# RESEARCH



# Risk factors and predictive model for pulmonary complications in patients transferred to ICU after hepatectomy

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## Abstract

**Objective** Postoperative pulmonary complications (PPCs) seriously harm the recovery and prognosis of patients undergoing surgery. However, its related risk factors in critical patients after hepatectomy have been rarely reported. This study aimed at analyzing the factors related to PPCs in critical adult patients after hepatectomy and create a nomogram for prediction of the PPCs.

**Methods** 503 patients' data were collected form the Peking University People's Hospital. Multivariate logistic regression analysis was used to identify independent risk factors to derive the nomogram. Nomogram's discriminatory ability was assessed using the area under the receiver operating characteristic curve (AUC), and calibration was assessed using the Hosmer–Lemeshow goodness-of-fit test and calibration curve.

**Results** The independent risk factor for PPCs are advanced age (odds ratio [OR] = 1.026; P = 0.008), higher body mass index (OR = 1.139; P < 0.001), lower preoperative serum albumin level (OR = 0.961; P = 0.037), and intensive care unit first day infusion volume (OR = 1.152; P = 0.040). And based on this, we created a nomogram to predict the occurrence of PPCs. Upon assessing the nomogram's predictive ability, the AUC for the model was 0.713(95% CI: 0.668–0.758, P<0.001). The Hosmer–Lemeshow test (P = 0.590) and calibration curve showed good calibration for the prediction of PPCs.

**Conclusions** The prevalence and mortality of postoperative pulmonary complications in critical adult patients after hepatectomy are high. Advanced age, higher body mass index, lower preoperative serum albumin and intensive care unit first day infusion volume were found to be significantly associated with PPCs. And we created a nomogram model which can be used to predict the occurrence of PPCs.

Keywords Risk factor, Postoperative pulmonary complication, Nomogram, Hepatectomy

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## Introduction

Postoperative pulmonary complications (PPCs) adversely influence the mortality and hospital stays of patients after upper abdominal surgery [1, 2]. Their incidence after abdominal surgery ranges from 10 to 80% [3, 4]. Hepatectomy is one kind of common upper abdominal surgery, performed close to the diaphragm, and patients undergo this surgery often complicated with liver insufficiency and hypoproteinemia [5], these lead to higher incidence of PPCs in this kind of patients. Meanwhile, with the development of critical care medicine and the increase quantity of surgeries, more and more critical patients are transferred to the ICU after hepatectomy. These patients have more complex complications and more likely to develop the PPCs [6, 7].

Several studies reporting the risk factors of pulmonary complications after hepatectomy, including a few multivariate analyses, are usually limited in those non-critical patients [4, 8, 9]. A small number of studies have looked at critically ill populations, but these studies have small sample sizes and just included few variables, and most do not contain detailed information about intraoperative anesthesia or surgery [5, 10].

To the best of our knowledge, there have been no high-quality studies on the risk of pulmonary complications after hepatectomy in the critically ill population and no study have created a nomogram for prediction of the PPCs in these people. And the analysis of the factors related to the occurrence of PPCs in critical patients and build a prediction model will have great clinical value in establishing a feasible path for clinical intervention to reduce the occurrence of PPCs in this kind of patients. In this study, data from a 7-year clinical database were retrospectively analyzed, aimed to determine the risk factors for PPCs of critical patients after hepatectomy and build a nomogram model for the prediction of PPCs.

#### Methods

## Study design and objectives

In this retrospective study, we sought to analyze the risk factors for PPCs and build a nomogram model for the prediction of PPCs. The study was approved by the local Ethics Committee, Peking University People's Hospital, China (No. 2021PHB024-001). The study was conducted in the Peking University People's Hospital, Beijing, China.

