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Original Article

Thoracoscopic segmentectomy versus lobectomy for early-stage non-small cell lung cancer: efficacy, postoperative recovery, and prognosis

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Abstract: Objective: To compare the clinical outcomes of thoracoscopic segmentectomy (TSE) and lobectomy (TLE) in early-stage non-small cell lung cancer (NSCLC) patients. Methods: A total of 129 patients with early-stage NSCLC (ES-NSCLC) treated at the First People's Hospital of Zunyi between May 2022 and May 2024 were retrospectively enrolled. Patients were divided into a control group (n=62; undergoing TLE) and a research group (n=67; undergoing TSE) based on their surgical approach. Surgical outcomes, intraoperative hemorrhagic blood loss, number of lymph nodes resected, surgical duration, chest drain duration and volume, minute ventilation, length of hospital stay, Visual Analogue Scale (VAS) scores, pulmonary function (PF), arterial blood gas parameters, postoperative complications, and prognosis was compared between the two groups. Results: Resection efficacy, lymph node harvest, chest tube duration, overall morbidity rate, and 1-year survival/recurrence were comparable between the two groups. However, TSE was associated with reduced intraoperative bleeding, shorter procedure time, lower postoperative drainage volume, shorter hospitalization time, and lower pain scores on postoperative days 1 and 5, with better minute ventilation values. Although PF and partial pressure of oxygen (PaO_2) in the research group decreased on postoperative day 5 compared with baseline, they remained markedly higher than the control group. Additionally, the arterial carbon dioxide partial pressure ($PaCO_2$) of the research group, though comparable to the preoperative level, was notably reduced compared to controls. Conclusion: TSE for ES-NSCLC is associated with improved ventilation volume, shorter hospital stays, alleviated postoperative pain, and better preservation of PF and arterial blood gas parameters.

Keywords: Thoracoscopic segmentectomy, thoracoscopic lobectomy, early-stage non-small cell lung cancer, therapeutic effect, postoperative recovery, prognosis

Introduction

Non-small cell lung cancer (NSCLC) accounts for approximately 85% of global lung cancer diagnoses and remains the most frequently diagnosed malignancy as well as the leading cause of cancer-related mortality [1]. In the United States, lung cancer is responsible for an estimated 350 daily deaths, with smoking implicated in up to 81% of these fatalities [2]. Early-stage NSCLC (ES-NSCLC) lacks specific clinical manifestations, resulting in delayed diagnosis. Nearly 70% of NSCLC patients are diagnosed at advanced stage, with fewer than 20% survive beyond 5 years [3, 4]. This is largely attributed to the aggressive biological behavior of the disease, whereas early detection and intervention greatly improve 5-year survival outcomes [5].

Radical lesion resection is the preferred and most potentially curative procedure for ES-NSCLC. Nevertheless, postoperative recurrence remains a clinical concern after tumor removal [6, 7]. Thoracoscopic lobectomy (TLE) and segmentectomy (TSE) are two surgical methods distinguished by the anatomical extent of resection, with TSE allowing for a smaller and more anatomically precise resection range [8]. As minimally invasive thoracoscopic procedures, both surgical methods achieve favorable therapeutic outcomes in patients with

ES-NSCLC. However, there is still controversy regarding their relative clinical advantages [9]. TSE has been proposed as an alternative to TLE in ES-NSCLC patients with tumor diameters ≤ 2 cm. TSE may be the preferred option for patients with limited cardiopulmonary reserve who are less likely to tolerate TLE [10].

In this study, we posit that TSE confers superior benefits compared with TLE in patients with ES-NSCLC, which is evaluated through a multi-dimensional comparative analysis.

Methods

Clinical data

General data: This retrospective study was approved by the Ethics Committee of the First People's Hospital of Zunyi (The Third Affiliated Hospital of Zunyi Medical University). A total of 129 ES-NSCLC patients treated between May 2022 and May 2024 were enrolled. According to the surgical approach, patients were classified into a control group (treated with TLE; n=62) and a research group (treated with TSE; n=67).

