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Therapeutic strategy and efficacy evaluation of chronic empyema after total pneumonectomy: individualized analysis of six patients

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Abstract

Background Chronic empyema after total pneumonectomy is a potentially fatal complication.The aim of the study is to explore the treatment strategy and clinical efficacy of chronic empyema after pneumonectomy.

Methods A retrospective analysis of 6 patients with chronic empyema after pneumonectomy in our hospital. Utilizing a staged surgical model, the treatment approach involved rib debridement drainage, open-window thoracostomy (OWT), and the application of autologous tissue flaps, including free myocutaneous flap, pedicled muscle flap, and pedicled greater omentum, to effectively eliminate the abscess cavity.

Results All patients with empyema were successfully treated after surgery, with follow-up durations ranging from 3 to 29 months and an average of (10.50 ± 9.67) months. Re-examination using chest computed tomography (CT) or magnetic resonance imaging (MRI) revealed that the empyema residual cavity had either completely disappeared or had significantly reduced.

Conclusion The treatment of chronic refractory empyema after total pneumonectomy by rib debridement drainage, OWT and autologous tissue flap transplantation has a high cure rate and satisfactory clinical effect.

Keywords Chronic empyema, Postpneumonectomy, Bronchopleural fistula, Autologous tissue flap, Open-window thoracostomy

Introduction

Postpneumonectomy empyema (PPE) refers to the obvious accumulation of pus or non-purulent fluid in the pleural cavity after operation but positive microbial culture, which is a very serious complication.The incidence of PPE is about 2-16%, of which the concurrent bronchopleural fistula (BPF) accounts for about 60-80%, and the mortality rate also ranges from 25-71% [1, 2].The management of this complication mainly depends on the occurrence time of empyema after pneumonectomy and the existence of BPF whether or not. For chronic empyema that occurs following total or partial lung resection,

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common clinical treatments include enhanced drainage, thoracoplasty, and autologous tissue flap transplantation. If BPF or necrotic bone is also present, treatment becomes more challenging. Patients frequently exhibit symptoms of chronic consumption, significant systemic poisoning, persistent cough, anemia, and even hemoptysis. Selecting the appropriate treatment method is crucial for managing refractory empyema after pneumonectomy, with the ultimate goal being the elimination of the residual cavity [3].The management of chronic refractory empyema, particularly when associated with BPF, necessitates a comprehensive treatment approach. These strategies can be quite challenging, as they involve the management of BPF and the abscess cavity, the degree of infection control, and the optimization of overall patient conditions [4, 5]. Consequently, effective infection control and the elimination of the abscess cavity are critical to successful treatment. While numerous methods exist for addressing the residual cavity, each has its limitations. In our study, we implemented individualized treatment plans for the six patients suffering from refractory empyema following pneumonectomy, yielding satisfactory short-term and long-term outcomes.

Patients and methods

Patients

The retrospective case study was approved by the Institutional review board. A total of six patients who developed empyema following pneumonectomy were treated in our hospital from January 2020 to December 2023 were selected for this study. The cohort consisted of five males and one female, aged between 49 and 71 years, with a mean age of (60.67±7.50) years. Among the patients, four had non-small cell lung cancer, while one case each involved a pulmonary cyst and pulmonary fungus. The surgical procedures included two patients who underwent right total pneumonectomy and four patients who underwent left total pneumonectomy, with one patient also presenting with BPF. All six patients had positive pus microbial cultures, revealing one case of *Pseudomonas aeruginosa*, two cases of *Proteus mirabilis*, one case of *Enterococcus avium*, one case of *Streptococcus griffin*, and one case of *Citrobacter koseri*. The interval from the onset of empyema to the initial surgical intervention ranged from 4.8 months to 100.8 months, with an average of (31.80±34.71) months. Preoperative assessments indicated that all patients were appropriate candidates for staged surgical treatment, which included empyema debridement and partial rib resection during the first stage, followed by autologous tissue flap transplantation and Clagett surgery in the second stage (Table 1).

Case-1 The patient was was an elderly male with a 35-year history of smoking. He had no history of hypertension, diabetes, or chronic kidney disease. Sixteen years ago, he was diagnosed with squamous-cell carcinoma of the left lung and subsequently underwent a left pneumonectomy, without receiving radiotherapy or chemotherapy afterward. Nearly 8 years post-surgery, he experienced recurrent fever. Upon confirming that the left empyema was not associated with BPF, he was treated with chest tube drainage, which yielded approximately 100 ml of fluid per day. The primary admission symptoms included paroxysmal cough, yellow sputum, and blood-tinged sputum.

