Chapter 14
Lung Injuries in Combat

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Deployment Experience:

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BLUF Box (Bottom Line Up Front)

1. Blast mechanisms often create a deadly combination of blunt lung injury (contusion) and penetrating parenchymal damage.
2. Simple chest tube drainage has a much higher failure rate than in civilian lung injuries – be prepared to operate!
3. Damage control surgery and temporary closure is not only for the abdomen – use it.
4. You do not need a CT scan to diagnose these injuries or to determine if an operation is needed.
5. Lateral decubitus positioning and double lumen endotracheal tubes are time-consuming luxuries that most bleeding patients can't afford.
6. The only VATS in combat trauma is Very Aggressive Thoracic Surgery.
7. Avoid retained hemothoraces by doing it right the first time – this means in the OR.
8. Pulmonary tractotomy is a great technique – and you will almost never use it. Most combat lung injuries will require anatomic or non-anatomic resection.
9. Review your thoracic anatomy and surgical techniques – consulting Cardiothoracic Surgery is usually not an option.
10. Don't forget about air embolus – it can kill you patient faster than hemorrhage.

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In massive insults to the organism, treat the patient for the insult, without waiting for the response to the insult.

Mark Ravitch (1910–1989)

This chapter is based on two universal truths in combat trauma: (1) You WILL be faced with severe thoracic injuries that require quick decisions and operative intervention, and (2) Most of you are not fellowship trained cardiothoracic surgeons and will not have one immediately available. You may be given the advice that "damage control in the chest is just like damage control in the abdomen" – don't be lulled into complacency. Losing the comfort level and deep understanding of anatomic relationships that you have in the abdomen makes combat chest surgery an entirely different and often unforgiving adventure. There are two things you can do to set yourself up for success in thoracic trauma – Prepare and Practice. Prepare by reviewing any anatomy text or surgical atlas to get familiar with the critical structures and relationships as well as basic operative techniques. Practice by either scrubbing in to elective thoracic cases if you can, or by reviewing common thoracic injury scenarios and how you will handle them. Do not forget the most basic lesson of the soldier – **"you will fight as you train."**

Surgical Approach ("You Can't Get There from Here")

The previous chapter describes in detail how you should approach chest injuries in combat trauma and the choice of incisions. The main point that cannot be repeated often enough is that you should almost always be approaching these injuries through an anterolateral thoracotomy or median sternotomy, with the patient supine. Inexperienced trauma surgeons use "elective" surgical approaches aimed at maximizing ease and exposure at the expense of flexibility and options. A good combat surgeon will accept less than perfect (although always adequate) exposure to maintain the maximal amount of flexibility and options. If you break this basic rule then you will inevitably end up with the patient in a lateral decubitus position when you realize that the bleeding is actually coming from the abdomen, the mediastinum, or the other side of the chest. You can do everything you need to do through an anterolateral thoracotomy – just make sure your incision is long enough and you have adequate self-retaining retraction. Rapid entry into the chest can be obtained with one or two aggressive swipes of the scalpel through skin, fat, and muscle followed by wide opening of the remaining intercostal muscle fibers and pleura using heavy scissors. The best, and most underutilized, maneuver to improve exposure is to extend your skin incision medially for 5–10 cm onto the opposite chest and divide the sternum. Now that you're there, establish your priorities and get to work.

Damage Control Principles in the Chest (This Ain't The Abdomen)

Just like a combat trauma laparotomy, a damage control approach should be your default when operating on major traumatic lung injuries. Do what needs to be done immediately and what the patient will tolerate, and then get out to finish the fight another day. But that is where the similarities to abdominal damage control end. In the abdomen the only *immediately* life-threatening concern you need to focus on is controlling hemorrhage. This is usually not the case in the chest. Tension pneumothorax, cardiac tamponade, arrhythmias, refractory hypoxia or hypercarbia, and the dreaded air embolus are all quick and silent killers that need to be on your mind and rapidly addressed or prevented. Close coordination with your anesthesia provider in these cases is of the utmost importance, particularly in the setting of lung injury. Do not waste time trying to get a double lumen endotracheal tube or bronchial blocker in perfect position before starting the operation – you will usually lose much more than you gain and it can wait until you have bleeding controlled. Some simple manipulations of the tidal volume and respiratory rate or positioning of the endotracheal tube (i.e. advanced to right mainstem) can make your life a whole lot easier and get the inflated lungs out of your way.

Just like in the abdomen, hemorrhage control is goal number one. Packing is not the first maneuver, particularly when the chest is full of blood! Rapidly scoop out the clot with your hands and then use some dry lap pads and suction to remove the remainder of the pooled fluid. Now assess the hemorrhage and determine if the bleeding can be easily controlled with manual compression or clamping – if so, proceed with definitive control. If you have large volume hemorrhage or bleeding from multiple sites then go ahead and pack the cavity, make sure your anesthesia provider is catching up and ready for more bleeding, and then begin pack removal and hemorrhage control. If the volume of bleeding is too great to allow for packing to assist in visualization, use your fingers as a clamp to occlude the main pulmonary artery and vein at the hilum while an assistant works on using sponges and a sucker to clear out the blood. If no assistant is available a large vascular clamp can replace your fingers to accomplish the same goal. At this point you can gradually release the hilar vessels to better localize the bleeding source. A kidney pedicle clamp is common in the field, although a larger, more gently curved, and less traumatic clamp if available is a better choice. Adequate exposure, retraction and packing of lung, and strong suction are your best allies for localizing the bleeding and obtaining control.

