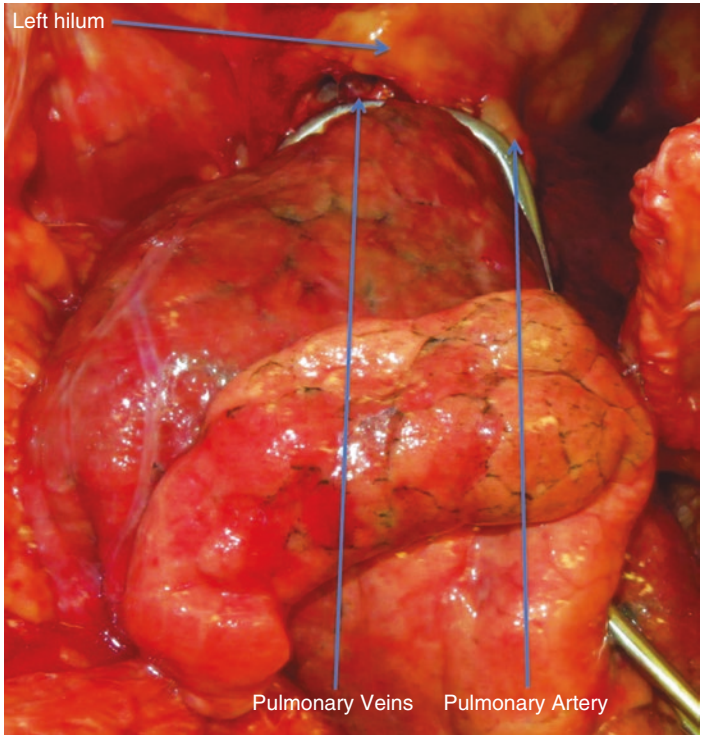

FIGURE 9.5 Clamping the left pulmonary hilum. Left main bronchus not visualized

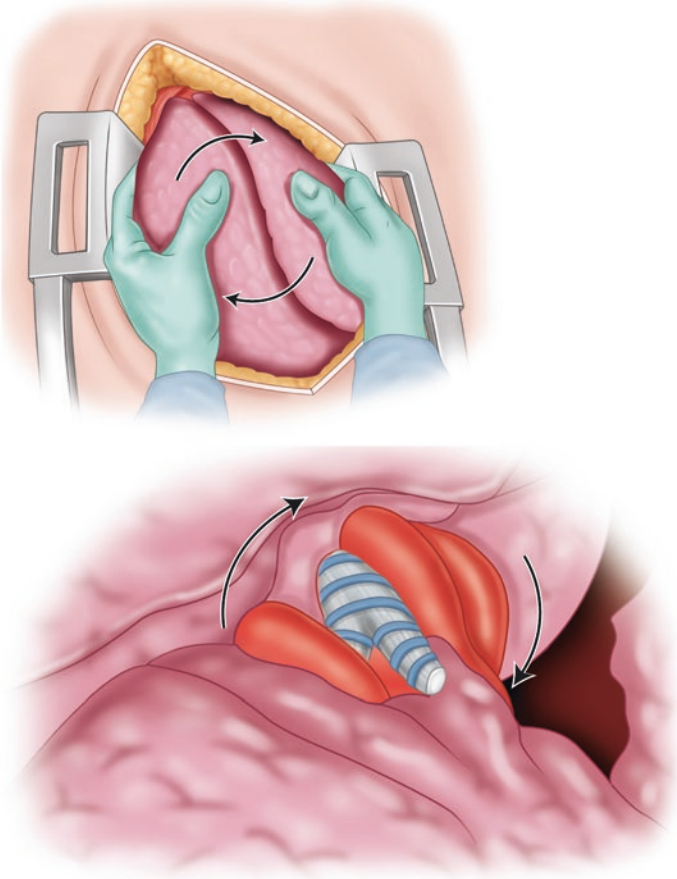

Figure 9.6 Pulmonary hilar twist. The pulmonary hilar twist being performed by rotating the upper and lower lobes clockwise, thereby occluding the proximal pulmonary vasculature

injuries may require opening the pericardium in an attempt to achieve vascular control [7] (Fig. 9.7).

Ideally, the pulmonary artery and vein branches are individually isolated and ligated, often with a vascular load of a stapler. Suture ligation with vascular sutures can also be used. The main stem bronchus is then also stapled, taking care to leave a short stump. If the patient is in extremis, the entire lobe may be resected en masse with a stapler (Fig. 9.8).