Patient selection criteria: Inclusion criteria: radiologically and histopathologically confirmed ES-NSCLC [11]; meeting relevant surgical indications [12]; treatment naive; absence of distant metastasis confirmed by imaging; anticipated survival time > 6 months; no severe major organ dysfunction; complete clinical data.

Exclusion criteria: receipt of preoperative radiotherapy/chemotherapy; significant pleural or chest wall adhesions; prior thoracotomy, TSE, or TLE; previous chest surgery; pre-existing pulmonary conditions or impaired pulmonary function (PF); other malignancies; metastasis to lymph nodes; severe infection or respiratory/immune/coagulation system diseases; mental disturbances.

Surgical methods

Thoracoscopic segmentectomy (TSE): After general anesthesia, patients were positioned in the lateral decubitus position, and access was initiated via a ~1.5 cm portal in the 7th-8th intercostal space at the midaxillary line. Another auxiliary operation hole was made nearby, approximately 2 cm in size. The primary ~3.5 cm operating port was then established between the third and fourth ribs along the anterior axillary line. Upon lesion localization, the target lung segment was dissected, followed by the full exposure and isolation of the corresponding bronchus and vasculature. The bronchus was clamped, and the target segment was resected thoracoscopically for pathological assessment.

Preoperative 3D computed tomography (CT) reconstruction was used to identify the fine structures of hilar segments. Following division of the target lung segment, the intersegmental plane was delineated using the inflation-deflation technique. Specifically, the pulmonary segmental bronchi were clamped for an inflation procedure, causing the diseased pulmonary segment to collapse or atrophy. Meanwhile, the normal surrounding tissues were kept in an expanded state to distinguish the resection boundaries of the pulmonary segment. Finally, the affected lung segment was removed with a surgical stapler. Postoperative pathological results confirmed an R0 resection rate of 98.51% (66/67), demonstrating its reliability and precision. After systematic mediastinal lymph node dissection, the wound was closed layer by layer.

Thoracoscopic lobectomy (TLE): After general anesthesia, the patient was positioned in lateral recumbency with the non-operative side down. Single-lung ventilation was maintained throughout the procedure. The surgical team employed an identical trocar configuration to the research group, establishing observation, assistance, and main operation ports. After lesion localization, the lobular arteries, veins, and bronchus were fully exposed and transected, and the affected lung lobe was removed using a thoracoscopic stapler for a pathological examination. Layer-by-layer wound closure was performed after lymph node dissection.

Outcome measures

Surgical resection status [13]: Resection margins were classified as R0 (no microscopic tumor cell infiltration at any surgical margins, including bronchial, vascular, parenchymal, or any adjacent involved structures), R1 (microscopic presence of tumor cells at any margin), or R2 (gross residual tumor visible to the naked eye). Margin status was independently completed by two experienced pathologists blinded to surgical approach.

Table 1. Comparison of baseline characteristics between the two groups

	Control group (n=62)	Research group (n=67)	χ^2/t	P
Sex			0.106	0.745
Male	36 (58.06)	37 (55.22)		
Female	26 (41.94)	30 (44.78)		
Age (years)	60.16±7.17	61.01±8.17	0.626	0.533
Body mass index (kg/m^2)	22.61±2.04	23.00±2.50	0.966	0.336
Tumor diameter (cm)	1.72±0.53	1.56±0.66	1.511	0.133
Pathological classification			1.159	0.282
Adenocarcinoma	45 (72.58)	54 (80.60)		
Squamous cell carcinoma	17 (27.42)	13 (19.40)		
Lesion site			0.005	0.943
Left lung	32 (51.61)	35 (52.24)		
Right lung	30 (48.39)	32 (47.76)		

Intraoperative measures: Intraoperative blood loss, number of lymph nodes retrieved, and surgical duration were recorded.

Early postoperative recovery metrics: Chest drain duration, total drainage volume, minute ventilation, and hospitalization time were documented.