In addition to hemorrhage, you must also consider and address the several other quick killers listed above. Opening the chest has removed the possibility of any tension physiology on that side, but don't forget about the contra-lateral chest. Be liberal about putting in a chest tube on the other side to rule out significant bleeding or pneumothorax. If you are using a median sternotomy, you can incise both pleura and open them widely with your fingers. If you are faced with life threatening hypoxia or

hypercarbia, then quickly look for a potentially treatable source such as a massive air leak from lung parenchyma or an injury to the proximal airways. Maximize ventilation of the normal lung by advancing the endotracheal tube to mainstem the opposite airway, placement of a bronchial blocker, or a double lumen tube. All of these take some time so try to control the air leak by clamping the lung or airway proximal to the site of injury. This may entail clamping the entire lung hilum for a very proximal injury, even using your fingers as a clamp initially as described above. Alternatively, if you have good exposure and visualization you can rapidly suture the injury and return later for definitive repair. For proximal airway injuries, use absorbable suture such as PDS or Maxon in case your rapid repair turns out to a durable one.

Don't forget about air embolism! It is a relatively common and often unrecognized killer in patients with a pulmonary laceration who have the potential for air entry into the pulmonary venous system. There are several things you can do to minimize the chance of an air embolus: rapid control and compression of the injured lung segment, proximal pulmonary hilar clamping, low pressure ventilation until the injury is controlled, and submerging the injured area under saline. If your patient experiences sudden cardiac decompensation with no other obvious source then air embolism should be assumed and you can follow the management principles outlined in the next section.

Performing a damage control closure of the thoracic cavity can be more complicated than the abdomen. Simply packing the cavity and closing is usually not an option, particularly when there is bilateral lung injury and the patient won't tolerate complete compression of one lung. Other factors you must consider are creating a tension pneumothorax or tamponade by closing the cavity without adequate drainage, and maintaining some degree of normal respiratory or chest wall mechanics. In any chest closure, you must leave adequate large bore chest tube drainage. In general, nothing less than two 32F tubes is adequate after a trauma thoracotomy, especially if transport out of theater is in the patient's near future. My preferred temporary closure is using a large monofilament suture incorporating muscle, fascia, and skin in an en masse running and locked closure. This will create a tight closure and control bleeding from the wound margins better than a skin-only closure. Rapid skin only closure can also be performed with a running suture, staples, or towel clips. Alternatively, the wound can be closed without suture by manually holding the wound edges together and applying a large Ioban dressing. Ioban is also useful in a complex incision that doesn't come together adequately and there is concern for air leak. Don't forget bleeding from your incision! The chest wall musculature, intercostals vessels, and internal mammary arteries will all bleed significantly if not properly assessed and controlled before leaving the OR.

Pneumothorax and Hemothorax

Pneumothoraces are relatively common in combat trauma, although the isolated pneumothorax without an associated hemothorax or other significant chest injury is much less common than in civilian trauma. Physical exam diagnosis is often

difficult, particularly in the noisy and chaotic trauma bay. You should familiarize yourself with the simple and highly reliable technique for ultrasound diagnosis of a pneumothorax (see Chap. 6) as you may not have x-ray immediately available. You will see many patients arrive with needle catheters placed in the field – these are often placed unnecessarily and frequently never actually penetrate into the thoracic cavity. You are not automatically obligated to place a chest tube – assess the patient and if their pulmonary status is stable, remove the needle and do your ultrasound or chest x-ray. If there is associated blood, then a large bore chest tube placed in the standard fashion (posteriorly to the apex) is appropriate. If it is an isolated pneumothorax then you are often better off placing a smaller tube in a more anterior position, and guiding it along the anterior chest wall to the apex.

Hemothorax in combat injuries should raise your concern for associated severe intra-thoracic injuries, continued bleeding, and the possible need for an operation. While the majority of civilian hemothoraces can be managed with tube thoracostomy only, we have found that to be much less successful in the combat setting. Always remember the limitations of your surroundings – the trauma bay in any forward deployed facility is a highly contaminated, crowded, and unsterile environment that is not optimized for procedures. You will also not have VATS available to easily manage problems like a retained hemothorax or empyema. If your patient has a significant hemothorax that requires chest tube drainage, then the best place to do that is in the controlled and more sterile environment of the operating room. If you make your incision slightly larger than usual (3 cm is fine) you can pass a large suction catheter into the chest to thoroughly evacuate the blood and perform large volume irrigation prior to placement of the chest tube. This way you are also prepared to rapidly get into the chest for persistent or large volume bleeding, massive air leak, or other injuries requiring surgical intervention.

