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Original Article

Evaluation of pneumonectomy outcomes in lung cancer: 18 years of surgical experience and prognostic factor analysis

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ABSTRACT

Background: Despite the widespread use of methods developed to preserve lung parenchyma as much as possible, pneumonectomy remains an essential surgical treatment option, particularly for lung cancers located centrally and/or invading bronchovascular structures. However, pneumonectomy has historically been associated with high morbidity and mortality. This study presents the complications, survival outcomes, and prognostic factors of patients who underwent pneumonectomy for lung cancer, drawing on 18 years of single-center experience.

Materials and Methods: Archived patient files from patients who underwent pneumonectomy at our center between 2006 and 2024 were retrospectively reviewed. Postoperative complications, 30- and 90-day mortality rates, overall survival, and recurrence-free survival were analyzed. Patients who underwent and did not undergo salvage surgery were analyzed as subgroups. Kaplan–Meier analysis was used for survival, and multivariate Cox regression analysis was used to examine prognostic factors.

Results: A total of 304 patients were included in the study. Postoperative 30- and 90-day mortality rates were consistent with the literature. Although there was no significant difference in overall survival between right and left pneumonectomy (p=0.504), the complication rate was higher in right pneumonectomies. Multivariate analysis revealed that age, adenocarcinoma histology, N2 positivity, receipt of adjuvant radiotherapy, and receipt of neoadjuvant therapy were independent predictors of poor prognosis.

Conclusions: Pneumonectomy remains an effective treatment option for selected patients with lung cancer. Advanced nodal disease, tumor size, and the presence of postoperative complications negatively impact survival. Effective use of a multidisciplinary tumor board, individualized treatment, and dedicated perioperative management are the most important criteria for improving long-term survival.

Keywords: pneumonectomy, lung cancer, salvage surgery, postoperative complications, bronchopleural fistula

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Introduction

Although lung parenchyma-sparing surgical methods have been widely used in recent years, pneumonectomy remains critically important. For centrally located tumors, tumors located in the main bronchus, and tumors invading major vascular structures, pneumonectomy is almost the only curative treatment option when sleeve lobectomy or extended resections are not possible [1].

Patients undergoing pneumonectomy are considered to have aggressive biological behavior and generally have advanced-stage tumors and a high probability of perioperative complications [2]. In fact, early-stage mortality rates reported in the literature range from 5% to 15% [1,3]. The most common complications include bronchopleural fistula (BPF), cardiac arrhythmias, and empyema. Many studies have shown that a right pneumonectomy is associated with higher BPF and mortality than a left pneumonectomy [4].

Pneumonectomy outcomes have reportedly improved due to more careful patient selection, improvements in intra- and postoperative fluid management, and better intensive care practices [5]. According to recent studies, 5-year survival rates range from 30% to 45% [6,7].

Another term encountered in the context of pneumonectomies is "salvage pneumonectomy". Salvage pneumonectomy is generally performed in patients who are considered inoperable due to metastatic disease and who require urgent resection due to progression in patients receiving chemotherapy or due to tumor-related complications (such as hemoptysis and lung abscess) [8,9]. This type of surgery is considered to have significantly higher mortality and morbidity. Therefore, separate evaluation of salvage pneumonectomies is crucial for clinical decision-making.

The prognosis after pneumonectomy is influenced by many factors, including age, histological type, the presence of N2 disease, and the administration of adjuvant therapy [10]. In particular, the N2 subclassification proposed in the 9th Tumor-Node-Metastasis (TNM) staging has enabled a more accurate assessment of nodal heterogeneity and strengthened prognostic discrimination.

This study retrospectively reviewed the medical records of patients who underwent pneumonectomy for lung cancer at our center over 18 years and evaluated their clinical, pathological, and oncological outcomes. The differences in survival and complications between right and left pneumonectomy, as well as the outcomes of salvage and non-salvage pneumonectomy, were examined. Prognostic factors affecting survival were analyzed.

