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Surgical Challenges of Chronic Empyema and Bronchopleural Fistula

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Abstract

Chronic empyema has always been a clinical challenge for physicians. There is no standard procedure or treatment to deal with the situation, and multi-modality approach is often necessary. Surgical intervention plays a very crucial role in the treatment of chronic empyema. Since bronchopleural fistula is often seen in chronic empyema patients, therefore it should also be mentioned. In this chapter, the focus will be on the different treatment options, various surgical approaches, and the rationale behind every single modality. Certain specific entity will be included as well, such as tuberculosis infection, post lung resection empyema, and intrathoracic vacuum assisted closure system application. Even with the advancement of technology and techniques, chronic empyema management is still evolving, and we look forward to less traumatic ways of approach with better outcome in the future.

Keywords: Empyema, bronchopleural fistula, open window thoracostomy, VAC, Clagett procedure, thoracoplasty, muscle flap transposition

1. Introduction

Empyema is a common clinical problem to both pulmonary physicians and thoracic surgeons. It affected 65,000 patients annually in the US [1]. Thanks to the advent of antibiotics and continuous advancement of minimally invasive procedures, most acute empyema patients can now receive tube thoracostomy and/or video-assisted thoracoscopic surgeries (VATS) to alleviate the infection with good recovery [2]. Empyema, also known to be pleural empyema or thoracic empyema, is defined as infection in the pleural cavity. The most common scenario is that the patient has a prior or ongoing pneumonia which the infection has extended to the lung surface, causing a series of inflammation and infection response on the visceral pleura and therefore parietal pleura. The products of the infection then accumulate in the pleural space resulting in empyema. Some patients would develop pleuritic pain which they easily mistake it as muscle strains or sprains, so they tend to overlook the real problem and lead to delay diagnosis. There are also a lot of other reasons that can eventually cause empyema, such as trauma, invasive procedures (including thoracic operation), liver abscess, spinal abscess, mediastinitis (because in the vicinity of an infection source) or being transmitted through hematogenous route.

2. Stages of empyema

According to American Thoracic Society classification, empyema is divided into three stages (**Table 1**) [3, 4]. In the early stage of pleural cavity infection, some fibrin would develop in this avascular space along with some body fluid. It is often recognized as parapneumonic pleural effusion. At this exudative phase, most fluid in the pleural cavity can be drained by a chest tube. If the infectious process continues and the fluid accumulates, the fluid will become thicker with more fibrin deposition. This second stage is often characterized by loculated pleural effusion which makes it difficult to drain all effusion in different areas with a single chest tube. Patients with this true empyema stage often require surgical intervention to deloculate the effusion for complete drainage. Fibrinolytic agent is another option for non-surgical candidate. When the disease progresses, more and more fibrin pile up and the fluid becomes denser and denser. A thick peel will form to cover all contact surfaces, including lung, inner chest wall, diaphragm, and mediastinum. This final stage of empyema, organizing phase, will restrict lung expansion and hence reduce lung compliance. More aggressive treatment modalities should always be considered to avoid long-term lung function impairment.

Stage	Phase	Characteristics	Status of Lung Parenchyma	Treatment
I	Exudative (Acute)	Pleural membrane thickening Fibrin deposition Presence of exudative fluid	Compliant Reexpansion possible with evacuation of fluid	Thoracentesis Closed-tube thoracostomy
II	Fibrinopurulent	Extensive fibrin deposition Pleural fluid becomes turbid or purulent Presence of loculated empyema	Partial compliance Lung entrapment due to fibrin deposition	Closed-tube thoracostomy with/ without fibrinolytics VATS Thoracotomy
III	Organized (Chronic)	Fibroblast in growth Thickened pus Granulation tissue replacement of the pleural space	No compliance Lung completely entrapped by fibrous peel	VATS (decortication) Thoracotomy (decortication) Open window thoracostomy
(Modified from Taylor and Kozower [3].)				

Table 1.
Stages of empyema.

3. Treatment principles

Since empyema equals to infected pleural cavity, the primary goal is to treat the infection. There are a few recognized treatment principles to such disease. First, sterilization of the pleural space. Second, adequate drainage. Third, optimizing lung expansion and reducing potential pleural space. These principles will be explained in detail below.

3.1 Sterilization of the pleural space

Just like treating other infectious disease, removal of pus or necrotic tissue and antibiotics therapy are the two key components to successful treatment. In

empyema, sterilization targets not only the pleural space but also the original infection source, such as pneumonia or liver abscess. To select effective antibiotics, obtaining cultures are important so that adjustment can be made according to susceptibility test after empirical antibiotics. Other effective ways to lower the pathogen colonization in the pleural cavity are removal of the infectious debri and irrigation. These procedures, debridement and irrigation, are often carried out during the surgery, either through VATS or thoracotomy. Although some doctors believe irrigation may result in unstable hemodynamics as capillary permeability increases due to transient bacteremia, the author thinks it is reasonable to do so as it is easier and faster to achieve sterilization. If the patient's blood pressure drops during the surgery, it is suggested to irrigate the pleural cavity with some diluted epinephrine with cautious monitoring. Since the patient's capillary permeability may increase, it is possible that the patient would develop tachycardia and hypertension if the medication is well-absorbed by the pleura.

3.2 Adequate drainage

Unlike airway, pleural cavity is a closed space. The fluid should be drained adequately to avoid further or repeated infection. A chest tube is sufficient for simple parapneumonic pleural effusion (stage I empyema) while complicated pleural effusion (stage II empyema) or organizing empyema (stage III empyema) often requires surgical intervention and a chest tube(s) after the surgery for adequate drainage.