Patients admitted to the ICU after hepatectomy at Peking University People's Hospital between January 2014 and December 2021 were considered eligible for this study. And the ICU admission standard for patients in our hospital are: 1.The patient was older than 75 years; 2. Patients with unstable control of complications or symptoms; 3. Intraoperative bleeding greater than 1000ml; 4. Patients need large dose of vasoactive drugs during surgery; 5. Patients with decreased oxygenation or difficulty in removing tracheal intubation during or after the operation; 6. Emergency events occur during the perioperative period; 7. Patients with high risk of postoperative bleeding or complications considered by surgeon(Those who meet one or more of the above criteria can be considered to transfer to ICU). Patients had an Acute Physiology and Chronic Health Evaluation II (APACHE II) score≥10 were defined as critical patients [11, 12]. The patients' data were retrospectively analyzed. The exclusion criteria were patients  $\leq 18$  years, those with preoperative pulmonary infection or other pulmonary diseases or the APACHEII score<10 (Fig. 1). Pulmonary diseases include history of chronic obstructive pulmonary disease, asthma, chronic bronchitis, lung surgery, chest trauma, etc. And, patients with pulmonary auscultation murmur, cough, phlegm and chest tightness complaints during preoperative routine examination or patients with preoperative oxygen saturation monitoring<93% will be excluded from the study. We recorded information in an electronic anesthetic documentation system certified by the Healthcare Information and Management Systems Society, which was rated stage 7 by Electronic Medical Records Adoption Model (HIMSS EMRAM7). All data were obtained from the electronic database on the server. The objectives of this study were to determine the risk factors for PPCs of critical patients admitted to the intensive care unit (ICU) after hepatectomy and create a nomogram model for predicting PPCs.

#### Variables and definitions

PPCs were defined according to the Standards for Definitions and use of Outcome Measures for Clinical Effectiveness Research in Perioperative Medicine: European Perioperative Clinical Outcome (EPCO) definitions, which included respiratory infection, respiratory failure, pleural effusion, atelectasis, pneumothorax, bronchospasm, and aspiration pneumonitis [13]; PPCs were defined as the development of one or more of these conditions.

All complications were diagnosed by chest radiography and/or computed tomographic (CT) scan. An experienced intensivist and a radiologist assessed the postoperative respiratory status of all patients. The respiratory infection was defined by chest radiography and/ or CT scan results associated with fever and hyperleukocytosis. Respiratory failure was defined as postoperative  $PaO_2 < 8 \text{ kPa}$  (60 mmHg) in room air, a  $PaO_2$ :FIO<sub>2</sub> ratio < 40 kPa (300 mmHg), and requiring oxygen therapy. Pleural effusion was defined as chest radiograph findings of blunting of the costophrenic angle or a hazy opacity in one hemithorax with preserved vascular shadows in the supine position. Atelectasis was defined as lung opacification with a shift of the mediastinum, hilum, or hemidiaphragm toward the affected area, and compensatory



Fig. 1 Study Flow

over-inflation in the adjacent non-atelectatic lung. Pneumothorax was defined as air in the pleural space with no vascular bed surrounding the visceral pleura. Bronchospasm was defined as newly detected expiratory wheezing treated with bronchodilators. Aspiration pneumonitis was defined as acute lung injury after the inhalation of regurgitated gastric contents.

## Data collection

We collected demographic data including sex, age, and body mass index (BMI). Preoperative variables included tobacco use, history of hepatectomy, comorbidities (diabetes, hypertension, coronary heart disease, chronic renal insufficiency), underlying liver disease (hepatitis B virus infection, cirrhosis, portal hypertension, splenomegaly, ascites, steatosis), and laboratory examination (preoperative serum albumin level, postoperative creatine kinase MB [CK-MB] and postoperative brain natriuretic peptide [BNP]). Intraoperative variables included liver lesion (benign/malignant), surgery characteristics (tumor size, tumor number, bilateral subcostal incision, hemihepatectomy, drainage tube, T-tube drainage, operative time, laparotomy, microwave ablation, portal triad clamping period, associated extrahepatic procedures) and anesthetic characteristics (general anesthesia method, intraoperative hypotension, temperature, intraoperative infusion volume, blood loss, urine volume, and nerve block), intraoperative or postoperative blood transfusion and ICU first day infusion volume. Intraoperative hypotension was defined as requiring continuous intraoperative pumping of vasoactive drugs, including norepinephrine, dopamine, and phenylephrine [14, 15]. Two intensivist verified data to avoid bias.