Lung Parenchymal Injuries

Injury to the lung parenchyma will be the most common problem you will face when operating in the chest. Fortunately it is usually not difficult to quickly identify the exact area of injury and to gain at least temporary control of bleeding. The injured area will typically demonstrate continuous low volume bleeding and will likely also have a visible or audible air leak. The first instruments you should be sticking into the chest to control bleeding should always be your hands. Simple bi-manual pressure on the injured area is usually sufficient to control bleeding and will also improve handling by compressing air out of the lung tissue. It may also be helpful to have the anesthesia provider lower the tidal volumes or advance the endotracheal tube to mainstem the opposite bronchus to facilitate exposure. Even with both lungs being fully ventilated, you can collapse the ipsilateral lung by applying gradual and continuous pressure during exhalation with laparotomy pads and then maintain the exposure with a self-retaining retractor.

Normal lung tissue is relatively fragile, so injured lung tissue is extremely easy to tear or disrupt with improper or overly aggressive handling. Use only your hands initially to expose the lung and compress the area of hemorrhage. Grasping and retracting the lung is aided by using a small lap pad or gauze for traction, but do not pull the tissue perpendicular to the injury as this will enlarge the parenchymal disruption and worsen the air leak. Duval lung clamps are available in the field and can be a useful adjunct when manipulating the lung. Additionally, using Duval lung clamps to temporarily oppose injured lung tissue can control the air leaks initially and free your hands to continue exploring the chest and deal with more urgent matters.

After you have adequately controlled hemorrhage and assessed parenchymal injuries, you must decide on the most expedient and complete method to control air leaks while at the same time preserving lung tissue (see Fig. 14.1). Young healthy soldiers will tolerate a significant amount of lung tissue loss, so do not be worried about large stapled wedge resections. The choice of staple load will depend on the thickness of the tissue to be divided; however staples with a depth of 3.5–3.8 mm in a linear stapler (this translates into a blue or gold Ethicon GIA load) are good choices that work in all situations. For missile wounds through the lung tissue, a stapled tractotomy (Fig. 14.2) may be an adequate method to initially control air leaks as well as get to the source of bleeding. One arm of the stapler is placed through the missile tract and the lung above the tract is divided. You may need more than one load to accomplish the above goals. Inspect the opened missile tract and ligate large vessels and air leaks with suture as needed. Pneumonorraphy, or over sewing of the entrance and exit wounds, should be avoided. You may not have an appropriate stapler or staple loads, so an alternative is to use clamps to secure and divide the tract (Fig. 14.3).

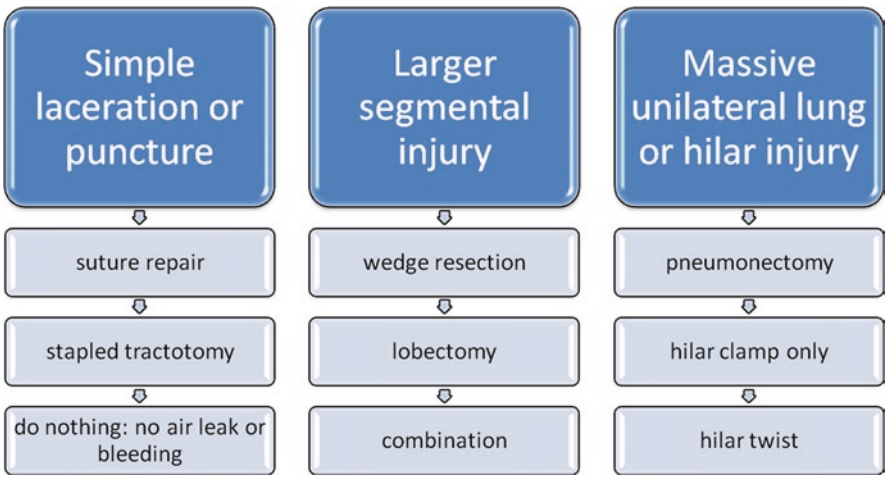

Fig. 14.1 Diagram outlining operative management strategies to consider based on the type and degree of lung injury

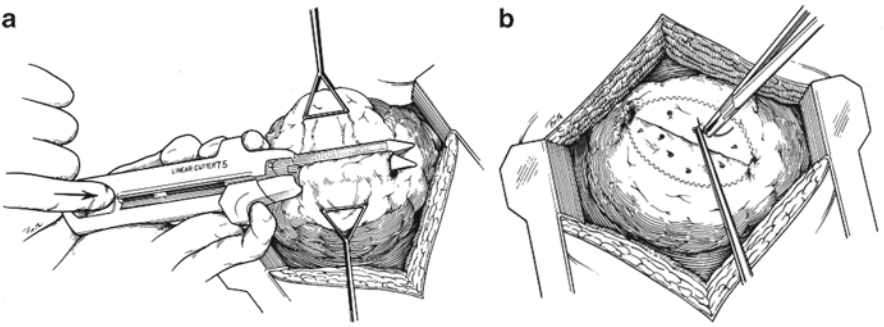

Fig. 14.2 Stapled tractotomy for a penetrating through and through lung injury. A linear stapler is passed through the defect and fired (**a**), opening the tract and exposing the underlying injured lung tissue. Direct suture repair of bleeding and parenchymal disruption can then be performed (**b**). (Reprinted with permission from Asensio et al., J Am Coll Surg 1997;185:486–487)

