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Original Article

Extended lung resections for NSCLC with adjacent structure involvement: a single-center experience

Okan Karataş*, Berkay Şen, Nilay Çavuşoğlu Yalçın, Gürhan Sinan Özgünlü, Ayşegül Güler, Emin Mert, Muharrem Özkaya

Department of Thoracic Surgery, University of Health Sciences, Antalya Training and Research Hospital, Antalya, Türkiye

ABSTRACT

Background: Extended lung resections for non-small cell lung cancer (NSCLC) requiring en bloc resection of adjacent structures remain technically demanding procedures and are associated with considerable perioperative risk. This study analyzes the outcomes of 29 consecutive patients undergoing extended lung resections, focusing on survival outcomes and potential prognostic factors.

Materials and Methods: We retrospectively analyzed 29 patients who underwent extended lung resections for non-small cell lung cancer (NSCLC) with suspected or confirmed invasion of adjacent structures between 2015 and 2023 at our institution. Extended resections included en bloc removal of structures such as the chest wall, pericardium, diaphragm, or vascular structures when necessary to achieve tumor clearance. Patient demographics, operative characteristics, pathological findings, postoperative complications, and long-term survival outcomes were evaluated using Kaplan–Meier survival analysis.

Results: The cohort included 26 males (89.7%) and 3 females (10.3%) with a mean age of 64.4 ± 10.7 years. Squamous cell carcinoma was the predominant histology (65.5%). TNM staging revealed Stage IB (34.5%) and Stage IIA (20.7%) as most frequent. All patients underwent thoracotomy with extended resections: chest wall (58.6%), pericardium (20.7%), and combined procedures (20.7%). R0 resection was achieved in 51.7% of patients. Mean operative time was 159 ± 62 minutes. Postoperative complications occurred in 27.6% of patients, with zero 30-day mortality. Mean follow-up was 29.4 ± 24.1 months with overall mortality of 72.4% and median survival of 24.0 months. Chest wall resection patients had higher mortality (82.4%) compared to other extended procedures (58.3%).

Conclusions: Extended lung resections may be performed with acceptable operative mortality in carefully selected patients. However, long-term survival remains limited, particularly in patients requiring chest wall resection. Rigorous patient selection and multidisciplinary evaluation are crucial for optimal outcomes.

Keywords: extended lung resection, non-small cell lung cancer, chest wall resection, survival analysis, locally advanced lung cancer

Corresponding Author*: Okan Karataş, MD. University of Health Sciences, Antalya Training and Research Hospital Department of Thoracic Surgery, Antalya, Türkiye.
E-mail address: dr.okankaratas@hotmail.com Phone: +90 5354968983
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Introduction

Non-small cell lung cancer (NSCLC) with invasion or suspected invasion of adjacent structures may require extended pulmonary resection to achieve complete tumor removal. Extended lung resections, defined as pulmonary resection combined with en bloc resection of invaded neighboring structures, offer the only potentially curative treatment option for selected patients with T3-T4 disease [1].

The evolution of extended resection techniques has been driven by advances in surgical methodology, improved perioperative care, and refined patient selection criteria [2]. These complex procedures typically involve resection of structures such as the chest wall, pericardium, great vessels, diaphragm, or adjacent organs, requiring specialized expertise and multidisciplinary coordination [3,4].

Current literature demonstrates variable outcomes for extended lung resections, with reported 5-year survival rates ranging from 23% to 71.7%, heavily dependent on patient selection criteria, completeness of resection, and institutional experience [5,6]. Critical prognostic factors consistently identified across studies include nodal status, achievement of R0 resection, histological subtype, and the specific anatomical structures involved in the extended procedure [7,8].

Patient selection remains the cornerstone of successful outcomes in extended lung resections. The presence of mediastinal nodal involvement (N2 disease) has been consistently identified as a relative contraindication to extended resection, while patients with N0-N1 disease demonstrate significantly improved survival outcomes [9,10]. Additionally, the ability to achieve complete microscopic resection (R0) is crucial for realizing long-term survival benefit [11,12].

Despite advances in surgical technique and perioperative management, extended lung resections continue to be associated with substantial morbidity and mortality, necessitating careful evaluation of the risk-benefit ratio for each individual patient [13,14]. The complexity of these procedures requires thorough preoperative assessment, including comprehensive staging, functional evaluation, and multidisciplinary team consultation [15].