## Statistical analysis

#### Primary statistical analysis

Continuous variables were analyzed using the Student's t-test or Mann–Whitney U test, as appropriate, and data were expressed as mean values±SD or median (interquartile range). Categorical variables were analyzed using the chi-squared test or Fisher's exact test, as appropriate, the n (%) was used to express the data. Statistical tests were done with R software (version 4.0.3; R Foundation for Statistical Computing, Vienna, Austria) and SPSS (version 23.0; SPSS, IBM). A P-value<0.05 was considered significant.

#### Model development

Univariable logistic regression analyses were performed to assess the association of predictive factors with PPCs. Multivariate analysis was conducted to derive the nomogram. The predictors included in the multivariable model were selected based on the result of univaribable logistic regression analyses (P<0.1). The backward procedure for variable selection was applied for the multivariable

### Table 1 Distribution of PPCs

Type of PPCs	N (%)
Pleural effusion	214(42.5)
Respiratory failure	159(31.7)
Atelectasis	113(22.5)
Respiratory infection	56(11.1)
Pneumothorax	2(0.4)
Aspiration pneumonitis	1(0.2)
Bronchospasm	0(0)

PPCs: postoperative pulmonary complications

logistic regression model. Regression coefficients were used to generate a nomogram.

#### Predictive ability

Nomogram model performance was assessed by examining discrimination and calibration. The discrimination was assessed by the area under the receiver-operator characteristic and area under curve (AUC) and its 95% confidence interval [CI]. The calibration was constructed to examine the agreement between the predicted probabilities with the observed outcome, which was assessed by the Hosmer–Lemeshow goodness-of-fit test and calibration curve. The calibration curve was calculated by the 500 repetitions bootstrap resampling.

## Results

## Patients

Between January 2014 and January December 2021, 579 patients were admitted to the ICU after hepatectomy, and 503 were finally analyzed (Fig. 1). Data on these patients were recorded in the electronic database on the server and analyzed retrospectively. The rate of PPC occurrence was 55.7% (n=280). The rates of overall pleural effusion, respiratory failure, atelectasis, respiratory infection, pneumothorax, aspiration pneumonitis, and bronchospasm were 42.5% (n=214), 31.7% (n=159), 22.5% (n=113), 11.1% (n=56), 0.4% (n=2), 0.2% (n=1), and 0% (n=0), respectively. The distribution of PPCs is shown in Table 1. And for the 159 respiratory failure patients, there are 47 patients with prolonged tracheal intubation duration(more than 24 h), 11 patients with subsequent non-invasive ventilator assistance, and 70 patients with prolonged ICU stay (more than 48 h).

Among the patients, there were 342 men (68.0%) and 161 women (32.0%), the patients had a mean age of  $60.3\pm12.0$  years. The underlying liver disease included 193 patients (38.4%) with hepatitis B, 120 patients (23.9%) with cirrhosis, 58 patients (11.5%) with portal hypertension, 71 patients (14.1%) with splenomegaly, 67 patients (13.3%) with ascites, and 14 patients (2.9%) with steatosis. Malignant disease was observed in 87.1% patients (n=438) and benign disease in 12.9% (n=65).

#### Table 2 Outcomes

Outcome	PPCs N=280	Non-PPCs N=223	Ρ
In-hospital mortality, n (%)	8 (2.9)	0 (0)	0.011
Length of ICU stay, (IQR days)	2 (2, 4)	2 (2, 2)	< 0.001
Length of hospital stay, (IQR days)	18 (15, 25)	15 (12, 19)	< 0.001
Duration of mechanical ventilation, (IQR hours)	8.0 (4.0, 15)	5.0 (3.0, 9.5)	< 0.001

PPCs: postoperative pulmonary complications. IQR: inter quartile range

The overall mortality rate was 1.6% (n=8). The causes of death were multiorgan failure (n=3), gastrointestinal bleeding (n=1), liver failure (n=1), heart failure (n=1), aspiration pneumonia (n=1), and respiratory distress (n=1).

## Postoperative pulmonary complications

The mortality rate of patients with PPCs was higher than patients with no PPCs (2.9% vs. 0%, P=0.011). Patients who developed PPCs had a statistically significant increase in the length of hospital stay (18 [15, 25] days vs. 15 [12, 19] days; P<0.001), length of ICU stay (2 [2, 4] days vs. 2 [2] days; P<0.001), and duration of mechanical ventilation (8.0 [4.0, 15.0] hours vs. 5.0 [3.2, 9.5] hours; P<0.001) (Table 2).

