Scientific Reports

https://doi.org/10.1038/s41598-026-39978-3

Article in Press

Elective thoracic oncologic resections in selected patients appear safe beyond four weeks after COVID-19 infection

Received: 12 October 2025

Accepted: 9 February 2026

Published online: 18 February 2026

Cite this article as: Zhang Y., Liu Y., Xu H. *et al.* Elective thoracic oncologic resections in selected patients appear safe beyond four weeks after COVID-19 infection. *Sci Rep* (2026). https://doi.org/10.1038/s41598-026-39978-3

Yang Zhang, Yuxian Liu, Hongxu Xu, Li Yin, Yudong Wang, Xiaozhong Zhu, Hui Liu & Bo Gui

Original Article

Elective Thoracic Oncologic Resections in Selected Patients Appear Safe Beyond Four Weeks After COVID-19 Infection

Yang Zhang, MD[1, †], Yuxian Liu, MD[2, †], Hongxu Xu, MD[1, †], Li Yin, MD[1], Yudong Wang, MD[3], Xiaozhong Zhu, MD[4, *], Hui Liu, MD, PhD[2,3, *], Bo Gui, MD, PhD[5, *]

[1] *Department of Anesthesiology and Perioperative Medicine, The First Affiliated Hospital of Nanjing Medical University, Nanjing, China.*

[2] *Department of Anesthesiology, The Affiliated Cancer Hospital of Nanjing Medical University, Jiangsu Cancer Hospital, Jiangsu Institute of Cancer Prevention and Treatment, Nanjing, China.*

[3] *Jiangsu Province Key Laboratory of Anesthesiology, Xuzhou Medical University, Xuzhou, China.*

[4] *Department of Anesthesiology, Taikang Xianlin Drum Tower Hospital, Affiliated Hospital of Medical School, Nanjing University, Nanjing, China.*

[5] *Department of Anesthesiology and Pain Medicine, Geriatric Hospital of Nanjing Medical University, Nanjing, China.*

[†]Yang Zhang, Yuxian Liu, and Hongxu Xu contributed equally to this work.

[*]***Correspondence to**: **Bo Gui** MD, PhD; **Hui Liu**, MD, PhD; **Xiaozhong Zhu**, MD.*

1. Department of Anesthesiology and Pain Medicine (Gui), Geriatric Hospital of Nanjing Medical University, No. 65 Jiangsu Road, 210009, Nanjing, China.

Tel: *+86 13675163272;* ***E-mail:*** *guibosy@njmu.edu.cn.*

1. Department of Anesthesiology ***(Liu)****, The Affiliated Cancer Hospital of Nanjing Medical University, Jiangsu Cancer Hospital, Jiangsu Institute of Cancer Prevention and Treatment, No. 42 Baiziting, 210029, Nanjing, China*

2. Jiangsu Province Key Laboratory of Anesthesiology, Jiangsu Province Key Laboratory of Anesthesiology and Analgesia Application Technology, Xuzhou Medical University, No. 209 Tongshan Road, 221004, Xuzhou, China.

Tel:*+86 13813043213;* ***E-mail:*** *huilium@163.com.*

*1. Department of Anesthesiology (****Zhu****), Taikang Xianlin Drum Tower Hospital, Affiliated Hospital of Medical School, Nanjing University, Nanjing, China.*

Tel:*+86 15151125611;* ***E-mail:*** *zxiaozhong@126.com.*

Abstract

Background: The global spread of coronavirus disease 2019 (COVID-19) has had a profound public health impact, particularly on perioperative management, rendering the optimization of timing for post-infection thoracic oncologic surgery a pressing clinical concern.

Methods: This multicenter retrospective cohort study included adult patients who underwent elective video-assisted thoracic oncologic surgery in February 2023 with confirmed COVID-19 infection ≥4 weeks prior. A matched historical control cohort from February 2019 was used for comparison. Propensity score matching (PSM) and inverse probability of treatment weighting (IPTW) were applied to adjust for confounders. Subgroup analyses were conducted based on clinical variables, and logistic regression was used to assess the association between infection-to-surgery interval and PPCs.

Results: A total of 846 patients were included. After PSM and IPTW, the incidence of PPCs remained comparable between the COVID-19 and no-COVID-19 groups (PSM: 26.1% *vs.* 31.8%, $p = 0.784$; IPTW: 28.0% *vs.* 29.7%, $p = 0.615$). No significant differences in PPC rates were observed across infection-to-surgery intervals (4–6, 6–8, and 8–12 weeks; $p = 0.953$). Prior COVID-19 infection was associated with higher postoperative WBC counts and lower lymphocyte levels, but not with increased PPCs risk.

Smoking history was an independent predictor of PPCs (OR: 2.503, p = 0.005), while infection timing was not.

Conclusions: Thoracic oncologic surgery may be considered ≥4 weeks after COVID-19 recovery in carefully selected patients. Further prospective studies are needed to assess safety in earlier postoperative intervals and among patients recovering from severe infection.

Keywords: COVID-19; inverse probability of treatment weighting; optimal surgical timing; postoperative pulmonary complications; thoracic oncologic surgery.

The global spread of coronavirus disease 2019 (COVID-19) over the past few years has profoundly impacted public health, particularly in perioperative management and postoperative recovery. Notably, a significant number of COVID-19 cases continue to emerge during the winter and spring seasons even after the end of the pandemic.[1] COVID-19 primarily affects the pulmonary system, induces endothelial dysfunction, provokes vascular inflammation, and initiates a systemic inflammatory response, which leads to multiple adverse outcomes such as fever, dry cough, dyspnea, myalgia, and fatigue.[2] Thus, COVID-19 infection increases perioperative complication risks even in mild cases,[3] with thoracic oncologic patients representing a particularly high-risk population.

Approximately 50% of COVID-19 patients developed severe postoperative pulmonary complications (PPCs), including acute respiratory distress syndrome (ARDS) and unplanned mechanical ventilation requirements.[2,4] Importantly, even clinically mild PPCs - such as atelectasis or prolonged oxygen dependency - were associated with increased morbidity and mortality following non-cardiothoracic procedures.[5] The PPCs risks are compounded by COVID-19-related pulmonary sequelae, such as fibrosis and mediastinal lymphadenopathy.[6] Undoubtedly, thoracic oncologic procedures are vulnerable to COVID-19–related pulmonary pathophysiology, which may simultaneously impair surgical exposure and increase susceptibility to postoperative pulmonary complications.

The optimal timing of thoracic oncologic surgery after COVID-19 infection remains clinically uncertain. While the ASA and APSF Joint Statement conservatively recommends a 2-7 week waiting period even for low-risk patients and procedures,[7] emerging evidence from comprehensive population-level analyses of diverse surgical cohorts indicates that elevated postoperative risks - specifically 90-day mortality and 30-day complications - are principally limited to the immediate two-week period following infection.[8]

This critical knowledge gap prompted our focused investigation into thoracic surgical oncology, which presents unique clinical challenges. Therefore, this multicenter retrospective cohort study was designed to assess whether thoracic oncologic surgery performed ≥4 weeks after confirmed COVID-19 infection is associated with an elevated risk of PPCs. The findings may guide individualized surgical timing strategies and reduce unnecessary delays in clinically time-sensitive thoracic oncologic procedures for high-risk patients.

Methods

Study Design

This multicenter retrospective study was approved by the Ethics Committee of the First Affiliated Hospital with Nanjing Medical University (Approval No. 2023-SR-174), the Affiliated Cancer Hospital of Nanjing Medical University (Approval No. 2023-KE-KUAI-038), and the Affiliated Taikang Xianlin Drum Tower Hospital with the Medical School of Nanjing University (Approval No. LS202317). The study was registered with the Chinese Clinical Trial Registry (ChiCTR; registration number: ChiCTR2400090009; date of registration: 23 September 2024). Electronic medical records were reviewed for patients admitted between February 1 and February 28 in both 2019 and 2023. This study adhered to the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) guidelines. Given the retrospective nature of the study and the use of anonymized patient data, the requirement for informed consent was waived by the Institutional Review Boards of the First Affiliated Hospital with Nanjing Medical University, the Affiliated Cancer Hospital of Nanjing Medical University, and the Affiliated Taikang Xianlin Drum Tower Hospital with the Medical School of Nanjing University. All methods were performed in accordance with relevant guidelines and regulations.