This study presents our institutional experience with 29 consecutive patients undergoing extended lung resections for locally advanced NSCLC over an 8-year period. We provide detailed analysis of patient demographics, operative characteristics, postoperative complications, and long-term survival outcomes, with the aim of contributing to the evidence base supporting extended resections in appropriately selected patients and identifying prognostic factors that may guide future patient selection strategies.

Materials and Methods

This retrospective cohort study analyzed 29 consecutive patients who underwent extended lung resections for locally advanced NSCLC at our institution between January 2015 and December 2023. The study was conducted in accordance with the Declaration of Helsinki and approved by the institutional ethics committee (Ethics Committee Approval Number: 21/18, Date: 11.12.2025). Patient informed consent was waived due to the retrospective nature of the study.

All patients had histologically confirmed NSCLC with clinical or radiographic evidence of invasion into adjacent structures, necessitating extended resection for complete tumor removal. Cases were reviewed and approved by a multidisciplinary thoracic oncology team including thoracic surgeons, medical oncologists, radiation oncologists, and pulmonologists. Although extended resections are commonly associated with T3-T4 disease, some patients in this cohort were pathologically staged as T1-T2 because invasion of adjacent structures was suspected preoperatively or identified intraoperatively. Extended resections were performed based on clinical, radiological, or intraoperative suspicion of adjacent structure invasion. However, in a subset of patients, histopathological examination did not confirm true tumor invasion of the resected adjacent structures. In such cases, pathological T staging was assigned according to the final histopathological findings, irrespective of the extent of surgical resection.

Patients were retrospectively identified from the institutional database. Eligible patients had a histologically confirmed diagnosis of primary non–small cell lung cancer (NSCLC) with clinical or radiographic evidence of T3-T4 disease requiring extended pulmonary resection. Adequate cardiopulmonary function was required, defined as a predicted $FEV_1 \geq 40\%$ and $DLCO \geq 40\%$. Only patients with an Eastern Cooperative Oncology Group (ECOG) performance status of 0-2 and a multidisciplinary tumor

board consensus for surgery were included. Patients were excluded if they presented with distant metastatic disease (M1) confirmed by imaging, unresectable N2 disease (>3 involved mediastinal nodal stations or bulky nodes), insufficient cardiopulmonary reserve to tolerate extended resection, prior ipsilateral thoracic surgery, or a concurrent malignancy within the preceding five years.

All patients underwent a standardized preoperative evaluation. This included a comprehensive medical history, physical examination, ECOG performance status determination, and comorbidity assessment. Pulmonary function tests with spirometry and diffusion capacity for carbon monoxide (DLCO), arterial blood gas analysis, and cardiopulmonary exercise testing were performed when indicated. Patients at high cardiovascular risk underwent echocardiography or cardiac catheterization. Staging studies consisted of contrast-enhanced computed tomography (CT) of the chest, abdomen, and pelvis, positron emission tomography-CT (PET-CT), and brain magnetic resonance imaging (MRI). Invasive mediastinal staging with endobronchial ultrasound-guided transbronchial needle aspiration (EBUS-TBNA) or mediastinoscopy was performed when required. Each case was discussed at a multidisciplinary thoracic oncology meeting, and all patients underwent preoperative anesthesiology consultation. Neoadjuvant therapy was considered according to disease stage and team consensus.

Surgical procedures were performed by experienced thoracic surgeons via posterolateral thoracotomy with patients in the lateral decubitus position under general anesthesia with single-lung ventilation. Extended resections were classified according to the invaded structures. Chest wall resections consisted of en bloc removal of the lung with involved ribs, intercostal muscles, and parietal pleura, with reconstruction indicated for defects exceeding 5 cm or involving three or more ribs, using prosthetic mesh, autologous grafts, or combined methods. Pericardial resections included partial or complete removal of the pericardium, with or without atrial involvement, and reconstruction with autologous pericardium, bovine pericardium, or synthetic substitutes when necessary. Diaphragmatic resections were repaired either primarily or with prosthetic material. Vascular resections involved reconstruction of pulmonary vessels, the superior vena cava, or other major vascular structures as indicated. Combined resections involving multiple structures were performed using multimodal reconstructive techniques.

In all cases, systematic mediastinal lymph node dissection was carried out in accordance with International Association for the Study of Lung Cancer (IASLC) recommendations. Completeness of resection was classified as R0 (microscopically complete), R1 (microscopically incomplete), or R2 (macroscopically incomplete).