The results of univariate analysis are summarized in Table 3. Advanced age, higher BMI, diabetes, hypertension, lower preoperative serum albumin level, postoperative CK-MB, malignant liver lesion, bilateral subcostal incision, prolonged surgery, associated extrahepatic procedures, intraoperative hypotension, greater intraoperative infusion volume, blood loss, urine volume, intra- or postoperative blood transfusion and the ICU first day infusion volume were risk factors for PPCs.

Multivariate analysis identified the following four independent risk factors for PPCs (Table 4): Advanced age (OR=1.026; P=0.008), higher BMI (OR=1.139; P<0.001), lower preoperative serum albumin level (OR=0.961; P=0.037), and ICU first day infusion (OR=1.152; P=0.040). And we created a nomogram for PPCs by using these factors (Fig. 2). The area under the curve (AUC) was 0.713 (95% confidence interval 0.668–0.758; Fig. 3). The nomogram had a bootstrapped concordance index of 0.713 and was well calibrated (Fig. 4).

## Discussion

Several studies have reported on PPCs after hepatic surgery. However, to the best of our knowledge, no highquality multivariate analysis has been published on a group of critical patients after hepatectomy in a large population and create a nomogram model for prediction of PPCs. And in our study, we use a clear and rigorous definition to define the PPCs [13].