Patient Cohort

The study population comprised consecutive adult patients (≥18 years)

undergoing elective video-assisted thoracoscopic oncologic surgery between February 1 and 28, 2023, with all procedures performed 4-12 weeks following laboratory-confirmed COVID-19 diagnosis. To ensure valid comparison, we identified a matched control cohort consisting of adults who underwent video-assisted thoracoscopic oncologic surgery in February 2019, a pre-pandemic period selected to eliminate any potential SARS-CoV-2 exposure while preserving seasonal comparability of perioperative respiratory risk. Exclusion criteria consisted of incomplete medical records, ambulatory procedures, and endoscopic thoracic sympathectomy. Enrolled patients were categorized into two groups: COVID-19 group and no-COVID-19 group. The COVID-19 cohort was stratified into three subgroups based on the interval between COVID-19 infection diagnosis and surgery: 4–6 weeks, 6–8 weeks, and 8–12 weeks. Propensity score matching (PSM) and inverse probability of treatment weighting (IPTW) were employed to adjust for known confounders and ensure balance between the two groups.

COVID-19 Diagnosis Exposure

Confirmation of COVID-19 infection required at least one positive result obtained through either nucleic acid amplification testing (including RT-PCR or viral genome sequencing) or antigen detection testing, using nasopharyngeal or oropharyngeal swab specimens. As reported,[9] asymptomatic infection was defined as a laboratory confirmed SARS-CoV-

2 infection without clinical symptoms; mild and moderate disease were distinguished by the absence or presence of radiologic evidence of pneumonia, respectively; whereas severe and critical disease were characterized by hypoxemic respiratory failure or organ dysfunction. COVID-19 vaccination status was recorded as a binary variable (vaccinated *vs.* unvaccinated), defined by history of at least one dose of any SARS-CoV-2 vaccine prior to surgery.

Study Outcomes

The primary outcome was the incidence of PPCs occurring within the first seven days following thoracic oncologic surgery. We focused on PPCs occurring within the initial 7 postoperative days, as most patients were discharged within this timeframe. PPCs were defined according to prior research and clinical guidelines, including pneumonia, respiratory failure, bronchospasm, atelectasis, pleural effusion, pneumothorax and aspiration pneumonitis. Notably, pleural effusion and pneumothorax were classified as PPCs only when occurring in the non-operated lung, thereby distinguishing them from routine post-surgical changes on the operative side.[10] Diagnosis of PPCs was determined by two independent, experienced researchers under the guidance of a radiologist. In the case of disagreements, the diagnosis was discussed within the research group. Secondary outcomes encompassed inflammatory markers (white blood cell and lymphocyte counts) measured on postoperative day 1, duration of

thoracic drainage, and length of postoperative hospitalization, postoperative cardiovascular and thromboembolic events before discharge.

Statistical Analysis

Statistical analysis was performed using R software (version 4.2.0, R Foundation for Statistical Computing, Vienna, Austria) and IBM SPSS Statistics for Windows (Version 21.0. Armonk, NY: IBM Corp.). Descriptive statistics were expressed as mean ± standard deviation (SD) or median (interquartile range, IQR) and analyzed using the independent Student's *t*-test or the Mann-Whitney *U* test, depending on data distribution. Categorical variables were reported as number (percentage) and analyzed using the Chi-square test or Fisher's exact test. Missing data <5% were handled with complete case analysis; otherwise, multiple imputations were applied. The propensity score models were estimated from age, sex, BMI, ASA class, smoking, comorbidities, and type of surgery. Patients were matched 1:1 (nearest neighbor, caliper 0.1), with covariate balance assessed by standardized mean differences (SMD<0.1). IPTW was also performed for sensitivity analysis.

In the COVID-19 cohort, logistic regression assessed the association between infection-to-surgery interval (4–6, 6–8, 8–12 weeks) and PPCs, adjusting for age, sex, BMI, ASA, smoking, comorbidities, vaccination status, COVID-19 severity, and type of surgery. Adjusted odds ratios (ORs) and 95% confidence intervals (CIs) were calculated. We also performed

predefined subgroup analyses stratified by age, gender, BMI, smoking, and type of surgery. A p value < 0.05 was considered statistically significant.

Results

Patient Demographics

The patient flow chart is shown in Fig.1. Our study initially enrolled 1,015 eligible patients who underwent thoracic oncologic surgery during February 2019 and February 2023. Ultimately, among the 846 enrolled patients, 350 patients (41.4%) were allocated to the no-COVID-19 group, and 496 patients (58.6%) were allocated to the COVID-19 group. Based on previous literatures,[4,11] the incidence of PPCs following thoracic oncologic surgery ranges from 25% to 33%. This study hypothesized that the incidence of PPCs would be 33% in the no-COVID-19 group and 50% in the COVID-19 group, respectively. To detect this difference with a significance level (α) of 0.025 and a power (1-β) of 0.90, at least 254 patients were required in each group, accounting for a 20% dropout rate. Therefore, the sample size of this present study is sufficient to meet statistical requirements.

Table 1 presents the baseline characteristics and perioperative variables before and after PSM. Before matching, significant between-group differences were observed in age (p = 0.054), gender (p = 0.034), hypertension status (p = 0.043), and type of surgery (p < 0.001). Following PSM, the matched cohort comprised 566 patients (283 per group), with no

significant differences in demographic or perioperative variables. Similarly, IPTW analysis demonstrated balanced baseline characteristics between groups. SMD for all variables before and after matching are shown in Supplementary Fig. 1.

Incidence of PPCs

After adjustment for baseline confounding using both PSM and IPTW, the incidence of PPCs remained comparable between the COVID-19 and no-COVID-19 groups (PSM: 26.1% *vs.* 31.8%, $p = 0.784$; IPTW: 28.0% *vs.* 29.7%, $p = 0.615$; Table 2). Consistently, no significant differences were observed in the incidence of pneumonia (PSM: 18.4% *vs.* 24.0%, $p = 0.839$; IPTW: 20.0% *vs.* 22.7%, $p = 0.375$), pleural effusion (PSM: 11.7% *vs.* 15.5%, $p = 0.220$; IPTW: 10.2% *vs.* 13.6%, $p = 0.145$), or atelectasis (PSM: 1.8% *vs.* 0.7%, $p = 0.447$; IPTW: 1.6% *vs.* 0.8%, $p = 0.379$). Pneumothorax was rare in both groups, and no meaningful difference was detected under either method (PSM: 0% *vs.* 0%; IPTW: 0.2% *vs.* 0%, $p = 0.321$).

Secondary Outcomes

Patients in the COVID-19 group exhibited significantly elevated postoperative inflammatory markers compared to those in the no-COVID-19 group. This was demonstrated by the increased WBC count ($10.9 \pm 3.4 \times 10^9$/L *vs.* $7.9 \pm 6.4 \times 10^9$/L, $p < 0.001$) and the decreased lymphocyte count ($1.3 \pm 1.1 \times 10^9$/L *vs.* $4.6 \pm 4.9 \times 10^9$/L, $p < 0.001$). The COVID-19 group also demonstrated shorter duration of surgery (94 [62, 135] min *vs.*

145 [102, 210] min, $p < 0.001$), reduced duration of thoracic drainage (2 [2, 4] d *vs.* 4 [3, 7] d, $p < 0.001$), and decreased length of postoperative hospitalization (3 [3, 5] d *vs.* 6 [4, 10] d, $p < 0.001$).

No major postoperative cardiovascular or thromboembolic events were observed in the no-COVID-19 group (n = 350). In the COVID-19 group (n = 496), two thromboembolic events were documented: one case of postoperative pulmonary embolism and one case of muscular calf vein thrombosis. No significant differences were observed between the two groups in the incidence of cardiovascular and thromboembolic complications ($p = 0.514$).