3.3 Optimizing lung expansion and reducing potential pleural space

When the empyema reaches to its final stage --- organizing stage, the lung would become completely trapped and therefore poorly expanded. This not only leads to restrictive lung (impaired lung function), but also leaves a potential dead space in the pleural cavity. This space would possibly result in repeated infection. Therefore, the initial treatment goal of empyema should also include best pleural apposition to prevent chronicity. To achieve this, remove "peels" from the lung and other pleural surfaces. This surgical procedure is known as "Decortication." As long as it is feasible, removing all debri and resuming patients' optimal pulmonary function are always recommended. However, there could be exceptions that the lung fails to fill the pleural cavity. If this is the case, other measures should be taken to reduce the potential pleural space.

From a thoracic surgeon's point of view towards managing empyema, it is always "the earlier the easier." In an acute setting of empyema (stage I or II), most patients can be cured by tube thoracostomy or VATS [2]. This further emphasizes the fact that early diagnosis and early aggressive treatment to prevent chronicity are crucial. In addition, the choice of first intervention is important as well. According to the literature, failure of the first attempted procedure was an independent predictor of death [5]. As a result, operation is the most successful initial procedure in this study. More and more studies demonstrated good outcomes of early surgical intervention treating complex empyema [5, 6]. Furthermore, VATS decortication is found to be superior to open surgery in the management of primary empyema [7]. In the author's hospital, empyema is a surgical disease. Once the diagnosis is made, almost all patients need surgical consult for further treatment planning. All surgeons tacitly agree that VATS is the gold standard procedure to treat acute empyema in the author's institution.

There are still certain patients who will eventually continue to have the infection and enter to a chronic phase. Several causes of chronic empyema include delayed

diagnosis, retained hematoma in the pleural cavity, bronchopleural fistula with continuous airway secretion spillage, a large potential pleural space (e.g. post lung resectional empyema) which is prone to have repeated infection, and the patient is too ill to receive definite treatment at the initial acute phase. Among all the causes, the author thinks that retained hematoma in the pleural cavity is the most preventable cause of chronic empyema. Blood clots are perfect culture medium for bacteria, so it is important to avoid too much oozing when one performs VATS debridement and decortication on empyema patients, especially those who have liver cirrhosis, end stage renal disease, or other bleeding tendency. Adequate hemostasis and diluted epinephrine irrigation are helpful to prevent retained hematoma. If retained hematoma still happens, at least it is detectable from the drainage fluid. The drained fluid would be bloody initially then turned to dark brown and remained in this color without turning to light yellow. As one recognizes the sign of retained hematoma in the pleural cavity, it is often required to do another operation to remove all the blood clots to prevent chronic empyema.

4. Treatment options

In this section, the focus will be solely on the treatment options of chronic empyema and to which treatment principles that each option fits in.

When dealing with empyema, following the above mentioned three treatment principles is the key to success. Although the principles are the same in different stages, treatment strategies may vary, especially in the chronic stage. Treating chronic empyema is more complicated, more unpredictable, and therefore more challenging. It may require staged operations, different surgical approaches, and there is no standardized option. Before establishing treatment plan for chronic empyema patients, comprehensive understanding between each option is necessary.

4.1 Optimizing lung expansion by decortication

Decortication can be done either through VATS or thoracotomy. It is basically surgeon's preference. During the same surgery, debridement is also done so that non-viable tissue and debri are removed to achieve "cleaning" in the pleural cavity. In stage III empyema, the lung is always restricted by thickened "cortex," so freeing the lung by decortication can optimize lung expansion and reduce the potential pleural space. Choosing proper surgical instruments accelerates the procedure. In the author's experience, Roberts artery forceps or long Kelly forceps are best tools to separate the lung from the overlying "cortex." This separation process can be done sometimes with the operated lung ventilating so that the correct pleural plane is evident. If pleural apposition still cannot be achieved after decortication, make sure to check the lung surface again. There may be some remnant peel from the multi-layered peel that restricts lung expansion. Sometimes the peel is extremely thick and firm. Using a scalpel cautiously to slit through the peel will aid in removal.

*Fitting in the treatment principles sterilization of the pleural cavity and reducing potential pleural space by optimizing lung expansion.

4.2 Optimizing lung expansion by other means

To optimize lung expansion, there are several other ways, but none are as effective as decortication.

4.2.1 Positive airway pressure

Some of these patients are ventilator dependent while others are not. If they still require ventilator support, it is acceptable to increase positive end-expiratory pressure (PEEP) a little, by 1 or 2 cmH2O, to further expand the lung. If patients can be weaned off from ventilator successfully after the operation, a strategical management option is to delay extubation time by 0.5 to 1 day. This may also allow the lung to further expand.

*Fitting in the treatment principle reducing potential pleural space by optimizing lung expansion.

4.2.2 Negative pleural pressure

Positive airway pressure expands the lung from internal while negative pleural pressure provides a tractive force externally. A suction pressure of −20 cmH2O is usually recommended with a traditional chest drainage system. Other modality that can create negative pressure in the pleural cavity is Vacuum-assisted closure (VAC) therapy. (see 4.4).

*Fitting in the treatment principles drainage and reducing potential pleural space by optimizing lung expansion.

4.3 Open window thoracostomy (OWT)

4.3.1 History of OWT

OWT was first described by Robinson in 1916 and then revised by Leo Eloesser in 1935 which was also called Eloesser flap thoracostomy window [8]. However, the most adopted OWT is modified by Symbas and coworkers in 1971 as modified Eloesser flap [9].

4.3.2 Rationale, advantage, and disadvantage of OWT

This procedure, an open drainage method, is often saved as the last resort to treat chronic empyema, especially when the pleural infection is difficult to be managed by debridement and decortication. It is also a treatment option for critically ill patients who are too weak to receive decortication. As the name presents itself, OWT is to create a window through the patient's chest so serial dressing changes are feasible to clean the infected pleural cavity and therefore alleviate the septic condition. The advantage of OWT is that it is proved to be safe and effective [10]. On the other hand, it affects the patient's appearance and may cause chronic pain after chest wall resection. Some of the patients will need another surgery to close up the wound.