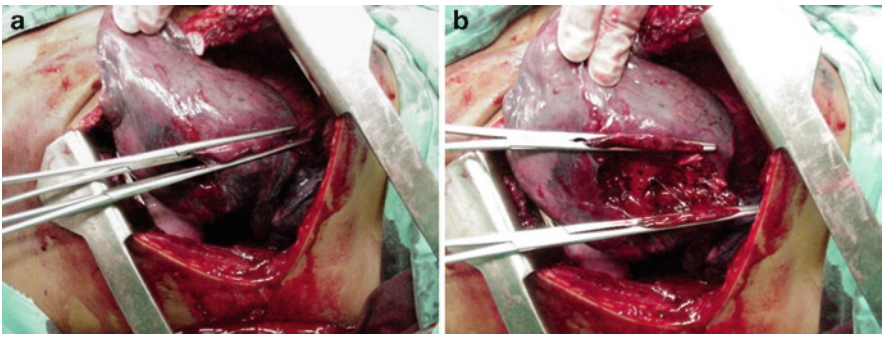

Fig. 14.3 Pulmonary tractotomy performed with large non-crushing clamps placed through the defect (**a**) and then sharp division of the tract to expose the underlying injured lung (**b**)

Do not expect a stapled tractotomy and a couple of stitches to be the answer for most combat type injuries. Unlike civilian low-velocity injuries, a high velocity missile or multiple fragments will deform or devascularize the tissue so severely that a tractotomy is not an option. For most peripheral injuries, the damaged lung can be wedged out with a stapler. Manually compress the area to be resected during exhalation to flatten it for placement of a linear stapler. Do not buttress the staple line with suture as you will likely make things worse. Some residual air leak is acceptable and expected. However, if a significant amount of tidal volume is being lost during ventilation, there is a tremendous observable air leak in the operative field, or the chest tubes placed are not adequately draining the pleural space as evidenced by a persistent pneumothorax on a post-operative chest x-ray, additional lung resection may be necessary. In the operating room, place water (sterile water works best, saline is okay) in the chest to try to localize the majority of the remaining air leak. A large volume air leak that can be isolated to a particular lobe that cannot tolerate more staples will likely need a formal lobectomy. Do not leave your patient

with a massive broncho-pleural fistula in the name of preserving an already damaged lobe – he will be much better off with a little less lung than with ongoing air leaks and contamination.

When operating in a controlled environment, lobectomy is a precise and deliberate operation that can be challenging. Without a solid idea of normal anatomy and the major variations that can be seen from one side to the other, a trauma lobectomy can quickly become a frustrating operation. While a thorough anatomical review is beyond the scope of this chapter, there are several points that will help you successfully complete the case. As a general rule when approaching the pulmonary arteries, be gentle as this artery does not have the same characteristics of arteries in the systemic circulation due to the low pressure of the pulmonary arterial circulation. They tear easily, they do not hold suture well, and have a tendency to dissect when handled roughly. The pulmonary artery branch vessels are especially fragile and can be transected by suture that is snugged down too tightly in the heat of battle. If you decide to individually suture ligate the branches of the pulmonary artery, be sure to use stick ties in addition to your ligatures. If a pulmonary artery is bleeding after being tied or stapled, avoid the urge to continue placing ligatures or stick ties. Remember this is a low pressure system so surgicel or a similar topical hemostatic agent should be placed with a sponge over the area of concern initially; this type of bleeding almost always stops without further intervention. The pulmonary veins are much more forgiving and will tolerate some manipulation. When possible, use linear staplers with a vascular load for all pulmonary arteries and veins; it is a quick and reproducible technique. If space seems limited in the chest for using standard linear staplers, consider using an endoscopic linear stapler if available. They can be placed through chest tube sized holes to allow for a better angle of approach to vascular structures.

The Pulmonary Hilum: Tread Lightly

Hilar anatomy is very predictable and constant between the two thoracic spaces (Fig. 14.4), while lobar and segmental anatomy is highly variable. As you look into the chest while standing at the patient's injured side, which will likely be through an anterolateral thoracotomy, reflect the lung posterior and laterally (toward yourself) so that branches of the pulmonary vein can been seen. They are usually overlying the pulmonary artery and usually must be divided first. This relationship is especially critical when removing the upper lobe as these two structures may be so closely associated, it will be difficult to distinguish them in a bloody field. The bronchus will be slightly deep to the pulmonary artery from this aspect. While this is great exposure for a pneumonectomy, additional manipulation of the lung superiorly and inferiorly will allow exposure of vascular structures to the individual lobe. As the lung is mobilized, retraction of the lobe needing resection anteriorly (away from you) will facilitate the dissection.

