Comparison of Cost Effectiveness between Video-Assisted Thoracoscopic Surgery (VATS) and Open Lobectomy: A Retrospective Study

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Research

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Abstract

Background

Lung cancer is highly prevalent in Chinese population. The association of operative approach with economic burden in these patients remains unknown.

Objectives

This institution-level cohort study aimed to compare the cost-related clinical outcomes and health care costs among patients undergoing video-assisted thoracoscopic surgery (VATS) and open lobectomy, and to investigate the factors associated with the costs.

Methods

This retrospective cohort study included patients who underwent VATS or open lobectomy in a provincial referral cancer center in China in 2018. Clinical effectiveness measures included post-operative blood transfusion, lung infection, and length of stay (LOS). Hospitalization costs were extracted from hospital information system to assess economic burden.

Results

Compared to open lobectomy group, the VATS lobectomy group had a lower blood transfusion rate (1.70% vs. 4.33%, P=0.033), lower lung infection rate (23.77% vs. 40.87%, P<0.001) and shorter post-operative LOS (9.42 ± 3.72 days vs. 10.97 ± 5.81 days, P<0.001). Total hospitalization costs of VATS lobectomy group and open lobectomy were similar: RMB 84,908.72±18,914.87, RMB 81,944.70 ±16,625.20, respectively. VATS approach, lung infection, longer post-operative length of stay, male sex, lung cancer diagnosis, and heart disease were associated with higher total hospitalization costs (P<0.05).

Conclusions

VATS lobectomy has a lower post-operative blood transfusion rate, lower lung infection rate, and shorter post-operative LOS than open lobectomy. Future studies are needed to investigate other aspects of clinical effectiveness and the economic burden from a societal perspective.

Background

Lung cancer is the leading cause of cancer-related death worldwide, and China has a relatively high mortality rate compared to most other countries. The incidence rate of lung cancer in 2018 was 18.1% in China, and the death rate due to lung cancer was 24.1% [1]. Lobectomy is a surgical procedure that removes an entire lobe of the lung. This procedure can be performed either through one or few small incisions (minimally invasive) or one long incision (thoracotomy/open lobectomy) [2]. Video-assisted thoracoscopic surgery (VATS) is a type of the minimally invasive thoracic surgery (MITS). It can complete the same task as the traditional thoracotomy and does not require spreading apart the ribs. Compared with traditional open lobectomy, VATS has smaller scars, fewer complications, shorter hospital stay, and less blood loss [3].

Various studies have compared complication rates of open lobectomy and VATS lobectomy. Patients with VATS lobectomy had a significantly lower incidence of short-term complications, a reduced readmission rate, and a shorter length of stay [4–11]. A few studies comparing the economic burden between the two approaches suggested that the
VATS lobectomy approach was associated with lower [5, 6, 12] or comparable [7, 8] costs compared to the open lobectomy approach.

In China, the application of MITS, especially VATS lobectomy, among primary lung cancer patients significantly increased from 2.4% in 2008 to 34.4% in 2014 [13]. In 2015, 86.6% of Chinese tertiary hospitals carried out VATS lobectomy, and 73.74% of lung cancer operations in these hospitals adopted the VATS technique [14]. With the rapid adoption of VATS technique in China, consequent outcome assessments are needed to ensure that VATS lobectomy provides equivalent or better outcomes compared with traditional open lobectomy approach. Few studies have paid attention to the Chinese population. In addition, there is a lack of evidence on the economic comparison between the open lobectomy and VATS lobectomy approaches. Thus, this study was to quantify the total medical costs during hospitalization as well as the costs breakdown associated with a lobectomy operation.

The objective of this study was to compare the clinical effectiveness and medical costs of these two existing lobectomy approaches in Chinese population using real-world data, and to address risk factors associated with total hospitalization costs. The findings of this study can provide the patients, physicians, and health caregivers a comprehensive view of the clinical effectiveness and economic burden of each approach. It can also help policymakers to make informed decisions to improve healthcare outcomes at both individual and population levels.

