Research Square

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CT-based classification of peri-empyema lung opacities predicts surgical complexity in chronic tuberculous empyema: a retrospective cohort study

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Research Article

Keywords: tuberculous empyema, video-assisted thoracoscopic surgery (VATS), atelectasis, active tuberculosis, computed tomography, pre-operative risk stratification

Posted Date: May 25th, 2026

DOI: https://doi.org/10.21203/rs.3.rs-9362577/v1

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Additional Declarations: No competing interests reported.

Abstract

Background

Preoperative computed tomography (CT) routinely reveals peri-empyema lung consolidations in chronic tuberculous empyema, but their pathological correlates and surgical implications remain poorly defined. We hypothesized that differentiating these opacities as either compressive atelectasis or active pulmonary tuberculosis would predict the feasibility, safety, and recovery of uniportal video-assisted thoracoscopic surgery (VATS).

Methods

This single-center retrospective cohort study included 150 consecutive patients who underwent uniportal VATS decortication for chronic tuberculous empyema (January 2021 – December 2023). A multidisciplinary team prospectively classified peri-empyema consolidations into an Atelectasis group (n = 88) or a Parenchymal Disease group (n = 62) based on preoperative CT and intraoperative findings. Group comparisons used the Mann-Whitney U test for continuous variables and the χ^2 or Fisher's exact test for categorical variables. Time-to-event outcomes (chest tube duration, lung re-expansion time) were analyzed with Kaplan-Meier curves and the log-rank test. Multivariable logistic regression was performed to identify factors associated with combined lung resection.

Results

Compared with the Atelectasis group, the Parenchymal Disease group required combined lung resection more frequently (37.1% vs. 10.2%; odds ratio [OR] 4.98, 95% confidence interval [CI] 2.12–11.68, $P < .001$), had a longer median operative time (140 vs. 95 minutes, $P < .001$), greater median blood loss (300 vs. 150 mL, $P = .002$), prolonged median chest tube duration (7 vs. 5 days, $P = .008$), and extended median postoperative stay (9 vs. 6 days, $P = .012$). Radiographic lung re-expansion was significantly delayed in the Parenchymal Disease group (median 3 vs. 1 month, $P< .01$). Overall complication rates (4.8% vs. 2.3%, $P = .71$) and ultimate therapeutic success (98.4% vs. 100%, $P = .38$) did not differ significantly.

Conclusions

This simple CT-based classification effectively stratifies operative complexity and recovery trajectory in patients undergoing uniportal VATS decortication for chronic tuberculous empyema. The presence of active parenchymal tuberculosis significantly increases surgical difficulty and delays recovery but does not compromise long-term prognosis. Prospective multicenter validation with tissue confirmation is warranted.

Background

Tuberculosis remains a leading cause of infectious disease mortality worldwide. According to the 2024 WHO Global Tuberculosis Report, an estimated 10.8 million incident cases and 1.25 million deaths occurred in 2023, restoring tuberculosis to its position as the leading single-pathogen cause of death from infectious disease[1]. China is among the high-burden countries[2,3]. with tuberculous pleurisy representing the most common form of extrapulmonary tuberculosis (≈ 35% of cases)[4]. Tuberculous empyema typically evolves from tuberculous pleurisy[5] and progresses through three stages: exudative, fibrinopurulent, and organizing (chronic) phase. The organizing phase is characterized by marked pleural thickening, calcification, and a trapped lung, which restricts pulmonary expansion and impairs lung function irreversibly[6–8]. Moreover, the dense fibrotic barrier impedes antimicrobial penetration, rendering the infection refractory to chemotherapy. Current guidelines from the American Thoracic Society and British Thoracic Society advocate early surgical intervention for empyema that fails closed drainage[9,10]. Video-assisted thoracoscopic surgery (VATS) has progressively replaced open thoracotomy[11], offering reduced surgical trauma and faster recovery[12]. However, dense pleural adhesions, fibrothorax, and ongoing sepsis make VATS technically demanding, and some cases require conversion to open thoracotomy[13,14]. Operative management enables radical debridement of infected tissue and facilitates full re-expansion of the lung, thereby achieving definitive control of infection[15].