*Fitting in the treatment principles sterilization of the pleural cavity and drainage.

4.3.3 Surgical techniques and special considerations of OWT

The most common use of OWT is modified Eloesser flap [11]. The window is usually created at the basal part of the hemithorax where most of the infected material accumulates (**Figure 1**). After confirming the chest CT image, an inverted U-shaped incision is made at this area. Electrocautery is used for dissection till the rib cage. In order to create a sufficient window, two or three

ribs need to be resected. Then, the tongue-shaped muscular-cutaneous flap is folded inward and sutured to the diaphragm (**Figure 2**). The remaining wound edge is sutured to the pleura so that the window can be maintained for a period of time without spontaneous closure. It is also imperative that the window is large enough for the convenience of frequent wet packings. Another key point that must be mentioned is the timing of OWT creation. From the Massera et al. study [12], immediate OWT requires lesser time for the resolution of empyema comparing to the delayed OWT after prolonged chest tube drainage. As a result, the median OWT closure time (between performing and closing of OWT) of immediate OWT was 8 months shorter than that of delayed OWT. The timing of attempted closure should be carefully decided by the surgeon after a thorough evaluation of the empyema patient's condition. This includes free from recurrent disease, good recovery of the pleural cavity with coverage by healthy granulation tissue, the patient's general condition, and to a lesser degree by the normalization of inflammatory parameters [12, 13]. Methods of OWT closure please see 4.6.2 below.

Figure 1.
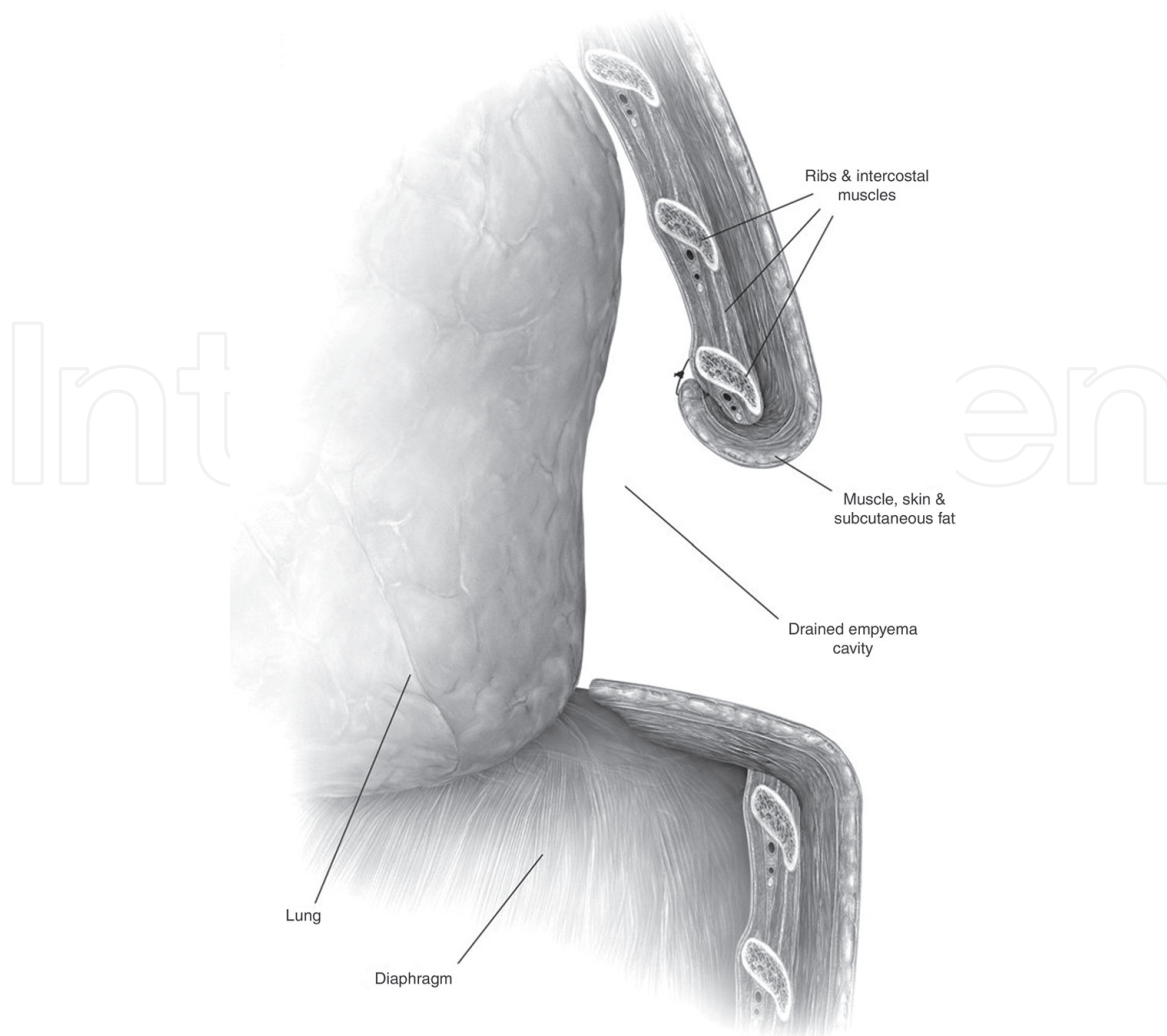*OWT. An OWT on the patient's left-side chest wall.*

Figure 2.
Coronal view of the Eloesser flap window. Demonstrating the supposition of the skin surface of the inferiorly based soft tissue flap to the diaphragmatic surface. (Adapted from Denlinger [11].)