**Methods**

**Study population**

This retrospective cohort study identified adult patients (> 18 years old) with diagnoses of lung diseases, who were admitted to the Department of Thoracic Surgery, Cancer Hospital of China Medical University, Liaoning Cancer Hospital & Institute for lobectomy in 2018. Exclusion criteria were a) patients underwent operations in other organs or systems during the same inpatient admission, or b) patients with incomplete data.

**Comparison groups**

Two lobectomy approaches were compared, 1) VATS lobectomy, and 2) open lobectomy. Lobectomy approaches were identified based on procedure names in the electronic medical record (EMR). Open lobectomy was defined as with the keywords of “open” AND “lobectomy”. VATS lobectomy was defined as having the keywords of “video-assisted thoracoscopic surgery” AND “lobectomy”.

**Measurement of cost-related clinical outcomes and costs**

EMR was used to collect baseline characteristics and to identify post-operative clinical outcomes and costs. Baseline characteristics included age, gender, health insurance coverage, lung cancer diagnosis status, comorbidities such as hypertension, diabetes, heart disease, and other diseases.

The primary outcomes in this study were cost-related clinical outcomes and hospitalization costs. Cost-related clinical outcomes were measured in terms of blood transfusion rate, lung infection rate, and post-operative length of stay (LOS). Blood transfusion was identified based on the procedures in the EMR and blood transfusion costs at discharge, with the keywords of “transfusion”, or “blood transfusion”. Lung infection was identified as with keywords of “infection” or “pneumonia” in the EMR. Post-operative LOS was measured as the time period from the date of surgery to the date of hospitalization discharge.

Medical costs during hospitalization included general medical service costs, diagnosis costs, nonsurgical treatment costs, anesthetic costs, procedure costs, drug costs, blood costs, supply costs for surgery (e.g. stapler costs, cartridge
costs, hemostatic material costs, and other supply costs for surgery), supply costs for diagnosis, supply costs for
treatment, and other costs (e.g., costs for nursing service or caregivers, and meals) during the hospital stay. We also
evaluated the non-surgery costs, which were defined as the total costs excluding anesthetic costs, procedure costs, and
supply costs for surgery. We evaluated the direct medical costs from the healthcare system’s perspective.

**Statistical analyses**

Descriptive analysis was used to report the baseline characteristics of the study population. Continuous variables were
presented as mean ± standard deviation (SD). Categorical variables were reported as counts and percentages. Between-
group comparisons were performed. T-tests were used to compare continuous variables, and chi-square tests were used
to compare categorical variables. Two-sample Wilcoxon rank-sum (Mann-Whitney) test was used to compare non-
normally distributed variables (i.e., post-operative LOS, and costs). Multivariable generalized linear model (GLM) with
gamma probability distribution and log-link was used to analyze the factors associated with total costs. Adjusted cost
ratio and 95% confidence interval (95% CI) were reported. GLM with gamma distribution can account for significant
skewed cost data without the need for retransformation and is the recommended modeling method for cost data in
health services research [15, 16]. Significance level was set at two tailed P < 0.05 for all tests. Patients with lung cancer
diagnosis were analyzed as a subgroup for above analysis concerned the clinical outcomes and medical costs. Stata
14.0 (StataCorp LLC, College Station, Texas, USA) was used to perform the statistical analyses.

**Results**

**Study population**

A total of 2,131 patients were admitted to thoracic department in 2018, and 1,639 (76.91%) of them were diagnosed
with lung disease. After excluding patients without lobectomy, patients who received surgeries in other organs or
systems and patients with incomplete data, 797 patients were included in our study. Out of 797 patients studied, 208
(26.10%) patients went through open lobectomy and 589 (73.90%) patients had VATS lobectomy (Fig. 1).