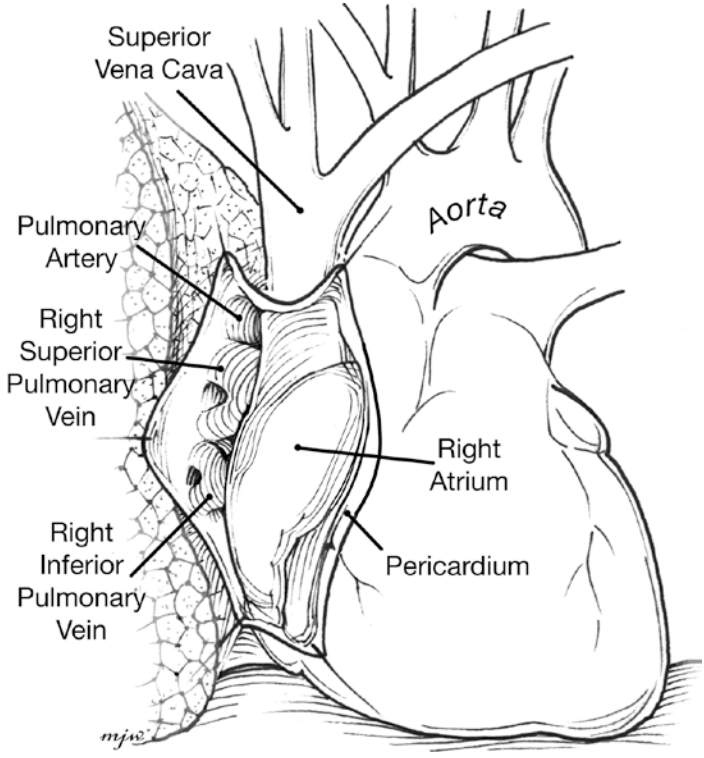

FIGURE 9.7 Intrapericardial exposure of the right hilum. Pericardial incision with exposure of the pulmonary veins lateral to superior vena cava and right atria

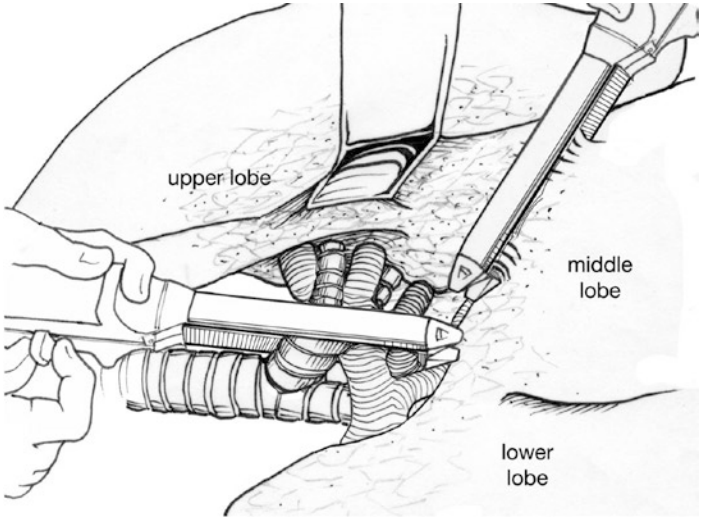

FIGURE 9.8 Stapled lobectomy. An expedited stapled lobectomy performed with a GIA stapler dividing the bronchus and vessels en masse and a GIA stapler dividing the fissure

If possible, we prefer to cover the bronchial stump closure. This is desirable in the event of lobectomy, but we feel more strongly if a pneumonectomy has been performed. Many options exist. Mobilizing an intercostal muscle is the easiest and is usually bulky enough to provide coverage (Fig. 9.9a, b). A tongue of pericardium or diaphragm also can be used. It can be made as large as needed. Finally, either a latissimus dorsi or pectoris flap can be used. These are bulky and provide the best coverage.

Trauma pneumonectomy is associated with significant postoperative morbidity and mortality. This is often associated with right heart failure due to an acute increase in pulmonary vascular resistance, with recent data showing worse outcomes when pneumonectomy is performed after blunt trauma [17]. The most important decision is to decide to do the pneumonectomy early. Acute right heart failure, while common, can be minimized if the procedure is performed