In recent years, video-assisted thoracoscopic surgery (VATS) has progressively supplanted open thoracotomy for tuberculous empyema, offering reduced surgical trauma and accelerated postoperative recovery[15–17]. Nevertheless, the dense pleural adhesions, pronounced fibrothorax, parenchymal compression, and ongoing sepsis that typify chronic tuberculous empyema render VATS technically demanding; a proportion of cases must be converted to open thoracotomy because of intra-operative difficulties or uncontrollable haemorrhage[18,19]. Consequently, an objective and reproducible pre-operative tool to stratify operative complexity is needed. We therefore aimed to develop and validate a simple CT-based classification of peri-empyema consolidations to optimize patient selection and surgical planning for uniportal VATS.

Emerging evidence indicates that ipsilateral parenchymal disease is a pivotal predictor of VATS conversion[18,19]. On computed tomography (CT), peri-empyema pulmonary lesions manifest as mass-like consolidations; our preliminary data demonstrate that the extent and character of these opacities correlate strongly with intra-operative difficulty, conversion rate, and long-term outcome[20]. In a subsequent analysis, we classified these peri-empyema consolidations into two distinct CT phenotypes —atelectasis versus active parenchymal disease—based on their pathogenesis and radiological features. The differential impact of these two entities on VATS feasibility is substantial, providing a practical imaging-based framework for pre-operative risk assessment.

Methods

Study Design and Patient Selection

This was a retrospective cohort study conducted at the Department of Thoracic Surgery, Wuhan Pulmonary Hospital. We screened 219 consecutive patients who underwent uniportal VATS decortication for chronic tuberculous empyema between January 2021 and December 2023. After applying exclusion criteria (absence of peri-empyema consolidations on CT, n = 50; rifampicin-/multidrug-/extensively drug-resistant tuberculosis without standardized pharmacotherapy, n = 11; conversion to open thoracotomy, n = 8), 150 patients were included in the final analysis. The study followed the STROBE (Strengthening the Reporting of Observational Studies in Epidemiology) checklist, as detailed in Fig. 1. It was approved by the Institutional Review Board of Wuhan Pulmonary Hospital (No. 2021024), and written informed consent was obtained from all participants.

CT-based Classification of Peri-empyema Consolidations

Classification was performed by a multidisciplinary panel consisting of one board-certified thoracic radiologist and two attending thoracic surgeons. The radiologist first assigned each consolidation to a provisional category based on pre-operative high-resolution CT findings. Intraoperatively, the two surgeons prospectively documented the macroscopic appearance and behavior of the lesion after removal of the fibrous peel. Final categorization was achieved only after concordance between imaging and operative observations was established. The two distinct CT patterns were defined as follows:

Atelectasis: Defined as parenchymal collapse secondary to extrinsic compression by the empyema cavity. CT demonstrates peripheral, band-like or wedge-shaped opacities abutting the empyema, typically without air bronchograms. Intraoperatively, these zones are sharply demarcated; upon release of the fibrous peel, the underlying lung promptly re-expands.

Parenchymal Disease: Encompasses active pulmonary tuberculosis or other concomitant parenchymal processes adjacent to the empyema. On CT, these lesions appear as irregular, mass-like consolidations that frequently contain air bronchograms and may extend medially. Cavitation and bronchial occlusion are not uncommon. Intraoperatively, the interface is indistinct, with tenacious adhesion between the fibrous peel and the parenchyma, precluding safe en bloc dissection. The affected lung fails to expand immediately after decortication.

Surgical Technique and Postoperative Management

All procedures were performed as uniportal VATS decortications. A single 4–5 cm incision was centered over the empyema cavity, typically at the sixth or seventh intercostal space along the mid-axillary line. Under thoracoscopic vision, systematic decortication proceeded in the following order: diaphragmatic, parietal, pulmonary, and mediastinal surfaces. Coexisting parenchymal lesions were resected by wedge resection or formal lobectomy as indicated. At the conclusion, one apical and one basal 28-F chest tube were placed. Chest tubes were removed upon full lung expansion, absence of air leak, and drainage of <

100 mL per 24 hours. All patients received uninterrupted anti-tuberculous chemotherapy for ≥ 12 months postoperatively.