Data were systematically retrieved from electronic medical records. Collected variables included demographics such as age, sex, body mass index, smoking history expressed in pack-years, and comorbidities including chronic obstructive pulmonary disease, coronary artery disease, hypertension, and diabetes mellitus, together with pulmonary function test results and clinical staging. Comorbidity burden was additionally quantified using the Charlson Comorbidity Index (CCI), which was retrospectively calculated based on age and documented comorbid conditions. The primary malignancy was not included in the CCI calculation to avoid artificial inflation of comorbidity scores. Tumor-related variables comprised histopathological diagnosis according to the World Health Organization classification, tumor size and anatomical location, TNM stage based on the 8th edition of the AJCC/UICC staging system, and histologic differentiation grade. Operative details included the type of pulmonary resection, the specific adjacent structures resected, operative time, estimated blood loss, and intraoperative complications. Postoperative outcomes assessed were intensive care unit stay, total hospital stay, postoperative complications categorized by the Clavien-Dindo classification, 30- and 90-day mortality, and resection margin status. Long-term data included overall survival, disease-free survival, recurrence patterns categorized as local, regional, or distant, and receipt of adjuvant therapy.

Patients were followed according to institutional protocol, with clinical examination and chest imaging every three months during the first two years, every six months between the third and fifth years, and annually thereafter. Additional imaging studies, including computed tomography or positron emission tomography-computed tomography, were performed when clinically indicated, and all recurrences were reviewed in a multidisciplinary setting.

Statistical Analysis

Statistical analyses were performed using SPSS software (version 28.0, IBM Corp., Armonk, NY, USA). Categorical variables were compared using the chi-square or Fisher's exact test, and continuous variables were analyzed with the Student's t test or Mann–Whitney U test, as appropriate. Survival outcomes, including overall survival and disease-free survival, were estimated by the Kaplan-Meier method and compared using the log-rank test. Due to the limited sample size, multivariable modeling was not performed. Survival comparisons were considered exploratory.

Descriptive statistics were applied to summarize patient characteristics and outcomes. Continuous variables were expressed as mean ± standard deviation for normally distributed data or as median with interquartile range for non-normally distributed data, while categorical variables were presented as absolute numbers and percentages. Overall survival was defined as the interval from the date of surgery to death from any cause or last follow-up, and disease-free survival was defined as the interval from surgery to the first documented recurrence, death, or last follow-up. Survival analyses were conducted using the Kaplan–Meier method, and survival curves were generated for overall survival as well as for relevant subgroups. All statistical tests were two-sided, and a p-value < 0.05 was considered statistically significant.

Results

During the study period, 29 patients underwent extended lung resections for locally advanced NSCLC. The cohort comprised 26 males (89.7%) and 3 females (10.3%) with a mean age of 64.4 ± 10.7 years (range: 41-83 years). The majority of patients (21, 72.4%) had a significant smoking history with a mean smoking exposure of 35.2 ± 18.6 pack-years among smokers.

Comorbidities were common, with chronic obstructive pulmonary disease present in 15 patients (51.7%), hypertension in 12 patients (41.4%), coronary artery disease in 8 patients (27.6%), and diabetes mellitus in 6 patients (20.7%). All patients had ECOG performance status 0-1 at the time of surgery. The mean Charlson Comorbidity Index (CCI) score was 2.83 ± 1.56, indicating a moderate comorbidity burden. Most patients were classified as having moderate comorbidity (CCI 2–3, 51.7%), while 31.0% had high comorbidity burden (CCI ≥4). Patient demographics and baseline clinical characteristics are summarized in Table 1.

Table 1. Patient demographics and clinical characteristics.

Characteristic	Value (n=29)
Age (years)	
Mean ± SD	64.4 ± 10.7
Median (range)	65.0 (41-83)
Gender, n (%)	
Male	26 (89.7)
Female	3 (10.3)
BMI (kg/m²), mean ± SD	26.8 ± 4.2
Smoking History, n (%)	
Current/Former smokers	21 (72.4)
Never smokers	8 (27.6)
Pack-years (smokers only), mean ± SD	35.2 ± 18.6
Comorbidities, n (%)	
COPD	15 (51.7)
Hypertension	12 (41.4)
Coronary artery disease	8 (27.6)
Diabetes mellitus	6 (20.7)
ECOG Performance Status, n (%)	
0	18 (62.1)
1	11 (37.9)
Preoperative PFTs	
FEV1 (% predicted), mean ± SD	78.5 ± 16.2
DLCO (% predicted), mean ± SD	72.3 ± 14.8

Squamous cell carcinoma was the predominant histological type, diagnosed in 19 patients (65.5%), followed by adenocarcinoma in 5 patients (17.2%). Other histological subtypes included large cell carcinoma (2 patients, 6.9%), adenosquamous carcinoma (1 patient, 3.4%), and neuroendocrine tumors (2 patients, 6.9%).