Materials and Methods

Patient selection for pneumonectomy

The decision to undergo pneumonectomy for all patients diagnosed with lung cancer was made after a multidisciplinary tumor board evaluation. Radiologic, functional, and oncologic criteria were considered in determining eligibility for pneumonectomy. Pneumonectomy was preferred if lung-sparing surgery was not possible. The criteria for performing a pneumonectomy included at least one of the following clinical or technical conditions: the presence of a centrally located tumor rendering sleeve lobectomy technically unfeasible, or involvement of the main pulmonary artery that precluded a vascular sleeve procedure. Additionally, cases involving invasion of both pulmonary veins, or situations where a lobectomy would result in an incomplete resection for tumors spanning multiple lobes, were managed with pneumonectomy. Other indications included technical constraints such as the inability to perform a safe anastomosis due to advanced fibrosis or tissue fragility following neoadjuvant therapy. Finally, life-threatening conditions like massive hemoptysis, obstructive pneumonia, lung abscess, or tumor progression under oncological treatment were also considered definitive indications for the procedure.

Functional assessment included pulmonary function testing, diffusing capacity of the lung for carbon monoxide (DLCO) measurement, cardiopulmonary exercise testing, predicted postoperative FEV1 (ppo-FEV1) calculation, and cardiac evaluation (ECG, ECHO ± advanced cardiac tests). Eligibility for surgery was defined as having a ppo-FEV1 ≥ 40%, DLCO ≥ 40%, maximal oxygen consumption (VO_2max) >10–15 mL/kg/min, and the absence of severe uncontrolled comorbidities.

Preoperatively, all patients underwent chest computed tomography, 18F-fluorodeoxyglucose positron emission tomography, brain magnetic resonance imaging, bronchoscopy, and, if necessary, mediastinal sampling (Endobronchial ultrasonography-transbronchial needle aspiration and/or mediastinoscopy). Excluding those who underwent salvage pneumonectomy, patients were only admitted to surgery if an R0 resection was deemed achievable.

All patients were evaluated by a multidisciplinary tumor board, including thoracic surgeons, medical oncologists, radiation oncologists, and pulmonologists, prior to surgical decision-making.

Study design

This study is a retrospective, single-center cohort study examining patients who underwent pneumonectomy for lung cancer at our center between 2006 and 2024. Patients who underwent curative pneumonectomy for lung cancer during this period were also included in the study. A total of 304 patients aged 18 and over who underwent complete mediastinal lymph node dissection without macroscopic or microscopic residue were included in the study. Patients with missing pathology reports or follow-up data, and those who underwent pneumonectomy for reasons other than lung cancer, were excluded from the study. Patients who died within 90 days postoperatively were not included in the long-term survival analysis. Overall survival (OS) of patients who underwent salvage and non-salvage pneumonectomy was also analyzed separately. Recurrence-free survival (RFS) analysis was performed only in patients who did not undergo salvage pneumonectomy and did not experience postoperative mortality.

Data collection and definitions

All data were obtained from our center's electronic record system. Epidemiology, radiology, nuclear medicine, and pathology reports, as well as operative notes and oncology follow-up data, were reviewed in detail. Demographic data (e.g., age and gender), surgical site, surgical technique, salvage/non-salvage differentiation, perioperative complications, postoperative mortality, histopathological diagnosis, tumor size, lymph node positivity, N2 subclassification, adjuvant treatments, recurrence, and death dates were recorded. Definitions are as follows: Salvage pneumonectomy: Cases undergoing emergency or mandatory pneumonectomy with or without oncological treatment, postoperative mortality: Death occurring within the first 30 to 90 days after surgery, complication: A medical problem that develops at any time after surgery and is thought to be related to the surgery, OS: Time from the date of surgery to death from any cause and RFS: Time from the date of surgery to the date of recurrence (local or distant).

This study received ethical approval from the Gaziantep University Non-Interventional Clinical Research Ethics Committee (Approval No: 2025/434, Date: 17/12/2025) and was conducted in accordance with the ethical principles of the Helsinki Declaration. Since the study was retrospective, the ethics committee did not require informed consent. All patient data were anonymized before analysis, and data confidentiality was maintained throughout the study.