Statistical Analysis

Statistical analyses were performed using SPSS (version 20.0; IBM Corp., Armonk, NY, USA) and R (version 4.3.1). Continuous variables are reported as mean ± standard deviation or median with interquartile range (IQR), as appropriate. Group differences were evaluated with the Student's t-test for normally distributed data and the Mann-Whitney U test for non-normally distributed data. Categorical variables are expressed as absolute numbers and percentages (n, %) and were compared using the χ^2 test or Fisher's exact test. All reported P values are two-sided, with $P < .05$ considered statistically significant.

To identify factors independently associated with the need for combined lung resection, multivariable logistic regression was employed, including variables with $P < .10$ in univariate analysis or of clinical relevance. Time-to-event outcomes (chest tube duration and lung re-expansion time) were analyzed using Kaplan-Meier curves and compared with the log-rank test. Cox proportional hazards regression was used to adjust for covariates.

Results

CT and Intra-operative Classification of Peri-empyema Consolidations

Representative cases illustrating the two distinct CT phenotypes and their corresponding surgical correlates are presented in Fig. 2 (Compressive Atelectasis) and Fig. 3 (Active Parenchymal Disease). As demonstrated in Fig. 2, cases of compressive atelectasis exhibited homogeneous, band-like or wedge-shaped opacities on CT, with a clear surgical plane allowing for straightforward decortication and immediate lung re-expansion. In contrast, as shown in Fig. 3, consolidations due to active parenchymal disease were characterized by irregular morphology, cavitation, or abscess formation on CT. Intra-operatively, these lesions demonstrated obliteration of the pleuroparenchymal plane and dense adhesions, complicating dissection and frequently necessitating parenchymal resection.

Baseline Characteristics and Operative Outcomes

Following the classification scheme illustrated above, 62 patients were assigned to the Parenchymal Disease group and 88 to the Atelectasis group. Baseline characteristics were well balanced between the two groups (Table 1). Peri-operative outcomes are summarized in Table 2. Compared with the Atelectasis group, the Parenchymal Disease group required combined decortication and parenchymal resection more frequently, resulting in longer operative time ($P < .001$) and greater intra-operative blood loss ($P = .002$). Although 72-hour cumulative drainage volumes did not differ significantly between the two groups, both duration of chest drainage ($P = .008$) and postoperative length of stay ($P = .012$) were prolonged in the Parenchymal Disease cohort.

Table 1
Comparison of Baseline Characteristics Between the Two Groups

Characteristic	Parenchymal Disease Group (n = 62)	Atelectasis Group (n = 88)	P-Value
Demographics			
Age, years, median (IQR)	36 (25–52)	33 (25–53)	0.794
Male sex, n (%)	46 (74.2)	74 (84.1)	0.136
Clinical Features			
Left side involved, n (%)	22 (35.5)	38 (43.2)	0.343
Preoperative ATT duration, months, median (IQR)	6 (2.8–10)	5 (3–12)	0.643
Disease extent, intercostal spaces, median (IQR)	7 (5–9)	7 (6–8)	0.418
Comorbidities present, n (%)	15 (24.2)	14 (15.9)	0.206
Laboratory Values			
Low hemoglobin, n (%)	16 (25.8)	24 (27.3)	0.842
Low albumin, n (%)	8 (12.9)	11 (12.5)	0.942
Elevated ESR, n (%)	33 (53.2)	40 (45.5)	0.348
Elevated CRP, n (%)	35 (56.5)	43 (48.9)	0.360

Data presented as median (interquartile range, IQR) or n (%). P values calculated using Mann-Whitney U test for continuous variables and χ^2 or Fisher's exact test for categorical variables.

ATT = antituberculous therapy; ESR = erythrocyte sedimentation rate; CRP = C-reactive protein.