Case-2 The patient was a 65-year-old male with a 20-year history of smoking and an 8-year history of hypertension. He was regularly prescribed amlodipine besylate at a dosage of 5 mg once daily. The patient had no medical history of other chronic diseases, such as diabetes. After being diagnosed with left lung squamous-cell carcinoma, he had a left pneumonectomy 7 months ago. A review of the medical history data from other hospital indicated that preoperative contrast-enhanced chest CT did not reveal any significant enhancement of lymph nodes around the bronchus. Additionally, no notable calcification was observed around the bronchial stump during the initial operation, and the bronchial stump was not pre-embedded following the pneumonectomy. Four months post-operation, he developed empyema with BPF, necessitating chest tube drainage. Upon admission, the main symptoms reported were chest tightness and fatigue following physical exertion.

Table 1 Characteristics of patients

Case	Sex	Age (years)	Smoking history	Chronic diseases	Pneumonectomy (side)	Primary diseases	Bacteria type	BPF
1	Male	71	Yes	No	Left	Lung squamous-cell carcinoma	*Proteus mirabilis*	No
2	Male	65	Yes	Hypertension	Left	Lung squamous-cell carcinoma	*Citrobacter koseri*	Yes
3	Male	63	Yes	No	Left	Lung cyst	*Proteus mirabilis*	No
4	Male	58	No	No	Right	Lung squamous-cell carcinoma	*Streptococcus griffin*	No
5	Male	58	No	Diabetes	Right	Lung adenocarcinoma	*Enterococcus avium*	No
6	Female	49	No	No	Left	Pulmonary aspergillosis	*Pseudomonas aeruginosa*	No

Case-3 The patient was a 63-year-old male with a history of smoking for 18 years. He denied a history of underlying diseases such as hypertension and diabetes. He underwent a left total pneumonectomy 23 years ago due to a left lung cyst. One year prior, he experienced empyema, which was managed with a chest tube; the daily drainage volume was minimal.

Case-4 The patient was a 58-year-old male with no history of smoking and denied any chronic medical history such as hypertension and diabetes. The patient was diagnosed with right lung squamous cell carcinoma and underwent a right total pneumonectomy one year ago. Following the surgery, he received chemotherapy. Approximately three months post-surgery, he developed fever, cough, and sputum. There was a history of sclerosing agent injection into the bronchial stump fistula (BSF). A bronchoscopy performed at our hospital revealed no significant fistula, and the drainage volume was approximately 50–100 ml per day.

Case-5 The patient was a 58-year-old male with a 12-year history of type 2 diabetes mellitus, for which was regularly prescribed metformin extended-release tablets at a dosage of 0.5 g twice daily. He had no history of smoking and denies having any other underlying conditions, such as hypertension.The patient was diagnosed with right lung adenocarcinoma and underwent a right total pneumonectomy 8 years prior. He has no history of postoperative radiotherapy or chemotherapy. Approximately 20 days post-operation, he began to experience fever, with a maximum recorded body temperature of 39 °C, but exhibited no significant cough or sputum production. Following a diagnosis of chronic empyema and BPF, he underwent thoracoplasty, fistula closure using a sclerosing agent, and pedicled muscle flap transposition. He is currently receiving treatment involving a chest tube for drainage.

Case-6 The patient was a 49-year-old female with no history of smoking, hypertension, diabetes, or chronic kidney disease. He underwent a left total pneumonectomy two years ago due to pulmonary *aspergillosis*. A few days post-operation, he developed a fever. Following the confirmation of empyema, he continued to have a chest tube in place for drainage, with an approximate drainage volume of 20 ml per day.