TNM staging according to the 8th edition AJCC classification revealed Stage IB disease in 10 patients (34.5%), Stage IIA in 6 patients (20.7%), Stage IA in 6 patients (20.7%), and Stage IIB in 7 patients (24.1%). The mean tumor size was 5.3 ± 2.3 cm (range: 2.0-10.0 cm). Although all patients underwent extended resection due to suspected adjacent structure invasion, histopathological confirmation of invasion was not present in all cases. In these patients, no tumor infiltration was identified in the resected adjacent tissues, leading to classification as lower T stage (T1-T2) and consequently early-stage disease according to the 8th edition TNM system.

Lymph node involvement was limited, with a mean of 6.5 ± 2.5 lymph nodes examined per patient and 0.3 ± 0.7 positive nodes. Lymphovascular invasion was present in 12 patients (41.4%), visceral pleural invasion in 15 patients (51.7%), and perineural invasion in 8 patients (27.6%). Detailed tumor characteristics and pathological findings are summarized in Table 2.

Table 2. Tumor characteristics and pathological findings.	
Characteristic	Value (n=29)
Histological Type, n (%)	
Squamous cell carcinoma	19 (65.5)
Adenocarcinoma	5 (17.2)
Large cell carcinoma	2 (6.9)
Adenosquamous carcinoma	1 (3.4)
Neuroendocrine tumors	2 (6.9)
TNM Stage (8th edition), n (%)	
Stage IA	6 (20.7)
Stage IB	10 (34.5)
Stage IIA	6 (20.7)
Stage IIB	7 (24.1)
T Stage, n (%)	
T1	6 (20.7)
T2	13 (44.8)
T3	8 (27.6)
T4	2 (6.9)
N Stage, n (%)	
N0	23 (79.3)
N1	5 (17.2)
N2	1 (3.4)
Tumor Size (cm)	
Mean ± SD	5.3 ± 2.3
Median (range)	5.0 (2.0-10.0)
Differentiation, n (%)	
Well differentiated	8 (27.6)
Moderately differentiated	15 (51.7)
Poorly differentiated	6 (20.7)
Lymph Node Data	
Total nodes examined, mean ± SD	6.5 ± 2.5
Positive nodes, mean ± SD	0.3 ± 0.7
Invasion Patterns, n (%)	
Lymphovascular invasion	12 (41.4)
Visceral pleural invasion	15 (51.7)
Perineural invasion	8 (27.6)

All 29 patients (100%) underwent extended resections through posterolateral thoracotomy. No video-assisted thoracoscopic surgery (VATS) procedures were performed due to the complexity and extent of resections required. The most commonly performed lung resections were left upper lobectomy (9 patients, 31.0%) and left lower lobectomy (8 patients, 27.6%).

Extended resections were categorized as follows:

- Chest wall resection only: 17 patients (58.6%)
- Pericardial resection only: 6 patients (20.7%)
- Combined chest wall and pericardial resection: 3 patients (10.3%)
- Diaphragmatic resection: 1 patient (3.4%)
- Other combined procedures: 2 patients (6.9%)

Among chest wall resections, the number of ribs resected ranged from 1-4 (mean: 2.3 ± 1.1). Chest wall reconstruction was performed in 12 of 17 patients (70.6%) using prosthetic mesh (8 patients), muscle flaps (3 patients), or combined techniques (1 patient).

All procedures were performed via posterolateral thoracotomy, and no video-assisted thoracoscopic surgery (VATS) approach was used. The most common type of lung resection was left upper lobectomy (31.0%), followed by left lower lobectomy (27.6%), right upper lobectomy (17.2%), and right lower lobectomy (10.3%). Bilobectomy and other types of resections were each performed in 6.9% of patients. Regarding the extent of resection, chest wall resection alone was the most frequent procedure (58.6%), while pericardial resection alone and combined resections were each performed in 20.7% of cases. Among patients undergoing chest wall resection, the mean number of ribs resected was 2.3 ± 1.1, and reconstruction was required in 60.0% of these cases. The mean operative time was 159 ± 62 minutes (median: 150 minutes, range: 90-280), and the mean estimated blood loss was 285 ± 195 mL (median: 250 mL, range: 100-800). Complete (R0) resection was achieved in 51.7% of patients, while 41.4% had microscopic residual disease (R1). No patients had macroscopic residual disease (R2), and resection margin status was not reported in 6.9% of cases.

