Research Square

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# Correlation between subclinical abnormalities of preoperative pulmonary function and recovery after laparoscopic hepatectomy: a retrospective cohort study

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## Abstract

# Background

The impact of isolated small airway dysfunction (SAD) or preserved-ratio impaired spirometry (PRISm) on outcomes following laparoscopic hepatectomy remains unclear.

# Aims

This study aimed to evaluate their association with postoperative pulmonary complications (PPCs).

# Method

This single-center retrospective study included 771 patients. Multivariable analyses and propensity score matching (PSM) were employed to compare outcomes between patients with normal spirometry and those with SAD or PRISm.

# Results

The PRISm group was associated with higher ICU admission rates (12.5% vs 5.0%, P = .001) and longer length of stay (LOS) (15.0 vs 12.0 days; P < .001). However, multivariable analysis identified operative duration as the sole independent risk factor for PPCs (OR = 1.200, P < .001). After 1:1 PSM, the matched cohorts (163 pairs vs. SAD; 101 pairs vs. PRISm) showed no significant differences in PPCs or other short-term outcomes. Surgical complexity (duration, transfusion), comorbidities (diabetes, age) and the occurrence of PPCs were the independent factors for prolonged LOS.

# Conclusion

Preoperative SAD and PRISm were not associated with an increased risk of PPCs after laparoscopic hepatectomy. Prolonged LOS was significantly associated with surgical complexity, patient comorbidities, and the development of PPCs, but not with baseline spirometric anomalies.

## Introduction

Although laparoscopic hepatectomy has several advantages, including reduced intraoperative blood loss, lower incidence of postoperative ascites, and shorter length of stay (LOS),[1,2] its special physiological interference to the cardiopulmonary system (such as pneumoperitoneum, Trendelenburg position) may make patients with insufficient pulmonary function reserve face unique postoperative risks and adversely affect prognosis.[3,4] Existing research on the impact of preoperative pulmonary

function testing (PFT) on pulmonary complications is insufficient, and evidence suggests that its predictive value is inconsistent. A prospective cohort study by Yokota et al. indicated that PFT could not effectively predict the risk of postoperative complications.[5] Additionally, S Sheshadri et al. found that preoperative obstructive and restrictive ventilation abnormalities in patients with gastric resection were associated with complications and long-term overall survival.[6] In clinical practice, preoperative pulmonary function assessment often focuses on chronic obstructive pulmonary disease (COPD), defined by a forced expiratory volume in the first second/ forced vital capacity ($FEV_1$/FVC) ratio < 0.70.[7] For individuals with subclinical pulmonary dysfunction—such as isolated small airway dysfunction (SAD) and preserved ratio impairment spirometry (PRISm)—whose $FEV_1$/FVC ratios do not meet the diagnostic criteria for respiratory disease, there remains a lack of evidence-based research regarding whether their postoperative risks is significantly increased and whether perioperative interventions are warranted.

Therefore, this study focused on patients who underwent laparoscopic hepatectomy. Using a large-sample retrospective cohort design combined with multivariable regression and propensity score matching (PSM) analysis, we aimed to clarify whether there are significant differences in postoperative outcomes between patients with SAD or PRISm and those with normal respiratory function; Besides, this study planned to investigate whether SAD and PRISm are independent risk factors for postoperative pulmonary complications (PPCs) and prolonged LOS, while further screening for other potential influencing factors. The study results may provide key clinical evidence for preoperative risk stratification and perioperative management strategies in such patients.

## Materials and Methods

# Patients

This single-center, retrospective cohort study included 1,396 patients who underwent laparoscopic hepatectomy at Ningbo First Hospital between January 2022 and February 2025. Of these, 625 patients were excluded from the flow chart because of the following exclusion criteria: PFT failed to meet requirements (n = 240), incomplete preoperative clinical data (n = 73), and missing or invalid preoperative pulmonary function data (n = 312) (Fig. 1). 312 patients had missing or incomplete lung function data due to insufficient cooperation, strong refusal, or inability to tolerate the procedure. Ultimately, 771 eligible patients with an $FEV_1$/FVC ratio of ≥ 0.70 were included and divided into three groups according to baseline pulmonary function: normal, SAD, and PRISm. This study was approved by the Ethics Committee of the Ningbo First Hospital (2025-209RS). The requirement for informed consent was waived owing to the retrospective nature of the study and the use of de-identified data.

## Measurement

All tests were performed using a spirometer (Jaeger, Hochberg, Germany) in accordance with the standardization of spirometry recommended by the American Thoracic Society/European Respiratory

Society. The spirometer was calibrated daily with a 3 L syringe every day to ensure measured volumes were within 3% of the syringe volume. The ambient temperature, humidity, and altitude were recorded daily. The following parameters were recorded: $FEV_1$, FVC, $FEV_1$/FVC ratio, MEF25, MEF50, and MMEF. Laparoscopic hepatectomy follows a standardized protocol: a $CO_2$ insufflation pressure of 12 mmHg, supine positioning and general anesthesia.