PSM and IPTW

After PSM and IPTW, significant differences remained between the two groups in terms of postoperative WBC count (PSM: 11.1 ± 3.6 × 10^9/L *vs.*8.4 ± 6.3 × 10^9/L, $p < 0.001$; IPTW: 10.9 ± 3.5 × 10^9/L *vs.*8.2 ± 6.3 × 10^9/L, $p < 0.001$), lymphocyte count (PSM: 1.4 ± 1.0 × 10^9/L *vs.*4.1 ± 4.6 × 10^9/L, $p < 0.001$; IPTW: 1.3 ± 1.2 × 10^9/L *vs.*4.3 ± 4.7 × 10^9/L, $p < 0.001$), and duration of surgery (PSM: 95 [61, 139] min *vs.* 131 [98, 184] min, $p < 0.001$; IPTW: 120.0 ± 78.6 min *vs.*151.7 ± 77.5 min, $p < 0.001$). Similarly, duration of thoracic drainage and length of postoperative hospitalization were significantly shorter in the COVID-19 group compared to the no-COVID-19 group after PSM (2 [2, 4] d *vs.* 3[2, 5] d, $P < 0.001$; 3 [3, 6] d *vs.* 5 [4, 7] d, $p < 0.001$) and after IPTW (3.3 ± 2.6 d *vs.* 4.8 ± 4.6 d, $p < 0.001$;

5.2 ± 3.9 d *vs.* 7.1 ± 6.3 d, $p < 0.001$).

Characteristics and Postoperative Outcomes by Infection-to-Surgery Interval

Patients in the COVID-19 group were then divided into three groups according to the interval from the diagnosis of COVID-19 infection to the day of surgery (4-6 weeks, 6-8 weeks and 8-12 weeks). Baseline characteristics and postoperative outcomes across the three groups are presented in Table 3. No statistically significant differences were observed among the three interval groups (4–6 weeks, 6–8 weeks, and 8–12 weeks) regarding age, gender, BMI, ASA status, vaccination status, COVID-19 severity, or residual post-COVID symptoms. However, significant differences were noted in types of surgery ($p < 0.001$). The incidence of PPCs was comparable across the three groups (27.4%, 29.2%, and 28.1%, respectively; $p = 0.953$). Similarly, no significant differences were observed in the requirement for home oxygen therapy within one-year follow-up (8.1%, 7.6%, and 5.2%, respectively; $p = 0.529$). In addition, residual post-COVID symptoms were documented in 61 patients, including residual cough (n = 51), sore throat (n = 6), chest tightness (n = 5), and myalgias (n = 5). All symptoms were mild, and none affected patients' fitness for elective surgery ($p = 0.478$).

Impact of COVID-19 Infection-to-Surgery Interval on PPCs After Adjustment

The multivariable logistic regression analysis (Table 4) revealed no significant association between infection-to-surgery interval and the risk of PPCs after adjusting for potential confounders. However, increased age (OR: 1.024, 95% CI: 1.004–1.045, $p = 0.020$) and smoking history (OR: 2.503, 95% CI: 1.314–4.767, $p = 0.005$) were identified as independent risk factors for PPCs. Other covariates including gender, BMI, hypertension, diabetes, ASA status, heart disease, vaccination status, COVID-19 severity, type of surgery, and duration of surgery were not significantly associated with PPCs.

Subgroup Analysis

As shown in Fig. 2, a post-hoc subgroup interaction analysis of this study was performed based on predefined variables. A statistically significant interaction was observed between smoking history and infection-to-surgery interval (p for interaction = 0.006). Patients with no history of smoking who underwent surgery 4–6 weeks after COVID-19 infection had a significantly lower risk of PPCs compared to those with a history of smoking (OR: 0.65, 95% CI: 0.47-0.90, $p = 0.009$). Although smokers exhibited an increased relative risk of PPCs, the increase was not statistically significant (OR: 2.09, 95% CI: 0.97-4.52, $p = 0.061$). No significant interactions were observed for other variables, including age, gender, BMI, ASA, and type of surgery ($p > 0.05$).

Discussion

A pre-pandemic control group was essential to ensure that all comparison patients were entirely free from SARS-CoV-2 exposure, avoiding potential contamination from asymptomatic infection or pandemic-related system effects inherent in 2020–2023 cohorts. The February 2019 population therefore provided a robust COVID-19 reference group. Prior institutional data from thoracic surgery cases (1998–2016) demonstrated no meaningful temporal trends in PPC rates,[12] and ERAS protocols, although effective in reducing hospital stay, have shown minimal impact on overall PPC incidence.[13]

Initial guideline recommended deferring elective surgeries for seven weeks post-COVID-19 diagnosis to mitigate perioperative complications.[14] In addition, these guidelines highlight the uncertainty that persists during the early recovery period and recommend individualized risk assessment for procedures scheduled between two and seven weeks after SARS-CoV-2 infection.[7] Given the elevated PPCs risk inherent to major thoracic procedures, we established an 8-week post-COVID threshold to ensure clinical generalizability. In our cohort, only ten patients underwent surgery within 0–2 or 2–4 weeks after COVID-19 infection during the study period, rendering the sample insufficient for meaningful analysis. Therefore, our investigation focused on patients undergoing surgery ≥ 4 weeks after infection. Notably, our dataset did not include cases diagnosed >12 weeks before surgery.

This study demonstrated that thoracic oncologic surgery ≥4 weeks after COVID-19 was not associated with increased PPCs compared to a matched historical cohort. Stratified analysis of surgical timing intervals (4-6 weeks, 6-8 weeks, and 8-12 weeks post-infection) revealed no statistically significant differences. These findings align with and substantially reinforce the current ASA and APSF guidelines.[7] However, as patients undergoing surgery within <4 weeks after infection were not evaluated and patients with moderate or severe COVID-19 were underrepresented, caution is warranted when extrapolating these results to earlier postoperative intervals or more severe disease.

Our primary outcome analysis following PSM and IPTW revealed no significant association between prior COVID-19 infection and an increased risk of PPCs. These findings align with evolving perioperative guidelines and provide oncologic thoracic-specific data, supporting individualized surgical decision-making in this high-risk population. Importantly, our results differ from earlier reports suggesting higher perioperative mortality and adverse outcomes associated with COVID-19.[15] Previous studies predominantly concentrated on the pandemic timeframe, often involving patients with active or severe COVID-19. It is unequivocal that any recent respiratory illness can increase the risk of perioperative complications.[16] Moreover, those studies frequently lacked thoracic oncologic surgery-specific data and included patients who underwent

surgery within four weeks of infection—a population excluded in our study. Therefore, while our findings may more accurately reflect contemporary clinical practice in the post-pandemic era, they should be interpreted within the context of selective case inclusion.

Notably, despite extensive adjustment using PSM and IPTW, patients in the COVID-19 group exhibited shorter operative duration, reduced thoracic drainage time, and shorter postoperative hospital stay. Rather than indicating a protective effect of prior COVID-19 infection, these findings are more likely to reflect a selection process in clinical practice. Specifically, surgeons and multidisciplinary teams may have preferentially deferred patients with greater surgical complexity or higher complication risk after COVID-19 infection. This selection bias may have partially contributed to the favorable perioperative recovery metrics observed in the COVID-19 group and should be carefully considered when interpreting comparative outcomes.

Our analysis revealed no significant differences in PPCs across varying recovery intervals (4–6 weeks, 6–8 weeks, and 8–12 weeks) between COVID-19 diagnosis and thoracic oncologic surgery. However, a longer duration from COVID-19 diagnosis to surgery was associated with reduced odds of major postoperative cardiovascular morbidity.[17] The interval between COVID-19 diagnosis and surgery was documented to influence both mortality and pulmonary risk, with the effect diminishing after 2

weeks.[18] Although current guidelines recommend that time-sensitive surgeries should be performed seven weeks after COVID-19 infection,[3] our data suggest that, in carefully selected patients, thoracic oncologic surgery may be performed safely beyond four weeks after COVID-19 infection; however, this observation should not be interpreted as evidence supporting earlier surgery in unselected or higher-risk populations.

Pneumonia rates observed in our cohort (22–25%) are consistent with previously reported incidences of PPCs following thoracic procedures. Published studies have documented a 31.9% incidence of postoperative pneumonia in patients undergoing thoracoscopic resection for non-small cell lung cancer,[19] as well as a 36.0% PPCs rate in ICU patients following noncardiac thoracic surgery, of which pneumonia accounted for 32.2% of all cases.[20] These data underscore the inherently elevated risk of pulmonary complications associated with thoracic procedures and validate the observed rates within our study cohort.