There was no 30-day mortality, while 90-day mortality occurred in 1 patient (3.4%). The mean intensive care unit (ICU) stay was 0.5 ± 1.0 days, and the mean length of hospital stay was 6.1 ± 2.7 days. Overall postoperative complications were observed in 27.6% of patients. According to the Clavien–Dindo classification, minor complications (Grade I-II) occurred in 20.7% of patients, whereas major complications (Grade III-IV) were observed in 6.9%. No Grade V complications were recorded. The most common complications included atelectasis (13.8%) and prolonged air leak lasting more than 7 days (6.9%). Other complications included pneumonia (3.4%), cardiac arrhythmia (3.4%), and wound infection (3.4%). Readmission within 30 days occurred in 6.9% of patients.

Complete follow-up data was available for all 29 patients with a mean follow-up duration of 29.4 ± 24.1 months (range: 2-96 months). During the follow-up period, 21 patients (72.4%) died, while 8 patients (27.6%) remained alive at last follow-up.

Overall survival analysis revealed a median survival of 24.0 months (95% CI: 18.2-29.8). The 1-year, 2-year, and 3-year overall survival rates were 82.8%, 51.7%,

and 27.6%, respectively. Disease-free survival analysis showed a median disease-free survival of 18.0 months (95% CI: 12.4-23.6). Overall survival outcomes are illustrated using Kaplan-Meier analysis in Figure 1.

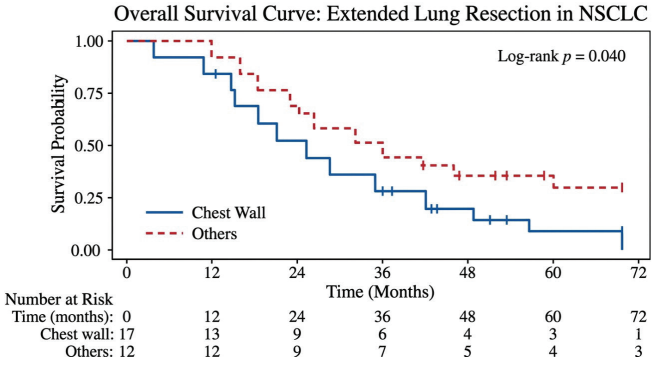


Figure 1. Kaplan-Meier Overall Survival Curve. Patients undergoing chest wall resection demonstrated significantly poorer survival compared with those undergoing other extended procedures (log-rank p = 0.040). The number of patients at risk at each time point is provided below the x-axis.

Recurrence occurred in 16 patients (55.2%) during follow-up, with patterns including local recurrence in 10 patients (34.5%), distant metastases in 6 patients (20.7%), and no evidence of recurrence in 13 patients (44.8%). The most common sites of distant recurrence were brain (3 patients), liver (2 patients), and bone (1 patient).

Subgroup analyses demonstrated variability in survival outcomes according to clinicopathological factors. Patients with adenocarcinoma exhibited longer mean survival compared with those with squamous cell carcinoma (47.6 vs. 26.5 months), although this difference did not reach statistical significance (p = 0.180), likely reflecting the limited sample size. Survival by TNM stage showed a trend toward improved outcomes in patients with stage I disease compared with stage II disease, with mean survival times of 30.3 and 26.8 months, respectively (p = 0.310). Type of extended resection was associated with significant differences in prognosis: patients undergoing chest wall resection experienced markedly poorer survival compared with those undergoing other types of extended procedures, with a mortality rate of 82.4% and mean survival of 26.7 months versus a mortality rate of 58.3% and mean survival of 33.2 months (p = 0.040). Resection margin status did not significantly influence survival, as no difference was observed between patients with R0 and R1 resections (p = 0.670), a finding that may be attributed to the aggressive biology of tumors necessitating extended resections or the limited cohort size. Subgroup survival analyses are detailed in Table 3.

Adjuvant therapy was administered to the majority of patients based on pathological findings and multidisciplinary team recommendations. Eighteen patients (62.1%) received adjuvant chemotherapy, typically consisting of platinum-based doublet regimens. Eight patients (27.6%) received adjuvant radiotherapy, and 5 patients (17.2%) received combined chemoradiotherapy.

The decision for adjuvant therapy was individualized based on factors including pathological stage, resection margin status, nodal involvement, and patient performance status. Patients with R1 resections were more likely to receive adjuvant radiotherapy (58.3% vs. 13.3% for R0 resections, p=0.020).