## Variables

Patient characteristics were obtained from the medical records. The data collected included age, sex, BMI, smoking status, alcohol status, comorbidities, MEF25% pred, MEF50% pred, MMEF% pred, resection location, resection scope, operative duration, intraoperative bleeding, and blood transfusion. Furthermore, this study evaluated patients' early outcomes, including PPCs, hypoproteinemia, ascites, pelvic effusion, postoperative fever, pericardial effusion, and postoperative atrial fibrillation (POAF), postoperative antibiotic use (duration and number of courses), LOS, and ICU admission, based on retrospective data extraction and strict adherence to standardized clinical guideline criteria.

## Definition

Postoperative complications were defined as adverse events or conditions that occurred within 30 days of the surgery. PPCs include productive cough, pneumonia, atelectasis, pleural effusion, respiratory failure, and pulmonary embolism. According to the 2014 American Association for Thoracic Surgery guidelines, POAF was defined as an ECG-documented episode lasting ≥ 30 seconds requiring drug treatment or anticoagulation.

# Statistical analysis

Descriptive statistics were used. Normally distributed continuous variables (age, BMI, MEF25% pred, MEF50% pred, MMEF% pred) are expressed as means ± SD; non-normally distributed variables (intraoperative bleeding, operation duration, antibiotic duration and type) are median (interquartile range, IQR); categorical variables are frequencies (%). Between-group comparisons: independent t-test or Mann-Whitney U for continuous variables, and $\chi^2$ or Fisher's exact test for categorical variables. Odds ratios (ORs) with 95% confidence intervals (CIs) were calculated to evaluate the independent factors related to PPCs. “Unknown” cases were grouped separately into multivariate analysis, in order to avoid the selection bias and the decline of statistical efficiency caused by the lack of data. Because LOS data were non-normally distributed, a log-transformation was used to meet the model assumptions before linear regression analysis, and the average change was (exp(B)-1) × 100%. All analyses were performed using SPSS 27.0 (IBM SPSS, Inc., Armonk, NY), with all statistical tests conducted two-sided.

## Results

A detailed comparison of baseline data and intraoperative characteristics is shown in Table 1. 172 patients (22.3%) were complicated with SAD. Compared with normal, the SAD group had a higher proportion of female patients (P = 0.011), a higher incidence of coronary artery disease (P = 0.030), and a higher rate of intraoperative blood transfusion (P = 0.037). 160 patients (20.8%) were complicated with PRISm. Compared with the normal, patients in the PRISm group were older (P < 0.001), and presented with higher prevalence of hypertension (P < 0.001), diabetes mellitus (P = 0.022) and coronary heart disease (P = 0.006). In addition, they had greater intraoperative blood loss (P < 0.001) and a higher rate of intraoperative blood transfusion (P = 0.003). Other baseline data and clinical characteristics showed no statistically significant differences between the groups.

The comparison results of postoperative complications and clinical outcomes between groups are shown in Table 2. There were no significant differences in postoperative complications and clinical outcomes between the SAD and normal. Compared with normal, the incidence of Cough and sputum (P < 0.001) and respiratory failure (P = 0.007) in PRISm patients were significantly higher. In terms of clinical outcomes, patients in the PRISm group had a significantly longer duration of antibiotic use (P = 0.005) and LOS (P < 0.001), as well as a higher ICU admission rate (P = 0.001). The incidence rates of other postoperative complications were similar between groups.

We used univariate and multivariate regression analyses to identify the independent risk factors associated with PPCs and prolonged LOS. The only independent risk factor associated with PPCs was operative duration (P < 0.001). The independent risk factors for prolonged LOS included age (P = 0.019), alcohol abuse (P = 0.019), diabetes (P = 0.003), intraoperative blood loss (P = 0.003), intraoperative blood transfusion (P < 0.001), operative duration (P < 0.001), length of antibiotic use (P = 0.002), types of antibiotics (P < 0.001), and PPCs (P = 0.024).

Following 1:1 PSM, 163 matched patient pairs were generated between the normal and the SAD group, and 101 matched pairs between the normal and the PRISm group. (Supplementary Table 1) All baseline and intraoperative characteristics were comparable between the matched groups. As shown in Tables 5 and 6, no significant differences were observed in postoperative outcomes between the matched groups.

Table 1
Baseline and intraoperative characteristics of enrolled patients.