Statistical Analysis

Descriptive statistics are presented as mean ± standard deviation or median (minimum–maximum) for continuous variables and frequency (%) for categorical variables. For intergroup comparisons, the chi-square test or Fisher's exact test was used for categorical variables. For continuous variables, the independent-samples t-test was used when the data were normally distributed, and the Mann–Whitney U test was used when the data were not normally distributed. The Kaplan–Meier method was used for survival analyses, and the log-rank test was used for group comparisons. Independent factors affecting survival were assessed using multivariate Cox regression analysis. All analyses were conducted using SPSS v22.0, and $p < 0.05$ was considered statistically significant.

Results

A total of 304 patients who underwent lung cancer surgery were included in the study. The mean age was 62.1 ± 8.9 years, and 95.1% of the patients were male. The tumor diameter was calculated as 6.26 ± 3.22 cm. Histopathologically, squamous cell carcinoma predominated (71.4%). The T stage was mainly pT4 (45.4%) and pT3 (32.2%). Mediastinal lymph node classification revealed a pN0 rate of 38.8% and a pN2b rate of 5.3%. The clinical and histopathological characteristics of the patients are shown in Tables 1 and 2.

Postoperative morbidity and mortality

The complication rate in the entire cohort was 24.0%. The BPF rate was 8.9%, and BPF was more common in right pneumonectomies than left pneumonectomies (14.6% vs. 3.8%). When all complications were evaluated, more complications were observed in right pneumonectomies (28.6% vs. 11.9%), and this difference was statistically significant (p=0.002). The distribution of postoperative complications and reoperation patterns is shown in Table 3.

Major early postoperative complications included bronchopleural fistula, postoperative bleeding requiring re-intervention, and respiratory failure. The distribution of these complications by pneumonectomy side is summarized in Table 3.

Postoperative 30-day mortality was 7.9%, and 90-day mortality was 15.1%. Early mortality was higher in salvage pneumonectomy patients than in non-salvage patients (30 days: 14.7% vs. 7.0%; 90 days: 26.4% vs. 12.2%).

Survival Analysis

OS was calculated excluding patients who died postoperatively, and the median OS was 39 months. One-, two-, three-, and five-year OS rates were 71.6%, 60.9%, 50%, and 43%, respectively (Figure 1). The median OS was 30 months for right pneumonectomy and 44 months for left pneumonectomy; this difference was not statistically significant (Figure 2).

After excluding patients who died postoperatively, the median OS was 48 months in the non-salvage group and 15 months in the salvage group. Thus, salvage pneumonectomy significantly worsened long-term survival (Figure 3).

After excluding salvage and early mortality (planned pneumonectomies), the median RFS was 41 months; 1-, 2-, and 5-year RFS were 73.8%, 59.8%, and 42-45%, respectively. The RFS curve declined, particularly in the first 24 months (Figure 4).

Cox Regression Analysis

Univariable analysis revealed that factors affecting OS were age, adenocarcinoma histology, neuroendocrine histology, salvage surgery, receipt of adjuvant radiotherapy, and pN2b stage. Multivariable analysis showed that factors other than neuroendocrine histology were poor prognostic factors (Table 4). These results indicated that adenocarcinoma histology, multiple-zone N2 metastases, and, in particular, salvage pneumonectomy had a significant negative impact on long-term survival.

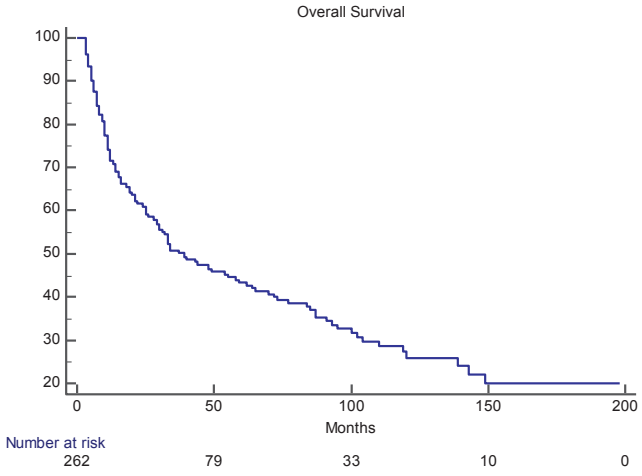


Figure 1. OS of all pneumonectomy patients (postoperative mortality excluded). Kaplan–Meier OS curve showing survival probabilities after exclusion of patients with postoperative mortality within 90 days.