A good place to start with any lobectomy is with division of the pulmonary ligament and incision of the pleura surrounding the lobe to be removed; both of these

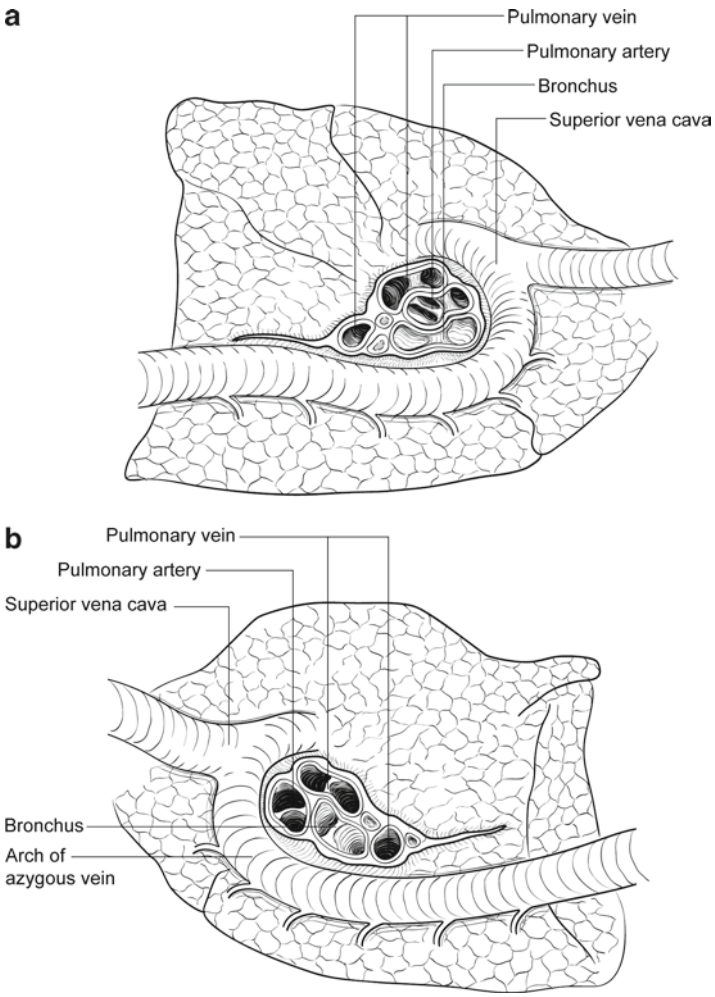

Fig. 14.4 Diagram of the pulmonary hilar anatomy for the *left* (**a**) and *right* (**b**) lung as seen from an anterolateral thoracotomy approach

maneuvers allow for better lung mobilization. Identifying the pulmonary artery deep in the major fissure is the easiest method to begin identification of pulmonary artery branches. Umbilical tapes and Rummel tourniquets are handy to have in order to isolate arterial branches you are not initially certain about or as a way to help guide the anvil of a stapling device. An umbilical tape is also useful when completing a fissure. After using a combination of your fingers and a kidney pedicle clamp to determine where the fissure should be completed, pass an umbilical tape through the space you created to guide the anvil of your stapler. Exposure and identification of key structures is aided by alternating your exposure dissection between an anterior and posterior approach – once the anterior dissection is done

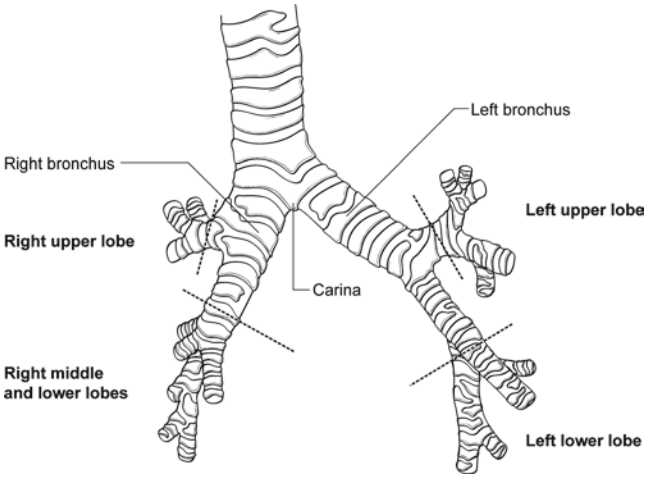

Fig. 14.5 Diagram of the basic bronchial anatomy, with dotted lines indicating the line of bronchial division for a formal lobectomy

or cannot proceed any further safely, flip the lung away from you and approach the lobar hilum from the posterior side. An understanding of the basic bronchial anatomy is particularly critical for identification and control of the correct bronchial structures (Fig. 14.5).

When operating on the right side, do not go through a great effort to spare the middle lobe, especially when removing the upper lobe as they share venous drainage from the superior pulmonary vein and the minor (or horizontal) fissure is usually incomplete. The middle lobe is easier to preserve when removing the lower lobe as the major (or oblique) fissure is often well-formed. As the pulmonary artery is exposed in the major fissure, look for a posterior ascending arterial branch to the posterior segment of the upper lobe. This will need to be divided in addition to the branches off the superior pulmonary trunk when removing the upper lobe. When the lower lobe is being resected, care must be taken to preserve this branch as it is easy to inadvertently divide when completing the major fissure. An additional technique to assist in exposing structures for procedures on the right upper lobe is to divide the azygous vein.