4.4 Vacuum-assisted closure (VAC) therapy

4.4.1 History of VAC therapy

VAC is a negative pressure wound therapy that is widely used in acute and extended open wounds. The first case report of intrathoracic VAC therapy was published in 2006 [14]. Varker et al. managed a postlobectomy empyema patient with VAC device successfully after open debridement of the empyema cavity. In the next following decade, with the popularity of VAC therapy, it was proved that it is safe and efficient to fight against all kinds of intrathoracic infections [13, 15–17].

4.4.2 Rationale, advantage, and disadvantage of VAC therapy

VAC device is able to create a negative pressure wound environment that promotes wound healing by reducing edema, promoting granulation tissue formation and perfusion, and removing exudate and infectious material. As to treating chronic empyema, it is a useful tool to apply on an open wound such as an OWT after debridement of the pleural cavity (**Figure 3**). In the setting of intrathoracic VAC usage, it may reduce the duration and frequency of dressing changes necessary for spontaneous chest closure or a space filling procedure, reducing patient's

Figure 3.
Intrathoracic VAC therapy. VAC therapy is applied through the patient's OWT.

discomfort, and resolving the infectious process faster [18]. When compared with conventional management of OWT, VAC therapy accelerates wound healing and helps re-expansion of residual lung parenchyma in patients with OWT [19]. In selected patients, applying Mini-VAC procedure can even avoid OWT by insertion of the ALEXIS (Applied Medical, Rancho Santa Margarita, CA, USA) wound retractor to create a similar window effect without resecting the ribs which preserves the chest wall integrity and avoids the consequences that OWT can cause (**Figure 4**) [20]. However, the biggest disadvantage of this device is that it is not suitable for everyone. VAC device should be used cautiously or be avoided on patients with bleeding tendency, presence of malignancy, or unstable hemodynamics. Because VAC creates a negative pressure environment, it may lead to continuous bleeding, promote cancer growth, or deteriorate hypotension. The reason why
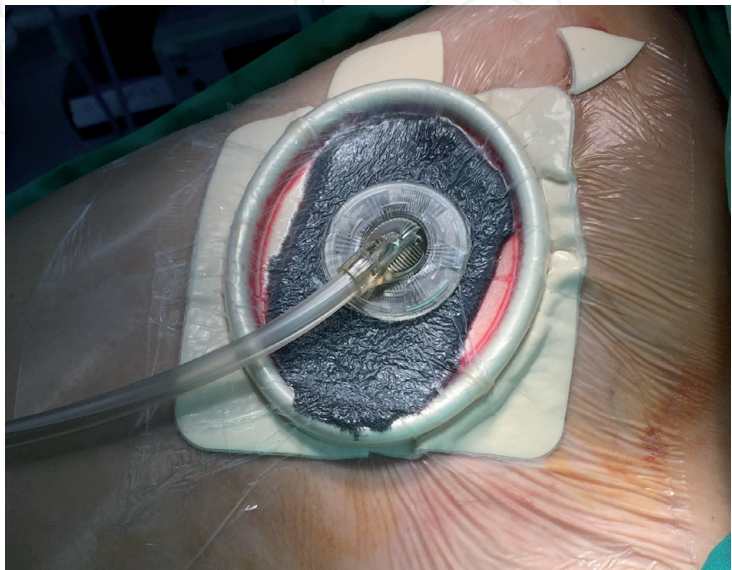

Figure 4.
Mini-VAC procedure. VAC therapy is applied through the ALEXIS wound retractor which creates a similar window effect without resecting the ribs.

hypotension may develop is probably due to the negative pressure effect intrathoracically causing decreased cardiac output. Thus, intrathoracic application in older patients must be monitored closely and should be avoided on patients with poor cardiac function.

*Fitting in the treatment principles drainage and reducing potential pleural space by optimizing lung expansion.

4.4.3 Surgical techniques and special considerations of VAC therapy

VAC therapy is designed to be applied on open wounds. To treat chronic empyema with VAC, an open chest wound or an OWT must be created during the surgical intervention. Some authors advocate leaving the thoracotomy wound open directly after the operation [13, 14] while others create an OWT to make dressing changes easier [17–19]. It is reasonable to decide on an individual basis depending on the size and depth of the residual pleural space. A large and deep residual pleural space is preferred for OWT. The advantage of OWT is that the chest will stay open for a longer period because of the inverted skin flap compared to just leaving the thoracotomy wound open. OWT would avoid the skin from healing before complete eradication of the infected pleural cavity. It is contraindicated to apply VAC on a dirty wound with necrotic tissue that has yet to be debrided. After adequate debridement in the pleural cavity, VAC sponges (GranuFoam) are inserted in the residual pleural space to fill the entire cavity. Placing the sponges directly in contact with exposed blood vessels, anastomotic sites, organs, or nerves are prohibited, except for the lungs. According to the literature [13, 21] and the author's personal experiences, VAC dressing can be safely applied directly on the visceral pleura or lung parenchyma without any complications. The negative pressure can be set at -50 mmHg from the start, and gradually increased to -125 mmHg if the patient does not have any discomfort. The dressing change should be done at least twice a week, and it can be performed at the bedside. During the VAC therapy period, the skin covered by the dressing should be well protected to prevent skin maceration problems. If negative pressure fails to be maintained due to significant air leak caused by bronchopleural fistula (BPF), combining a one-way valve may solve this issue [21].