Table 3. Survival analysis by subgroups.

Subgroup	N	Deaths (%)	Mean Survival (months)	Median Survival (months)	p
Overall	29	21 (72.4)	29.4	24.0	-
Histology					0.180
SCC	19	15 (78.9)	26.5	24.0	
Adenocarcinoma	5	5 (100.0)	47.6	36.0	
Other	5	1 (20.0)	22.2	24.0	
TNM Stage					0.310
Stage I (IA+IB)	16	12 (75.0)	30.3	24.0	
Stage II (IIA+IIB)	13	9 (69.2)	26.8	24.0	
Extended Resection					0.040*
Chest wall	17	14 (82.4)	26.7	24.0	
Other procedures	12	7 (58.3)	33.2	33.0	
Resection Margins					0.670
R0	15	11 (73.3)	30.1	24.0	
R1	12	9 (75.0)	28.3	24.0	

**Statistically significant (p<0.05)*

Discussion

This study presents our institutional experience with extended lung resections for locally advanced NSCLC, demonstrating low perioperative mortality but limited long-term survival outcomes. Our findings add to the growing body of literature supporting the technical feasibility of extended resections in carefully selected patients, while underscoring the critical importance of rigorous patient selection and realistic discussions regarding expected outcomes.

The absence of 30-day mortality in our cohort compares favorably with previously reported operative mortality rates for extended lung resections, which range from 0% to 12.3% [16,17]. This favorable outcome likely reflects careful patient selection, advances in perioperative management, and accumulated institutional expertise in complex thoracic procedures. The overall complication rate of 27.6% is in line with contemporary series reporting major complication rates between 11.4% and 35% [18]. Respiratory complications such as atelectasis, pneumonia, and prolonged air leak predominated, as expected in procedures requiring single-lung ventilation and extensive resections. The low incidence of major complications (6.9%) suggests that extended resections can be performed safely in high-volume centers. Operative time and blood loss were within acceptable ranges for complex thoracic procedures, though these values likely underestimate the true technical demands of extended resections. The exclusive use of open thoracotomy in this series reflects the need for wide exposure and reliable reconstruction when multiple adjacent structures are involved.

Achieving complete resection with negative margins (R0) remains a cornerstone of oncologic surgery and is generally associated with improved long-term survival. In this study, the R0 resection rate was 51.7%, while 41.4% of patients had microscopic positive margins (R1). These findings highlight the inherent challenge of achieving adequate margins in tumors involving adjacent critical structures. The relatively low R0 rate observed in this cohort may reflect the complexity of tumors requiring extended procedures, borderline resectability in some patients, and the limitations of a small retrospective series. Reported R0 rates in the literature vary, suggesting that outcomes may be influenced by surgical technique, patient selection, and the use of neoadjuvant strategies.

Interestingly, survival did not differ significantly between patients with R0 and R1 resections. While this observation contrasts with most reports showing superior survival following complete resection, it may reflect small sample size, the aggressive biology of tumors necessitating extended procedures, or the mitigating effect of adjuvant therapy in cases with positive margins. The relatively low R0 resection rate observed in this study may be attributed to several factors. Many tumors were located in close proximity to critical anatomical structures such as major vascular structures, pericardium, and vertebral bodies, making complete resection technically challenging. In addition, some cases represented borderline resectable disease, in which extended resection was undertaken despite uncertain margins to achieve maximal tumor clearance. Another important consideration is the absence of neoadjuvant therapy in this cohort. Contemporary evidence supports the use of neoadjuvant chemotherapy and, more recently, chemoimmunotherapy in patients with locally advanced (T3-T4) NSCLC. These approaches have been shown to improve tumor downstaging, increase the likelihood of complete (R0) resection, and enhance long-term survival outcomes. Landmark trials have demonstrated significantly higher pathological response rates and improved resectability with neoadjuvant immunotherapy-based regimens. The lack of neoadjuvant treatment in our series may therefore have contributed to both the relatively low R0 resection rate and suboptimal long-term survival outcomes. This reflects historical treatment patterns and institutional practice variability during the study period. Future strategies incorporating neoadjuvant approaches may improve surgical and oncological outcomes in similar patient populations.