Notably, despite comparable PPC rates, patients with prior COVID-19 infection exhibited higher postoperative WBC counts and lower lymphocyte counts, reflecting persistent immunologic alterations. Lymphopenia is prevalent among patients with COVID-19.[21,22] The magnitude and duration of peripheral blood lymphocyte count decline is predictive of disease severity and death.[23] This discrepancy suggests that while COVID-19 may induce an inflammatory response, the induced inflammatory response does

not necessarily lead to a higher incidence of PPCs. It is possible that advancements in perioperative management and surgical techniques have mitigated the potential risks posed by this heightened inflammatory state. In addition to inflammatory markers, postoperative cardiovascular and thromboembolic events were also evaluated. In our cohort, these events occurred infrequently in both the COVID-19 and non-COVID-19 groups. Due to the low event rates, the study was underpowered to detect meaningful between-group differences in cardiovascular and thromboembolic outcomes. Consequently, the absence of statistically significant differences should be interpreted with caution and cannot be taken as conclusive evidence of comparable risk between the groups.

Finally, a post-hoc subgroup analysis was conducted to explore potential effect modification. Patients without a history of smoking exhibited a lower risk of PPCs after thoracic oncologic surgery following COVID-19 infection, consistent with established evidence supporting smoking cessation as a key strategy for reducing PPCs risk.[24] Quitting smoking for more than 4 weeks can effectively reduce the risk of PPCs.[25] This emphasizes the importance of considering individual risk factor on the assessment of postoperative adverse outcomes. It should be noted that all subgroup and interaction analyses were exploratory and performed post hoc; therefore, these results carry an increased risk of type I error and should be interpreted with caution as hypothesis-generating rather than

confirmatory.

Our present study has several limitations. First, preoperative pulmonary function data were unavailable for many patients because infection control policies during the study period suspended such tests, which were considered high-risk aerosol-generating procedures. Second, only 10 patients underwent surgery within 0–4 weeks after COVID-19 infection, rendering the sample size insufficient for meaningful analysis of this early postoperative interval. Third, although PSM and IPTW were used to balance measured confounders, the use of a historical pre-pandemic control cohort may still introduce residual confounding due to unmeasured systematic changes over time. These include potential differences in surgical indications, case selection, perioperative decision-making, and healthcare system organization between the pre-pandemic and post-COVID-19 periods. Such factors could influence the observed associations and should be considered when interpreting the results. Finally, sensitivity analyses using alternative definitions of PPCs were not performed. Future prospective studies incorporating broader complication definitions, standardized pulmonary risk assessment tools, and contemporaneous control cohorts are warranted to further validate these findings.

Conclusion

In summary, for appropriately selected patients, elective thoracic

oncologic surgery performed ≥4 weeks after COVID-19 infection is not associated with an increased risk of PPCs compared with a pre-pandemic historical cohort. Further prospective studies are needed to assess safety in earlier postoperative intervals and among patients recovering from severe infection.

Acknowledgements

Thank Professor Jin Liu of the First Affiliated Hospital with Nanjing Medical University for the guidance of statistics in this study.

Data availability

Data are available from the corresponding author upon reasonable request.

Funding

No external funding was procured for this clinical trial.

Disclosures

All authors have no conflicts of interest or financial ties to declare that may be relevant to the contents of this study.

Ethics approval and consent to participate

Ethical approval for this multicenter study was obtained from the Institutional Review Boards of all three participating hospitals, and the requirement for informed consent was waived.

Author Contributions Statement

Y.Z. and Y.L. performed the formal analysis and investigation, and drafted the original manuscript. H.X. contributed to the formal analysis, investigation, methodology, and visualization. L.Y. and Y.W. were responsible for data curation and visualization. X.Z., H.L., and B.G. contributed to study conceptualization and supervision, and critically reviewed the manuscript. B.G. also acquired the funding. All authors reviewed and approved the final manuscript.

References

1 WHO. *WHO (2024) Number of COVID-19 Cases Reported to WHO (Cumulative Total)*, <https://data.who.int/dashboards/covid19/cases?n=c> (2024).

2 Lei, S. *et al.* Clinical characteristics and outcomes of patients undergoing surgeries during the incubation period of COVID-19 infection. *EClinicalMedicine* **21**, 100331 (2020). https://doi.org/10.1016/j.eclinm.2020.100331

3 O'Glasser, A. Y. & Schenning, K. J. COVID-19 in the perioperative setting: A review of the literature and the clinical landscape. *Perioper Care Oper Room Manag* **28**, 100272 (2022). https://doi.org/10.1016/j.pcorm.2022.100272

4 Mortality and pulmonary complications in patients undergoing surgery with perioperative SARS-CoV-2 infection: an international cohort study. *Lancet (London, England)* **396**, 27-38 (2020). https://doi.org/10.1016/s0140-6736(20)31182-x

5 Fernandez-Bustamante, A. *et al.* Postoperative Pulmonary Complications, Early Mortality, and Hospital Stay Following Noncardiothoracic Surgery: A Multicenter Study by the Perioperative Research Network Investigators. *JAMA surgery* **152**, 157-166 (2017). https://doi.org/10.1001/jamasurg.2016.4065

6 Leonardi, B. *et al.* Outcomes of Thoracoscopic Lobectomy after Recent COVID-19 Infection. *Pathogens* **12** (2023). https://doi.org/10.3390/pathogens12020257

7 Foundation, A. S. o. A. a. A. P. S. *ASA and APSF Joint Statement on Elective Surgery Procedures and Anesthesia for Patients After COVID-19 Infection*, <https://www.asahq.org/about-asa/newsroom/news-releases/2023/06/asa-and-apsf-joint-statement-on-elective-surgery-procedures-and-anesthesia-for-patients-after-covid-19-infection> (2023).

8 Leeds, I. L. *et al.* Postoperative Outcomes Associated with the Timing of Surgery After SARS-CoV-2 Infection. *Annals of Surgery* **280**, 241-247 (2024). https://doi.org/10.1097/sla.0000000000006227

9 Verhagen, N. B. *et al.* Severity of Prior Coronavirus Disease 2019 is Associated With Postoperative Outcomes After Major Inpatient Surgery. *Ann Surg* **278**, e949-e956 (2023). https://doi.org/10.1097/sla.0000000000006035

10 Li, X. F. *et al.* Comparative Effect of Propofol and Volatile Anesthetics on Postoperative Pulmonary Complications After Lung Resection Surgery: A Randomized Clinical Trial. *Anesth Analg* **133**, 949-957 (2021). https://doi.org/10.1213/ANE.0000000000005334

11 Zhang, Y. *et al.* Unveiling the protective role of sevoflurane in video-assisted thoracoscopic surgery associated-acute lung injury: Inhibition of ferroptosis. *Pulmonary pharmacology & therapeutics* **86**, 102312 (2024). https://doi.org/10.1016/j.pupt.2024.102312

12 Shewale, J. B. *et al.* Time Trends of Perioperative Outcomes in Early Stage Non-Small Cell Lung Cancer Resection Patients. *The Annals of Thoracic Surgery* **109**, 404-411 (2020). https://doi.org/10.1016/j.athoracsur.2019.08.018

13 Bang, H. T. *et al.* Effectiveness of the enhanced recovery after surgery (ERAS) program after lobectomy for lung cancer: a single-center observational study using propensity score matching in Vietnam. *J Thorac Dis* **16**, 7686-7696 (2024). https://doi.org/10.21037/jtd-24-1053

14 El-Boghdadly, K. *et al.* SARS-CoV-2 infection, COVID-19 and timing of elective surgery. *Anaesthesia* **76**, 940-946 (2021). https://doi.org/https://doi.org/10.1111/anae.15464

15 Quinn, K. L. *et al.* Complications Following Elective Major Noncardiac Surgery Among Patients With Prior SARS-CoV-2 Infection. *JAMA Netw Open* **5**, e2247341 (2022). https://doi.org/10.1001/jamanetworkopen.2022.47341

16 Canet, J. *et al.* Prediction of postoperative pulmonary complications in a population-based surgical cohort. *Anesthesiology* **113**, 1338-1350 (2010). https://doi.org/10.1097/ALN.0b013e3181fc6e0a

17 Bryant, J. M. *et al.* Association of Time to Surgery After COVID-19 Infection With Risk of Postoperative Cardiovascular Morbidity. *JAMA network open* **5**, e2246922 (2022). https://doi.org/10.1001/jamanetworkopen.2022.46922

18 Aziz, M. F. *et al.* Perioperative Mortality of the COVID-19 Recovered Patient Compared to a Matched Control: A Multicenter Retrospective Cohort Study. *Anesthesiology* **140**, 195-206 (2024). https://doi.org/10.1097/aln.0000000000004809