When dealing with postpneumonectomy empyema (PPE), VAC therapy should be used carefully, especially for patients who develop the complication shortly after the initial surgery. This is because negative pressure would shift the mediastinum which may cause heart or great vessels herniation leading to obstructive shock or even cardiac arrest. On the contrary, if PPE is developed at a later stage, such events will not happen as the mediastinal shift has already completed and the patient's body has compensated it well.

4.5 Empyema tube --- rationale, advantage, and disadvantage

There are two scenarios where chronic empyema patients would need an empyema tube for long-term drainage. One is that the patient is too unstable and fragile to receive general anesthesia and adequate surgical intervention. To alleviate the septic condition, empyema tube (tube thoracostomy) can be placed to decrease the burden of infection until definite treatment can be initiated. Another scenario is that the chronic empyema is somehow localized in a small area without systemic infection. It is either a tube thoracostomy left after previous surgical intervention or a new chest tube inserted into this localized area for drainage if the patient is not a surgical candidate.

In the author's opinion, this treatment option is only reserved for those who are not able to receive other definite treatment because of the low success rate, and not

all infected materials can be drained adequately. However, if adequate drainage can be achieved, the tube may be slowly retracted over a period of weeks to months while the infected space heals behind it [3].

*Fitting in the treatment principle drainage.

4.6 Filling the potential pleural space with different measures

4.6.1 Clagett procedure

4.6.1.1 History, rationale, advantage, and disadvantage of Clagett procedure

Clagett procedure was first described by Clagett and Geraci in 1963 [22]. It is a method that obliterate the pleural cavity with antibiotic solution. As a precondition of the procedure, there must be no BPF and the pleural cavity should be sterilized by debridement and irrigation. In other words, if the patient has BPF and primary repair is impossible, Clagett procedure is not suitable for the patient. Nonetheless, this procedure has a good overall success rate in selected patients (no BPF at the time of the procedure), range from 81–100% [12, 23–25]. Those who fail from the procedure are mainly due to persistent or recurrent BPF.

*Fitting in the treatment principle reducing potential pleural space.

4.6.1.2 Surgical techniques and special considerations of Clagett procedure

After confirming that there is no active BPF in the pleural cavity or it is firmly closed, antibiotic fluid can be instilled to fill the remaining pleural cavity after it is fully cleansed. DAB solution (gentamicin 80 mg/L, neomycin 500 mg/L, and polymyxin B 100 mg/L) is one of the antibiotic solution choices [23]. The combination of the fluid can be chosen according to the microbiological findings [26].

4.6.2 Tissue flap transposition

4.6.2.1 Rationale, advantage, and disadvantage of tissue flap transposition

Tissue flap transposition technique is frequently used in chronic empyema patients for the purpose of either closure of the BPF or OWT, and/or obliteration of the residual pleural space. It can also be used for the prophylactic reinforcement of a bronchial stump after major lung resection to avoid BPF formation. Because the flap tissue is full of mesenchymal cells, it can promote granulation tissue growing under good circulation and secure the bronchial stump as a backup layer. A bulky muscle flap is extremely helpful to reduce the residual pleural space while a smaller residual space only requires a smaller tissue flap. However, not every patient is medically fit for long-hour flap surgery especially the critically ill. A successful flap reconstructive surgery is determined by a well-perfused flap which is highly dependent on patients' stable hemodynamics.

*Fitting in the treatment principle reducing potential pleural space.

4.6.2.2 Surgical techniques and special considerations of tissue flap transposition

Tissue flaps commonly used in chronic empyema are latissimus dorsi (LD) muscle flap (**Figure 5**), serratus anterior (SA) muscle flap, pectoralis major (PM) muscle flap, intercostal muscle flap, pedicled omental flap, and other free flaps. LD is the largest muscle among all chest wall muscles. Therefore, it is an ideal option for pleural cavity obliteration. However, if the patient has received a standard
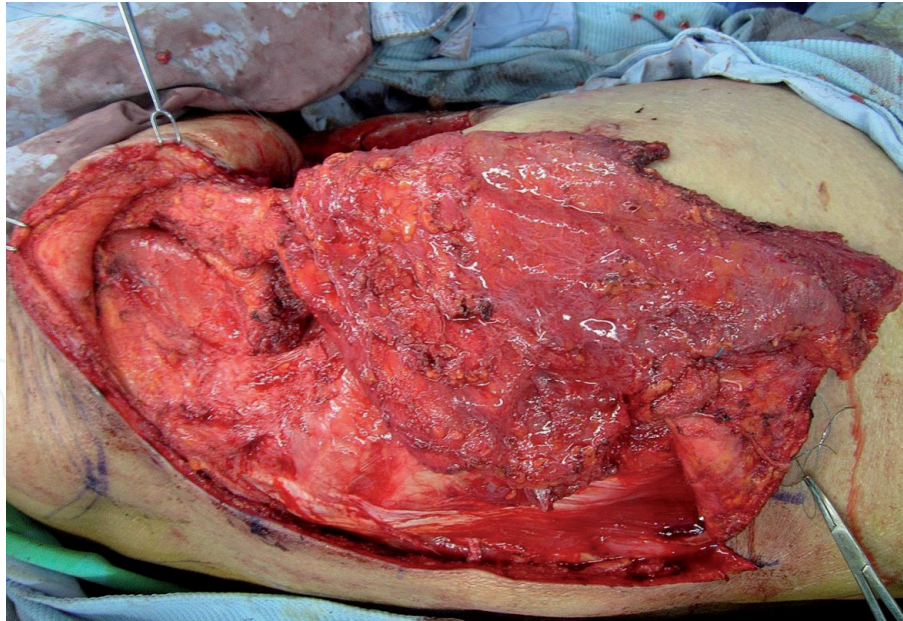
Figure 5.
LD muscle flap. Harvest of the LD muscle flap to reinforce the PPE BPF closure.

posterolateral thoracotomy previously, this muscle may have been compromised and hence not suitable. PM flap is another good alternative for it is the second largest chest wall muscles. Because of its anatomy and orientation, PM flap is particularly useful to obliterate the apical residual pleural space [3, 27]. Although SA flap and intercostal muscle flap are relatively small compared to LD and PM flaps, they can be sufficient to help accelerate BPF healing as long as the pedicle is healthy. Omental flap is another option if no chest wall muscle is available [28]. However, entering the peritoneal cavity may potentially spread the infection and complicate the situation. Sometimes the remaining pleural space is too big that only by combining two flaps will fill the space [27]. Free flap may also be considered in highly selected patients.