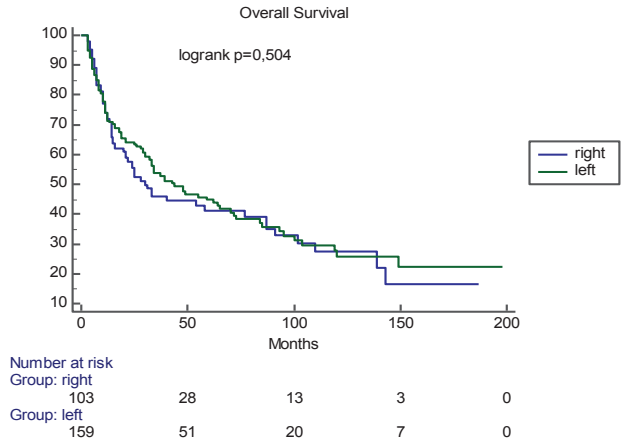


Figure 2. OS by side of pneumonectomy. Comparison of OS between right-sided and left-sided pneumonectomy patients; statistical difference evaluated by the log-rank test.

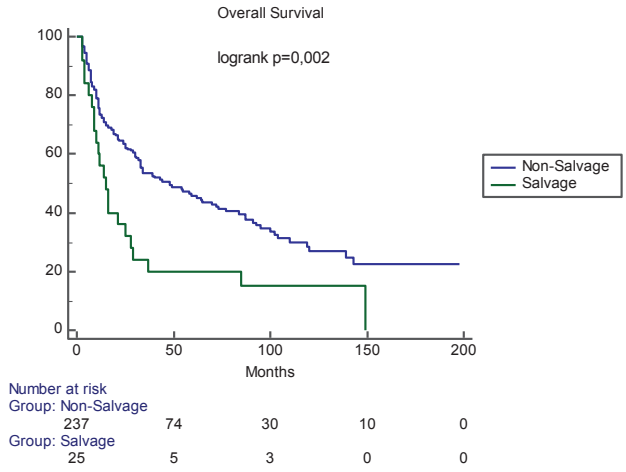


Figure 3. OS of salvage versus non-salvage pneumonectomy patients (postoperative mortality excluded). Kaplan–Meier analysis demonstrating survival outcomes of patients undergoing salvage pneumonectomy compared with planned oncologic pneumonectomy.

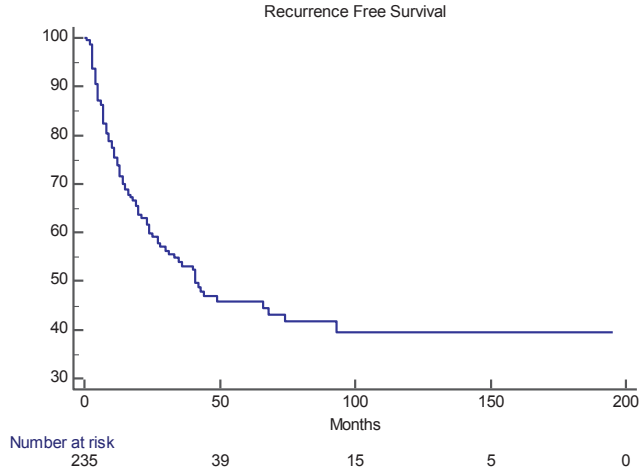


Figure 4. RFS in patients undergoing curative pneumonectomy. RFS curve showing median RFS and long-term disease control among patients who underwent pneumonectomy with curative intent (excluding cases of salvage or postoperative mortality).

Table 1. Baseline characteristics of pneumonectomy patients.