19 You, J., Chen, D., Liu, X., Zhang, H. & Zheng, Z. Postoperative pneumonia in patients with non-small cell lung cancer undergoing thoracoscopic surgery: What should we care about? *Front Oncol* **15**, 1564042 (2025). https://doi.org/10.3389/fonc.2025.1564042

20 He, X. *et al.* Prediction models for postoperative pulmonary complications in intensive care unit patients after noncardiac thoracic surgery. *BMC Pulm Med* **24**, 420 (2024). https://doi.org/10.1186/s12890-024-03153-z

21 Huang, C. *et al.* Clinical features of patients infected with 2019 novel coronavirus in Wuhan, China. *Lancet (London, England)* **395**, 497-506 (2020). https://doi.org/10.1016/s0140-6736(20)30183-5

22 Guan, W. J. *et al.* Clinical Characteristics of Coronavirus Disease 2019 in China. *The New England journal of medicine* **382**, 1708-1720 (2020). https://doi.org/10.1056/NEJMoa2002032

23 Cheng, L. L. *et al.* Effect of Recombinant Human Granulocyte Colony-Stimulating Factor for Patients With Coronavirus Disease 2019 (COVID-19) and Lymphopenia: A Randomized Clinical Trial. *JAMA internal medicine* **181**, 71-78 (2021). https://doi.org/10.1001/jamainternmed.2020.5503

24 Miskovic, A. & Lumb, A. B. Postoperative pulmonary complications. *British journal of anaesthesia* **118**, 317-334 (2017). https://doi.org/10.1093/bja/aex002

25 Myers, K., Hajek, P., Hinds, C. & McRobbie, H. Stopping smoking shortly before surgery and postoperative complications: a systematic review and meta-analysis. *Archives of internal medicine* **171**, 983-989 (2011). https://doi.org/10.1001/archinternmed.2011.97

Figure Legends

Figure 1. Study Enrollment and Participant Flow

Flowchart depicting the enrollment and selection process of the study participants. Initially, 1,015 patients were assessed for eligibility, with 169 patients excluded due to endoscopic thoracic sympathectomy (n = 5) or missing COVID-19 infection data (n = 164). The analysis included an unmatched cohort of 846 patients, divided into the no-COVID-19 group (n = 350) and COVID-19 group (n = 496). Propensity score matching and inverse probability of treatment weighting were applied to compare outcomes before and after matching.

Figure 2. Subgroup Analysis of Postoperative Pulmonary Complications (PPCs)

Forest plot illustrating the odds ratio (OR) of PPCs in various subgroups defined by patient characteristics including gender (female *vs.* male), age (≥65 years *vs.* <65 years), ASA status (Ⅰ, Ⅱ or Ⅲ), BMI (≥30 kg/m^2 *vs.* <30 kg/m^2), smoking status (yes *vs.* no), and type of surgery (pulmonary or mediastinal surgery *vs.* esophageal surgery). Interaction analyses were performed for each subgroup, with statistically significant interactions (p<0.05) highlighted.

Table 1. Comparisons of baseline features between no-COVID-19 group and COVID-19 group before matching and after matching

Variables		Before matching			After PSM			After IPTW		
	Total	No-COVID	COVID	*P*	No-COVID	COVID	*P*	No-COVID	COVID	*P*
n	846	350	496	NA	283	283	NA	838.6	848.3	NA
Age, mean (± SD)	57.3 (12.3)	56.3 (12.0)	58.0 (12.5)	0.054	57.2 (11.7)	56.8 (13.0)	0.691	57.0 (12.1)	57.1 (12.9)	0.971
Gender, *n* (%)				0.034			0.611			0.938
Male	366 (43.3)	167 (47.7)	199 (40.1)		121 (42.8)	128 (45.2)		364.0 (43.4)	365.6 (43.1)	
Female	480 (56.7)	183 (52.3)	297 (59.9)		162 (57.2)	155 (54.8)		474.6 (56.6)	482.6 (56.9)	
BMI, mean (± SD)	23.7 (3.5)	23.7 (3.2)	23.7 (3.7)	0.727	23.8 (3.2)	23.9 (3.8)	0.628	23.8 (3.3)	23.7 (3.7)	0.805
ASA status, *n* (%)				0.734			0.875			0.895
I	63 (7.4)	29 (8.3)	34 (6.9)		19 (6.7)	22 (7.8)		57.9 (6.9)	59.5 (7.0)	
II	650 (76.8)	266 (76.0)	384 (77.4)		219 (77.4)	215 (76.0)		661.3 (78.9)	658.1 (77.6)	
III	133 (15.7)	55 (15.7)	78 (15.7)		45 (15.9)	46 (16.3)		119.4 (14.2)	130.6 (15.4)	
Smoking history, *n* (%)	143 (16.9)	51 (14.6)	92 (18.5)	0.154	45 (15.9)	44 (15.5)	1.000	138.0 (16.5)	142.4 (16.8)	0.912
Comorbidities, *n* (%)										
Hypertension	190 (22.5)	66 (18.9)	124 (25.0)	0.043	63 (22.3)	60 (21.2)	0.838	196.8 (23.5)	192.9 (22.7)	0.836
Diabetes	69 (8.2)	23 (6.6)	46 (9.3)	0.198	22 (7.8)	21 (7.4)	1.000	61.5 (7.3)	68.4 (8.1)	0.723
Heart disease	25 (3.0)	7 (2.0)	18 (3.6)	0.241	6 (2.1)	10 (3.5)	0.447	25.0 (3.0)	25.9 (3.1)	0.963
Type of surgery (%)				□0.001			0.597			0.960
Wedge resection	115 (13.6)	30 (8.6)	85 (17.1)		29 (10.2)	35 (12.4)		128.6 (15.3)	115.9 (13.7)	
Segmentectomy	236 (27.9)	62 (17.7)	174 (35.1)		46 (16.3)	46 (16.3)		200.5 (23.9)	220.2 (26.0)	
Lobectomy	325 (38.4)	163 (46.6)	162 (32.7)		144 (50.9)	137 (48.4)		339.7 (40.5)	343.5 (40.5)	
Mediastinal mass resection	55 (6.5)	21 (6.0)	34 (6.8)		18 (6.4)	26 (9.2)		56.1 (6.7)	57.6 (6.8)	
Esophagectomy	115 (13.6)	74 (21.1)	41 (8.3)		46 (16.3)	39 (13.8)		113.7 (13.6)	111.1 (13.1)	

Notes: Values are shown in n (%) or mean (SD). BMI: Body Mass Index (kg/m²); ASA status: American Society of Anesthesiologists physical status classification; PSM: propensity score matching; IPTW: inverse probability of treatment weighting.

Table 2. Comparisons of perioperative outcomes between no-COVID-19 group and COVID-19 group before matching and after matching.

Variables		Before matching			After PSM			After IPTW		
	Total	No-COVID	COVID	*p*	No-COVID	COVID	*p*	No-COVID	COVID	*p*
n	846	350	496	NA	283	283	NA	838.61	848.27	NA
PPCs	258 (30.5)	117 (33.4)	141 (28.4)	0.139	90 (31.8)	74 (26.1)	0.784	249.4 (29.7)	237.8 (28.0)	0.615
Pneumonia, n (%)	190 (22.5)	89 (25.4)	101 (20.4)	0.098	68 (24.0)	52 (18.4)	0.839	190.3 (22.7)	169.5 (20.0)	0.375
Pleural effusion, n (%)	106 (12.5)	51 (14.6)	55 (11.1)	0.161	44 (15.5)	33 (11.7)	0.220	113.9 (13.6)	86.8 (10.2)	0.145
Atelectasis, n (%)	9 (1.1)	3 (0.9)	6 (1.2)	0.879	2 (0.7)	5 (1.8)	0.447	6.8 (0.8)	13.2 (1.6)	0.379
Pneumothorax, n (%)	1 (0.1)	0 (0.0)	1 (0.2)	1.000	0 (0.0)	0 (0.0)	NA	0 (0.0)	1.4 (0.2)	0.321
Duration of surgery, median [IQR]	113 [75,173]	145 [102,210]	94 [62,135]	□0.001	131 [98,184]	95 [61,139]	□0.001	151.7 (77.5)	120.0 (78.6)	□0.001
Postoperative WBC, mean (± SD)	9.7 (5.1)	7.9 (6.4)	10.9 (3.4)	□0.001	8.4 (6.3)	11.1 (3.6)	□0.001	8.2 (6.3)	10.9 (3.5)	□0.001
Postoperative lymphocyte, mean (± SD)	2.7 (3.7)	4.6 (4.9)	1.3 (1.1)	□0.001	4.1 (4.6)	1.4 (1.0)	□0.001	4.3 (4.7)	1.3 (1.2)	□0.001
Length of postoperative hospitalization, median [IQR]	4[3,7]	6 [4,10]	3 [3,5]	□0.001	5 [4,7]	3 [3,6]	□0.001	7.1 (6.3)	5.2 (3.9)	□0.001
Duration of thoracic drainage, median [IQR]	3[2,5]	4 [3,7]	2 [2,4]	□0.001	3 [2,5]	2 [2,4]	□0.001	4.8 (4.6)	3.3 (2.6)	□0.001
Postoperative cardiovascular complications	0 (0.0)	0 (0.0)	0 (0.0)	NA	0 (0.0)	0 (0.0)	NA	0 (0.0)	0 (0.0)	NA
Thromboembolic events	2 (0.2)	0 (0.0)	2 (0.4)	0.514	0 (0.0)	1 (0.4)	0.500	0 (0.0)	3.4 (0.4)	0.123