Pain assessment: Preoperative and postoperative (days 1 and 5) pain levels were quantified using the Visual Analog Scale (VAS) [14], where scores from 0 to 10 reflect increasing pain severity.

Pulmonary function: PF was assessed preoperatively and 5 days postoperatively using a spirometer. The percentage of predicted values for maximal voluntary ventilation (MVV%), forced expiratory volume in 1 second (FEV1%), and forced vital capacity (FVC%) were recorded. Patients were advised to avoid strenuous exercise for 2 hours preceding the evaluation.

Blood gas analysis: Arterial partial pressure of oxygen (PaO_2) and carbon dioxide ($PaCO_2$) before surgery and on day 5 after surgery were monitored utilizing a biochemical blood gas analyzer.

Postoperative complications: Adverse events, encompassing pleural effusion, pulmonary infection, air leakage, and arrhythmia, were recorded to calculate the overall incidence.

Prognosis: Patients' one-year survival and recurrence were analyzed through medical record review. The follow-up rate was 100%. Recurrence was suspected based on newly detected or progressively enlarging nodules/masses on high-resolution contrast-enhanced chest CT. For suspected recurrent lesions, especially those isolated or accessible, tissue specimens were obtained through CT-guided biopsy, bronchoscopy biopsy, or re-surgical resection for pathological examinations. Recurrence diagnosis requires meeting any of the following conditions: Histopathological confirmation of the same type of NSCLC as the primary tumor; for typical imaging metastatic lesions that cannot be re-biopsied (e.g., multiple brain metastases, bone metastases with clear bone destruction), a clinical diagnosis was made after comprehensive assessment by a multidisciplinary team.

Statistical methods

Normality testing employed the Shapiro-Wilk test. SPSS version 26.0 was used for all statistical analyses. Continuous data with normal distribution were reported as mean ± SD. Differences between the two groups were analyzed by Student's t-test, while pre- and post-treatment comparisons were performed using paired t-tests. Continuous data that did not conform to a normal distribution were expressed as the median (interquartile range) [M(Q1, Q3)], with differences between groups assessed using the Mann-Whitney U test. Categorical variables were reported as frequencies (percentages) and were compared using chi-square tests. A P value < 0.05 was considered statistically significant.

Results

Baseline demographics

As shown in **Table 1**, the comparison of baseline characteristics revealed no significant differences in sex, age, body mass index (BMI), tumor diameter, pathological classification, or lesion site between the two groups (P > 0.05).

Table 2. Comparison of surgical resection outcomes between the two groups

	Control group (n=62)	Research group (n=67)	X^2	P
R0 resection	62 (100.00)	66 (98.51)	0.933	0.334
R1 resection	0 (0.00)	1 (1.49)		
R2 resection	0 (0.00)	0 (0.00)		

Note: R0, Resection with no residual tumor; R1, Resection with microscopic residual tumor; R2, Resection with macroscopic residual tumor.

Surgical resection outcomes

As shown in **Table 2**, surgical outcome analysis demonstrated comparable R0 resection rates between the two groups (P > 0.05).

Intraoperative parameters

As shown in **Table 3**, no significant intergroup disparity was observed in the lymph node yield (P > 0.05). However, the research group demonstrated a significant reduction in both surgical duration and intraoperative blood loss compared to the control group (P < 0.05).

Early postoperative clinical parameters

As shown in **Table 4**, the analysis of key clinical outcomes indicated similar time to chest tube removal for both groups (P > 0.05). In contrast, the research group demonstrated significantly lower total drainage output, shorter hospitalization period (P < 0.01 for both), and superior minute ventilation (P < 0.001).

Pain assessment

VAS-based pain assessment showed no intergroup disparity in preoperative scores (P > 0.05) (**Table 5**). Scores in both groups peaked at postoperative day 1 and then declined by postoperative day 5 (both P < 0.05). Notably, the reduction in pain was sharper in the research group, achieving significantly lower VAS scores than the controls on both postoperative days (P < 0.05).