**Patient characteristics**

Among the 797 patients, the average age of the study population was 59.92 ± 8.78 years old (Table 1). Mean age in
open lobectomy group was 60.23 ± 8.01 years old, while the mean age in the VATS lobectomy group was 59.82 ±
9.04 years old. Difference in age was not statistically significant between two groups (P = 0.563). There was a
statistically significant difference in the gender distribution between groups (P < 0.001). 131 (62.98%) patients in the
open lobectomy group were male, compared to 244 (41.43%) patients in the VATS lobectomy group. Most patients in
both groups had health insurance (90.38% in open lobectomy group vs. 91.34% in VATS lobectomy group, P = 0.677).
Lung cancer diagnosis in two groups was similar (84.62% in open lobectomy group vs. 88.29% in VATS lobectomy

group, P = 0.171). All the comorbidities were comparable between groups (P > 0.05). The most common comorbidities
in both groups was hypertension (15.38% in open lobectomy group and 19.35% in VATS lobectomy group). Baseline
patient characteristics were similar between the selected study population and excluded patients (Supplementary
Table 1).
Table 1
Demographic characteristics comparison between groups

| Baseline characteristics | Patients with lung disease n = 797 | Patients with lung cancer n = 696 |
|--------------------------|-----------------------------------|----------------------------------|
|                          | Overall n = 797                   | Overall n = 696                  |
|                          | Open lobectomy n = 208 (26.10%)   | Open lobectomy n = 176 (25.29%)  |
|                          | VATS lobectomy n = 589 (73.90%)   | VATS lobectomy n = 520 (74.71%)  |
| P-value                  | 0.563                             | 0.563                            |
| Age (years), mean ± SD   | 59.92 ± 8.78                      | 60.54 ± 8.55                     |
|                          | 60.23 ± 8.01                      | 61.07 ± 7.61                     |
|                          | 59.82 ± 9.04                      | 60.36 ± 8.85                     |
| Age group, n (%)         | 0.359                             | 0.062                            |
| < 50 years old           | 100 (12.55)                       | 75 (10.78)                       |
|                          | 21 (10.10)                        | 11 (6.25)                        |
|                          | 79 (13.41)                        | 64 (12.31)                       |
| 50–59 years old          | 272 (34.13)                       | 234 (33.62)                      |
|                          | 77 (37.02)                        | 66 (37.50)                       |
|                          | 195 (33.11)                       | 168 (32.31)                      |
| ≥ 60 years old           | 425 (53.32)                       | 387 (55.60)                      |
|                          | 111 (52.88)                       | 99 (56.25)                       |
|                          | 315 (53.48)                       | 288 (55.38)                      |
| Gender, n (%)            | < 0.001                           | < 0.001                          |
| Male                     | 375 (47.05)                       | 324 (46.55)                      |
|                          | 131 (62.98)                       | 109 (61.93)                      |
|                          | 244 (41.43)                       | 215 (41.35)                      |
| Female                   | 422 (52.95)                       | 372 (53.45)                      |
|                          | 77 (37.02)                        | 67 (38.07)                       |
|                          | 345 (58.57)                       | 305 (58.65)                      |
| Health insurance, n (%)  | 0.677                             | 0.859                            |