| Variables | Normal (n = 439) | SAD (n = 172) | PRISm (n = 160) | P value (Normal vs SAD) | P value (Normal vs PRISm) |
|---|---|---|---|---|---|
| Age, mean ± SD, years | 61.2 ± 12.0 | 63.8 ± 10.7 | 65.7 ± 11.3 | .120 | < .001 |
| Sex, n (%) | | | | .011 | .078 |
| Male sex | 203 (46.2) | 60 (34.9) | 87 (54.4) | | |
| Female sex | 236 (53.8) | 112 (65.1) | 73 (45.6) | | |
| BMI, mean ± SD, kg/$m^2$ | 24.7 ± 27.0 | 22.7 ± 2.9 | 23.6 ± 3.4 | .338 | .600 |
| Smoker status, n (%) | | | | .146 | .177 |
| Current smoker | 34 (7.7) | 19 (11.0) | 20 (12.5) | | |
| Former smoker | 19 (4.3) | 3 (1.7) | 8 (5.0) | | |
| Nonsmoker | 386 (87.9) | 150 (87.2) | 132 (82.5) | | |
| Alcohol abuse status, n (%) | | | | .900 | .766 |
| Current drinker | 34 (7.7) | 14 (8.1) | 15 (9.4) | | |
| Former drinker | 10 (2.3) | 3 (1.7) | 5 (3.1) | | |
| Nondrinker | 394 (89.7) | 155 (90.1) | 140 (87.5) | | |
| Comorbidity, n (%) | | | | | |
| Hypertension | 149 (33.9) | 63 (36.6) | 83 (51.9) | .530 | < .001 |
| Diabetes | 55 (12.5) | 25 (14.5) | 32 (20.0) | .508 | .022 |
| Mental illness | 3 (0.7) | 1 (0.6) | 2 (1.3) | .888 | .500 |
| Hepatitis B | 42 (9.6) | 18 (10.5) | 11 (6.9) | .737 | .305 |
| Tachycardia | 6 (1.4) | 1 (0.6) | 4 (2.5) | .412 | .338 |
| Alcoholic liver disease | 1 (0.2) | 1 (0.6) | 0 (0) | .491 | .546 |
| Hyperlipidemia | 22 (5.0) | 7 (4.1) | 6 (3.8) | .623 | .518 |

SAD, small airway dysfunction; PRISm, preserved-ratio impaired spirometry; BMI, Body Mass Index; Unknown, the information on the surgical resection location is unclear

| Variables | Normal (n = 439) | SAD (n = 172) | PRISm (n = 160) | P value (Normal vs SAD) | P value (Normal vs PRISm) |
|---|---|---|---|---|---|
| Coronary artery disease | 3 (0.7) | 5 (2.9) | 6 (3.8) | .030 | .006 |
| Cerebral infarction | 4 (0.9) | 4 (2.3) | 2 (1.3) | .167 | .713 |
| Gout | 5 (1.1) | 0 (0.0) | 1 (0.6) | .160 | .576 |
| Allergic to antibiotics, n (%) | 6 (1.4) | 5 (2.9) | 4 (2.5) | .198 | .338 |
| Surgical history, n (%) | 222 (50.6) | 90 (52.3) | 87 (54.4) | .696 | .410 |
| MEF25% pred, mean ± SD | 115.0 ± 62.9 | 49.4 ± 16.8 | 59.4 ± 34.9 | < .001 | < .001 |
| MEF50% pred, mean ± SD | 103.9 ± 45.3 | 59.6 ± 12.4 | 54.7 ± 18.5 | < .001 | < .001 |
| MMEF% pred, mean ± SD | 100.9 ± 21.9 | 53.6 ± 9.1 | 52.7 ± 18.8 | < .001 | < .001 |
| Resection location, n (%) | | | | .307 | .916 |
| Left resection | 124 (28.2) | 55 (32.0) | 41 (25.6) | .470 | .063 |
| Hemihepatectomy | 59 (47.6) | 26 (47.3) | 27 (65.9) | | |
| Lobectomy of lateral sector | 9 (7.3) | 7 (12.7) | 4 (9.8) | | |
| Segment resection | 56 (45.2) | 22 (40.0) | 10 (24.4) | | |
| Right resection | 140 (31.9) | 56 (32.6) | 53 (33.1) | .357 | .165 |
| Hemihepatectomy | 29 (20.7) | 15 (26.8) | 16 (30.2) | | |
| Segment resection | 111 (79.3) | 41 (73.2) | 37 (69.8) | | |
| Bilateral hepatectomy | 4 (0.9) | 4 (2.3) | 2 (1.3) | | |
| Unknown | 171 (39.0) | 46 (33.1) | 64 (40.0) | | |
| Intraoperative bleeding, median (IQR), mL | 50.0 (20.0-200.0) | 50.0 (20.0-200.0) | 100.0 (50.0-300.0) | .842 | < .001 |
| Intraoperative blood transfusion, n (%) | 130 (29.6) | 66 (38.4) | 68 (42.5) | .037 | .003 |

SAD, small airway dysfunction; PRISm, preserved-ratio impaired spirometry; BMI, Body Mass Index; Unknown, the information on the surgical resection location is unclear

Table 2
Postoperative outcomes of patients according to baseline lung function categories.