Treatment methods

All six patients underwent empyema debridement combined with fenestration drainage or partial rib resection as the first-stage surgery. This initial procedure primarily focused on resecting portions of the ribs and removing purulent material to achieve adequate drainage. Following the operation, patients received symptomatic treatment with appropriate antibiotics. This approach aimed to achieve initial control of the intracavity infection. When the re-culture of the pus returned negative results, and the drainage volume significantly decreased to less than 100 ml, or the characteristics of the drainage improved (including a reduction in purulent exudate, a transition to clearer fluid, and the presence of healthy wound granulation), preparations for the second-stage surgery were actively initiated. Combining the patient's chest CT, chest MRI, and intraoperative conditions from first-stage surgery, we analyzed data from six patients. The initial abscess volume ranged from a minimum of 20 ml to a maximum of 230 ml, with an average volume of (98.33±78.59) ml. The time interval between the first-stage surgery and second-stage surgery varied from 30 days to 72 days, averaging (48.00±17.57) days. The second-stage surgery had a minimum abscess volume of 20 ml, a maximum of 210 ml, and an average of (88.33±72.02) ml (Table 2). Based on our treatment experience, for abscess cavities less than 100 ml, the primary treatment involves a pedicled muscle flap or pedicled greater omentum. For cavities larger than 200 ml, the main treatment is a free myocutaneous flap, with pedicled tissue flap as a supplementary option if necessary. For abscess cavities between 100 ml and 200 ml, treatment methods are evaluated based on intraoperative exploration during first-stage surgery, considering options such as pedicled tissue flap, free tissue flap, or a combination of both.

In both Case 1 and Case 2, the patient's abscess cavity was small, meeting the treatment criteria for a pedicled muscle flap. The chosen combined pedicled muscle flaps

Table 2 Surgical information

Case	Time of empyema(months)	Initial abscess cavity volume(mL)	Second-stage surgery abscess volume (mL)	Types of autologous tissue flap	Autologous tissue flap size(cm x cm)	The time interval between stage-I and stage-II (days)	Follow-up time(months)
1	100.8	90.0	85.0	Pedicle muscle flap	20.0×15.0	32	29.0
2	4.8	50.0	45.0	Pedicle muscle flap	20.0×8.0	36	3.0
3	19.2	150.0	135.0	Free myocutaneous flap	20.0×12.0	58	13.0
4	15.6	230.0	210.0	Free myocutaneous flap	25.0×16.0	60	6.0
5	21.6	20.0	20.0	Pedicled greater omentum	30.0×20.0	72	5.0
6	28.8	50.0	40.0	/	/	30	7.0

were the latissimus dorsi and serratus anterior. **Stage II surgical procedure**:An oblique surgical incision was made along the outer edge of the latissimus dorsi, extending from the apex of the axilla to expose the muscle's outer border. The thoracodorsal artery and vein were carefully isolated at the plane corresponding to the inferior angle of the scapula, approximately 3 cm from the latissimus dorsi's outer border. Following the complete dissection of the muscle, a latissimus dorsi muscle flap, inclusive of the thoracodorsal vessels, was created. The serratus anterior muscle flap was also freed to a sufficient size along the original incision, with an effort to preserve the rib periosteum. The free combined muscle flaps were then turned over to fully fill the abscess cavity (Fig. 1A-D). It is important to note that in case 2, a 4 mm fistula was identified at the bronchial stump during the first-stage surgery. Consequently, we opted to place a unidirectional endobronchial one-way valve (EBV) under bronchoscopic guidance prior to the second-stage surgery to effectively close the fistula. Both patients underwent placement of chest drainage tube and subcutaneous drainage tube postoperatively.

In Cases 3 and 4, the abscess cavities were large. Following a comprehensive preoperative evaluation, we opted for the free vastus lateralis musculocutaneous flap to fill the abscess cavities. The dimensions of the selected vastus lateralis musculocutaneous flaps were approximately 20.0 cm x 12.0 cm and 25.0 cm x 16.0 cm respectively. **Stage II surgical procedure**: a.Following successful general anesthesia, the patient was positioned at a 45° lateral angle to facilitate access to the abscess cavity. The abscess cavity was debrided again through the original chest incision, and it was thoroughly irrigated with a substantial volume of normal saline, hydrogen peroxide, and iodophor solution. The thoracodorsal artery and vein were meticulously dissected and separated at the level of the subscapular angle. b.The lower limb surgical incision was made between the left (or right) anterior superior iliac spine and the outer edge near the patella. After incising the skin and subcutaneous tissue, the vastus lateralis muscle was fully dissociated and exposed. Based on the size of the abscess cavity, a vastus lateralis musculocutaneous flap was designed, and the lateral femoral circumflex artery and vein supplying the vastus lateralis muscle group were subsequently dissected. The myocutaneous flap, consisting of a skin paddle and the vastus lateralis muscle group, was harvested with a vessel pedicle of suitable length measuring 8–10 cm. The free vastus lateralis musculocutaneous flap was employed to fill the abscess cavity. The lateral femoral circumflex artery and vein of the pedicle were anastomosed to the thoracodorsal artery and vein using microsurgical techniques with 9−0 Prolene sutures. c.The transferred muscle flap was appropriately sutured and secured to the surrounding chest wall tissue, while the skin paddle was sutured to the healthy skin of the chest wall. Finally, negative pressure drainage tubes were placed in both the thoracic cavity and subcutaneous tissue (Fig. 2A-E).