| Insured                  | 726 (91.09)                       | 635 (91.24)                      |
|                          | 188 (90.38)                       | 160 (90.91)                      |
|                          | 538 (91.34)                       | 475 (91.35)                      |
| Not insured              | 71 (8.91)                         | 61 (8.76)                        |
|                          | 20 (9.62)                         | 16 (9.09)                        |
|                          | 51 (8.66)                         | 45 (8.65)                        |
| Primary diagnosis, n (%) | 0.171                             | NA                               |
| Lung cancer              | 696 (87.33)                       | NA                               |
|                          | 176 (84.62)                       | NA                               |
|                          | 520 (88.29)                       | NA                               |
| Other lung diseases      | 101 (12.67)                       | NA                               |
|                          | 32 (15.38)                        | NA                               |
|                          | 69 (11.71)                        | NA                               |
| Comorbidity, n (%)       | 0.203                             | 0.124                            |
| Hypertension             | 0.664                             | 0.980                            |
| Yes                      | 146 (18.32)                       | 130 (18.68)                      |
|                          | 32 (15.38)                        | 26 (14.77)                       |
|                          | 114 (19.35)                       | 104 (20.00)                      |
| No                       | 651 (81.68)                       | 566 (81.32)                      |
|                          | 176 (84.62)                       | 150 (85.23)                      |
|                          | 475 (80.65)                       | 416 (80.00)                      |
|                | Patients with lung disease n = 797 | Patients with lung cancer n = 696 |
|----------------|-----------------------------------|----------------------------------|
|                | Yes                               | No                               |
| Yes            | 75 (9.41)                         | 18 (8.65)                        | 57 (9.68)                       | 59 (8.48)                        | 15 (8.52)                        | 44 (8.46)                        |
| No             | 722 (90.59)                       | 190 (91.35)                      | 532 (90.32)                     | 637 (91.52)                      | 161 (91.48)                      | 476 (91.54)                      |
| **Heart disease** | 0.272                             | 0.195                            |
| Yes            | 64 (8.03)                         | 13 (6.25)                        | 51 (8.66)                       | 60 (8.62)                        | 11 (6.25)                        | 49 (9.42)                        |
| No             | 733 (91.97)                       | 195 (93.75)                      | 538 (91.34)                     | 636 (91.38)                      | 165 (93.75)                      | 471 (90.58)                      |
| **Other diseases** | 0.771                             | 0.565                            |
| Yes            | 54 (6.78)                         | 15 (7.21)                        | 39 (6.62)                       | 45 (6.47)                        | 13 (7.39)                        | 32 (6.15)                        |
| No             | 743 (93.22)                       | 193 (92.79)                      | 550 (93.38)                     | 651 (93.53)                      | 163 (92.61)                      | 488 (93.85)                      |