## Table 3 Univariate analysis of characteristics between the two groups

N=280         N=223           Gender         0.647           Male         188         154           Famala         92         69           Age (mean ±50), kg/m2         25.13 ± 3.37         23.7 ± 3.41         <0.003           BMI (mean ±50), kg/m2         25.13 ± 3.37         23.7 ± 3.41         <0.001           Toaccro use, r0(%)         45 (15.1)         20.17 ± 3.1         <0.017           Interacro use, r0(%)         66 (2.43)         31 (13.0)         0.004           Uppertansion, r0(%)         21 (82.2)         20.(9.0)         <0.075           Coronobilities         21 (82.2)         20.(9.0)         <0.004           Uppertansion, r0(%)         21 (82.2)         20.(9.0)         <0.014           Upderbying Inversion, r0(%)         21 (82.2)         20.(9.0)         <0.014           Upderbying Inversion, r0(%)         21 (82.1)         47 (1.3.1)         0.81           Splanomogaly, n (%)         21 (1.1)         20.(1.1.2)         0.81           Splanomogaly, n (%)         32 (1.1.4         20.(1.1.2)         0.82           Splanomogaly, n (%)         32 (1.1.4         20.(1.2.1)         83.(3.6)         0.33           Splanomogaly, n (%)         32 (1.9.4.8         41.0.5 .3	Characteristic	PPCs	Non-PPCs	Р
Gender		N=280	N=223	
Male         188         151           Pernale         92         69           Age (mean ±50), kyms         6167±1147         58.47±1241         0.003           BML (mean ±50), kyms         6167±1147         58.47±1241         0.003           Diabeca Use, n(%)         65.12±13         401(17:95)         0.149           History of hepatectomy, n(%)         65.04:31         21:03         0.20           Comorbidines         U         U         0.00         0.76           Underlying (weights)         66.04:31         31:13.9         0.00           Coroary heart disease, n(%)         23:62.2         20:90,0         0.764           Chronic fields (weights)         1113:66,5         82:166.8         0.011           Coroary heart disease, n(%)         32:02.1         31:13.0         0.86           Coroary heart disease         U         U         0.00         0.83           Selenomessity, n(%)         32:02.1         31:13.0         0.86         0.83           Selenomessity, n(%)         32:01.1         32:01.0         0.85         32:01.0         0.85           Selenomessity, n(%)         32:01.0         0.81         32:01.0         0.82           Destoperative CiroN	Gender			0.647
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Coronary heart disease, (%)23 (8.2)09(0)0.76Underlying liver disease93.1.30.186Underlying liver disease111 (39.6)82.06.8)0.511Cirnois n (%)73 (26.1)47 (21.3)0.318Portal hypettersion, n (%)22 (11.4)26 (11.7)0.690Splenomegaly, n (%)38 (13.6)29 (13.3)0.853Statosis, n (%)6 (2.1)83.6)0.933Asctes, n (%)6 (2.1)83.6)0.020Statosis, n (%)6 (2.1)83.6)0.020Postoperative serum abumi level, (mean ± SD), g/L90.97.630.05 ± 4.640.020Postoperative (KM.8)2.9 (19.4.8)2.4 (1.56.3.9)0.027Postoperative (KM.8)2.9 (19.4.8)2.4 (1.56.3.9)0.027Postoperative (KM.8)2.9 (19.4.8)2.4 (1.56.3.9)0.020Postoperative (KM.8)2.9 (19.4.8)2.4 (1.50.6.3.9)0.020Postoperative (KM.8)2.9 (19.4.8)2.4 (1.50.6.3.9)0.020Postoperative (KM.8)2.9 (19.4.3.9)2.9 (1.9.1.3.9)0.036Dirano con	Hypertension, n (%)	113 (40.5)	55 (24.8)	< 0.001