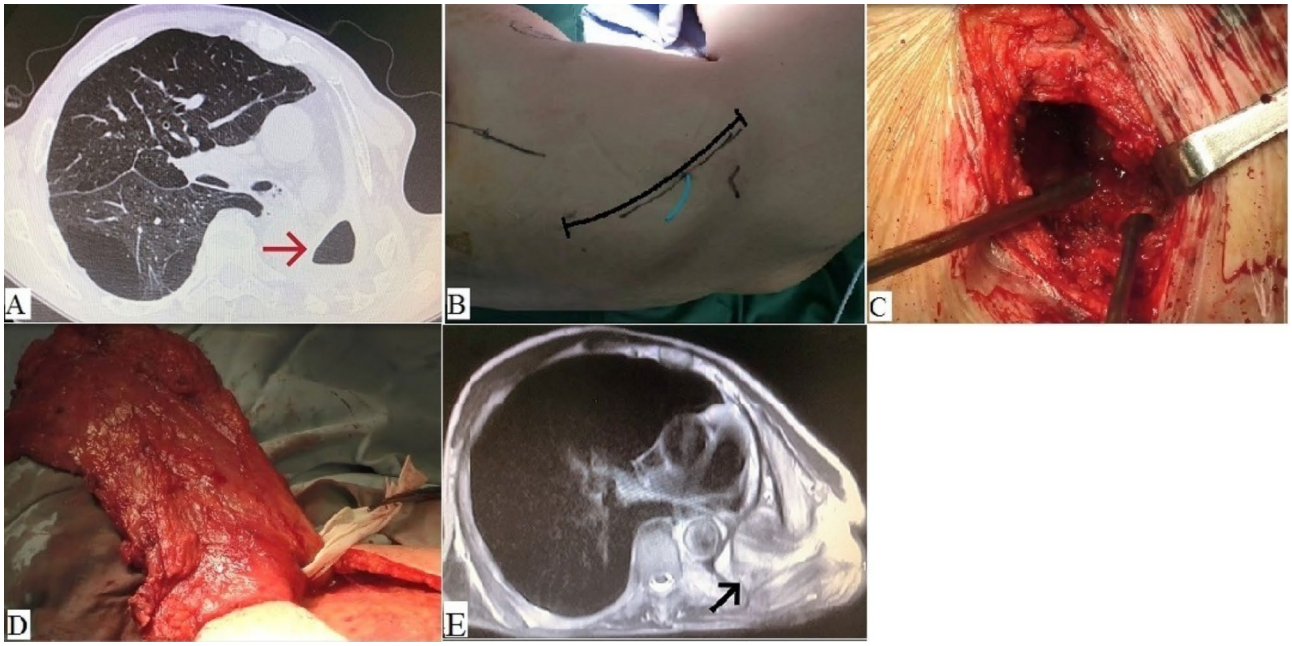

Fig. 1 Clinical images on application of pedicled muscle flap. (**A**) A preoperative chest CT showed a empyema cavity containing pleural effusion in the left thorax; (**B**) Appearance and incision design of the chest wall before operation; (**C**)Appearance of abscess cavity after debridement; (**D**) Harvesting of the pedicled latissimus dorsi and serratus anterior muscle flap; (**E**) Postoperative MRI showed that the pedicled muscle flap completely filled the abscess cavity(black arrow)