| Variables | Normal (n = 439) | SAD (n = 172) | PRISm (n = 160) | P value (Normal vs SAD) | P value (Normal vs PRISm) |
|---|---|---|---|---|---|
| Cough and sputum, n (%) | 5 (1.1) | 5 (2.9) | 13 (8.1) | .121 | < .001 |
| PPCs, n (%) | 171 (39.0) | 78 (45.3) | 72 (45.0) | .148 | .182 |
| Pneumonia | 68 (15.5) | 27 (15.7) | 32 (20.0) | .949 | .190 |
| Atelectasis | 44 (10.0) | 19 (11.0) | 13 (8.1) | .708 | .484 |
| Pleural effusion | 149 (33.9) | 68 (39.5) | 58 (36.3) | .194 | .599 |
| Respiratory failure | 2 (0.5) | 1 (0.6) | 5 (3.1) | .841 | .007 |
| Pulmonary embolism | 4 (0.9) | 2 (1.2) | 1 (0.6) | .777 | .733 |
| Hypoproteinemia, n (%) | 42 (9.6) | 12 (7.0) | 15 (9.4) | .310 | .943 |
| Seroperitoneum, n (%) | 22 (5.0) | 12 (7.0) | 12 (7.5) | .341 | .244 |
| Pelvic effusion, n (%) | 44 (10.0) | 18 (10.5) | 16 (10.0) | .871 | .993 |
| Postoperative pyrexia, n (%) | 24 (5.5) | 11 (6.4) | 13 (8.1) | .657 | .232 |
| Pericardial effusion, n (%) | 18 (4.1) | 4 (2.3) | 6 (3.8) | .290 | .847 |
| POAF, n (%) | 6 (1.4) | 3 (1.7) | 6 (3.8) | .728 | .065 |
| Postoperative antibiotic use, median (IQR) | | | | | |
| Length of antibiotic use, days | 7.0 (5.0–10.0) | 7.5 (5.0–10.0) | 8.0 (5.0-12.8) | .340 | .005 |
| Usage types, kind | 1.0 (1.0–1.0) | 1.0 (1.0–1.0) | 1.0 (1.0–1.0) | .166 | .031 |
| Length of stays, median (IQR), days | 12.0 (8.0–17.0) | 12.0 (8.0–17.0) | 15.0 (10.0-20.75) | .934 | < .001 |
| ICU admission, n (%) | 22 (5.0) | 11 (6.4) | 20 (12.5) | .496 | .001 |

SAD, small airway dysfunction; PRISm, preserved-ratio impaired spirometry; PPCs, postoperative pulmonary complications; POAF, postoperative new-onset atrial fibrillation

Table 3
Risk factors for postoperative pulmonary complications.

| Variables | PPCs (n = 321) | No PPCs (n = 450) | P value |
|---|---|---|---|
| **Univariate analysis** | | | |
| SAD, n (%) | 78 (24.3) | 94 (20.9) | .148 |
| PRISm, n (%) | 72 (22.4) | 88 (19.6) | .182 |
| Age, mean ± SD, year | 63.0 ± 11.4 | 62.5 ± 11.9 | .542 |
| Sex, n (%) | | | .489 |
| Male sex | 141 (43.9) | 209 (46.4) | |
| Female sex | 180 (56.1) | 241 (53.6) | |
| BMI, mean ± SD, $kg/m^2$ | 23.1 ± 3.1 | 23.0 ± 3.37 | .743 |
| Smoking status, n (%) | | | .848 |
| Current smoker | 30 (9.3) | 43 (9.6) | |
| Former smoker | 14 (4.4) | 16 (3.6) | |
| Nonsmoker | 277 (86.3) | 391 (86.9) | |
| Alcohol status, n (%) | | | .239 |
| Current drinker | 21 (6.5) | 43 (9.6) | |
| Former drinker | 6 (1.9) | 12 (2.7) | |
| Nondrinker | 294 (91.6) | 395 (87.8) | |
| Comorbidity, n (%) | | | |
| Hypertension | 123 (38.3) | 172 (38.2) | .979 |
| Diabetes | 47 (14.6) | 65 (14.4) | .939 |
| Mental illness | 2 (0.6) | 4 (0.9) | .679 |
| Hepatitis B | 24 (7.5) | 47 (10.4) | .160 |
| Tachycardia | 4 (1.2) | 7 (1.6) | .721 |
| Alcoholic liver disease | 1 (0.3) | 1 (0.2) | .810 |

PPCs, postoperative pulmonary complications; SAD, small airway dysfunction; PRISm, preserved-ratio impaired spirometry; BMI, Body Mass Index; Unknown, the information on the surgical resection location is unclear

Multivariate P-values for left resection range were derived from the left resection patients, and those for other variables from the all participants

| Variables | PPCs (n = 321) | No PPCs (n = 450) | P value |
|---|---|---|---|
| Hyperlipidemia | 12 (3.7) | 23 (5.1) | .367 |
| Coronary artery disease | 6 (1.9) | 8 (1.8) | .925 |
| Cerebral infarction | 4 (1.2) | 6 (1.3) | .916 |
| Gout | 1 (0.3) | 5 (1.1) | .213 |
| Allergic to antibiotics, n (%) | 9 (2.8) | 6 (1.3) | .145 |
| Surgical history, n (%) | 175 (54.5) | 224 (49.8) | .194 |
| Intraoperative bleeding, median (IQR), mL | 100.0 (50.0-300.0) | 50.0 (20.0-200.0) | < .001 |
| Intraoperative blood transfusion, n (%) | 122 (38.0) | 142 (31.6) | .063 |
| Operative duration, median (IQR), hour | 3.0 (2.0-4.5) | 2.5 (1.5-4.0) | < .001 |
| Resection location, n (%) | | | .120 |
| Left resection | 91 (28.3) | 129 (28.7) | .010 |
| Hemihepatectomy | 57 (62.6) | 55 (42.6) | |
| Lobectomy of lateral sector | 8 (8.8) | 12 (9.3) | |
| Segment resection | 26 (28.6) | 62 (48.1) | |
| Right resection | 117 (36.4) | 132 (29.3) | .258 |
| Hemihepatectomy | 32 (27.4) | 28 (21.2) | |
| Segment resection | 85 (72.6) | 104 (78.8) | |
| Bilateral hepatectomy | 5 (1.6) | 5 (1.1) | |
| Unknown[3] | 108 (33.6) | 184 (40.9) | |
| Variables | Odds ratio (95% CI) | | P value |
| **Multivariate analysis** | | | |
| SAD | 1.345 (0.935–1.935) | | .111 |
| PRISm | 1.145 (0.785–1.669) | | .482 |