Pulmonary function assessment

Analysis of PF parameters (MVV%, FEV1%, and FVC%; **Figure 1**) revealed no notable differences between the two groups at baseline (P > 0.05). Postoperatively, both groups exhibited marked reductions in all parameters (P < 0.05). However, the research group maintained statistically higher MVV%, FEV1%, and FVC% compared to control group (P < 0.05).

Blood gas measurements

As shown in **Figure 2**, blood gas parameters (PaO_2 and $PaCO_2$) were similar between groups at baseline (P > 0.05). An obvious post-surgical reduction in PaO_2 and a rise in $PaCO_2$ were noted in the control group (P < 0.05). In the research group, PaO_2 also decreased markedly post-treatment, but remained significantly higher than that in the control group (P < 0.05), while $PaCO_2$ showed no significant change from baseline (P > 0.05) and was significantly lower than that in the control group (P < 0.05).

Postoperative complications

As summarized in **Table 6**, no significant difference in overall incidence of complications was observed between the two groups (P > 0.05; **Table 6**). The incidences of pleural effusion, pulmonary infection, air leakage, and arrhythmia were comparable.

Prognostic outcomes

As shown in **Table 7**, the two groups exhibited no discernible difference in their one-year survival (82.26% versus 89.55%) or recurrence rates (6.45% versus 2.99%) (both P > 0.05).

Discussion

In this study, we first observed that TSE and TLE achieved comparable R0 resection rates and lymph node yield in patients with ES-NSCLC. Zhang W et al. [15] reported that TSE improved perioperative efficacy while maintaining non-inferior survival compared with TLE in patients with IA1-2 NSCLC, which complements our results and implies that TSE may have outstanding efficacy for ES-NSCLC. In addition, TSE was superior to TLE in reducing operative time and intraoperative blood loss. This may be related to the fact that TSE is relatively less traumatic, resulting in reduced intraoperative blood loss and shorter operation time. TSE has been shown to be effective in reducing the levels of inflammatory markers

Table 3. Comparison of intraoperative parameters between the two groups

	Control group (n=62)	Research group (n=67)	t	P
Intraoperative hemorrhagic volume (mL)	267.48±63.54	185.64±48.59	8.253	< 0.001
Number of lymph nodes retrieved	10.21±2.33	10.73±2.26	1.286	0.201
Surgical duration (min)	136.35±29.70	124.24±28.66	2.356	0.020

Table 4. Comparison of clinical outcomes between the two groups

	Control group (n=62)	Research group (n=67)	Z/t	P
Chest drain duration (d)	4.00 (3.00, 5.00)	4.00 (3.00, 6.00)	-1.355	0.175
Drainage output (mL)	149.18±49.93	125.54±30.57	3.270	0.001
Minute ventilation (l)	4.94±1.17	6.15±1.76	4.560	< 0.001
Length of hospitalization (d)	8.00 (7.00, 9.00)	6.00 (5.00, 7.00)	-5.845	< 0.001

Table 5. Comparison of perioperative VAS scores between the two groups

	Control group (n=62)	Research group (n=67)	Z	P
VAS (points)				
Preoperative	2.00 (1.00, 3.00)	2.00 (2.00, 3.00)	-1.173	0.241
1 day post-operation	6.00 (5.00, 7.00)**	5.00 (4.00, 6.00)**	-4.545	< 0.001
5 days post-operation	4.00 (3.00, 5.00)*	3.00 (2.00, 4.00)*	-3.959	< 0.001

Note: *P < 0.05, **P < 0.01 (within-group comparison versus the preoperative measurement). VAS, Visual Analogue Scale.