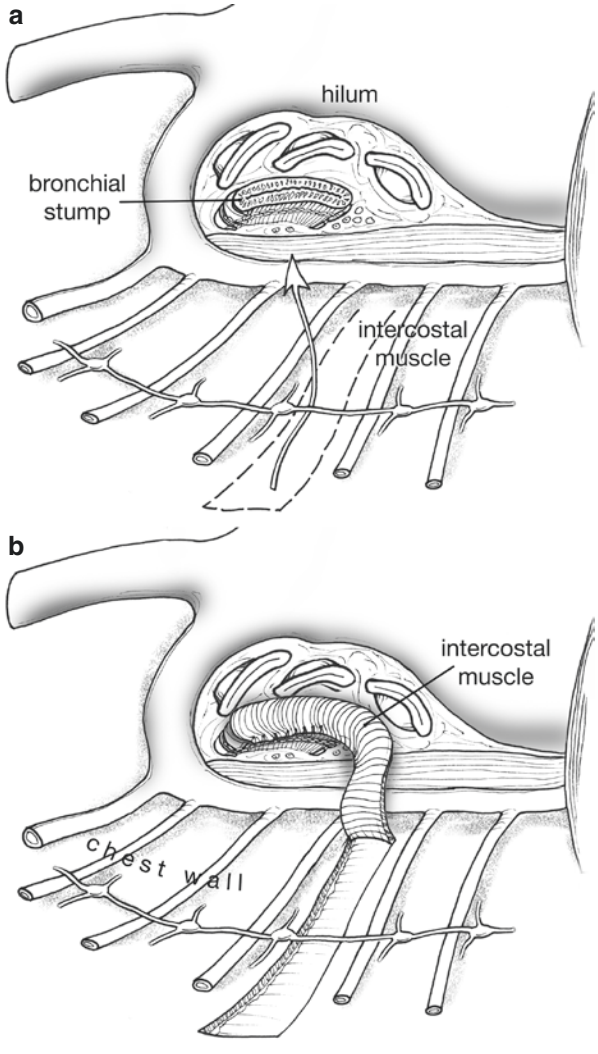

FIGURE 9.9 (**a**, **b**) Intercostal muscle flap. (**a**) Construction of intercostal pedicle flap adjacent to right hilum before application of the pedicle flap over the bronchus. (**b**) Flap applied to bronchus and suture applied to peribronchial tissues

early, before the patient is in refractory shock. We often begin supportive therapy such as pulmonary artery vasodilators and vasodilating inotropic support in the OR. A transesophageal echocardiogram can provide useful information. Finally, we typically leave the pericardium open to allow room for the right side of the heart to swell to avoid tamponade. There are also some limited experiences that suggest early initiation of ECMO support that may also improve outcomes [18]. In contrast to elective pneumonectomy which often does not have continuous post-op drainage of the pleural cavity, trauma pneumonectomy patients will often require at least passive drainage due to concern for postoperative bleeding and coagulopathy. The chest tube should be connected to water seal but not suction.

Damage Control

The principle of damage control involves an abbreviated operative procedure in which life-threatening hemorrhage is controlled, the chest is temporarily closed, and the patient is taken to the intensive care unit. Once stabilized physiologically, the patient is returned to the operating room for definitive management and chest closure [19]. Patients with severe chest trauma and associated physiologic derangements with associated shock that requires emergent thoracic operations should be considered for a damage control approach. The temporary chest closure helps prevent thoracic compartment syndrome while the patient is resuscitated in the intensive care unit [20]. Specific types of pulmonary wounds include those with penetrating thoracic injuries and a systolic blood pressure <90 mmHg and those patients who underwent an emergency department thoracotomy [21].

Maneuvers for thoracic damage control for severe pulmonary injury include cross clamping the pulmonary hilum, stapling across the hilum, and the hilar twist. The hilar twist involves taking down the inferior pulmonary ligament and rotating the lower lobe up, thus twisting the major pulmonary

vasculature and controlling the hemorrhage. Formal lung resections and classic control of the hilar vasculature are deferred for these faster techniques [22–24]. Other thoracic damage control strategies include utilizing large staplers for nonanatomic wedge resections and tractotomy. Suture closure of deep entry and exit wounds to the lung with significant bleeding and air leak should be avoided in order to prevent air embolism and continued intraparenchymal bleeding with subsequent infection [23, 24]. Finally, other considerations to minimize morbidity include minimization of excessive fluid infusion and attempts at blood salvage with cell savers or autotransfusion [25].

Post-op Complications

Postoperative complications are common following thoracic trauma procedures with atelectasis and persistent air leaks as two of the most frequent ones. Treatment of atelectasis involves early mobilization, incentive spirometry, nasotracheal suctioning, and aggressive secretion management that may also necessitate bronchoscopy. Air leaks often resolve, but additional procedures such as bronchoscopy and even reoperation may be necessary for leaks lasting longer than a few weeks. Development of a delayed leak is often associated with infection and requires immediate drainage and antibiotics and if no improvement surgical repair of the bronchial stump with a buttressed closure. In general, mortality and morbidity increase with extensiveness of pulmonary resection. In particular, traumatic pneumonectomy patients have greater than 50% mortality and overall very poor outcomes. Other morbidities include infection, pneumonia, respiratory failure, coagulopathy, and empyema [4, 26]. An important early intervention to try and reduce such postoperative complications is early bronchoscopy. This procedure is frequently performed immediately upon conclusion of the operation in which residual blood and clot is removed from the airways. This helps clear the airways,

which optimizes a patient's oxygenation and ventilation while simultaneously reducing the potential for infection and should be considered a routine procedure.

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