PPCs, postoperative pulmonary complications; SAD, small airway dysfunction; PRISm, preserved-ratio impaired spirometry; BMI, Body Mass Index; Unknown, the information on the surgical resection location is unclear

Multivariate P-values for left resection range were derived from the left resection patients, and those for other variables from the all participants

| Variables | PPCs (n = 321) | No PPCs (n = 450) | P value |
|---|---|---|---|
| Intraoperative bleeding | 1.000 (1.000-1.001) | | .124 |
| Operative duration | 1.200 (1.091–1.320) | | < .001 |
| Left resection range<br><br>(Reference: hemihepatectomy) | | | |
| Lobectomy of lateral sector | 1.257 (0.746–2.119) | | .391 |
| Segment resection | 0.546 (0.148–2.013) | | .363 |
| PPCs, postoperative pulmonary complications; SAD, small airway dysfunction; PRISm, preserved-ratio impaired spirometry; BMI, Body Mass Index; Unknown, the information on the surgical resection location is unclear | | | |
| Multivariate P-values for left resection range were derived from the left resection patients, and those for other variables from the all participants | | | |

Table 4
Risk factors for prolonged length of stay.

| Variable | B | Se | 95%CI | P value |
|---|---|---|---|---|
| **Univariate analysis** | | | | |
| Age, year | 0.006 | 0.002 | 0.003 to 0.010 | < .001 |
| Males sex | −0.194 | 0.041 | −0.275 to − 0.113 | < .001 |
| BMI kg/$m^2$ | −0.002 | 0.001 | −0.004 to 0.000 | .064 |
| Current smoker | 0.082 | 0.034 | 0.015 to 0.150 | .016 |
| Current drinker | 0.106 | 0.037 | 0.034 to 0.178 | .004 |
| Hypertension | 0.005 | 0.043 | −0.079 to 0.089 | .915 |
| Diabetes | 0.246 | 0.058 | 0.131 to 0.360 | < .001 |
| Mental illness | 0.184 | 0.236 | −0.280 to 0.648 | .437 |
| Hepatitis B | 0.093 | 0.072 | −0.048 to 0.234 | .195 |
| Tachycardia | 0.090 | 0.175 | −0.254 to 0.434 | .607 |
| Alcoholic liver disease | −0.039 | 0.409 | −0.841 to 0.764 | .925 |
| Hyperlipidemia | 0.068 | 0.100 | −0.128 to 0.264 | .497 |
| Coronary artery disease | 0.159 | 0.156 | −0.146 to 0.465 | .306 |
| Cerebral infarction | 0.062 | 0.184 | −0.299 to 0.422 | .738 |
| Gout | 0.159 | 0.236 | −0.305 to 0.623 | .501 |
| Allergic to antibiotics | 0.096 | 0.150 | −0.200 to 0.391 | .525 |
| Surgical history | 0.075 | 0.042 | −0.007 to 0.156 | .073 |
| Resection location | 0.099 | 0.044 | 0.012 to 0.186 | .025 |
| Left vs Right | 0.037 | 0.053 | −0.067 to 0.141 | .485 |
| Left vs bilateral | 0.449 | 0.184 | 0.087 to 0.812 | .015 |
| Right vs bilateral | −0.413 | 0.184 | −0.774 to − 0.051 | .025 |
| Intraoperative bleeding | 0.000 | 0.000 | 0.000 to 0.000 | < .001 |
| Intraoperative blood transfusion | 0.436 | 0.041 | 0.355 to 0.516 | < .001 |
| Operative duration | 0.200 | 0.009 | 0.182 to 0.218 | < .001 |

BMI, Body Mass Index; VTE, Venous Thromboembolism; SAD, small airway dysfunction; PPCs, postoperative pulmonary complications; PRISm, preserved-ratio impaired spirometry