Table 2
Perioperative Outcomes by CT-Based Classification Group

Outcome	Parenchymal Disease Group (n = 62)	Atelectasis Group (n = 88)	P Value
Surgical Procedure, n (%)			< 0.001
Decortication only	39 (62.9)	81 (92.0)	
Decortication + lung resection	23 (37.1)	7 (8.0)	
Operative time, min, mean ± SD	321.1 ± 104.5	278.9 ± 91.5	0.010
Blood loss, mL, median (IQR)	400 (300–725)	300 (200–600)	0.008
72-h drainage volume, mL, mean ± SD	1073.3 ± 617.5	910.3 ± 465.2	0.067
Chest tube duration, days, median (IQR)	13 (7.8–25.3)	9 (7-17.8)	0.006
Postoperative stay, days, median (IQR)	14 (9–21)	10.5 (8-15.8)	0.009
Complications, n (%)	3 (4.8)	2 (2.3)	0.339
Data presented as mean ± standard deviation (SD), median (interquartile range, IQR), or n (%).			

Complications occurred in three patients in the Parenchymal Disease group: one developed a localised pneumothorax detected at 1-month follow-up, successfully managed with tube thoracostomy; one experienced Aspergillus empyema superimposed on pre-existing Aspergillus pneumonia, resolved after drainage, lavage and systemic antifungal therapy (drains removed on postoperative day 65); and one developed a suspected bronchopleural fistula that ceased air leakage on day 101, allowing drain removal with a small asymptomatic residual cavity. In the Atelectasis group, two complications occurred: one chylothorax controlled by dietary fat restriction and drainage (tube removed on day 55), and one postoperative haemorrhage necessitating re-thoracotomy at 12 h for haemostasis. There was no statistically significant difference in overall complication rates between the two groups (P = .71).

Lung re-expansion was significantly delayed in the Parenchymal Disease group compared with the Atelectasis group (P < .01, Table 3). Overall therapeutic success, however, did not differ between the two cohorts (P = .38). One patient in the Parenchymal Disease group was classified as treatment failure: after combined decortication and left lower lobectomy, a bronchopleural fistula developed that required prolonged drainage for 218 days. The empyema eventually became a small, clinically silent residual cavity; the patient declined further intervention and remains under close surveillance.

Table 3
Postoperative Recovery

Recovery Measure	Parenchymal Disease Group (n = 62)	Atelectasis Group (n = 88)	P Value
Lung re-expansion time, months, median (IQR)	5 (3–9)	4 (2.3-6)	0.030
Therapeutic outcome, n (%)			0.070
Cure	42 (67.7)	71 (80.7)	
Improvement	19 (30.6)	17 (19.3)	
Failure	1 (1.6)	0 (0)	

Discussion

In this retrospective cohort study, we demonstrated that a simple, CT-based classification of peri-empyema consolidations effectively stratifies operative complexity and recovery trajectory in patients undergoing uniportal VATS decortication for chronic tuberculous empyema. Our analysis establishes that active parenchymal tuberculosis adjacent to empyema, distinct from compressive atelectasis, predicts greater surgical challenge and protracted recovery, yet does not diminish ultimate therapeutic success.

Pathogenesis of tuberculous empyema follows two principal routes.

First, and most common, is the chronic evolution of tuberculous pleurisy[7,21]. Copious early exudate precipitates compressive atelectasis, while subsequent pleural fibrosis permanently restrains pulmonary re-expansion, producing the classic “trapped-lung” scenario[11,22].

Second, direct pleural seeding may occur when contiguous or remote tuberculous foci—within the lung parenchyma, parietal pleura, diaphragm, thoracic vertebrae, or mediastinal lymph nodes—rupture into the pleural space via contiguous spread, haematogenous dissemination, or iatrogenic insult[5,21,23]. In these cases the infective load is high, and frank communication between parenchymal disease and the empyema cavity is frequent, yielding a fulminant clinical course[24].

These divergent mechanisms generate distinct radiological signatures. Compressive atelectasis manifests as peripheral, homogeneous, band-like or wedge-shaped opacities confined to the segmental bronchial distribution[25,26]. Conversely, active parenchymal disease presents as irregular, heterogeneous with cavitation, intrapulmonary abscess formation, or bronchial occlusion[27,28]. Recognition of these characteristic CT patterns permits accurate pre-operative aetiopathogenic stratification and informs surgical planning.