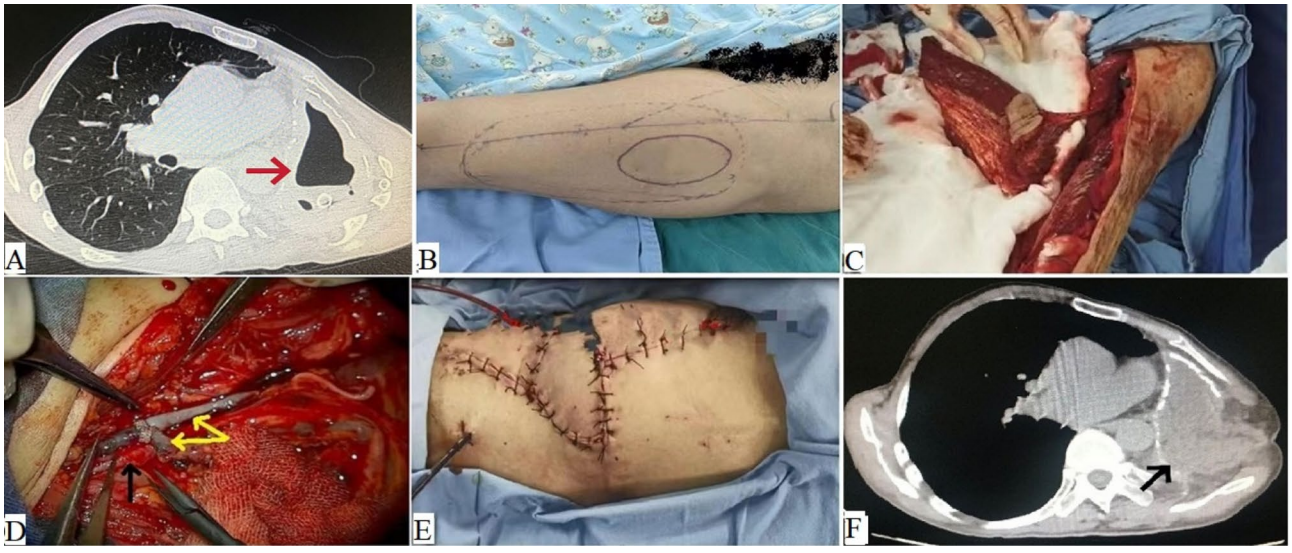

Fig. 2 Clinical images on application of free vastus lateralis musculocutaneous flap. (**A**) Preoperative chest CT showed a large abscess cavity on the left side after total pneumonectomy(red arrow). (**B**) A preoperative incision design of lower limb; (**C**) Harvesting of the vastus lateralis musculocutaneous flap; (**D**) Anastomosis of blood vessels under microscope(yellow arrow: vein; black arrow: artery); (**E**) The appearance of the chest wall after the myocutaneous flap filled the abscess cavity; (**F**) Postoperative chest CT showed that the free vastus lateralis myocutaneous flap completely filled the abscess cavity, and the myocutaneous flap survived(black arrow)

Fig. 3 Clinical images on application of pedicled greater omentum. (**A**) Preoperative chest CT showed a abscess cavity in the right chest with pleural effusion; (**B**) An intact pedicled greater omentum was dissociated from the abdominal cavity; (**C**) Postoperative chest CT showed that the pedicled greater omentum was completely filled with abscess cavity and the empyema disappeared (black arrow)

Cases 5 and 6 presented unique challenges. The patient in Case 5 had a history of right thoracoplasty and pedicled muscle flap transplantation, which resulted in thoracic collapse and deformity. Following a thorough preoperative evaluation, the pedicled greater omentum was chosen to fill the abscess cavity. **Surgical procedure**: The patient was positioned supine, and the right empyema was debrided, with a portion of the third rib resected to ensure that the wound in the abscess cavity was adequately fresh. A midline incision was then selected in the abdomen as the primary operating port. The right gastroepiploic artery was preserved, while the left gastroepiploic artery was severed to eliminate the blood supply to the greater omentum. An greater omentum flap measuring approximately 30 cm x 20 cm was retained The subcutaneous tunnel was opened and cleared to access the pus cavity. Finally, the harvested pedicled greater omentum was carefully extended through the subcutaneous tunnel to fill the abscess cavity(Fig. 3A-B). The latter case, characterized by a thin body, moderate malnutrition, and weak muscles, was unable to undergo a pedicled muscle flap transfer. Therefore, we opted to perform OWT during the initial stage of the operation. The dressing was changed daily post-operatively until the walls of the abscess cavity appeared bright and smooth, with fresh granulation tissue. **Stage II surgical procedure**: Initially, the wound was carefully separated along the original incision, and the thickened pleura was excised. Subsequently, a substantial volume of normal saline, hydrogen peroxide, and diluted iodophor solution was repeatedly used to irrigate the abscess cavity. Once the cavity surface was thoroughly cleansed, a solution consisting of 50 ml of sterile saline and 240,000 units of gentamicin was injected into the abscess cavity. Finally, a thin drainage tube was clipped in place before the incision was sutured (Fig. 4A-C).