The median survival of 24 months and 3-year survival rate of 27.6% observed in this cohort are concerning but consistent with the poor prognosis of locally advanced NSCLC requiring extended resections. Published outcomes vary widely, with 5-year survival ranging from 23% to 71.7% placing our results at the lower end of this spectrum [19,20]. Several factors likely contributed to these outcomes. A high proportion of patients underwent chest wall resection, a subgroup that demonstrated significantly worse survival, with a mortality rate of 82.4% compared to 58.3% in patients undergoing other extended procedures ($p = 0.040$). This may reflect both the aggressive tumor biology associated with chest wall invasion and the technical challenges of achieving complete resection in this setting. The predominance of squamous cell carcinoma (65.5%) may also have contributed, as squamous histology is often associated with poorer prognosis compared to adenocarcinoma [21]. Furthermore, although most patients were staged as early disease (I-II), the requirement for extended resection indicates locally advanced behavior, diminishing the prognostic value of clinical stage. The apparent discrepancy between extended resections and early pathological stage observed in this study is explained by the lack of histopathological confirmation of invasion in some patients. Although these cases were managed surgically as locally advanced disease based on clinical, radiological, or intraoperative suspicion, fi-

nal pathology demonstrated no tumor infiltration of adjacent structures. This phenomenon represents a known limitation in preoperative and intraoperative assessment, where inflammatory adhesions or desmoplastic reactions may mimic true tumor invasion. Therefore, pathological staging in this study reflects definitive histological findings rather than the surgical indication for extended resection. Although extended resections are traditionally associated with locally advanced (T-T4) tumors, several patients in this cohort were pathologically staged as T1-T2. This discrepancy may reflect differences between clinical suspicion of adjacent structure invasion and final pathological staging, as well as intraoperative findings that necessitated extended resection to achieve adequate margins.

Among the types of extended resections, patients undergoing chest wall resections had the poorest outcomes, while those undergoing pericardial or vascular resections fared comparatively better, consistent with prior reports suggesting that cardiac resections, particularly limited atrial resections without cardiopulmonary bypass, can be performed with acceptable morbidity and survival [22,23]. The high recurrence rate of 55.2%, dominated by local recurrence (34.5%), further illustrates the challenge of achieving durable local control in this population. This finding may reflect the influence of tumor biology, patient selection, and treatment-related factors on survival outcomes [24]. Distant recurrences most frequently involved the brain, in keeping with the natural history of NSCLC and reinforcing the role of systemic therapy in disease management. The cohort included heterogeneous extended resections involving different anatomical structures such as the chest wall, pericardium, diaphragm, and combined resections. These procedures represent biologically and surgically distinct entities with potentially different prognostic profiles. However, due to the limited sample size, stratified analyses for each procedure type were not feasible, and the cohort was analyzed as a single group to present a descriptive institutional experience.

Adjuvant therapy was administered in the majority of cases, with 62.1% receiving chemotherapy. Patients with R1 resections were more likely to receive adjuvant radiotherapy, reflecting guideline-concordant efforts to improve local control in cases with positive margins. However, the lack of survival difference between R0 and R1 groups suggests either effective mitigation of margin positivity by adjuvant therapy or that systemic factors ultimately dominate survival irrespective of local control [25].

When compared with published literature, our findings are broadly consistent with previous reports demonstrating acceptable perioperative outcomes but limited long-term survival in patients undergoing extended resections for locally advanced NSCLC. Variability in survival outcomes across studies may be attributed to differences in patient selection, tumor biology, and extent of resection. These findings carry important clinical implications. Refinement of patient selection criteria is essential, particularly for patients requiring chest wall resections, in whom outcomes were significantly worse. Consideration of neoadjuvant or intensified adjuvant strategies, or enrollment in clinical trials, may be appropriate in this subgroup. The complexity of extended resections reinforces the importance of multidisciplinary evaluation and coordinated treatment planning involving thoracic surgeons, oncologists, radiation oncologists, and supportive care teams. The relatively poor long-term outcomes highlight the need for transparent discussions with patients regarding prognosis and quality-of-life expectations. Future research should focus on the development of molecular or imaging biomarkers to refine patient selection, optimization of neoadjuvant approaches, assessment of minimally invasive strategies where feasible, incorporation of quality-of-life outcomes, and cost-effectiveness analyses of extended resections in locally advanced NSCLC.