*SD: standard deviation.*

**Cost-related clinical outcomes**

Three cost-related clinical outcomes assessed in this study were 1) blood transfusion rate, 2) lung infection rate, and 3) post-operative LOS (Table 2). Overall, 19 patients had blood transfusion post operation. The open lobectomy group (n = 9, 4.43%) had the higher blood transfusion rate, compared with the VATS lobectomy group (n = 10, 1.70%) (P = 0.033). 225 patients experienced post-operative lung infections in the study sample. Patients with open lobectomy (n = 85, 40.87%) had a higher lung infection rate post operation than patients in the VATS lobectomy group (n = 140, 23.77%) (P < 0.001). On average, the post-operative LOS for all patients was 9.83 ± 4.42 days. A longer post-operative LOS was observed in patients with open lobectomy, as mean of 10.97 ± 5.81 days. For patients who underwent the VATS lobectomy, the average post-operative LOS was 9.42 ± 3.72 days. The difference was statistically significant between these two groups (P < 0.001).
Table 2
Cost related clinical outcomes and hospitalization costs comparisons between groups

| Patients with lung disease n = 797 | Patients with lung cancer n = 696 |
|-----------------------------------|-----------------------------------|
| **Clinical outcomes**             | **Clinical outcomes**             |
| Overall n = 797                   | Overall n = 696                   |
| Open lobectomy n = 208 (26.10%)   | Open lobectomy n = 176 (25.29%)   |
| VATS lobectomy n = 589 (73.90%)   | VATS lobectomy n = 520 (74.71%)   |
| **Blood transfusion, n (%)**      | **Blood transfusion, n (%)**      |
| 19 (2.38)                         | 15 (2.16)                         |
| 9 (4.33)                          | 5 (2.84)                          |
| 10 (1.70)                         | 10 (1.92)                         |
| **Lung infection, n (%)**         | **Lung infection, n (%)**         |
| 225 (28.23)                       | 191 (27.44)                       |
| 85 (40.87)                        | 72 (40.91)                        |
| 140 (23.77)                       | 119 (22.88)                       |
| **Post-operative LOS (days), mean ± SD** | **Post-operative LOS (days), mean ± SD** |
| 9.83 ± 4.42                      | 9.89 ± 4.11                      |
| 10.97 ± 5.81                     | 10.97 ± 4.77                     |
| 9.42 ± 3.72                      | 9.52 ± 3.79                      |
| **Total hospitalization costs (RMB), mean ± SD** | **Total hospitalization costs (RMB), mean ± SD** |
| 84135.17 ± 18380.91              | 85538.19 ± 18662.07              |
| 81944.70 ± 16625.20              | 82884.97 ± 16859.85              |
| 84908.72 ± 18914.87              | 86436.20 ± 19165.98              |
| **Total non-surgery costs (RMB), mean ± SD** | **Total non-surgery costs (RMB), mean ± SD** |
| 43323.48 ± 14581.41              | 44053.15 ± 15241.67              |
| 45761.06 ± 10273.35              | 46581.11 ± 10513.53              |
| 42462.67 ± 15742.62              | 43197.54 ± 16459.53              |

LOS: length of stay. SD: standard deviation.

Total hospitalization costs and cost breakdown

VATS lobectomy and open lobectomy did not differ in the total hospitalization costs (RMB 84,908.72 ± 18,914.87 vs. RMB 81,944.70 ± 16,625.20, P = 0.065) (Table 2). Non-surgery costs were significantly lower for VATS lobectomy than open lobectomy (RMB 42,462.67 ± 15,742.62 vs. RMB 45,761.06 ± 10,273.35, P < 0.001).

Figure 2 and Supplementary Table 2 present the hospitalization cost breakdown by cost categories. In all categories of cost breakdown, supply costs for surgery was the biggest driver of the total hospitalization costs, and it was significantly higher for VATS lobectomy than open lobectomy (RMB 30,432.77 ± 8,121.19 in VATS lobectomy vs. RMB 26,358.83 ± 11,000.13 in open lobectomy, P < 0.001). Among the supply costs for surgery, cartridge costs were significantly higher in VATS lobectomy group, while hemostatic material costs in VATS group was significantly lower (Supplementary Table 3). The second biggest cost driver for both groups was drug costs, and it was significantly lower for VATS lobectomy than open lobectomy (RMB 17,307.46 ± 8,306.92 in VATS lobectomy vs. RMB 19,934.11 ± 6,980.19 in open lobectomy, P < 0.001).

Associated factors of total hospitalization costs

Lobectomy approach types, baseline characteristics and clinical outcomes were included in the GLM regression to further evaluate their impacts on the total hospitalization costs (Table 3). Age group was used in the model instead.
### Table 3
Multivariable generalized linear model for total hospitalization costs