Notes: Values are shown in n (%) or mean (SD) or median [IQR]. PPCs: Postoperative Pulmonary Complications; WBC: Postoperative white blood cell count (×10⁹/L); PSM: propensity score matching; IPTW: inverse probability of treatment weighting; IQR, interquartile range.

Table 3. Characteristics and Postoperative Outcomes by Infection-to-Surgery Interval

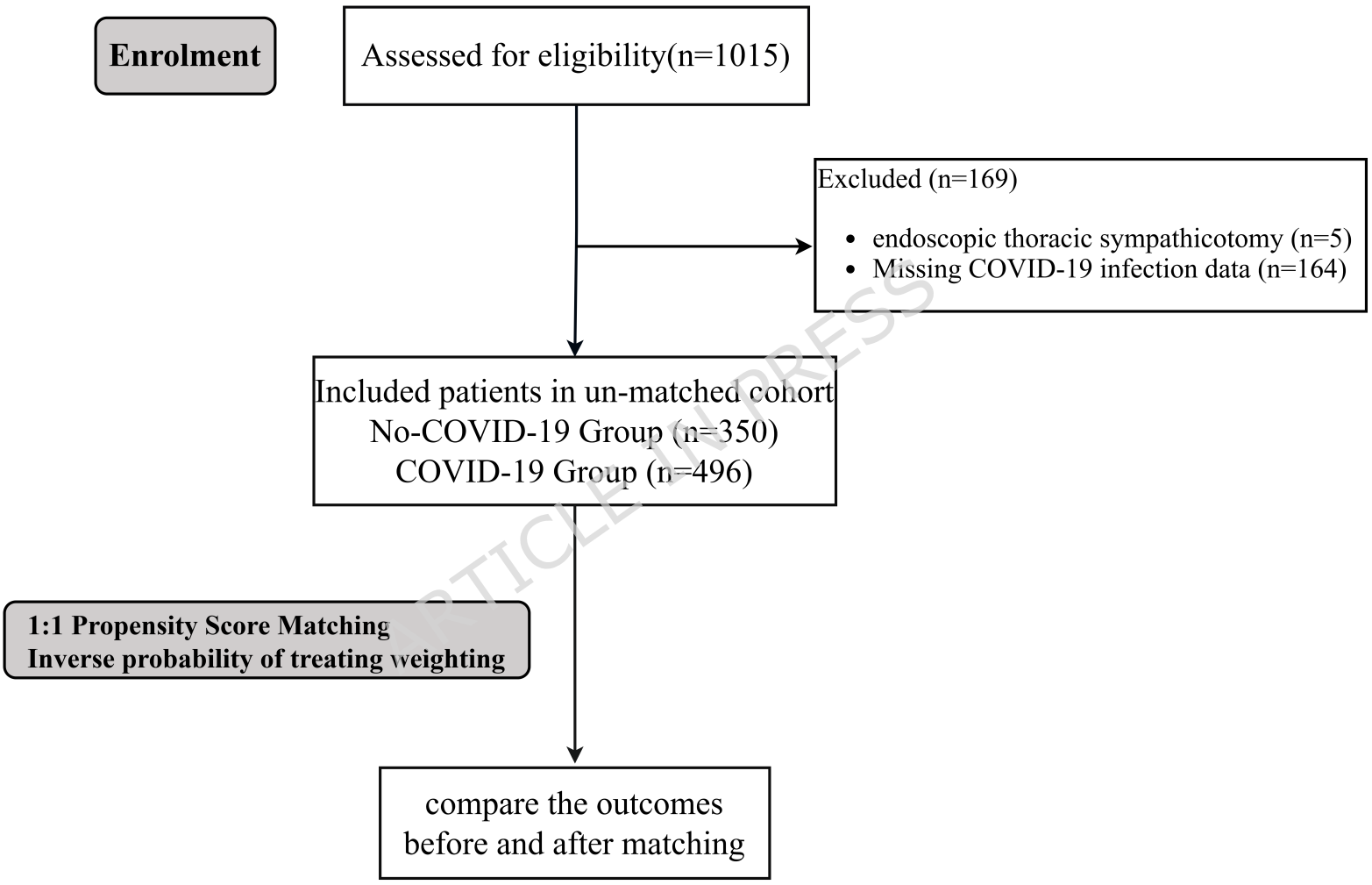
Variable	4–6 weeks N=62	6–8 weeks N=185	8-12 weeks N=249	*p*-value
Age, mean (± SD)	61.2 (12.1)	57.7 (11.7)	57.4 (13.0)	0.092
Gender, n (%)				0.999
Male	25 (40.3%)	74 (40.0%)	100 (40.2%)	
Female	37 (59.7%)	111 (60.0%)	149 (59.8%)	
BMI (mean ± SD)	23.9 (5.0)	23.6 (2.9)	23.8 (3.8)	0.749
ASA status, n (%)				0.358
I	3 (4.8)	10 (5.4)	21 (8.4)	
II	45 (72.6)	146 (78.9)	193 (77.5)	
III	14 (22.6)	29 (15.7)	35 (14.1)	
Smoking history (%)	14 (22.6)	30 (16.2)	48 (19.3)	0.494
Comorbidities, n (%)				
Hypertension	20 (32.3)	45 (24.3)	59 (23.7)	0.383
Diabetes	4 (6.5)	19 (10.3)	23 (9.2)	0.668
Heart disease	1 (1.6)	8 (4.3)	7 (2.8)	0.504
Type of surgery (%)				<0.001
Wedge resection	11 (17.7)	39 (21.1)	85 (17.1)	
Segmentectomy	12 (19.4)	54 (29.2)	108 (35.1)	
Lobectomy	25 (40.3)	66 (35.7)	71 (28.5)	
Mediastinal tumor resection	3 (4.8)	9 (4.9)	22 (8.8)	
Esophagectomy	11 (17.7)	17 (9.2)	13 (5.2)	
Vaccinated (%)	57 (91.9)	170 (91.9)	229 (92.0)	1.000
COVID-19 severity				0.058
Asymptomatic	1 (1.6)	19 (10.3)	24 (9.6)	
Mild	57 (91.9)	162 (87.6)	222 (89.2)	
Moderate	3 (4.8)	2 (1.1)	3 (1.2)	
Severe	1 (1.6)	2 (1.1)	0 (0.0)	
Residual symptoms				0.478
Cough	18 (29.0)	12 (6.5)	20 (8.0)	
Sore throat	2 (3.2)	2 (1.1)	2 (0.8)	
Chest distress	0 (0.0)	3 (1.6)	2 (0.8)	
Myalgias	3 (4.8)	1 (0.5)	1 (0.4)	
Home oxygen therapy within one-year-follow-up	5 (8.1)	14 (7.6)	13 (5.2)	0.529
PPCs	17 (27.4)	54 (29.2)	70 (28.1)	0.953

Notes: Values are shown in n (%) or mean (SD). BMI: Body Mass Index (kg/m²); ASA status: American Society of Anesthesiologists physical status classification; PPCs: Postoperative Pulmonary Complications.