Limitations of the Study

This study has several limitations that should be acknowledged. The relatively small cohort of 29 patients limits the statistical power of subgroup analyses and multivariable modeling, raising the possibility of type II error in detecting clinically meaningful differences. Although comorbidity burden was assessed using the Charlson Comorbidity Index (CCI), its impact on survival could not be robustly evaluated due to the limited sample size. Its retrospective design introduces inherent biases, including selection bias, information bias, and potential confounding that may not be fully controlled. Being a single-institution experience, the results may not be generalizable to centers with different patient populations, surgical expertise, or perioperative protocols. Variability in follow-up duration and the potential for loss to follow-up could also influence the accuracy of survival analyses. Missing data, particularly with respect to detailed adjuvant therapy regimens and quality-of-life assessments, represent another constraint. Furthermore, the heterogeneity of extended resection types analyzed together may obscure procedure-specific outcomes and prognostic factors. Finally, the eight-year study period encompasses temporal changes in staging systems, adjuvant therapy recommendations, and surgical techniques, all of which may have influenced observed outcomes. In addition, the mean number of lymph nodes examined in this cohort was relatively low compared with values reported in studies adhering to strict mediastinal lymphadenectomy protocols. This may reflect variability in surgical sampling, pathological examination, or limitations inherent to retrospective data collection. As a result, the possibility of pathological understaging cannot be excluded and represents a limitation of this study.

Future research should focus on refining patient selection and treatment strategies. The development and validation of predictive models integrating clinical, pathological, and molecular variables may help identify patients most likely to benefit from extended resections. Prospective studies are needed to evaluate the role of neoadjuvant approaches, including chemotherapy, immunotherapy, or chemoradiotherapy, in improving resectability and long-term outcomes. The feasibility and safety of minimally invasive strategies, such as robotic or video-assisted approaches for selected cases, warrant investigation to potentially reduce morbidity without compromising oncological efficacy. Comprehensive assessment of quality of life, functional outcomes, and patient-reported measures in long-term survivors is also critical. Multi-institutional collaborations will be essential to increase sample size and enhance the generalizability of findings. Finally, the incorporation of molecular profiling into clinical decision-making may provide more individualized treatment pathways and help determine which patients are most likely to benefit from extended resections versus alternative modalities.

In conclusion, extended lung resections for locally advanced NSCLC can be performed with acceptable operative mortality and morbidity in carefully selected patients at experienced centers, yet long-term survival outcomes remain limited, particularly in those requiring chest wall resection. Our findings highlight that extended resections can be achieved with zero 30-day mortality and complication rates within the expected range, underscoring the importance of meticulous patient selection and standardized perioperative protocols. Nevertheless, overall survival remains poor, with a median survival of 24 months and a 3-year survival rate of only 27.6%. The type of extended resection emerged as a key prognostic factor, with chest wall resection associated with significantly worse survival compared with other procedures. Although R0 resection remains the oncologic ideal, the absence of survival difference between R0 and R1 resections in this cohort may reflect the aggressive biology of tumors necessitating extended procedures or the mitigating effects of adjuvant therapy.

These observations emphasize the critical role of rigorous selection criteria, incorporating functional reserve, nodal status, and multidisciplinary evaluation, in optimizing outcomes. The decision to proceed with extended resection should carefully balance potential survival benefit against the inherent risks and should be reserved for centers with substantial expertise and comprehensive multidisciplinary support. Realistic expectations regarding prognosis must be communicated to patients and families, and for high-risk subgroups, alternative strategies or enrollment in clinical trials may be appropriate.

Looking forward, research should prioritize refinement of patient selection, optimization of multimodal treatment strategies, and exploration of less invasive techniques while preserving oncologic integrity. The integration of molecular profiling and predictive modeling holds promise for identifying patients most likely to benefit from these complex operations. Extended lung resection remains an important therapeutic option for selected patients with locally advanced NSCLC, but continued innovation and collaborative research are essential to improve long-term outcomes.

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Ethics approval

This study was conducted in accordance with the principles of the Declaration of Helsinki. Ethical approval was obtained from the Antalya Training and Research Hospital Scientific Research Ethics Committee (Approval Number. 21/18, Date: 11 December 2025). Due to the retrospective nature of the study, the requirement for informed consent was waived by the Ethics Committee.

Authors' contribution

All authors made a significant contribution to the work reported, including the conception and design of the study, execution, acquisition of data, analysis, and interpretation. All authors participated in drafting the article or revising it critically for important intellectual content, gave final approval of the version to be published, agreed on the journal to which the manuscript was submitted, and accept accountability for all aspects of the work.

AI Use Disclosure

In the preparation of this manuscript, an artificial intelligence tool (Chatgpt 5.2) was used solely to assist with literature review support and improvement of English language, including grammar and stylistic refinement. All content generated or suggested by the AI tool was carefully reviewed, verified, and edited by the authors. The AI tool was not used for data generation, data analysis, or interpretation of results. The authors take full responsibility for the originality, accuracy, validity, and integrity of the content of this manuscript.

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