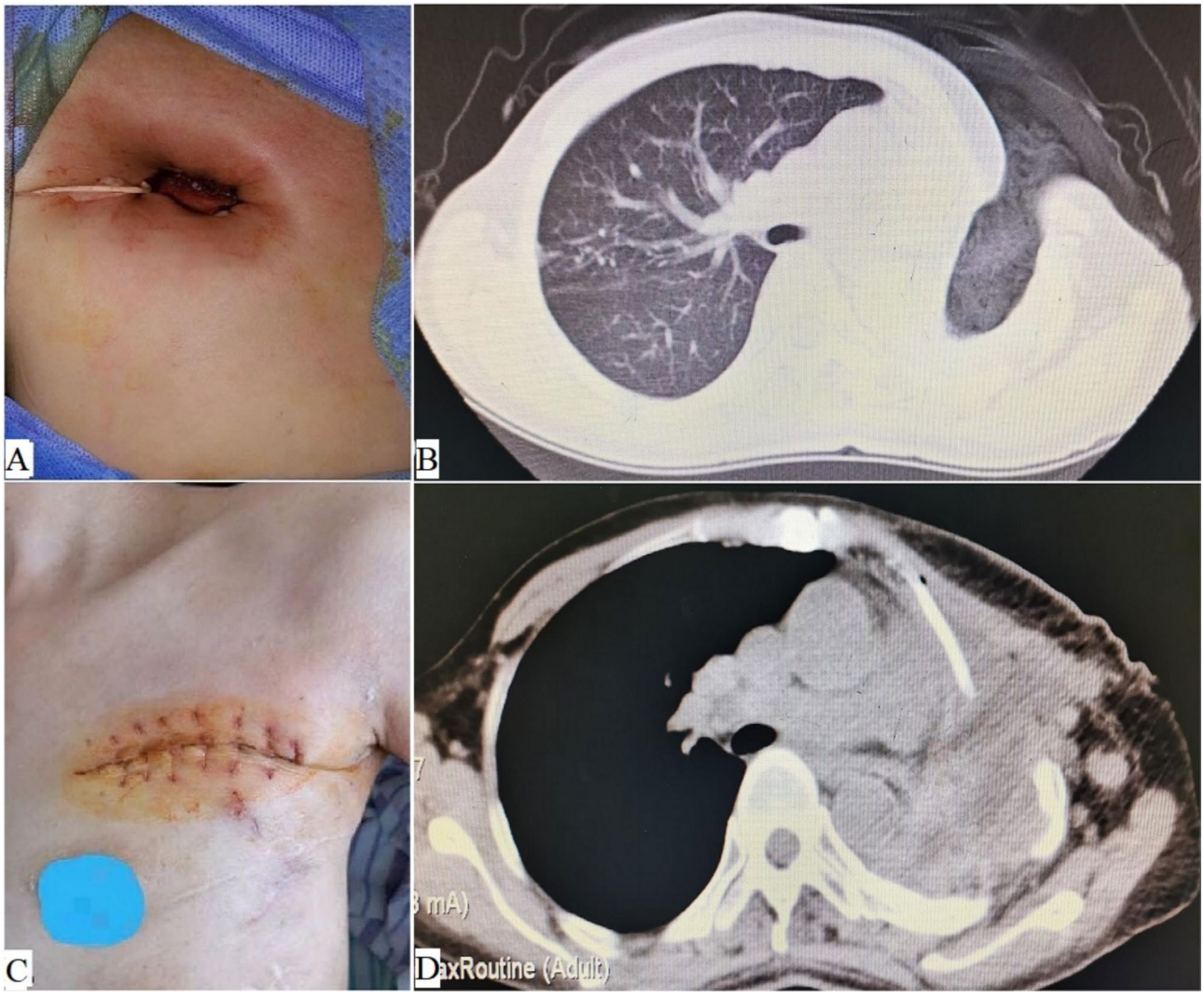

Fig. 4 Clinical images of case 6. (**A**) The patient underwent OWT after first-stage surgery; (**B**) Chest CT showed a defect on the left chest wall after OWT; (**C**) The postoperative incision of case 6 healed well and the thoracic drainage tube had been pulled out; (**D**) After Clagett surgery, Re-examination of chest CT showed no recurrence of empyema

The five patients who underwent autologous tissue flap transfer received active treatment with anti-infection, anti-coagulation, and anti-vasospasm therapies postoperatively. The skin temperature, color, and activity of the tissue flaps were closely monitored, and the area of the transplanted autologous tissue flap was illuminated with a thermal insulation lamp to prevent compression of the supplying vessels and the transplanted tissue flap. One patient who underwent Clagett surgery was provided with anti-infection treatment and nutritional support following the procedure. Additionally, body temperature and the incision site were closely monitored.