Variable	
Age (year) (mean±SD)	62.1±8.85
Gender n(%)	
• Female	15 (4.9%)
• Male	289 (95.1%)
Tumor location n (%)	
• Right main bronchus	53 (17.4%)
• Right upper lobe	36 (11.8%)
• Right middle lobe	4 (1.3%)
• Right lower lobe	31 (10.2%)
• Left main bronchus	64 (21.1%)
• Left upper lobe	81 (26.6%)
• Left lower lobe	35 (11.5%)
Tumor SUVmax (mean±SD)	14.75±6.6
Bronchoscopic tumor n (%)	
• No	106 (34.9%)
• Yes	198 (65.1%)
Salvage surgery n (%)	
• No	270 (88.8%)
• Yes	34 (11.2%)
Operation n (%)	
• Right extended pneumonectomy	42 (13.8%)
• Right pneumonectomy	70 (23%)
• Left extended pneumonectomy	77 (25.3%)
• Left pneumonectomy	107 (35.2%)
• Right tracheal sleeve pneumonectomy	5 (1.6%)
• Left tracheal sleeve pneumonectomy	3 (1%)

Table 3. Distribution of postoperative complications and reoperations in pneumonectomy patients.

Complication n (%)	Total
None	231 (76%)
Bronchopleural fistula	27 (8.9%)
Postoperative bleeding	10 (3.3%)
Postpneumonectomy pulmonary edema	7 (2.3%)
Respiratory Failure	6 (2%)
Pneumonia	4 (1.3%)
Postpneumonectomy empyema	4 (1.3%)
Myocardial infarction	3 (1%)
Postpneumonectomy syndrome	3 (1%)
Wound infection	3 (1%)
Arrhythmia	3 (1%)
Brain embolism	1 (0.3%)
Pulmonary embolism	1 (0.3%)
Chylothorax	1 (0.3%)
Reoperation n (%)	
None	269 (88.5%)
Omentum transposition	17 (5.6%)
Bleeding control	5 (1.6%)
Tracheobronchial stent	4 (1.3%)
Revision of thoracotomy	3 (1%)
Resuture of main bronchial stump	2 (0.7%)
Tube thoracostomy	2 (0.7%)
Removal of gossypiboma	1 (0.3%)
Bronchoscopic fistula closure (fibrin glue)	1 (0.3%)

Table 2. Histopathological features of pneumonectomy patients.

Histopathological diagnosis n (%)	
Squamous cell carcinoma	217 (71.4%)
Adenocarcinoma	46 (15.1%)
Neuroendocrine carcinoma	15 (4.9%)
Other	26 (8.6%)
Tumor diameter (cm) (mean±SD)	6.26±3.22
T descriptor n (%)	
Tumor size	198 (65.1%)
Other*	106 (34.9%)
pT (9th) n (%)	
T1a	2 (0.7%)
T1b	3 (1%)
T1c	21 (6.9%)
T2a	20 (6.6%)
T2b	22 (7.2%)
T3	98 (32.2%)
T4	138 (45.4%)
pN (9th) n (%)	
N0	118 (38.8%)
N1	130 (42.8%)
N2a	40 (13.2%)
N2b	16 (5.3%)
Stage n (%)	
IA1	1 (0.3%)
IA2	2 (0.7%)
IA3	10 (3.3%)
IB	5 (1.6%)
IIA	19 (6.3%)
IIB	49 (16.1%)
IIIA	158 (52%)
IIIB	26 (8.6%)
IVA	31 (10.2%)
IVB	3 (1%)
Number of N2 stations n (%)	
0	248 (81.6%)
1	40 (13.2%)
2	11 (3.6%)
3	3 (1%)
4	2 (0.7%)