| Patients with lung disease n = 797 | Patients with lung cancer n = 696 |
|-----------------------------------|-----------------------------------|
| Lobectomy approach (reference: open lobectomy) | Lobectomy approach (reference: open lobectomy) |
| Adjusted cost ratio | 1.084 | 1.102 |
| 95% CI | (1.056, 1.113) | (1.071, 1.133) |
| P value | < 0.001 | < 0.001 |
| Blood transfusion (reference: no) | Blood transfusion (reference: no) |
| Adjusted cost ratio | 1.000 | 1.002 |
| 95% CI | (0.929, 1.076) | (0.925, 1.086) |
| P value | 0.997 | 0.957 |
| Lung infection (reference: no) | Lung infection (reference: no) |
| Adjusted cost ratio | 1.108 | 1.116 |
| 95% CI | (1.080, 1.136) | (1.086, 1.146) |
| P value | < 0.001 | < 0.001 |
| Post-operative length of stay | Post-operative length of stay |
| Adjusted cost ratio | 1.017 | 1.020 |
| 95% CI | (1.014, 1.020) | (1.017, 1.023) |
| P value | < 0.001 | < 0.001 |
| Age group (reference: <50 years old) | Age group (reference: <50 years old) |
| 50–59 years old | 1.020 | 1.009 |
| 95% CI | (0.983, 1.058) | (0.969, 1.052) |
| P value | 0.305 | 0.654 |
| ≥ 60 years old | 1.036 | 1.022 |
| 95% CI | (0.999, 1.074) | (0.982, 1.064) |
| P value | 0.054 | 0.278 |
| Gender (reference: female) | Gender (reference: female) |
| Adjusted cost ratio | 1.036 | 1.030 |
| 95% CI | (1.012, 1.060) | (1.006, 1.055) |
| P value | 0.003 | 0.015 |
| Health insurance (reference: not insured) | Health insurance (reference: not insured) |
| Adjusted cost ratio | 1.020 | 1.019 |
| 95% CI | (0.982, 1.061) | (0.978, 1.062) |
| P value | 0.307 | 0.362 |
| Lung cancer diagnosis (reference: no) | Lung cancer diagnosis (reference: no) |
| Adjusted cost ratio | 1.128 | NA |
| 95% CI | (1.091, 1.167) | NA |
| P value | < 0.001 | NA |
| Hypertension (reference: no) | Hypertension (reference: no) |
| Adjusted cost ratio | 1.008 | 1.010 |
| 95% CI | (0.978, 1.039) | (0.979, 1.042) |
| P value | 0.586 | 0.536 |
| Diabetes (reference: no) | Diabetes (reference: no) |
| Adjusted cost ratio | 1.020 | 1.014 |
| 95% CI | (0.981, 1.062) | (0.971, 1.058) |
| P value | 0.320 | 0.535 |
| Heart disease (reference: no) | Heart disease (reference: no) |
| Adjusted cost ratio | 1.052 | 1.042 |
| 95% CI | (1.008, 1.097) | (0.999, 1.088) |
| P value | 0.019 | 0.057 |
| Other diseases (reference: no) | Other diseases (reference: no) |
| Adjusted cost ratio | 0.995 | 0.995 |
| 95% CI | (0.951, 1.041) | (0.588, 1.044) |
| P value | 0.818 | 0.837 |

95% CI: 95% confidence interval.

**Supplementary table 1.** Sensitivity analysis of baseline characteristics comparison between included population and missing population.

In the overall study population, after controlling for covariates, the VATS lobectomy approach was significantly associated with higher total hospitalization costs. Comparing to open lobectomy, VATS lobectomy approach increased the total hospitalization costs by 8.4% (coefficient = 1.084, 95% CI: 1.056, 1.113. P < 0.001). Lung infection post operation also increased the total hospitalization costs by 1.108 times (95% CI: 1.080, 1.136), comparing with patients without lung infection (P < 0.001). An additional day of post-operative LOS increased the total hospitalization costs by 1.017 times (95% CI: 1.014, 1.020. P < 0.001).
Patients aged above 60 years old had the highest total hospitalization costs, however, its impact on the hospitalization costs was not significant (P = 0.054). Comparing with the patients aged below 50 years old, hospitalization costs for patients aged above 60 years old were 1.036 times (95% CI: 0.999, 1.074) higher. The total hospitalization costs for male patients were 1.036 times (95% CI: 1.012, 1.060. P = 0.003) higher than female patients. Controlling for other covariates, heart disease history increased the total hospitalization costs by 1.052 times (95% CI: 1.008, 1.097. P = 0.019). Additionally, the total hospitalization costs for patients with lung cancer diagnosis was 1.128 times (95% CI: 1.091, 1.167. P < 0.001) higher than patients without lung cancer diagnosis.

Subgroup analyses

Demographic characteristics. Among 696 patients with lung cancer, 176 (25.29%) patients had open lobectomy and 520 (74.71%) patients had VATS lobectomy (Table 1). The characteristics of the subgroup were similar to the overall study sample.