| Variable | B | Se | 95%CI | P value |
|---|---|---|---|---|
| VTE | 0.048 | 0.014 | 0.020 to 0.077 | < .001 |
| Cough and sputum | 0.538 | 0.121 | 0.302 to 0.775 | < .001 |
| Length of antibiotic use | 0.070 | 0.003 | 0.065 to 0.075 | < .001 |
| Types of antibiotics | 0.417 | 0.037 | 0.344 to 0.490 | < .001 |
| SAD | −0.048 | 0.050 | −0.146 to 0.050 | .339 |
| PPCs | 0.316 | 0.041 | 0.236 to 0.395 | < .001 |
| PRISm | 0.162 | 0.051 | 0.062 to 0.261 | .002 |
| **Multivariate analysis** | | | | |
| Age, year | 0.003 | 0.001 | 0.000 to 0.005 | .019 |
| Male sex | −0.059 | 0.029 | −0.115 to -0.002 | .042 |
| Current smoker | −0.031 | 0.026 | −0.082 to 0.019 | .218 |
| Current drinker | 0.062 | 0.026 | 0.010 to 0.114 | .019 |
| Diabetes | 0.111 | 0.037 | 0.038 to 0.184 | .003 |
| Left vs bilateral | −0.224 | 0.113 | −0.447 to − 0.002 | .048 |
| Right vs bilateral | −0.273 | 0.113 | −0.494 to − 0.051 | .016 |
| Intraoperative bleeding | 0.000 | 0.000 | 0.000 to 0.000 | .003 |
| Intraoperative blood transfusion | 0.149 | 0.029 | 0.091 to 0.206 | < .001 |
| Operative duration | 0.112 | 0.009 | 0.094 to 0.129 | < .001 |
| VTE | 0.007 | 0.010 | −0.012 to 0.026 | .469 |
| Cough and sputum | 0.099 | 0.079 | −0.057 to 0.255 | .215 |
| Length of antibiotic use | 0.085 | 0.027 | 0.032 to 0.138 | .002 |
| Types of antibiotics | 0.045 | 0.003 | 0.040 to 0.050 | < .001 |
| PRISm | 0.005 | 0.032 | −0.058 to 0.068 | .880 |
| PPCs | 0.061 | 0.027 | 0.008 to 0.114 | .024 |
| BMI | −0.001 | 0.001 | −0.002 to 0.000 | .240 |

BMI, Body Mass Index; VTE, Venous Thromboembolism; SAD, small airway dysfunction; PPCs, postoperative pulmonary complications; PRISm, preserved-ratio impaired spirometry

Table 5
Postoperative outcomes of normal respiratory and isolated small airway dysfunction in 1:1 propensity score matching.

| Variables | Normal (n = 163) | SAD (n = 163) | P value |
|---|---|---|---|
| Cough and sputum, n (%) | 4 (2.5) | 4 (2.5) | 1.000 |
| PPCs, n (%) | 75 (46.0) | 71 (43.6) | .656 |
| Pneumonia | 26 (16.0) | 27 (16.6) | .881 |
| Atelectasis | 17 (10.4) | 25 (15.3) | .185 |
| Pleural effusion | 66 (40.5) | 60 (36.8) | .495 |
| Respiratory failure | 1 (0.6) | 0 (0) | .317 |
| Pulmonary embolism | 2 (1.2) | 2 (1.2) | 1.000 |
| Hypoproteinemia, n (%) | 11 (6.7) | 9 (5.5) | .644 |
| Seroperitoneum, n (%) | 12 (7.4) | 8 (4.9) | .356 |
| Pelvic effusion, n (%) | 17 (10.4) | 14 (8.6) | .571 |
| Postoperative pyrexia, n (%) | 10 (6.1) | 12 (7.4) | .659 |
| Pericardial effusion, n (%) | 4 (2.5) | 9 (5.5) | .157 |
| POAF, n (%) | 3 (1.8) | 3 (1.8) | 1.000 |
| Postoperative antibiotic use, median (IQR) | | | |
| Length of antibiotic use, day | 7.0 (5.0–10.0) | 8.0 (4.0–11.0) | .743 |
| Usage types, kind | 1.0 (1.0–1.0) | 1.0 (1.0–1.0) | .605 |
| Length of stay, median (IQR), day | 12.0 (8.0–17.0) | 13.0 (8.0–17.0) | .466 |
| ICU admission, n (%) | 10 (6.1) | 4 (2.5) | .101 |

PPCs, postoperative pulmonary complications; POAF, postoperative new-onset atrial fibrillation

Table 6
Postoperative outcomes of normal respiratory and preserved-ratio impaired spirometry in 1:1 propensity score matching.

| Variables | Normal (n = 101) | PRISm (n = 101) | P value |
|---|---|---|---|
| Cough and sputum, n (%) | 4 (4.0) | 4 (4.0) | 1.000 |
| PPCs, n (%) | 41 (40.6) | 43 (42.6) | .775 |
| Pneumonia | 13 (12.9) | 21 (20.8) | .132 |
| Atelectasis | 12 (11.9) | 7 (6.9) | .228 |
| Pleural effusion | 35 (34.7) | 35 (34.7) | 1.000 |
| Respiratory failure | 1 (1.0) | 2 (2.0) | .561 |
| Pulmonary embolism | 0 (0) | 1 (1.0) | .316 |
| Hypoproteinemia, n (%) | 7 (6.9) | 7 (6.9) | 1.000 |
| Seroperitoneum, n (%) | 4 (4.0) | 3 (3.0) | .700 |
| Pelvic effusion, n (%) | 9 (8.9) | 7 (6.9) | .602 |
| Postoperative pyrexia, n (%) | 8 (7.9) | 8 (7.9) | 1.000 |
| Pericardial effusion, n (%) | 4 (4.0) | 4 (4.0) | 1.000 |
| POAF, n (%) | 1 (1.0) | 3 (3.0) | .312 |
| Postoperative antibiotic use, median (IQR) | | | |
| Length of antibiotic use, day | 8.0 (5.0–11.0) | 8.0 (5.0–12.0) | .516 |
| Usage types, kind | 1.0 (1.0–1.0) | 1.0 (1.0–1.0) | .914 |
| Length of stay, median (IQR), day | 13.0 (9.0–20.0) | 14.0 (9.0–20.0) | .785 |
| ICU admission, n (%) | 8 (7.9) | 8 (7.9) | 1.000 |