The objective of surgical therapy for tuberculous empyema is complete extirpation of infected tissue coupled with restoration of pulmonary expansion and definitive infection control[29,30]. The principal challenge—particularly in the thoracoscopic setting—lies in the separation of the visceral fibrous peel from the underlying lung parenchyma[31,32]. When the natural cleavage plane is obliterated, dissection becomes protracted, parenchymal injury and intra-operative haemorrhage escalate, and the incidence of postoperative air leaks and bronchopleural fistula rises substantially[33].

Although the majority of patients whose empyema arises from chronic tuberculous pleurisy ultimately develop some degree of parenchymal involvement, the surrounding lung is predominantly collapsed rather than diseased[34]. In this setting the interface between the visceral pleura and the fibrous peel remains relatively well defined, permitting straightforward extrapleural dissection. Conversely, when active tuberculous lesions involve the pleura or the adjacent lung parenchyma, the two layers become densely fused, obliterating the natural plane and transforming decortication into a laborious, high-risk undertaking associated with increased haemorrhage and parenchymal injury[19,23].

Upon release of the fibrous peel, atelectatic lung re-expands immediately once the compressive force is removed[35]. Active pulmonary tuberculosis, however, defies such rapid restoration; sustained pharmacological control of infection is required before re-aeration can occur, resulting in a considerably prolonged recovery trajectory[36]. In the present study, the Parenchymal Disease cohort exhibited significantly longer operative times, greater intra-operative blood loss, extended chest-drain duration, length of stay, and delayed radiographic lung re-expansion compared with the Atelectasis cohort. These findings underscore that peri-empyema tuberculous parenchymal disease exerts a far greater adverse impact on both operative complexity and postoperative recovery than does simple compressive atelectasis.

Moreover, our data demonstrate that baseline nutritional status, inflammatory burden, and radiographic extent of disease were comparable between the Atelectasis and Parenchymal Disease groups, indicating that the genesis of peri-empyema consolidations is independent of these factors. Of note, although pharmacological therapy may reduce the size of parenchymal tuberculous lesions, the dense adhesions and fusion between diseased lung and the fibrous peel persist and continue to complicate surgery[20]. Consequently, when pre-operative CT suggests active parenchymal tuberculosis adjacent to the empyema cavity, the surgical team should prepare meticulously—comprehensive patient counselling, cross-matched blood, and contingency plans for major bleeding or prolonged air leak—to minimise intra-operative risk and to avert the anxiety and erosion of trust that accompany unexpected delays. Importantly, despite the increased operative complexity and prolonged recovery observed in the Parenchymal Disease group, neither complication rates nor long-term therapeutic outcomes differed between the cohorts. These findings confirm that peri-empyema parenchymal tuberculosis augments surgical trauma and delays convalescence, but does not compromise ultimate prognosis.

This study elucidates the two dominant patho-aetiologies underlying peri-empyema consolidations in chronic tuberculous empyema and clarifies their divergent clinical impact. Active parenchymal

tuberculosis adjacent to the empyema cavity significantly elevates operative risk, technical complexity, and convalescent burden, mandating heightened vigilance and tailored peri-operative planning.

Several limitations warrant acknowledgment. First, the absence of confirmatory histopathological or microbiological sampling from the peri-empyema lung mandates reliance on CT morphology for classification; inherent subjectivity may have introduced misclassification bias. Second, the single-centre, retrospective design inevitably incorporates institutional preferences in patient selection and peri-operative protocols, limiting external validity. Multi-centre prospective studies incorporating tissue-level verification are required to corroborate and refine these findings.

In summary, peri-empyema consolidations on CT in chronic tuberculous empyema arise chiefly from either compressive atelectasis or active pulmonary tuberculosis. The latter significantly amplifies thoracoscopic surgical risk and operative trauma, and markedly prolongs postoperative recovery. The distinctive radiological signatures of these two entities provide objective, readily applicable criteria for pre-operative risk stratification.