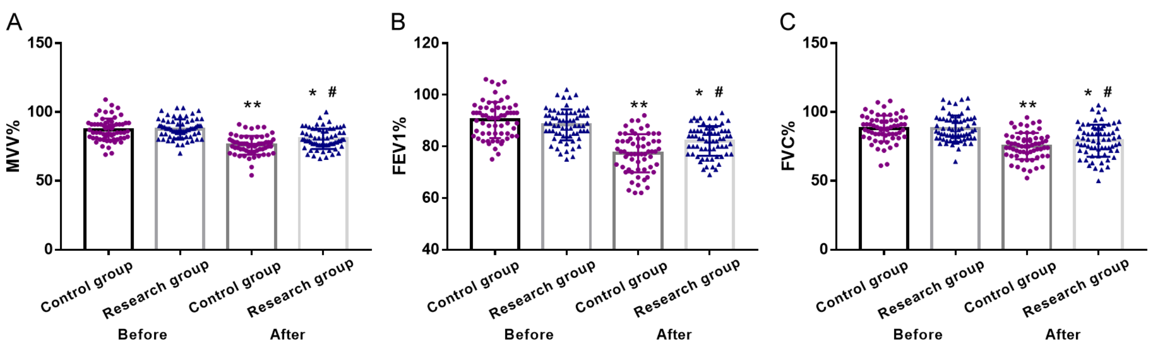

Figure 1. Comparison of pulmonary function between the two groups. A. Percent predicted maximum voluntary ventilation (MVV%) measured preoperatively and on postoperative day 5. B. Percent predicted forced expiratory volume in 1 second (FEV1%) measured preoperatively and on postoperative day 5. C. Percent predicted forced vital capacity (FVC%) measured preoperatively and on postoperative day 5. Note: *P < 0.05 and **P < 0.01, compared with preoperative values; #P < 0.05, compared with the control group.

such as C-reactive protein (CRP), interleukin (IL)-1β, IL-6, and tumor necrosis factor (TNF)-α in lung tissues, thereby attenuating local or systemic inflammatory responses and alleviating pain [16]. Furthermore, TSE effectively promoted postoperative recovery, as evidenced by significantly reduced drainage volume, shorter hospital stay, and improved ventilation function. This may be due to the preservation of functional lung tissues, which reduces the impact of surgical trauma and preserves the immune function of patients, promoting their smooth recovery. Moreover, the limited impact of inflation on adjacent lung segments may contribute to significantly improved ventilation capacity. Consistent with our findings, Ji D et al. [16] reported that TSE was associated with diminished postoperative drainage, shorter hospitalization, and enhanced postoperative (3 months) PF compared with TLE in ES-NSCLC patients. Our findings further indicated that for ES-NSCLC, TSE provided significantly better

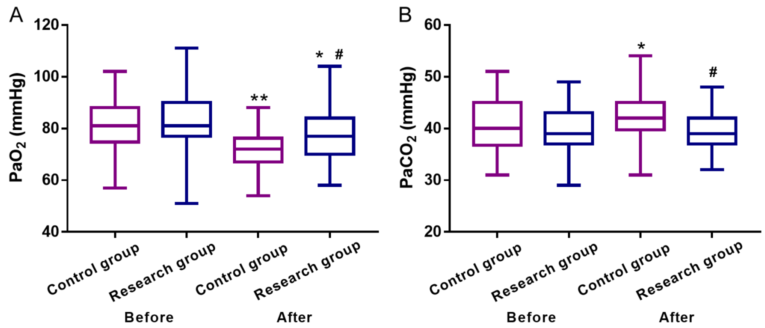

Figure 2. Comparison of blood gas parameters between the two groups. A. Arterial partial pressure of oxygen (PaO_2) before surgery and on postoperative day 5. B. Partial pressure of arterial carbon dioxide ($PaCO_2$) before surgery and on postoperative day 5. Note: *P < 0.05, **P < 0.01, compared with pre-operative values; #P < 0.05, compared with the control group.