PPCs, postoperative pulmonary complications; POAF, postoperative new-onset atrial fibrillation

# Discussion

Studies have shown inconsistent findings regarding the association between preoperative pulmonary dysfunction and postoperative complications. Sheshadri et al. found that it was significantly associated with postoperative complications and long-term survival in patients with gastric cancer resection.[6] Another study has shown that insufficient cardiopulmonary reserve assessed by stair climbing test can effectively predict the risk of postoperative cardiopulmonary complications.[8] However, the finding of this study is consistent with studies by Yokota et al.[5] and Khan et al.[9], indicating that preoperative PFT has limited predictive value for abdominal surgery outcomes. The reasons for the differences are

measurement modalities[8], population characteristics, regional backgrounds[10], surgical procedures[6], confounding factor adjustment and so on. This study adds clinical evidence for SAD and PRISm to postoperative risk assessment after laparoscopic hepatectomy, and offers an evidence-based basis for preoperative risk stratification and personalized clinical management. Specifically, PRISm serves as a valuable early warning for perioperative prognosis rather than the independent factor, and is more sensitive to prolonged operative duration. At the same time, it can guide the individualized intervention strategies during the perioperative period. For normal, the key is to strictly control the operation duration. For PRISm, systematic respiratory protection can effectively reduce the incidence of PPCs and improve short-term outcomes. Much evidence has demonstrated that perioperative postoperative care protocols, such as chest physiotherapy and incentive spirometry, can significantly reduce the incidence of PPCs and ICU admission rate[11–13]. Moreover, the preventive effect of the whole perioperative intervention was significantly better than that of the single preoperative or postoperative intervention[14].

The discovery of prolonged LOS is consistent with previous research findings on surgical complexity.[15,16] It is worth noting that other factors including pneumoperitoneum pressure, surgical positioning, anesthetic regimens, ventilation strategies and intraoperative fluid balance, which this study did not analyze, can markedly affect postoperative complications. Existing evidence indicates that low-pressure 8 mmHg pneumoperitoneum reduces $CO_2$ retention and cardiopulmonary stress compared with 12 mmHg, without increasing surgical morbidity or acid-base disturbance[17]. Morise Z suggested that optimized left lateral or semi-prone positioning facilitates surgical exposure and minimizes tissue injury in laparoscopic hepatectomy[18]. In terms of anesthesia management, an ASA-PS score ≥ 3 predicts poor postoperative prognosis[19], while combined general-epidural anesthesia protects perioperative hepatorenal function in the elder[20]. Besides, mild hypercapnic ventilation maintains cerebral oxygenation without raising postoperative complications under low central venous pressure[21]. Although previous studies have reported an association between diabetes and increased risk of COPD[22], impaired T-cell activation and abnormal dendritic cell metabolism may also contribute to poor recovery and prolonged LOS.[23] Alcohol may induce persistent liver injury via oxidative stress and epigenetic changes, ultimately prolonged LOS.[24,25] In addition, postoperative antibiotic use can effectively reflect the incidence of short-term postoperative complications. Whether prolonged LOS leads to increased complication exposure or whether complications simply extend LOS, which requires further investigation in the future.

This study had several limitations. First, the single-center retrospective study is limited in information bias from medical record. Second, although the PFT is a routine examination, a considerable proportion of patients have not completed or the results are invalid. Meanwhile, since up to 37.9% of cases lacked clear anatomical site documentation in surgical records, the conclusions of this study regarding the impact of "resection location " on prognosis primarily apply to patients undergoing non-anatomical local resection or those with complete records. For the unknown cases, extrapolation to all types of hepatic resection should be approached with caution. Prospective studies can be conducted in the future to further validate the results. Third, intraoperative factors including $CO_2$ pressure and surgical position, as

well as perioperative management such as anesthetic regimen, ventilatory strategy and intraoperative fluid balance were not included in this analysis and may serve as unmeasured confounding factors.

In summary, based on the analysis of 771 patients undergoing laparoscopic hepatectomy, our findings do not support the routine inclusion of SAD or PRISm in conventional risk-prediction models. These subclinical indicators showed limited predictive value for postoperative complications in this cohort, suggesting that clinical focus should shift towards established risk factors and surgery-related variables.

# Abbreviations

SAD
isolated small airway dysfunction
PRISm
preserved-ratio impaired spirometry
PPCs
postoperative pulmonary complications
PSM
multivariable analyses and propensity score matching
LOS
longer length of stay
PFT
pulmonary function testing
COPD
chronic obstructive pulmonary disease
FEV1/FVC
first second/ forced vital capacity
POAF
postoperative atrial fibrillation.