Table 4. Cox regression analysis of pneumonectomy patients.				
	Univariable analysis		Multivariable analysis	
	HR (95% CI)	p	HR (95% CI)	p
Age	1.041 (1.021-1.062)	0.000	1.048 (1.027-1.070)	0.000
Gender				
Female	1			
Male	0.648 (0.317-1.321)	0.232		
Tumor SUVmax	0.989 (0.964-1.014)	0.380		
Side				
Left	1			
Right	1.114 (0.809-1.532)	0.509		
Complication				
Yes	1			
No	0.774 (0.516-1.161)	0.215		
Reoperation				
Yes	1			
No	1.118 (0.645-1.936)	0.691		
Histopathology				
Squamous cell carcinoma	1	0.007	1	0.003
Adenocarcinoma	1.854 (1.244-2.762)	0.002	2.170 (1432-1.381)	0.000
Neuroendocrine carcinoma	2.213 (1.021-4.797)	0.044	1.799 (0.809-1.176)	0.150
Other	1.014 (0.545-1.888)	0.965	1.046 (0.558-4.313)	0.888
Tumor diameter	1.015 (0.963-1.069)	0.582		
T descriptor				
Other*	1	0.292		
Tumor size	0.690 (0.168-2.834)	0.607		
Invasion	0.776 (0.562-1.072)	0.124		
Salvage surgery				
No	1		1	
Yes	1.966 (1.252-3.088)	0.003	1.630 (1.010-2.630)	0.045
Neoadjuvant therapy				
No	1			
Yes	1.087 (0.648-1.823)	0.753		
Adjuvant chemotherapy				
No	1			
Yes	0.974 (0.677-1.401)	0.888		
Adjuvant radiotherapy				
No	1		1	
Yes	2.082 (1.450-2.988)	0.000	2.328 (1.574-3.442)	0.000
pN (9th)				
pN0	1	0.002		0.024
pN1	0.966 (0.680-1.374)	0.849	0.962 (0.670-1.381)	0.832
pN2a	1.097 (0.668-1.802)	0.714	0.695 (0.410-1.176)	0.175
pN2b	3.234 (1.716-6.093)	0.000	2.239 (1.163-4.313)	0.016

** Nodule on the same side and in the same lobe as the primary tumor; Nodule on the same side and in a different lobe than the primary tumor; More than one T descriptor.*

Discussion

This study evaluated the early and long-term outcomes of patients who underwent pneumonectomy for primary lung cancer at a single institution over 18 years. It aimed to demonstrate that, despite advances in parenchymal-sparing techniques, pneumonectomy remains a critical option for select patients with centrally located, anatomically complex tumors. Consistent with recent studies, this patient group represents a high-risk population. Pneumonectomy is generally performed in patients with advanced disease, in whom sleeve lobectomy is not feasible [11,12]. The 5-year OS rate in our study group is consistent with previously published large cohorts reporting 30-45% [11-13]. Although pneumonectomy outcomes have been reported in previous series, the pre-

sent study provides a large contemporary single-center experience with long-term follow-up and specifically evaluates survival differences between salvage and non-salvage pneumonectomy, reflecting current real-world surgical practice.

Although pneumonectomy is most often performed for locally advanced tumors, some patients with early-stage tumors may still require it. Centrally located tumors involving the main bronchus, pulmonary artery, or extensive hilar structures may rule out lung-sparing procedures like sleeve lobectomy. Pneumonectomy may also be necessary intraoperatively due to uncontrolled bleeding, technical complications, or inability to achieve safe and complete resection with a parenchyma-sparing approach. In such situations, pneumonectomy may be the only way to achieve adequate oncological or surgical control.

Differences in the risk profile between right and left pneumonectomy are well known. Right pneumonectomy is associated with higher morbidity and mortality due to factors such as a shorter bronchial stump and a larger post-resection pleural space [14]. Indeed, in our study, postoperative complications and mortality were more common after right pneumonectomy. However, no significant difference in long-term OS was found between right and left pneumonectomy (log-rank $p = 0.504$). Recent studies also indicate that the historical survival disadvantage of right pneumonectomy can be overcome with more careful patient selection and improved perioperative management [8,10].