Post-operative outcomes. Among 696 patients with lung cancer, 15 patients had blood transfusion. 5 (2.84%) patients were from the open lobectomy group, and 10 (1.92%) patients were from the VATS lobectomy group. The difference in blood transfusion between open lobectomy and VATS lobectomy group was not significant in this subgroup (P = 0.469). The VATS group had a lower lung infection rate (22.88% vs. 40.91%, P < 0.001) and a shorter LOS (9.52 ± 3.79 vs. 10.97 ± 4.77, P < 0.001), compared to the open lobectomy group (Table 2).

Hospitalization costs and cost breakdown. In the subgroup, the mean difference in total hospitalization costs between open lobectomy and VATS lobectomy became significant (RMB 82,884.97 ± 16,859.85 in the open lobectomy group vs. RMB 86,436.20 ± 19,165.98 in the VATS lobectomy group, P = 0.039) (Table 2). Non-surgery costs were significantly lower for VATS lobectomy than open lobectomy (RMB 43197.54 ± 16459.53 in VATS lobectomy vs. RMB 46581.11 ± 10513.53 in open lobectomy, P < 0.001). Diagnosis costs, general medical services costs, blood product costs and other costs remained equivalent between the two lobectomy groups (P > 0.05). Other types of costs remained significantly different between the open lobectomy group and VATS lobectomy group (P < 0.05) (Fig. 2).

Associated factors of total hospitalization costs. Undergoing VATS lobectomy, having lung infection, longer post-operative LOS, and male gender, were positively associated with total hospitalization costs P < 0.05) (Table 3).

Discussion

To our best knowledge, this was the first study comparing the post-operative outcomes and costs with the most comprehensive cost analysis between VATS lobectomy and open lobectomy among Chinese patients with lung diseases, regardless of lung cancer status. The post-operative outcomes of VATS lobectomy were significantly better than open lobectomy. And this was the first study assessing risk factors for high hospitalization costs of lobectomy operation in Chinese population. Overall, total hospitalization costs among the patients with VATS lobectomy were similar to open lobectomy. However, the total non-surgery costs were significantly lower in VATS compared to open lobectomy.

Our findings were consistent with the previous studies [4, 7, 9, 17, 18]. First, post-operative clinical outcomes including blood transfusion, lung infection, and post-operative LOS were all significantly better in the VATS lobectomy group, comparing with the open lobectomy group. It indicated that minimally invasive technology indeed reduced the complications. Second, the procedure costs, cartridge costs for VATS lobectomy was significantly higher, it may be due to the advanced technology of VATS lobectomy. Blood costs, drug costs and hemostatic material costs in the open lobectomy group were significantly higher, it might result from a relatively greater trauma from open lobectomy approach. A study also found hospitalization costs in VATS lobectomy group were significantly higher due to higher
operative and instrument costs, compared with open lobectomy approach [18]. The GLM regression results showed that the total hospitalization costs were associated with post-operative lung infection, post-operative LOS, gender, lung cancer diagnosis status, and heart disease.

Long-term survival from these two approaches was also evaluated in the previous studies. Most study findings showed the long-term survival was comparable between open lobectomy and VATS lobectomy [19–24]. We did not include this as a measurement as the clinical outcomes in our study. The main reason was that either VATS or open lobectomy could lead to blood loss, infection, and physical pain, however, significant bleeding during lung resection surgery was found to be rare in a retrospective matched cohort analysis using real-world data [25]. Thus, we did not consider the complications from either lobectomy approach to significantly increase death from the procedure. In addition, many other aspects including post-operation recovery, development of other comorbidities, cancer upstage, or cancer reoccurrence might have even a bigger impact on the long-term survival. Other ways to measure the clinical safety and effectiveness of VATS lobectomy can also include readmission due to the lobectomy surgery complications in a short-term period post the hospital discharge, which can further affect the overall hospitalization costs [26].