Chronic renal insufficiency, n(%)9(3.2)3(1.3)0.186Underlying liver diseaseHill infection, n(%)111 (39.4)42 (36.8)0.511Cirrhoss, n (%)72 (2.1)47 (21.3)0.318Portal hypertension, n(%)39 (13.9)32 (14.3)0.833Splenomegaly, n (%)39 (13.6)29 (13.0)0.833Statosis, n (%)62.018 (3.6)0.333Iaboratory examination7.60.022Preoperative serum alburnin level, (mean ± 50), g/L9.099 ± 7.630.014.4)0.022Postoperative CKM82.01 (9.4)2.4 (1.56.3)0.027Postoperative KCM82.01 (9.4)2.4 (1.56.3)0.027Postoperative KCM82.01 (9.4)2.4 (1.56.3)0.027Postoperative CKM82.01 (9.4)0.44 (1.56.3)0.027Postoperative CKM82.01 (9.4)0.3331.60.027Postoperative CKM82.01 (9.4)0.0280.0270.027Postoperative CKM82.01 (9.4)0.0280.0270.028Liner Issici0.010.9360.0270.027Postoperative CKM82.01 (9.4)0.010.0280.027Dariage quibe, (OR m)1.11 (4.21)0.6 (3.10)0.9360.012Liner Issici1.11 (4.21)1.6 (3.1) (1.0)0.0210.012Dariage quibe, (OR)1.01 (2.2)0.0210.0220.022Postoperative CMC, Minh2.02 (50.420)2.00 (2.6)0.012Liner Iss	Coronary heart disease, n (%)	23 (8.2)	20 (9.0)	0.764
Underlying liver disease         Visit disease           HBV infection, n (%)         73 (26.1)         47 (21.3)         0.511           Cirhosis, n (%)         73 (26.1)         47 (21.3)         0.893           Asches, n (%)         32 (11.4)         26 (11.7)         0.893           Splenomegaly, n (%)         32 (13.4)         29 (13.0)         0.853           Stackes, n (%)         8 (13.6)         29 (13.0)         0.853           Laboratory examination         Preoperative serum albumin level, (mean ± 5D), g/L         909 ± 7.63         40.5 ± 4.64         0.020           Pestoperative serum albumin level, (mean ± 5D), g/L         29 (19, 4.8)         24 (1.56, 3.9)         0.027           Pestoperative StMR (0R pg/ml)         65 25 (35, 119.5)         60 (30, 10.44)         0.328           Level esion	Chronic renal insufficiency, n (%)	9 (3.2)	3 (1.3)	0.186
HW Infection, n (%)111 (9.6)82 (6.8)0.511Cinhosis, n (%)73 (26.1)47 (2.3)0.318Portal hypertension, n (%)20 (11.2)0.690Splenomegaly, n (%)39 (13.9)32 (14.3)0.893Accites, n (%)8 (3.6)0.333Laboratory examination6 (2.1)8 (3.6)0.333Laboratory examination99 09 ± 7.6340.5 ± 4.640.020Postoperative (K-M629 (10, 9.4)2.4 (15.6, 3.9)0.027Postoperative (K-M620 (19.4)2.4 (15.6, 3.9)0.027Postoperative (K-M62002.53.5Liver (Ission2501883.6Surgery characteristics184Tumor size, (IQR cm)6 (3.3, 10)6 (4.10)0.966Charage tumo, n(%)14 (4.2.1)86 (38.6)0.417Bilateral subcostal incision54 (19.3)7 (25.6)0.021Pariage tumo, (QR)1.(1,2)1.1,2)0.011Pruine partenting, n(%)263 (93.9)204 (91.5)0.232Operative time, (QR min)20.25,4002.0220.612Laparotomy, n(%)253 (93.9)24 (42.2)0.512Portal hypertension **, n(%)263 (93.9)204 (91.5)0.292Microwave ablation, n (%)75 (26.8)54 (24.2)0.512Portal turd adamping portod, (QR min)0.0,120.0120.012Associated extrepative procedures, n (%)263 (93.9)204 (91.5)0.292Combined intravenous inhalational	Underlying liver disease			
Cirrhosis, n (%)73 (26.1)47 (21.3)0.318Portal hypertension, n (%)32 (11.4)26 (1.7)0.690Splenomegaly, n (%)32 (14.3)0.893Ascites, n (%)38 (13.6)29 (13.0)0.853Steatosis, n (%)6.2.1)8 (3.6)0.333Laboratory examination"""""""""""""""""""""""""""""""""	HBV infection, n (%)	111 (39.6)	82 (36.8)	0.511
Portal hypertension, n(%)32 (11.4)26 (11.7)0.690Splenomegaly, n(%)39 (13.9)32 (14.3)0.933Acches, n(%)6 (1.0)8 (3.6)0.333Laboratory examination909±7.6340.5±.4.640.020Postoperative CK-MB2.9 (1.9, 4.8)2.4 (1.56, 3.9)0.027Postoperative Str.MB2.9 (1.9, 4.8)2.4 (1.56, 3.9)0.027Postoperative BNP, (QR pg/ml)65.25 (35, 119.5)6.0 9 (3.0 104.4)0.328Liver lesion031Ensign30351Malign2.0 (0.8, cm)64.10)0.986Tumor size, (QR cm)6 (3.3, 10)6 (4, 10)0.986Tumor size, (QR cm)6 (3.3, 10)6 (4, 10)0.986Tumor size, (QR cm)54 (19.3)57 (25.6)0.093Prelate subcostal incision54 (19.3)2.0 (25.0)0.010Prainage tube, (QR)1 (1, 2)1 (1, 2)0.701Tube chainage, n(%)2.0 (25.0, 42.0)2.0 (25.0, 42.0)0.012Derature im, (%)32 (25.0, 42.0)0.0120.2120.212Portal triad clamping period, (QR min)2.0 (20.2)2.0 (20.2)0.010Ansettic characteristics7771.0 (21.2)0.012Portal triad clamping period, (QR min)6.0 (22.2)3.0 (20.0)0.012Associated extrahepatic procedures*, n(%)6.0 (20.2)7.20.012Intraoperative hypotension**, n(%)6.0 (25.0, 30.0)7.0 (21.0)0.012In	Cirrhosis, n (%)	73 (26.1)	47 (21.3)	0.318