# Declarations

### Ethic approval and consent to participate

This study was approved by the Ethics Committee of the Ningbo First Hospital (2025-209RS). The requirement for informed consent was waived owing to the retrospective nature of the study and the use of de-identified data.

### Consent for publication

Not Applicable.

### Availability of data and materials

The data that support the findings of this study are available from The First Affiliated Hospital of Ningbo University but restrictions apply to the availability of these data, which were used under license for the current study, and so are not publicly available. Data are however available from the authors upon reasonable request and with permission of The First Affiliated Hospital of Ningbo University.

**Competing Interests**

Not Applicable.

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**Author's contribution**

Shuling Zhang: Writing — original draft, Formal analysis, Data curation, Conceptualization. Xingyu Li: Data curation, Conceptualization. Weiping Ding: Investigation, Methodology. Hongying Ma: Supervision. Jingjing Zhong and Jing Yang: Writing — review & editing.

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**Clinical trial number**

Not applicable.

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# Figures

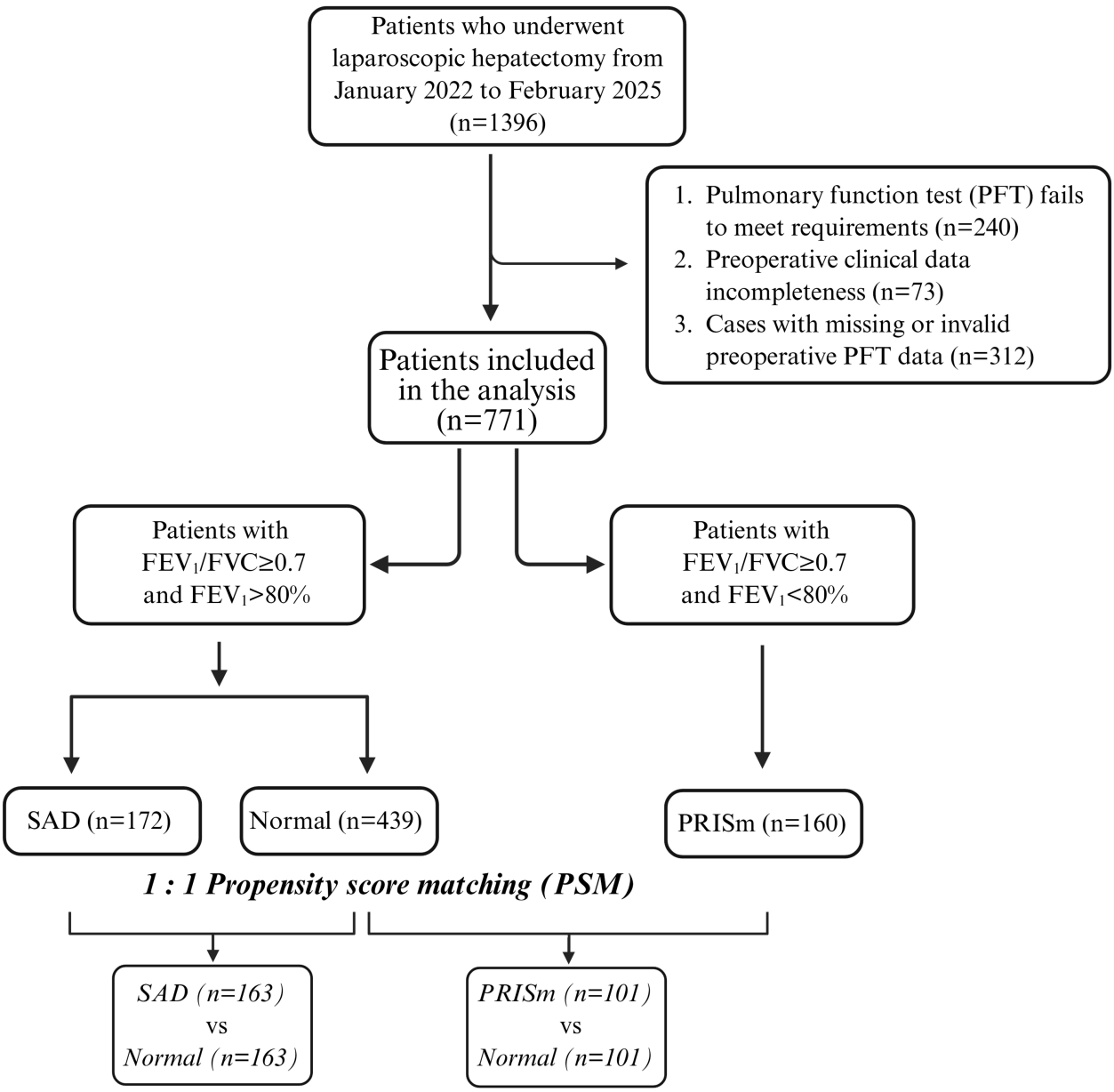



**Figure 1**

Flow of patients through trial. $FEV_1$, forced expiratory volume in the first second; FVC, forced vital capacity; SAD, small airway dysfunction; PRISm, preserved-ratio impaired spirometry.

## Supplementary Files

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