Declarations

Funding

The author(s) declare financial support was received for the research and/or publication of this article. This research was supported by the Preventive Medicine Association of Hubei Province (No. 2025SWGKY391); Wuhan Pulmonary Hospital (Wuhan Institute for Tuberculosis Control), Hubei Province Branch of National Center for Clinical Medicine of Infectious Diseases (No. WF2025Y08; No. WF2025Y08)

Author Contribution

Y.J., X.D.; Data curation: Y.J., Q.L., L.Y.; Formal analysis: Q.L., C.D.; Funding acquisition: X.D.; Investigation: L.Y., L.Q.; Methodology: Y.J., Q.L.; Project administration: X.D.; Resources: L.Q., C.D.; Supervision: X.D.; Validation: L.Y., L.Q.; Visualization: C.D.; Writing – original draft: Y.J.; Writing – review & editing: Q.L., X.D.

Acknowledgement

The authors thank the medical staff of the Department of Thoracic Surgery at Wuhan Pulmonary Hospital for their assistance in data collection and patient care. We also acknowledge the statistical support provided by the hospital's research unit.

Ethics statement

In accordance with the Declaration of Helsinki, this study was approved by the Institutional Review Board/Ethics Committee of Wuhan Pulmonary Hospital (No.2021024). Written informed consent was obtained from both patients for publication of this case series and accompanying images.