Table 6. Comparison of postoperative complication rates between the two groups

	Control group (n=62)	Research group (n=67)	χ^2	P
Pleural effusion	0 (0.00)	1 (1.49)		
Pulmonary infection	2 (3.23)	1 (1.49)		
Pulmonary air leakage	2 (3.23)	1 (1.49)		
Arrhythmia	3 (4.84)	2 (2.99)		
Total	7 (11.29)	5 (7.46)	0.559	0.455

Table 7. Comparison of 1-year prognosis between the two groups

	Control group (n=62)	Research group (n=67)	χ^2	P
1-year survival rate	51 (82.26)	60 (89.55)	1.427	0.232
1-year recurrence rate	4 (6.45)	2 (2.99)	0.873	0.350

pain relief at postoperative days 1 and 5. Similarly, Jiang H et al. [17] reported that TSE applied to stage I NSCLC cases resulted in less intraoperative blood loss compared to TLE, together with statistically reduced VAS scores at postoperative days 1, 3, and 5, which supports the findings of this study.

Furthermore, TSE also led to more considerable enhancements in PF and blood gas parameters for ES-NSCLC patients, with less pronounced postoperative variations. Although TSE is more surgically demanding, it contributes to better lung tissue preservation than TLE, as it only removes the specific diseased lung segments of the lung lobe while preserving the healthy lung segments, thus maximizing PF preservation and improving patients' minute ventilation. This, in turn, facilitates early postoperative recovery and shortens hospitalization time. Besides, preservation of functional lung volume helps to limit postoperative loss of vital capacity, thereby reducing adverse effects on arterial blood gas indicators. These results align with the work of Saito et al. [18], who reported segmentectomy was more advantageous for PF restoration six months after surgery compared to lobectomy in stage I NSCLC patients. According to Zhang Y et al. [19], TSE for patients with tumors ≤ 2 cm promoted postoperative recovery and improved patient well-being while minimally impacting PF. These works further corroborate our findings.

In terms of safety, we found that TSE was non-inferior to TLE in ES-NSCLC, as evidenced by comparable overall complication rates. Hong Q et al. [20] similarly documented comparable postoperative morbidity between the two procedures in ES-NSCLC patients. Finally, we observed statistically indistinguishable one-year survival and recurrence rates between the two procedures. This may be related to the small sample size and insufficient observation time. Ding C et al. [21] also demonstrated equivalence in 1- and 3-year recurrence-free survival between TSE and TLE in patients with early invasive lung adenocarcinoma, corroborating our observations.

An increasing number of scholars have focused on the surgical strategies for ES-NSCLC and have provided valuable clinical suggestions. For example, Isaka T et al. [22] reported that in Stage 0-I primary lung cancer, the mortality outcome following segmentectomy and lobectomy was primarily determined by the presence and severity of comorbidities. Jiang F et al. [23] stated that thoracoscopic wedge resection for lung cancer patients helps to reduce surgical trauma, alleviate lung function damage, and inhibit oxidative stress. In addition, based on 11 years of real-world data, another study indicated better perioperative results with robotic lobectomy than with video-assisted lobectomy in N1-2 NSCLC patients, provided that adequate lymphadenectomy was performed [24].

There are several limitations in this study that need to be acknowledged. First, no subgroup analysis was conducted based on the specific ES-NSCLC stages (e.g., IA1, IA2, IA3). Future studies should include such analyses to compare the therapeutic efficacy differences (e.g., recurrence, PF preservation) between TSE and TLE in different stages. Second, long-term PF follow-up data were unavailable. Follow-up data of PF at 3, 6, and 12 months after operation should be supplemented to analyze the difference between the two procedures in long-term PF preservation. Third, due to relatively limited sample size, risk factors for postoperative complications were not analyzed. Larger-scale studies employing univariate and multivariate regression analyses are needed to clarify the associations between tumor location (upper vs. lower lobe), operation duration, and postoperative air leak, and patient-related factors such as age and arrhythmia.

Conclusion

TSE is non-inferior to TLE in resection efficiency, lymph node yield, perioperative safety, and one-year prognosis in patients with ES-NSCLC. Importantly, TSE excels in improving surgical and recovery outcomes, together with better post-operative pain control and superior recovery of PF and blood gas parameters.

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Disclosure of conflict of interest

None.

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