4.6.3 Thoracoplasty

4.6.3.1 History, rationale, advantage, and disadvantage of thoracoplasty

Thoracoplasty has a long history in the field of thoracic surgery. It was first described by Estlander in the late 19th century when tuberculosis was a troublesome pandemic without medical cure [29]. The original concept of this surgery is to collapse the chest wall to minimize the cavitary pleural space caused by mycobacterium. To achieve this goal, multiple ribs are resected resulting in loss of rigid chest wall configuration and therefore obliteration of the infected pleural space. Although it is an effective way to fill the potential pleural space, this procedure can cause significant morbidity, including chronic pain, chest wall deformity, thoracic spine scoliosis, limited ipsilateral shoulder range of motion, and finally resulting in poor quality of life.
*Fitting in the treatment principle reducing potential pleural space.

4.6.3.2 Surgical techniques and special considerations of thoracoplasty

Thoracoplasty can be classified into three types, full, extended, and tailored thoracoplasty. Full thoracoplasty is defined as removing first 11 ribs to collapse the whole hemithorax. Extended thoracoplasty, on the other hand, is removing 7
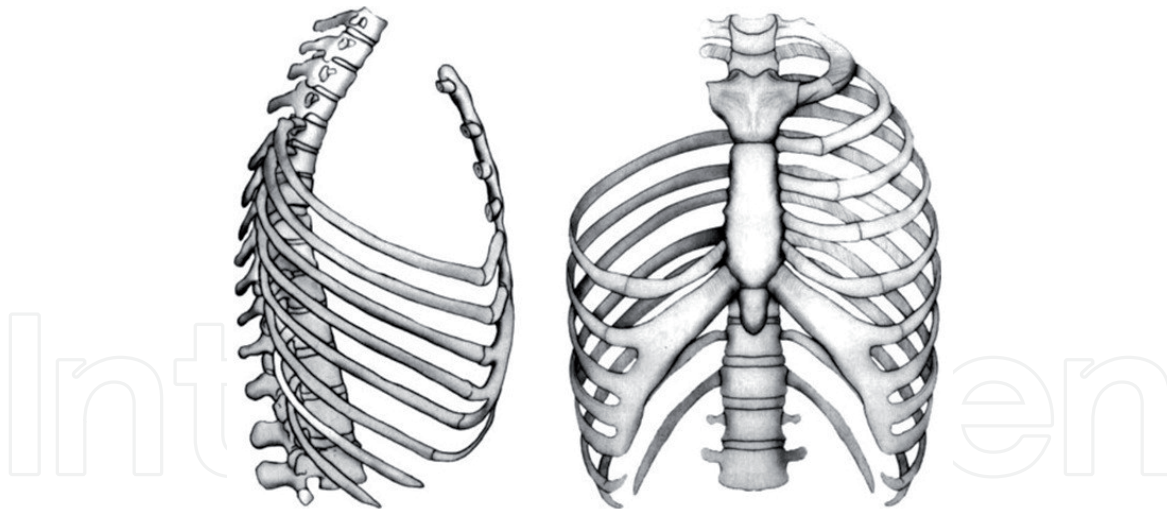
Figure 6.
Thoracoplasty. Complete resection of the 4 right upper ribs. (Adapted from Lewis and Wolfe [31].)

to 9 ribs while tailored thoracoplasty is removing fewer than 5 ribs at certain area [30]. Resection of 7 ribs can lead to approximately 50% reduction of the pleural space, and resection of 5 ribs results in 25% reduction (**Figure 6**) [31]. The key to a successful thoracoplasty is complete resection of the targeted ribs which means from the transverse process of the thoracic spine posteriorly to the costosternal joint anteriorly. In the modern era, this procedure is seldom conducted alone. Combining with muscle flap transposition is an effective alternative so that chest wall deformity can be less significant [32, 33].

Managing chronic empyema is art. There is no standardized option. Knowing the different measures in depth and applying each principle with these measures will certainly increase the success rate of treatment. Making a customized treatment plan according to the patient's physical condition, complications, and special requirements cannot be emphasized enough. There are special circumstances which will be introduced below for better understanding of how to put the different treatment options in use.

5. Special circumstances

5.1 Post-resectional empyema

The main issue contributed by post-resectional empyema is that the residual pleural space is often large. The treatment strategy therefore should be emphasized on how to fill the space. If post-lobectomy empyema occurs in a delayed setting, the size of the residual pleural space would not be a concern because the pleural cavity should have been remodeled by diaphragm elevation, mediastinum shifting, and narrowing of the intercostal space over time. However, if post-resectional empyema happens in an acute phase when the remodeling has not been completed yet, different filling procedures should always be considered. For instance, if a patient who is medically fit for surgery develops a post-lobectomy empyema in a delayed phase, VATS or thoracotomy debridement and decortication are usually amenable to solving the problem.