Table 4. Adjusted Odds Ratios for Risk Factors Associated with PPCs

Variable	OR	95%CI	*p*-value
Main Exposure			
4-6weeks	Ref	Ref	0.633
6-8weeks	1.233	(0.627-2.390)	0.554
8-12weeks	1.084	(0.514-1.941)	0.996
Covariates			
Age	1.024	(1.004-1.045)	0.020
Gender	0.644	(0.367-1.131)	0.126
BMI	1.035	(0.974-1.100)	0.267
ASA status			
Ⅰ	Ref	Ref	0.577
Ⅱ	1.645	(0.632-4.283)	0.308
Ⅲ	1.522	(0.484-4.794)	0.473
Smoking history	2.503	(1.314-4.767)	0.005
Hypertension	0.597	(0.346-1.029)	0.063
Diabetes	1.074	(0.505-2.284)	0.853
Heart disease	0.682	(0.197-2.364)	0.547
Type of surgery			
Wedge resection	Ref	Ref	0.636
Segmentectomy	1.470	(0.768-2.814)	0.245
Lobectomy	1.296	(0.663-2.535)	0.449
Mediastinal tumor resection	1.391	(0.522-3.708)	0.510
Esophagectomy	2.294	(0.732-7.187)	0.154
Duration of surgery	0.999	(0.995-1.003)	0.597
Vaccinated (%)	2.255	(0.945-5.379)	0.067
COVID-19 severity			
Asymptomatic	Ref	Ref	0.842
Mild	0.768	(0.386-1.525)	0.450
Moderate	0.440	(0.044-4.379)	0.483
Severe	Ref	Ref	0.999

***Notes**:* BMI: Body Mass Index (kg/m²); ASA status: American Society of Anesthesiologists physical status classification.



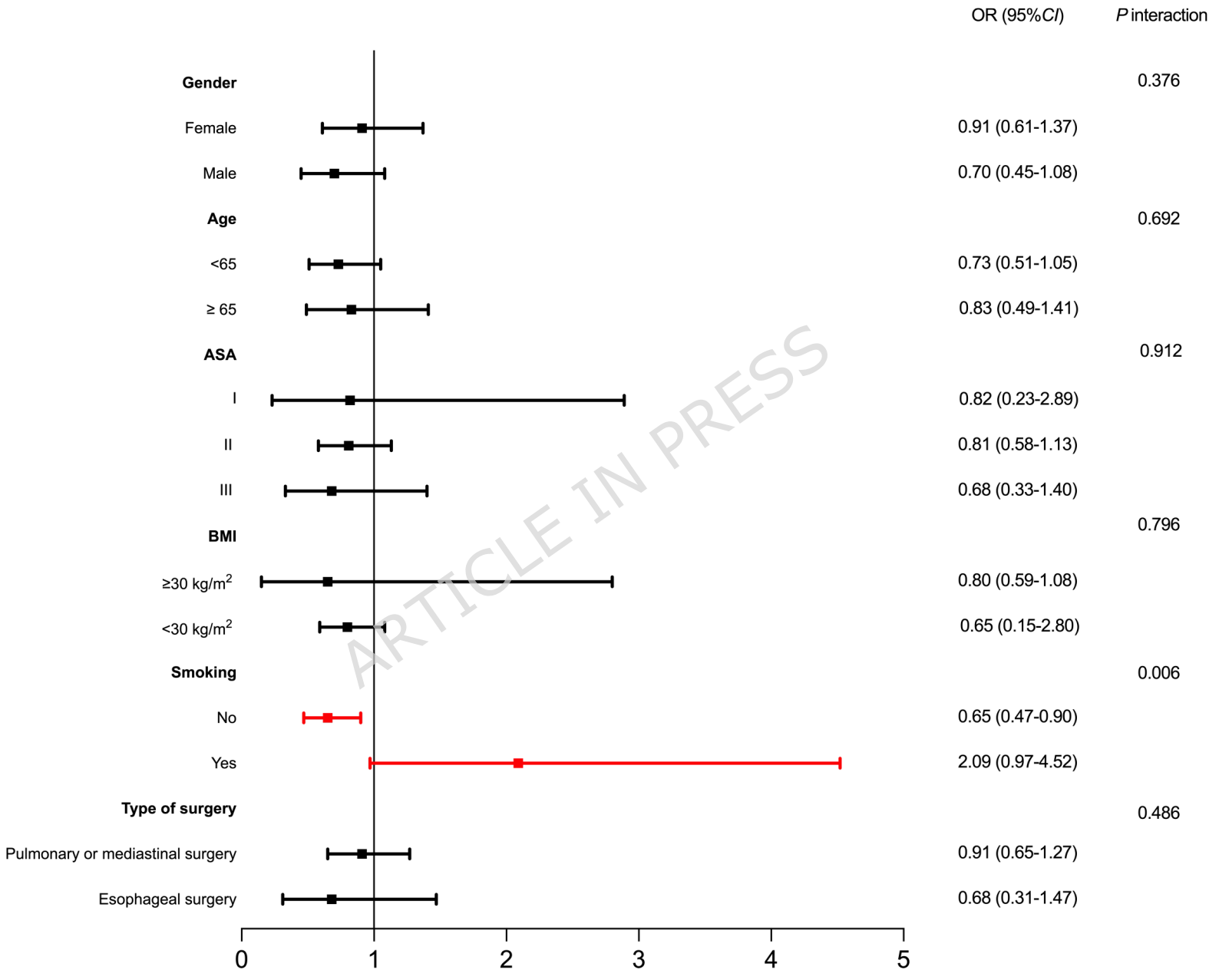


Table 1. Comparisons of baseline features between no-COVID-19 group and COVID-19 group before matching and after matching

Variables		Before matching			After PSM			After IPTW		
	Total	No-COVID	COVID	*P*	No-COVID	COVID	*P*	No-COVID	COVID	*P*
n	846	350	496	NA	283	283	NA	838.6	848.3	NA
Age, mean (± SD)	57.3 (12.33)	56.3 (12.0)	58.0 (12.5)	0.054	57.2 (11.7)	56.8 (13.0)	0.691	57.0 (12.1)	57.1 (12.9)	0.971
Gender, *n* (%)				0.034			0.611			0.938
Male	366 (43.3)	167 (47.7)	199 (40.1)		121 (42.8)	128 (45.2)		364.0 (43.4)	365.6 (43.1)	
Female	480 (56.7)	183 (52.3)	297 (59.9)		162 (57.2)	155 (54.8)		474.6 (56.6)	482.6 (56.9)	
BMI, mean (± SD)	23.7 (3.5)	23.7 (3.2)	23.7 (3.7)	0.727	23.8 (3.2)	23.9 (3.8)	0.628	23.8 (3.3)	23.7 (3.7)	0.805
ASA status, *n* (%)				0.734			0.875			0.895
I	63 (7.4)	29 (8.3)	34 (6.9)		19 (6.7)	22 (7.8)		57.9 (6.9)	59.5 (7.0)	
II	650 (76.8)	266 (76.0)	384 (77.4)		219 (77.4)	215 (76.0)		661.3 (78.9)	658.1 (77.6)	
III	133 (15.7)	55 (15.7)	78 (15.7)		45 (15.9)	46 (16.3)		119.4 (14.2)	130.6 (15.4)	
Smoking history, *n* (%)	143 (16.9)	51 (14.6)	92 (18.5)	0.154	45 (15.9)	44 (15.5)	1.000	138.0 (16.5)	142.4 (16.8)	0.912
Comorbidities, *n* (%)										
Hypertension	190 (22.5)	66 (18.9)	124 (25.0)	0.043	63 (22.3)	60 (21.2)	0.838	196.8 (23.5)	192.9 (22.7)	0.836
Diabetes	69 (8.2)	23 (6.6)	46 (9.3)	0.198	22 (7.8)	21 (7.4)	1.000	61.5 (7.3)	68.4 (8.1)	0.723
Heart disease	25 (3.0)	7 (2.0)	18 (3.6)	0.241	6 (2.1)	10 (3.5)	0.447	25.0 (3.0)	25.9 (3.1)	0.963
Type of surgery (%)				□ 0.001			0.597			0.960
Wedge resection	115 (13.6)	30 (8.6)	85 (17.1)		29 (10.2)	35 (12.4)		128.6 (15.3)	115.9 (13.7)	
Segmentectomy	236 (27.9)	62 (17.7)	174 (35.1)		46 (16.3)	46 (16.3)		200.5 (23.9)	220.2 (26.0)	
Lobectomy	325 (38.4)	163 (46.6)	162 (32.7)		144 (50.9)	137 (48.4)		339.7 (40.5)	343.5 (40.5)	
mediastinal tumor resection	55 (6.5)	21 (6.0)	34 (6.8)		18 (6.4)	26 (9.2)		56.1 (6.7)	57.6 (6.8)	
Esophagectomy	115 (13.6)	74 (21.1)	41 (8.3)		46 (16.3)	39 (13.8)		113.7	111.1	

	(13.6)	(13.1)

***Notes**:* Values are shown in n (%) or mean (SD). BMI: Body Mass Index (kg/m^2); ASA status: American Society of Anesthesiologists physical status classification; PSM: propensity score matching; IPTW: inverse probability of treatment weighting.