Results

In cases 1 and 2, there was no necrosis of the muscle flap, no recurrence of empyema, and no incision infections in the patients who received pedicled muscle flap transplantation. Postoperative chest CT or MRI revealed complete occlusion of the abscess cavity(Fig. 1E). In cases 3 and 4, the postoperative capillary test was positive, the skin color of the transplanted skin-muscle flap area appeared normal, and there was no recurrence of chronic empyema. Re-examination of chest CT or MRI indicated that the abscess cavity had disappeared(Fig. 2F). In case 5, the patient recovered well following pedicled greater omentum transplantation, with no recurrence of empyema noted during postoperative follow-up(Fig. 3C). In case 6, re-examination of chest CT demonstrated that the abscess cavity had been fixed. After the drainage tube was removed, the patient experienced no recurrence of empyema (Fig. 4D). Follow-up assessments conducted between 3 and 29 months post-operation revealed that all patients were able to walk, run, and jump normally. Furthermore, their lung function did not show significant

reduction as a result of the surgery. Notably, their nutritional status improved markedly, with many patients experiencing weight gain. All individuals successfully returned to their normal working conditions, and their overall quality of life showed significant enhancement.

Discussion

The incidence of empyema following pneumonectomy is notable, particularly in cases of refractory empyema, which poses significant challenges for clinicians. When accompanied by BPF, the duration of treatment tends to be extended, and mortality rates may increase [2, 5, 6]. Most patients with PPE develop early and are often associated with the emergence of BPF [7], however, refractory empyemas can also occur in the absence of fistulas. The presence of abscesses and fistulas, which are difficult to eliminate completely, may result in residual necrotic tissue, complicating local infection control. This prolongs the disease course, complicates treatment, diminishes therapeutic efficacy, and severely impacts quality of life [8]. Therefore, a comprehensive strategy is essential for the effective management and diagnosis of PPE. In terms of management standards, the following measures should be implemented: a.Monitor cardiopulmonary function closely and effectively regulate the volume and rate of intravenous fluid administration; b.Manage patients' respiratory tracts by ensuring timely sputum excretion, administering anti-asthma treatments, and providing appropriate antibiotic therapy to prevent lung infections; c.Vigilantly observe the patient's wound and change dressings promptly to maintain cleanliness; d.Focus on dietary care, ensuring the intake of an appropriate amount of high-protein, low-fat, and easily digestible foods while maintaining water, electrolyte, and acid-base balance; e.Advise patients to engage in functional rehabilitation exercises to prevent venous thrombosis; f.In the early stages, ensure adequate drainage to control infection, while later stages should focus on closing the BPF and eliminating residual cavity [9–12]. Based on an analysis of the diagnostic and treatment processes, it is essential to evaluate not only the size and location of the abscess cavity, the presence of any associated fistula, the severity of the infection, the original surgical incision, and the integrity of the local chest wall muscle, but also to establish a multidisciplinary treatment strategy that considers the overall nutritional and psychological status of the patients.

We previously noted that evaluating stage I operations can provide valuable insights for selecting surgical methods in stage II, particularly regarding the size of the abscess cavity. In the top five cases, autologous tissue flaps were employed to fill the residual cavity, resulting in a significant clinical therapeutic effect. In recent years, the use of autologous tissue flap transplantation has emerged as an ideal approach in the treatment of chronic empyema. This technique effectively aims to completely or substantially eliminate the abscess cavity while maintaining the thoracic shape largely unchanged [13, 14]. Furthermore, it minimally impacts respiratory and circulatory functions. Additionally, autologous tissue flap exhibit strong anti-infection properties, particularly the greater omentum and muscle tissue, which are particularly beneficial in treating BPF associated with chronic empyema [15, 16]. Of course, there are clinical reports of successful cases utilizing negative-pressure wound therapy (NPWT) to treat chronic empyema associated with BPF. Compared to traditional passive drainage methods, NPWT represents a more proactive approach to drainage. Its primary aim is to effectively control infection, reduce residual cavity, and promote the growth of granulation tissue [17, 18]. However, NPWT has certain limitations. Based on our experience, it is not suitable for patients with large abscess cavities or significant fistulas, as it may introduce potential risks such as mediastinal deviation and aspiration pneumonia. Additionally, if the intrathoracic infection is not adequately managed, it may be necessary to reinsert a negative pressure device or employ subsequent OWT. Therefore, while NPWT serves as an alternative strategy for treating chronic empyema, individualized assessment remains essential to achieve clinical resolution in some patients.