Post-pneumonectomy empyema (PPE) is notorious for its high morbidity and mortality rate [12]. It is a challenging situation clinically, especially when BPF is present (**Figure 7**). According to the literature [12, 25, 30], approximately 65 to 84% PPE patients have BPF. Closure of the BPF is imperative or else spillage from
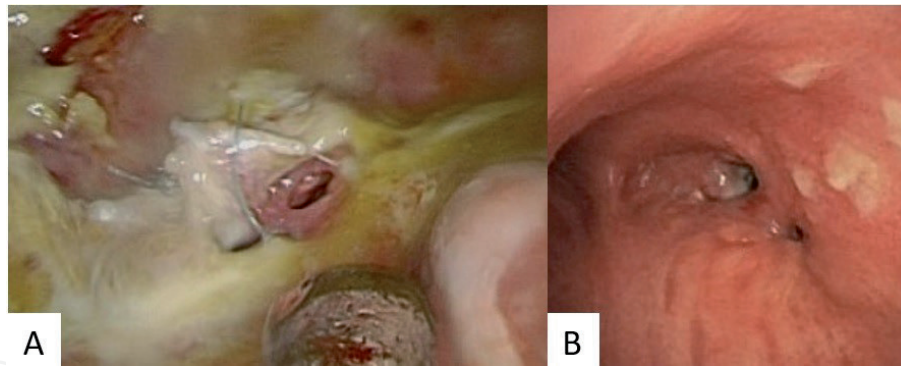
Figure 7.
PPE with BPFs. (A) from the thoracoscopic view of the BPFs (B) from the bronchoscopic view of the BPFs.

the infected cavity into the airway can cause pneumonia or even acute respiratory distress syndrome (ARDS). On the other hand, the secretion from the airway would also leak into the pleural space continuously and contaminate the cavity. After closing the BPF, as per treatment of other empyema, sterilization of the cavity with debridement, irrigation, parenteral antibiotics, and adequate drainage, the most important is effective obliteration of the remaining pleural space. Since the BPF is often failed by primary suture alone, covering the stump with pedicled muscle flap ensures secondary healing as well and obliteration the pleural space at the same time. For example, if a debilitated patient suffers from severe sepsis caused by late onset right-sided PPE with BPF, it is reasonable to lay out a staged surgical plan. First, do a tube thoracostomy and forbid the patient to lie in a left decubitus position to protect the contralateral lung. This first stage is for drainage and lung protection. Second, perform simple debridement, OWT, and primary BPF repair added on a buttressed intercostal muscle flap. Instead of frequent dressing changes after OWT, VAC therapy can be initiated under the circumstance without any contraindication. VAC dressings can be changed at least twice a week. After a period of aggressive treatment plus appropriate nutritional support, successful BPF closure, a clean pleural cavity covered with healthy granulation tissue, and improved physical status of the patient can be expected. The second stage is for sterilization of the pleural space and open drainage. The third stage is purely for filling. Choose an appropriate procedure, such as Clagett procedure, to obliterate the pleural cavity.

5.2 Bronchopleural fistula (BPF)

As mentioned in the last paragraph, BPF connects the bronchus to the pleural cavity leading to infection burden and possible respiratory distress. Life threatening events, such as ARDS or septic shock, must be managed as top priority. Successful closure of the BPF may prevent those critical situations from happening. As long as the patient's physical condition is suitable for intervention, attempts to close the BPF should be carried out as early as possible.

There are several ways to manage BPF, either bronchoscopically or surgically. Treatment choices mainly depend on patients' clinical status, duration before the development of BPF, and number and size of the BPF [30]. An algorithm for treatment of BPF at the European Oncologic Institute [34] (**Figure 8**) was created according to these principles. If the BPF occurs in an early setting (<14 days after surgery), surgical repair of the bronchial stump is always encouraged. In a delayed setting (>14 days after surgery), bronchoscopic application with sealants, fibrin glue, silver nitrate, coils, endobronchial stents, Endobronchial Watanabe Spigot, or atrial septal defect occluder device [35–38] can be used for small BPF size <8 mm or for patients who are physically unfit for surgery. As for BPF size >8 mm, patients
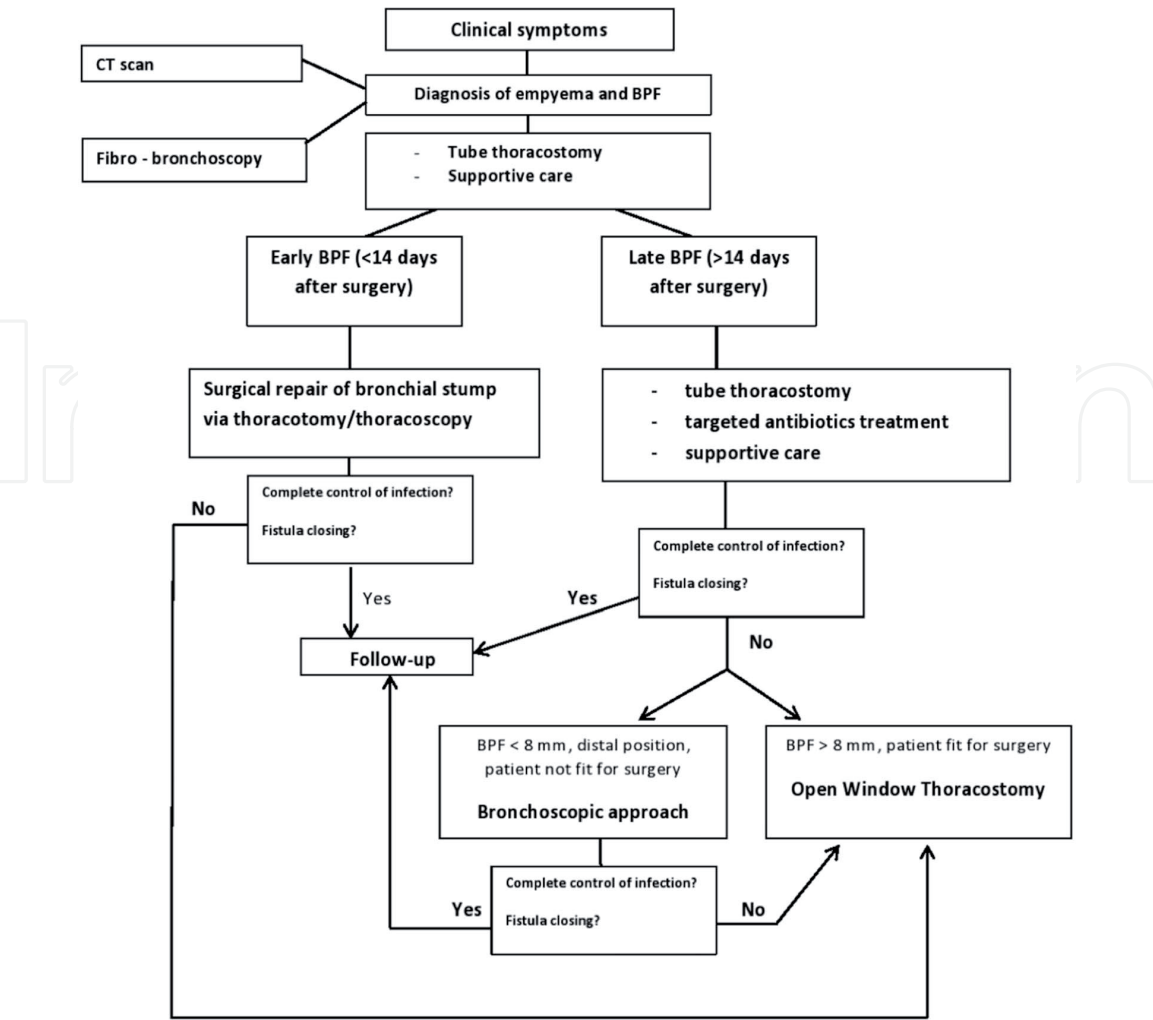
Figure 8.
Management of PPE BPF: EOI algorithm. (Adapted from Mazzella et al. [34].)