Table 2. Comparisons of perioperative outcomes between no-COVID-19 group and COVID-19 group before matching and after matching.

Variables		Before matching			After PSM			After IPTW		
	Total	No-COVID	COVID	*p*	No-COVID	COVID	*p*	No-COVID	COVID	*p*
n	846	350	496	NA	283	283	NA	838.61	848.27	NA
PPCs	258 (30.5)	117 (33.4)	141 (28.4)	0.139	90 (31.8)	74 (26.1)	0.784	249.4 (29.7)	237.8 (28.0)	0.615
Pneumonia, n (%)	190 (22.5)	89 (25.4)	101 (20.4)	0.098	68 (24.0)	52 (18.4)	0.839	190.3 (22.7)	169.5 (20.0)	0.375
Pleural effusion, n (%)	106 (12.5)	51 (14.6)	55 (11.1)	0.161	44 (15.5)	33 (11.7)	0.220	113.9 (13.6)	86.8 (10.2)	0.145
Atelectasis, n (%)	9 (1.1)	3 (0.9)	6 (1.2)	0.879	2 (0.7)	5 (1.8)	0.447	6.8 (0.8)	13.2 (1.6)	0.379
Pneumothorax, n (%)	1 (0.1)	0 (0.0)	1 (0.2)	1.000	0 (0.0)	0 (0.0)	NA	0 (0.0)	1.4 (0.2)	0.321
Duration of surgery, median [IQR]	113 [75,173]	145 [102,210]	94 [62,135]	□0.001	131 [98,184]	95 [61,139]	□0.001	151.7 (77.5)	120.0 (78.6)	□0.001
Postoperative WBC, mean (± SD)	9.7 (5.1)	7.9 (6.4)	10.9 (3.4)	□0.001	8.4 (6.3)	11.1 (3.6)	□0.001	8.2 (6.3)	10.9 (3.5)	□0.001
Postoperative lymphocyte, mean (± SD)	2.7 (3.7)	4.6 (4.9)	1.3 (1.1)	□0.001	4.1 (4.6)	1.4 (1.0)	□0.001	4.3 (4.7)	1.3 (1.2)	□0.001
Length of postoperative hospitalization, median [IQR]	4[3,7]	6 [4,10]	3 [3,5]	□0.001	5 [4,7]	3 [3,6]	□0.001	7.1 (6.3)	5.2 (3.9)	□0.001
Duration of thoracic drainage, median [IQR]	3[2,5]	4 [3,7]	2 [2,4]	□0.001	3 [2,5]	2 [2,4]	□0.001	4.8 (4.6)	3.3 (2.6)	□0.001
Postoperative cardiovascular complications	0 (0.0)	0 (0.0)	0 (0.0)	NA	0 (0.0)	0 (0.0)	NA	0 (0.0)	0 (0.0)	NA
Thromboembolic events	2 (0.2)	0 (0.0)	2 (0.4)	0.514	0 (0.0)	1 (0.4)	0.500	0 (0.0)	3.4 (0.4)	0.123

Notes: Values are shown in n (%) or mean (SD) or median [IQR]. PPCs: Postoperative Pulmonary Complications; WBC: Postoperative white blood cell count (×10⁹/L); PSM: propensity score matching; IPTW: inverse probability of treatment weighting; IQR, interquartile range.

Table 3. Characteristics and Postoperative Outcomes by Infection-to-Surgery Interval

Variable	4–6 weeks N=62	6–8 weeks N=185	8–12 weeks N=249	*p*-value
Age, mean (± SD)	61.2 (12.1)	57.7 (11.7)	57.4 (13.0)	0.092
Gender, n (%)				0.999
Male	25 (40.3%)	74 (40.0%)	100 (40.2%)	
Female	37 (59.7%)	111 (60.0%)	149 (59.8%)	
BMI (mean ± SD)	23.9 (5.0)	23.6 (2.9)	23.8 (3.8)	0.749
ASA status, n (%)				0.358
I	3 (4.8)	10 (5.4)	21 (8.4)	
II	45 (72.6)	146 (78.9)	193 (77.5)	
III	14 (22.6)	29 (15.7)	35 (14.1)	
Smoking history (%)	14 (22.6)	30 (16.2)	48 (19.3)	0.494
Comorbidities, n (%)				
Hypertension	20 (32.3)	45 (24.3)	59 (23.7)	0.383
Diabetes	4 (6.5)	19 (10.3)	23 (9.2)	0.668
Heart disease	1 (1.6)	8 (4.3)	7 (2.8)	0.504
Type of surgery (%)				<0.001
Wedge resection	11 (17.7)	39 (21.1)	85 (17.1)	
Segmentectomy	12 (19.4)	54 (29.2)	108 (35.1)	
Lobectomy	25 (40.3)	66 (35.7)	71 (28.5)	
Mediastinal tumor resection	3 (4.8)	9 (4.9)	22 (8.8)	
Esophagectomy	11 (17.7)	17 (9.2)	13 (5.2)	
Vaccinated (%)	57 (91.9)	170 (91.9)	229 (92.0)	1.000
COVID-19 severity				0.058
Asymptomatic	1 (1.6)	19 (10.3)	24 (9.6)	
Mild	57 (91.9)	162 (87.6)	222 (89.2)	
Moderate	3 (4.8)	2 (1.1)	3 (1.2)	
Severe	1 (1.6)	2 (1.1)	0 (0.0)	
Residual symptoms				0.478
Cough	18 (29.0)	12 (6.5)	20 (8.0)	
Sore throat	2 (3.2)	2 (1.1)	2 (0.8)	
Chest distress	0 (0.0)	3 (1.6)	2 (0.8)	
Myalgias	3 (4.8)	1 (0.5)	1 (0.4)	

Home oxygen therapy within one-year-follow-up	5 (8.1)	14 (7.6)	13 (5.2)	0.529
PPCs	17 (27.4)	54 (29.2)	70 (28.1)	0.953

***Notes**:* Values are shown in n (%) or mean (SD). BMI: Body Mass Index (kg/m²); ASA status: American Society of Anesthesiologists physical status classification; PPCs: Postoperative Pulmonary Complications.

Table 4. Adjusted Odds Ratios for Risk Factors Associated with PPCs

Variable	OR	95%CI	*p*-value
Main Exposure			
4-6weeks	Ref	Ref	0.633
6-8weeks	1.233	(0.627-2.390)	0.554
8-12weeks	1.084	(0.514-1.941)	0.996
Covariates			
Age	1.024	(1.004-1.045)	0.020
Gender	0.644	(0.367-1.131)	0.126
BMI	1.035	(0.974-1.100)	0.267
ASA status			
Ⅰ	Ref	Ref	0.577
Ⅱ	1.645	(0.632-4.283)	0.308
Ⅲ	1.522	(0.484-4.794)	0.473
Smoking history	2.503	(1.314-4.767)	0.005
Hypertension	0.597	(0.346-1.029)	0.063
Diabetes	1.074	(0.505-2.284)	0.853
Heart disease	0.682	(0.197-2.364)	0.547
Type of surgery			
Wedge resection	Ref	Ref	0.636
Segmentectomy	1.470	(0.768-2.814)	0.245
Lobectomy	1.296	(0.663-2.535)	0.449
Mediastinal tumor resection	1.391	(0.522-3.708)	0.510
Esophagectomy	2.294	(0.732-7.187)	0.154
Duration of surgery	0.999	(0.995-1.003)	0.597
Vaccinated (%)	2.255	(0.945-5.379)	0.067
COVID-19 severity			
Asymptomatic	Ref	Ref	0.842
Mild	0.768	(0.386-1.525)	0.450
Moderate	0.440	(0.044-4.379)	0.483
Severe	Ref	Ref	0.999

***Notes**:* BMI: Body Mass Index (kg/m^2); ASA status: American Society of Anesthesiologists physical status classification.