As on the left side, be aware of pulmonary artery branches supplying the upper lobe as the main artery travels through the interlobar fissure. Specifically, there may be one or two lingular branches as well as a smaller artery to the posterior subsegment of the anterior segment of the upper lobe. These three vessels may also exist as a common trunk. Vessels to the lower lobe should take off from the pulmonary artery directly opposite from the lingular branches. At times the bronchus to the superior segment of the lower lobe must be divided separately. If you have a large air leak after a left lower lobectomy, look for this portion of the bronchus to ensure it is secured.

Pulmonary Hilar Control

As with all pulmonary injuries that present to the surgeon with a field of frothing blood, it is imperative to gain immediate control of hemorrhage with techniques described above and elsewhere in this book. If you have adequately controlled bleeding and air leaks from the lobes and you are still having difficulty, look centrally. You will be faced with deciding if the injury is vascular, tracheobronchial, or both. You can gain immediate and rapid hilar control with your hand without any mobilization – simply retract the lung laterally and encircle the hilar structures which are tethering the lung to the mediastinum with one hand (Fig. 14.6). This will gain time for you to do a little mobilization and switch out your hand for a vascular clamp. Incise the inferior pulmonary ligament for 2–3 cm to allow full retraction of the inferior lobe, but beware that further division will lead into the inferior pulmonary vein. You can now pass a large straight or slightly angled vascular clamp across the proximal hilum and clamp tight enough to compress both the bronchus and the vessels. An alternative technique that has been described is the "hilar twist," which is accomplished by dividing the inferior pulmonary ligament and then rotating the lung to twist the hilum and cut off pulmonary blood flow (Fig. 14.7). The lung is secured in the twisted position by placing packs

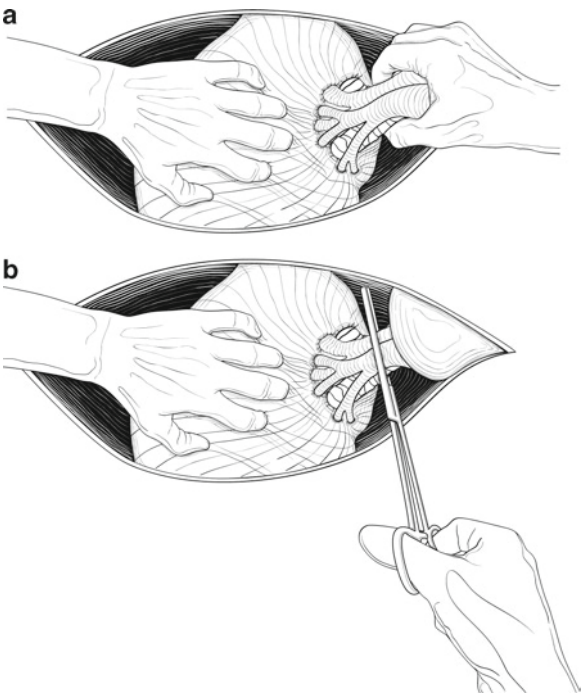

Fig. 14.6 Approach for obtaining manual control of the pulmonary hilum, followed by placement of a vascular clamp if necessary

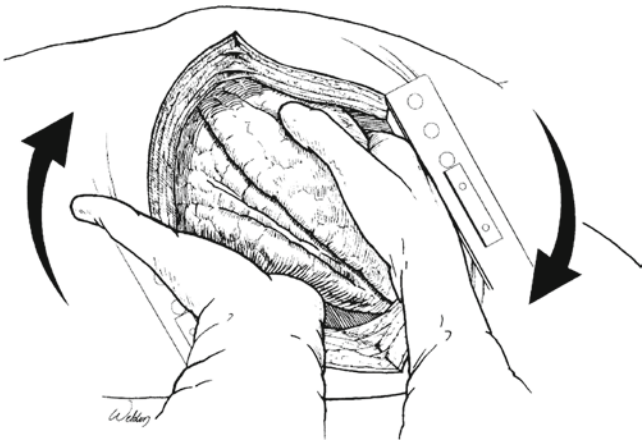

Fig. 14.7 Hilar twist maneuver for control of pulmonary hemorrhage. The inferior pulmonary ligament is released and the lung is then twisted clockwise 180° (reprinted with permission from Wilson et al., Am J Surg 2003;186:49–52)

superiorly and inferiorly, and then a damage control closure can be performed. Formal pneumonectomy can then be completed at a later time if needed.

Pneumonectomy (It Is Not a Dirty Word)

A pneumonectomy in the trauma setting carries a high associated morbidity and mortality, due to both the physiologic impact of the procedure as well as the severity of injuries. The key to a successful outcome in this scenario is making the decision early and performing the procedure rapidly and in concert with your anesthesia provider. Too often the pneumonectomy is performed as a "last-ditch" measure after an hour or two of failed attempts at lung salvage. Typical indications for a pneumonectomy will be massive multi-lobar injury, complex hilar injuries, or any significant injury that will require complex reconstruction in an unstable patient.