who are fit for surgery, patients who had failure from other treatment strategies, surgical intervention is unavoidable. In addition to primary closure of the bronchial stump, muscle flap transposition to cover the sutured stump provides a good environment for secondary healing which may increase the success rate of closure. If the BPF is deemed to be closed during the operation, Clagett procedure may be considered after thorough cleansing of the infected pleural cavity. Since continuous spillage from the BPF may occur, therefore OWT is often a treatment option to enable frequent dressing changes to eliminate the infection.

5.3 Malignant pleural empyema

At times, malignant pleural effusion can be infected either through hematogenous or direct inoculation by invasive procedures. The treatment principles are essentially the same. Sterilization of the pleural cavity and adequate drainage are not difficult to achieve. Since the pleura tumor cells cannot be eradicated immediately by surgical procedures or medical treatment, it is almost impossible to fully expand the lung via decortication and therefore a possible residual pleural space which can cause repeated infection. Under this circumstance, a thorough decortication is not practical because tumor cells are prone to bleed and cause the underneath lung tissue to be more fragile. Too much "peeling" will lead to excessive bleeding resulting in hematoma retention and causing the lung to tear. To weigh the benefits and risks of surgical intervention is crucial since the patient's life expectancy may

be limited. From the author's personal experience, debridement, irrigation, and limited decortication followed by a tube thoracostomy are sufficient to treat the infected pleural cavity.

5.4 Tuberculous empyema

Although some surgical measures for chronic empyema originated from treating tuberculous (TB) empyema [8, 29], such as Eloesser flap thoracostomy window and thoracoplasty, these intensive procedures are now rarely used to treat TB empyema. It is not that TB empyema patients do not need invasive procedures, but it is that most of these patients can be managed by tube thoracostomy or VATS debridement with decortication. When it comes to uncontrolled TB empyema with initial treatment attempt failure, more aggressive modalities should be considered which are the same as treating other bacterial chronic empyema.

5.5 Application of double lumen endotracheal tube

Double lumen endotracheal tube intubation is frequently seen in thoracic surgery for lung isolation. It can be an adjunct to help with BPF treatment after pneumonectomy if the patient still requires ventilator support or to protect the remaining lung from fistular spillage. Application of this device would help ventilate the remaining side of the lung and leave the fistular side of the hemithorax unventilated to accelerate fistular healing. However, the diameter of the double lumen tube is certainly greater than the single lumen tube which would make the patient feel uncomfortable if not sedated. Another frequently encountered issue is that the left-sided tube tip would slide outward easily, and this malposition may cause failure of lung isolation. Although the whole diameter of the double lumen is greater than the single lumen tube, each individual double lumen tube diameter is smaller. This would make it difficult to clean the airway by suction as the suction tip may not always reach to the proper depth. As a result, airway hygiene may become a serious issue if the tube is placed in the bronchus for a long time.

6. Future directions

With the development of modern medicine and minimally invasive technology, the role of both bronchoscopic and thoracoscopic (VATS) procedures have become increasingly important replacing some of the traditional surgeries in treating chronic empyema. More studies should focus on solving existing issues like, Mini-VAC replacing OWT completely, customized device to help repairing BPF, and 3D bioprinting assisting BPF closure. The author believes that chronic empyema management is still evolving, and look forward to less traumatic ways of approach with better outcome in the future.

7. Conclusions

Treating chronic empyema and BPF are certainly clinical challenges that thoracic surgeons would encounter from time to time. It is necessary to thoroughly comprehend each treatment option and some management key points of different situations. With the development of modern technology, more treatment modalities can be anticipated.

Notes/Thanks/Other declarations

The author has nothing to declare.

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