Splenomegaly, n (%)39 (13.9)32 (14.3)0.893Acttes, n (%)38 (13.6)29 (13.0)0.853Steatosis, n (%)6 (2.1)8 (3.6)0.333Laboratory examination909 ± 7.6340.5 ± 4.640.020Postoperative serum alkumin level, (mean ± 5D, g/L)29 (19, 4.8)24 (156, 3.9)0.027Postoperative BNF, (QR pg/m)62 (25 (35, 119.5)60.9 (0.44.4)0.238Liver lesion2501818Surgery characteristics70.86 (3.6.0)0.417Tumor number ≥ 2, n(%)6 (3.1, 0)6 (4, 10)0.986Tumor number ≥ 2, n(%)118 (42.1)86 (38.6)0.417Bitarel Subcostal incision4 (19.3)7 (25.6)0.093Hemihepatectomy, n(%)10 (1, 2)1 (1, 2)0.236Drainage tube, (QR m)263 (03.9)204 (91.5)0.229Microwae ablation, n (%)75 (26.8)54 (24.2)0.512Drainage tube, (QR min)0.0, 12)0.1210.326Derative time, (QR min)0.0, 12)0.1210.326Derative time, (QR min)0.0, 12)0.1210.321Asociated extrahepatic procedures*, n (%)2533592+0.910.723Intraoperative hypotension*, n (%)272727Combined intravenous inshalational anesthesia2727Combined intravenous inshalational anesthesia258 64:2.233592+0.910.723Intraoperative hypotension*, n (%)28 (62,7.28)3592+0.910.723 <td< td=""><td>Portal hypertension, n (%)</td><td>32 (11.4)</td><td>26 (11.7)</td><td>0.690</td></td<>	Portal hypertension, n (%)	32 (11.4)	26 (11.7)	0.690
Ascies, n (%)38 (13.6)29 (13.0)0.853Steatosis, n (%)(.1)8 (3.6)0.353Steatosis, n (%)39.09 ± 7.6340.5 ± 4.640.020Postoperative Schmalbumin level, (mean ± SD), g/L39.09 ± 7.6340.5 ± 4.640.020Postoperative Schmalbumin level, (mean ± SD), g/L39.09 ± 7.6360.9 (3.0104.4)0.328Liver lesion	Splenomegaly, n (%)	39 (13.9)	32 (14.3)	0.893
Steatosis, n (%)6 (2.1)8 (3.6)0.333Laboratory examination39.09 ± 7.6340.5 ± 4.640.027Preoperative serum albumin level, (mean ± SD), g/L39.09 ± 7.6340.5 ± 4.640.027Postoperative CK-MB2.9 (1.9, 4.8)2.4 (1.5, 5.3)0.027Postoperative SNP, (QR pg/m)65.25 (35, 119.5)60.9 (30, 104.4)0.328Liver lesion3035Malign3035Surgery characteristics1819.00.96Tumor size, (QR cm)6 (3.3, 10)6 (4.10)0.968Tumor size, (QR cm)6 (3.3, 10)6 (3.8, 0.04170.97Bilateral subcostal incision11.8 (42.1)86 (38.6)0.417Bilateral subcostal incision54 (19.3)57 (25.6)0.093Hem ihepatectomy, n(%)88 (31.4)74 (33.2)0.676Drainage tube, (QR)11.2, 2)11.2, 2)0.710Tutbe drainage, n(%)320 (250, 420)200 (25.360)<0.001	Ascites, n (%)	38 (13.6)	29 (13.0)	0.853
Laboratory examinationPreoperative serum allomin level, (mean ± SD), g/L3909 ± 7.6340.5 ± 6.640.020Postoperative CK-MB2.9 (1,9,4.8)2.4 (1.56,3.9)0.027Postoperative RNP, (0R pg/ml)6.25 (35, 119.5)0.9 (30,104.4)0.328Liver lesion353535Malign20 (1.0 × 0.05)1.8 (2.0 × 0.05)0.018Surgery characteristics510.0190.018Tumor size, (0R cm)6 (3.3, 10)6 (4, 10)0.986Tumor number ≥ 2, n(%)118 (42.1)86 (38.6)0.417Bilateral subcostal incision54 (12.2)0.0210.026Deniage tube, (0R)1 (1, 2)1 (1, 2)0.011Tube company, n(%)36 (31.4)74 (33.2)0.676Deniage tube, (0R)1 (1, 2)21 (9.5)0.326Deniage tube, (0R, min)320 (250, 420)204 (21.5)0.202Microwave ablation, n (%)75 (26.8)54 (24.2)0.512Portal triad clamping period, (0R min)0.0, 12)0.0, 12)0.012Associade extrahepatic procedures r, n(%)272727Combined intravenous inhalational anesthesia272727Combined intravenous inhalational anesthesia25335.92±0.910.021Intraoperative hypotension**, n(%)62 (22.2)35.02 ±0.910.020Diado doss, (0R, 1)1.28 (0.51, 2.40)100 (0.50, 1.80)0.001Bilateral substision volume, (0R, 1)1.28 (0.51, 2.40)100 (0.50, 1.80)0.001<	Steatosis, n (%)	6 (2.1)	8 (3.6)	0.333