Many previous studies have applied the PSM to control the inherent biases in non-randomized comparison [4, 27–30], common parameters for matching from previous studies included age, gender, smoking history, body mass index, American Society of Anesthesiologists (ASA) Risk Scale, Eastern Cooperative Oncology Group (ECOG) score, surgical side, tumor size, histological type, preoperative chemotherapy or radiotherapy, and comorbidities such as hypertension, coronary artery disease, cardiac failure, diabetes, and cerebrovascular disease. However, propensity score matching can only match on the observables. It cannot manage the differences in unobservable variables, and it may still introduce selection bias.

In our study population, patients in open lobectomy group and VATS lobectomy group were similar, except for the gender distribution. More males received open lobectomy, while more females received VATS lobectomy. It may be because more males were smokers, with worse pulmonary function, and with advanced lung cancer. Thus, open lobectomy might be more appropriate in this situation, as it would be safer and more likely to remove the whole tumor [31]. However, gender was not an important factor for the difference in complication rates between these two lobectomy approaches, it might still introduce selection bias without a propensity score matching (PSM) to control the difference. In addition, many of the controlled variables from previous studies were not available from the dataset we used. Gender was the only variable that was differently distributed in the study population. And it was not the most important factor that would lead to the difference in complication rates between the two approaches. Thus, PSM was not chosen in our approach. The lack of clinical pre-operative characteristics, such as smoking history, more comorbidity types, pulmonary function that may have impact on the complication rates, were not available. And we were unable to appropriately control the non-randomized selection bias was another limitation.

There were some additional limitations in our study. First, either open lobectomy or VATS lobectomy requires surgeons to have sufficient training and experience, and it plays an important role in the assessment of complications and hospitalization costs, as the economic impact could be magnified as the surgeons’ experience increases [5]. Surgeons with limited experience in open lobectomy can achieve satisfactory outcomes in VATS lobectomy comparable to their more experienced seniors [32]. Thus, without the consideration of surgeons’ experience, the interpretation of the comparison between open lobectomy and VATS lobectomy might be biased. Second, this study used medical records for a single hospital. Due to the unbalanced development of the thoracic surgery technology in different regions in China, the study population may not be representative for the target population.

More assessments are still needed in the future. A more comprehensive list of comorbidities and pre-operative pulmonary function should be included and matched. Different measurements for clinical outcomes, such as patient-
reported outcomes, readmission rate, need be considered. In the meantime, indirect medical costs due to loss of productive time should be considered from the societal perspective.

**Conclusions**

Our study suggested that from the health system’s perspective, the utilization of VATS lobectomy approach led to higher hospitalization costs, however, this direct procedure costs was offset by significantly reduction in post-operative blood transfusion rate, lung infection rate and hospital LOS, compared with open lobectomy approach. A more comprehensive comparison is needed to include patient-reported outcomes, as well as to assess it from the societal perspective.

**Abbreviations**

VATS  
Video-Assisted Thoracoscopic Surgery

LOS  
length of stay

MITS  
minimally invasive thoracic surgery

EMR  
extronic medical record

SD  
standard deviation

GLM  
generalized linear model

CI  
confidence interval

**Declarations**

*Ethics approval and consent to participate*

This retrospective study used de-identified data. The need for approval and consent was waived.

*Consent for publication*

All named authors have read and approved this manuscript and there are no other persons who satisfied the criteria for authorship but are not listed. In addition, the order of authors listed in the manuscript has been approved by all co-authors.

*Availability of data and materials*

The data that support the findings of this study are available from the corresponding author upon reasonable request.

*Competing interests*

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Author's contributions

Wei Chen, Zhanwu Yu, and Hongxu Liu contributed equally to the conception and/or design of the work, revised the manuscript critically for important intellectual content, approved the final version to be published, and agreed to be accountable for all aspects of the work to ensure that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved. Yichen Zhang prepared the manuscript for publication, revised the manuscript critically for intellectual content, and approved the final version to be published.

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