The only reason not to do a stapled pneumonectomy in the trauma setting is that you don't have a stapler available. Simple en masse ligation of the hilar structures should never be attempted – you will not be able to adequately compress the vascular structures due to the rigidity of the bronchus. This may be immediately obvious, or may manifest as sudden exsanguinating hemorrhage once the patient is better resuscitated and the blood pressure increases. There are several techniques to be aware of to perform an expedient trauma pneumonectomy. If you can gain control of the hilum with a large clamp or your hand, a stapled pneumonectomy is very simple and fast (Fig. 14.8). Pass a large TA stapler (at least 60 mm, possibly a 90 mm) through the space you created to encompass all vascular and bronchial structures. If you can safely pass a second stapler to create a doubled stapled pneumonectomy, this may make for a better long term result. Make sure you cross the "blood-brain

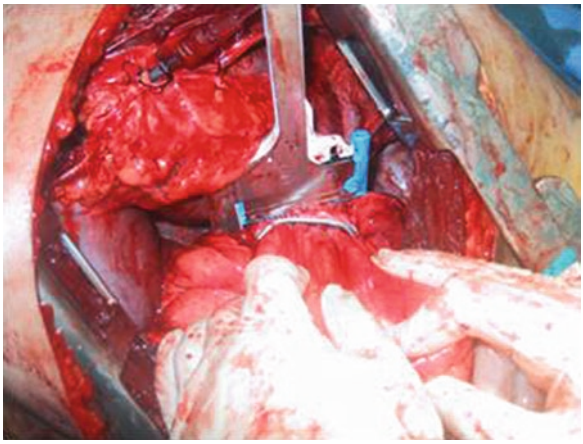

Fig. 14.8 A trauma pneumonectomy can be rapidly performed by en-masse stapling of the hilar structures once control has been obtained. One or two staple lines are applied and the hilum is then sharply divided

barrier" and communicate with the anesthesia providers at the head of the table! When you clamp the hilum you will not only take one lung out of duty, you will create massive right heart afterload which is often not well tolerated. We would recommend starting a dobutamine infusion with hilar clamping to improve right heart contractility and decrease the pulmonary artery pressures, and have additional vasopressors ready to go as needed. The patient will also likely require continued volume support as well as a high fraction of inspired oxygen and careful ventilatory management to avoid undue barotrauma to the remaining lung.

A large chest tube should be placed after pneumonectomy and placed to water seal, not suction. You want to ensure the mediastinum is balanced; if you find the mediastinal shift to the operated side is great enough to cause hemodynamic instability, introduce air into the empty pleural place and check your results with a chest x-ray. If you are unsure pneumonectomy is necessary and can get the patient out of the OR without this, pack the chest as necessary, make a temporary closure and plan to bring the patient back when better resuscitated. If a pneumonectomy is still indicated, a more controlled operation can be planned with deliberate dissection of the hilar structures, better securing of the bronchus, and less chance of injuring surrounding structures such as the phrenic and vagus nerves and esophagus. In several cases of ongoing lung hemorrhage that could not be easily controlled in a far-forward setting, topical hemostatic agents or dressings have been used along with packing to control bleeding and get the patient to the ICU or to a higher level of care. Figure 14.9 shows a granular hemostatic (QuikClot) which was applied by a Forward Surgical Team and achieved complete hemostasis until the patient reached a level III facility. Quick thinking and using all of the tools at your disposal will save lives in thoracic trauma.

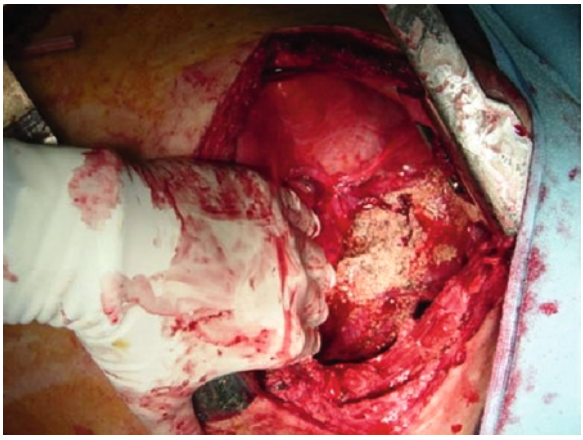

Fig. 14.9 Damage control thoracotomy with application of QuikClot topical hemostatic granules to diffusely bleeding area of lung and chest wall

Air Embolism

As mentioned above, air embolism is a quick and often unrecognized killer in the setting of major bronchial disruption with associated pulmonary vein injury. It can occur in both penetrating and blunt trauma, which includes blast injury. The best chance for survival is early control of the source of the air. A high index of suspicion is critical as associated injuries in the multi-trauma patient may have similar symptoms, which includes profound hypotension and sudden cardiac arrest. Remember that air entrained into the injured pulmonary veins will enter the left side of the heart, not the right. This makes it a very different entity that the usual air embolism seen with inadvertent air injected into a peripheral or central vein. A large amount of air can be tolerated on the right side, but an extremely small volume of air on the left side can be deadly. This is due to the impact of air bubbles entering the coronary arteries (as little as 0.5 ml into the left anterior descending artery) resulting in acute occlusion and cardiac arrest. Larger amounts of air may also cause significant neurologic injury if it reaches the cerebral circulation (Fig. 14.10).