One of the important findings of our study is the difference in prognosis between salvage pneumonectomy and non-salvage pneumonectomy. Our patients who underwent salvage surgery had higher 30- and 90-day postoperative mortality, higher complication rates, and worse survival outcomes. These findings are consistent with the literature [15,16]. Tumor progression despite oncological treatment, tissue damage and vascular deterioration due to radiotherapy, increased technical difficulties, and the frequent need for emergency intervention all contribute to poorer outcomes of a procedure that already carries high morbidity and mortality [17]. These aggressive indications for salvage surgery necessitate separate evaluation of this group from patients undergoing planned pneumonectomy, and our findings support this conclusion. The long-term survival outcomes in our study were influenced by several prognostic factors, as reported in previous studies [18]. Adenocarcinoma histology, the presence of salvage surgery, adjuvant radiotherapy, neoadjuvant therapy, and age were associated with poor outcomes. The prognostic significance of lymph node subclassification in the 9th edition of the TNM staging system is consistent with our findings. Previous studies have reported that squamous cell carcinoma is associated with better outcomes than some subtypes, such as large cell neuroendocrine carcinoma [19], and our study group has similar findings. Many studies have shown that postoperative complications have a significant impact on survival after pneumonectomy. In particular, BPF, empyema, cardiopulmonary complications, and respiratory failure are significant problems that increase early mortality [20]. In our study, BPF after right pneumonectomy was high, consistent with numerous studies reporting factors such as differences in the right-left main bronchial blood supply and the effect of pleural space size [21].

Furthermore, the sudden loss of pulmonary vascular bed and increased cardiac afterload following pneumonectomy have been reported to lead to postpneumonectomy pulmonary edema and cardiovascular instability [22]. The high complication rate after pneumonectomy underscores the need for an optimized multidisciplinary care approach, including perioperative fluid management, effective ventilation strategies, bronchial stump-preserving techniques, and prompt treatment of early complications [23,24]. Although individualized perioperative management practices and advanced center experience have reduced complication rates in recent years, pneumonectomy remains one of the highest-risk procedures in a thoracic surgery clinic [25].

The strengths of this study are its large sample size, long-term follow-up, and the use of a comprehensive clinicopathological dataset. Furthermore, the separate evaluation of salvage and non-salvage cases has rarely been reported in the previous pneumonectomy literature. Multivariate Cox regression identified independent predictors of survival.

Limitations of the Study

Significant limitations include its retrospective design,

single-center nature, and the lack of molecular data, which may increasingly play a role in prognosis. Another limitation of this study is the limited availability of detailed perioperative oncological treatment data, including neoadjuvant or adjuvant chemoradiotherapy. Therefore, the impact of contemporary multimodality treatment strategies could not be comprehensively analyzed.

Our findings suggest that pneumonectomy is a feasible and sometimes even necessary option for selected patients in the treatment of lung cancer. However, this procedure continues to carry significant risks, particularly in salvage surgeries, right-sided resections, advanced lymph node disease, and patients experiencing significant postoperative complications. Better outcomes depend on careful patient selection, meticulous operative planning, a center with robust perioperative care, and modern multidisciplinary management strategies. The widespread adoption of molecular studies and modern oncological therapies may help refine prognostic models and further personalize selection criteria for pneumonectomy.

In conclusion, despite its well-known morbidity and mortality risks, pneumonectomy remains an important treatment option in selected patients when complete oncological resection cannot be achieved with lung-preserving procedures.

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Declaration of conflicting interests

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Ethics approval

This study was approved by the Gaziantep University Clinical Research Ethics Committee (Approval No: 434, Date: 17/12/2025).

Authors' contribution

Concept and Design: BE, AF; Definition of Intellectual Content: BE, AFI; Literature Search: BE, MS; Clinical Studies: BE, AU, MS, AFI; Data Acquisition: BE, AU; Statistical Analysis: BE; Manuscript Preparation: BE; Editing: AFI, AU; Review: MS, AFI

Artificial intelligence and language editing disclosure

The authors declare that artificial intelligence–based image processing tools were used solely to enhance the resolution and visual quality of figures in accordance with the journal's technical requirements.

Additionally, Grammarly® was used to edit English for grammar, spelling, and clarity.

No artificial intelligence tools were used for data analysis, result interpretation, or the generation of scientific content. The authors take full responsibility for the integrity, originality, and accuracy of the manuscript.

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