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Figures

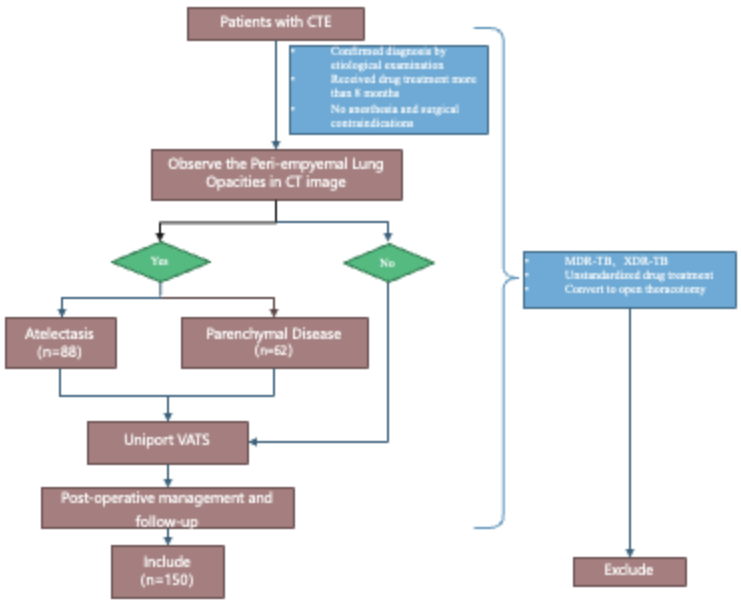


Figure 1. Patient Selection and Group Allocation Flowchart

Figure 1

See image above for figure legend

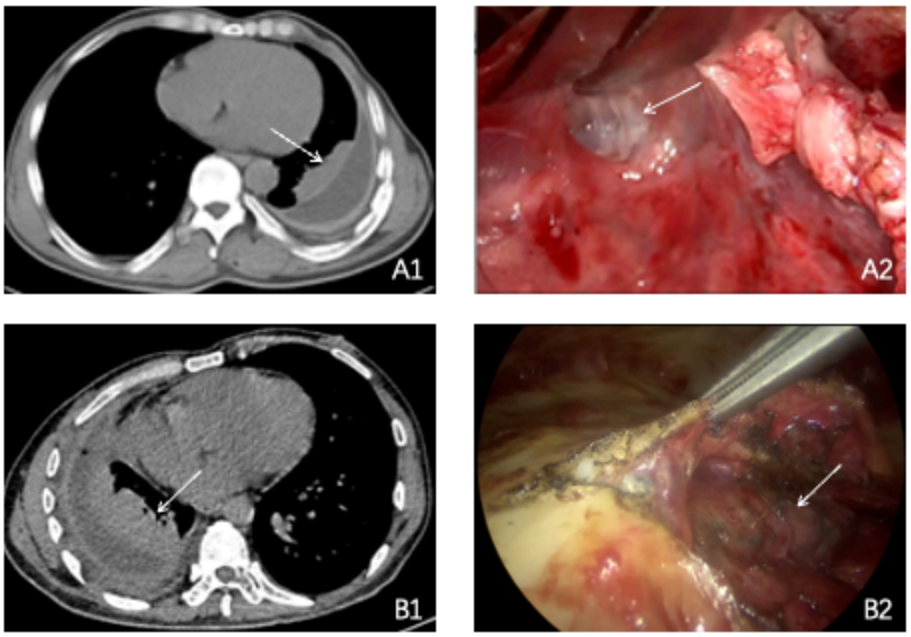


Figure 2. Computed tomographic and intra-operative appearances of compressive atelectasis adjacent to chronic tuberculous empyema; A1. Axial CT demonstrates a homogeneous, band-like opacity (white arrow) conforming to the empyema cavity; A2. Intra-operative view reveals a clearly demarcated, loosely adherent fibrous peel (white arrow) that is readily separated from the underlying lung; B1. CT image shows a peripheral, wedge-shaped consolidation of uniform density; patent bronchi are visible within the lesion (white arrow); B2. At operation a discrete plane is present between the fibrous peel and the lung; following decortication the collapsed parenchyma re-expands immediately (white arrow).

Figure 2

See image above for figure legend

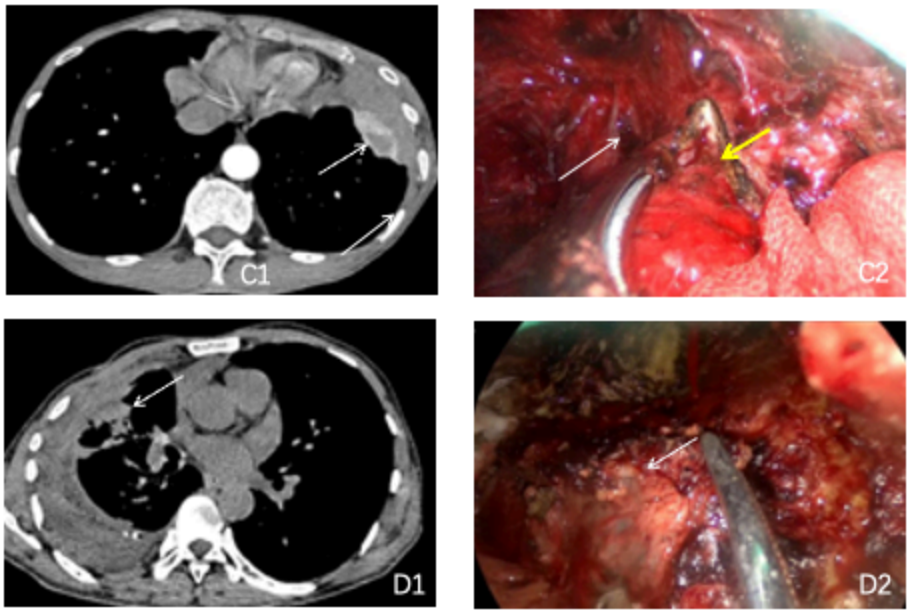


Figure 3. Computed tomographic and intra-operative findings of active pulmonary tuberculosis surrounding chronic tuberculous empyema; C1. CT reveals a loculated parenchymal abscess (white arrow) adjacent to the empyema; C2. Intra-operative inspection confirms rupture of the abscess onto the pleural surface, forming a shallow ulcer (white arrow); Dense, inseparable adhesions between the fibrous peel and the diseased lung are evident (Yellow arrow); D1. CT depicts an irregular, heterogeneous consolidation with air bronchograms (white arrow); D2. Surgical exploration shows complete obliteration of the pleuroparenchymal plane; the fibrous peel is densely fused to the underlying lung, precluding safe en bloc dissection (white arrow).

Figure 3

See image above for figure legend