The most critical point in management has been mentioned: control the air leak as quickly as possible by placing clamps across the injured lung parenchyma. If this is unsuccessful, clamp the hilum as expeditiously as possible. If there are no clamps immediately available, use your hands to compress the lung tissue or compress the hilum. You can also fill the chest with saline while awaiting the tools you need. Simultaneously, the anesthesia provider should be lowering airway pressures, attempting to exclude the injured lung by advancing the endotracheal tube to the uninjured side, placing the patient in steep head down position, and starting pressors and fluid to maintain blood pressure. As the surgeon, you

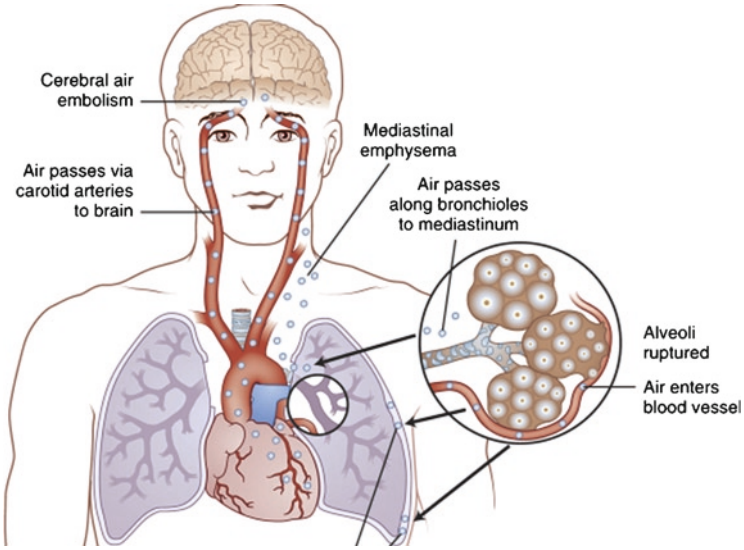

Fig. 14.10 Air embolism to coronary and cerebral circulation can occur with traumatic disruption of alveoli and pulmonary veins resulting in air entry into left ventricle via pulmonary venous return (modified with permission from Wilderness Trauma, Auerbach P. editor, Mosby Publishing, New York 2007)

must tell the anesthesia provider to do these maneuvers. At this point you will likely be resuscitating an arrested heart. If the left chest is already opened, clamp the descending aorta to help with hypotension and also help to flush the air through the arterial system. This should only be attempted if the air leak is controlled or you risk disseminating air to the rest of the organ systems. Additionally, open the pericardium and aspirate the left ventricle. If you have the right chest opened, divide the sternum, complete a clamshell incision, and proceed with the above maneuvers. The only option at this point is to continue to support the patient with open cardiac massage, defibrillation with paddles applied directly to the heart, and intracardiac pressors as needed. If you are successful in supporting the patient through this, consider leaving your clamps on the lung tissue in place, removing the aortic cross clamp, and temporarily closing the patient before undertaking a major pulmonary resection.

Evacuation

The medical evacuation process is covered in more detail elsewhere in this book. For the patient with a major lung injury, you can expect significant challenges in the postoperative hemodynamic and ventilatory management. You most likely will not have access to any advanced support modalities such as cardiopulmonary bypass, high frequency ventilation, or inhaled nitric oxide. When you max out your

standard ventilator settings and have 100% inspired oxygen running, you have nowhere to go and no room for any further deterioration. You must make evacuation arrangements for these high-risk patients as early and rapidly as possible. You may have a very narrow window of stability during which they could tolerate a transport ventilator to get them to a higher level facility with access to these salvage modalities. An alternative developed during the current conflicts in Iraq and Afghanistan is the Acute Lung Rescue Team (ALRT), based at Landstuhl Regional Medical Center. This group can bring advanced ventilatory modalities and a critical care transport team to the combat theater to evacuate patients who would otherwise not survive standard medical evacuation. Consult them as early as possible to avoid any delays in assembling or transporting the team where they are needed.

Final Points

Pulmonary injuries require the surgeon to operate outside their usual comfort zone on an injury pattern that can cause the rapid demise of the patient if not quickly addressed. There is no time to spare when addressing these injuries so be prepared prior to seeing one. Know what clamps, chest tubes, and staplers are available immediately upon your arrival at a new duty station, combat support hospital, or FST and replace or order what you think is appropriate. Fast thinking during these cases and control of your environment to include addressing the actions of the anesthesia provider will save lives. Do not let them delay your saving of the patient with one more IV or another attempt at a bronchial blocker. You do not need a lung to be deflated in order to fix it. Remember that the heart and lungs are like Siamese twins: what affects one organ will affect the other. Expect that the necessary and rapid control of bleeding from the hilum may put your patient in right heart failure and be prepared to handle such situations postoperatively. Your best tool to gaining initial control is your hands, so don't forget to use them.