For PPE patients who are suitable for pedicled tissue flap therapy, the following advantages are summarized: a.Pedicled tissue flaps, such as the serratus anterior muscle, pectoralis major muscle, and greater omentum, exhibit distinct tissue levels, facilitate easy positioning of the vascular pedicle, demonstrate relatively few anatomical variations, and offer flexibility in cutting and manipulation; b.The strong anti-infection capability and plasticity of the pedicled tissue flap, combined with the robust blood supply from the pedicled blood vessels, provide a unique advantage in addressing chronic empyema resulting from fixed space after lobectomy or pneumonectomy; c.Following the activation and repair of the transplanted tissue flap, the dispersal of the newly generated vascular network and its associated inflammatory response plays a facilitating role [15, 19–21].Similarly, In cases where we encounter patients with pleural space infections (PPE) who present with large abscess cavities that cannot be treated using a pedicled tissue flap, it is important to note that many of these patients have previously undergone interventions such as chest tube drainage, OWT, or thoracoplasty. These procedures are often associated with local lesions affecting large muscle groups and major vascular supply. In such instances, the use of a free muscle flap, potentially in combination with a pedicled tissue flap, is advantageous for treating empyema with extensive abscess cavities. Typically,

the free muscle flap selected is derived from the lateral femoris muscle group, with the donor vessels being the descending branch of the lateral femoral artery and its accompanying vein. The recipient vessels are generally the thoracodorsal arteries and veins. If required, we may also consider utilizing the internal mammary and transverse cervical vessels [22, 23].The advantages of the free vastus lateralis musculocutaneous flap are as follows: (a) The anatomy is straightforward, and the muscle structure is robust, which can adequately fill large abscess cavities and blind ends within these cavities; (b) The vascular pedicle of the free myocutaneous flap is sufficiently long to ensure effective vascular anastomosis; (c) Following transplantation, the skin flap allows for easy observation of color and morphology, and no skin grafting is required after tension-free suturing, making it an ideal choice for transplantation [14, 24–26].

The last patient with PPE mentioned above weighed only 35 kg due to malnutrition, which made it extremely challenging to select viable tissue flaps. Relevant literature suggests that OWT may be considered after debridement in certain patients with advanced PPE, and that pedicled muscle flap or greater omental transfer closure could be supplemented if necessary, particularly in cases accompanied by BPF [27, 28]. Fortunately, the patient's abscess cavity was small and not associated with BPF. Consequently, a sterile antibiotic solution was prepared and filled in the cavity post-surgery, resulting in a favorable treatment outcome.

Conclusion

In summary, we employed a multidisciplinary model to guide the treatment strategy for refractory empyema following pneumonectomy, supplemented by an individualized comprehensive treatment plan. Postoperative follow-up indicated that patients expressed satisfaction with both short-term and mid-term clinical outcomes, and there was a notable improvement in their quality of life. While considering the contemporary approach of rapid recovery post-surgery, it is important to acknowledge the potential drawback of larger wound surfaces, which may lead to an increased incidence of postoperative complications. Nevertheless, when taking into account the pain associated with the patient's condition, the provision of spiritual and emotional support may offer hope for those undergoing treatment for complex empyema after pneumonectomy.

Abbreviations

BPF	Bronchopleural fistula
CT	Computed tomography
MRI	Magnetic resonance imaging
OWT	Open-window thoracostomy
PPE	Postpneumonectomy empyema
EBV	Endobronchial one-way valve
NPWT	Negative-pressure wound therapy

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Author contributions

Lei Wang, Yunjie Lv, Guoxue Zhao, Yunchao Huang, Guangqiang Zhao and Guangjian Li designed the study. Lei Wang and Guangjian Li collected the data. Material preparation and the data analysis were performed by Lei Wang and Zhongliang He. All authors read and approved the final manuscript.

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Data availability

No datasets were generated or analysed during the current study.

Declarations

Competing interests

The authors declare no competing interests.

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