Preoperative serum albumin level, (mean ± SD), g/L         39.09 ± 7.63         40.5 ± 4.64         0.020           Postoperative CK-MB         2.9 (1.9, 4.8)         2.4 (1.56, 3.9)         0.027           Postoperative BNP, (QR pg/ml)         65.25 (35, 119.5)         60.9 (30, 104.4)         0.328           Liver lesion         30         35	Laboratory examination			
Postoperative CK-MB         2.9 (1.9, 4.8)         2.4 (1.56, 3.9)         0.027           Postoperative BNP, (IQR pg/ml)         65.25 (35, 119.5)         60.9 (30, 104.4)         0.328           Liver lesion         0.098         8         0.093         35           Malign         250         188         1.009         9.001         9.	Preoperative serum albumin level, (mean±SD), g/L	$39.09 \pm 7.63$	$40.5 \pm 4.64$	0.020
Portoperative BNP, (IQR pg/ml)         6525 (35, 119.5)         60.9 (30, 104.4)         0.328           Liver lesion         0.098           Benign         30         35           Malign         250         188           Surgery chracteristics         1         198           Tumor size, (IQR cm)         6 (3.3, 10)         6 (4, 10)         0.986           Tumor number 2.2, n(%)         118 (42.1)         86 (38.6)         0.417           Bilateral subcostal incision         54 (19.3)         7 (25.6)         0.093           Hemihepatectomy, n(%)         88 (31.4)         7 (3.2)         0.676           Drainage tube, (IQR)         1 (1, 2)         1 (1, 2)         0.701           T-tube drainage, n(%)         34 (12.2)         21 (9.5)         0.326           Operative time, (IQR min)         202 (250, 420)         202 (25, 360)         <0.001	Postoperative CK-MB	2.9 (1.9, 4.8)	2.4 (1.56, 3.9)	0.027
Liver lesion       0.098         Benign       30       35         Malign       250       188         Surgery characteristics       1       186         Tumor size, (QR cm)       6 (3.3, 10)       6 (4, 10)       0.986         Tumor number ≥ 2, n(%)       118 (42.1)       86 (38.6)       0.417         Blateral subcostal incision       54 (19.3)       57 (25.6)       0.093         Hemihepatectomy, n(%)       88 (31.4)       74 (33.2)       0.676         Drainage tube, (QR)       1 (1, 2)       1 (1, 2)       0.701         Tube drainage, n(%)       320 (250, 420)       290 (225, 360)       <0.001	Postoperative BNP, (IQR pg/ml)	65.25 (35, 119.5)	60.9 (30, 104.4)	0.328
Benign3035Malign250188Surgery characteristicsTumor size, (0R cm)6 (3, 10)6 (4, 10)0,903Tumor size, (0R cm)6 (3, 10)8 6 (38.6)0,417Bilateral subcostal incision54 (19.3)57 (25.6)0.093Hemihepatectomy, n(%)54 (19.3)74 (33.2)0,676Drainage tube, (0R)1 (1, 2)1 (1, 2)0,701T-tube drainage, n(%)34 (12.2)20 (25, 360)<0,002	Liver lesion			0.098
Main Diamon Surgery characteristics250188Surgery characteristics50.986Tumor number ≥ 2, n(%)6 (3.3, 10)6 (4, 10)0.986Blateral subcostal incision54 (19.3)57 (25.6)0.093Hemihepatectomy, n(%)88 (31.4)74 (32.2)0.676Drainage tube, (IQR)1 (1, 2)1 (1, 2)0.701T-tube drainage, n(%)34 (12.2)21 (9.5)0.326Operative time, (IQR min)220 (250, 420)290 (225, 360)<0.001	Benian	30	35	
Surgery characteristics Tumor size, (IQR cm) 6 (3.3, 10) 6 (4, 10) 0.986 Tumor number ≥ 2, n(%) 118 (42.1) 86 (38.6) 0.417 Bilateral subcostal incision 54 (19.3) 57 (25.6) 0.093 Hemihepatectomy, n(%) 88 (31.4) 74 (33.2) 0.676 Drainage tube, (IQR) 1 (1, 2) 1 (1, 2) 0.701 T-tube drainage, n(%) 34 (12.2) 21 (9.5) 0.326 Operative time, (IQR min) 200 (250, 420) 290 (225, 360) <0.001 Laparotomy, n (%) 263 (93.9) 204 (91.5) 0.292 Microwave ablation, n (%) 75 (26.8) 54 (24.2) 0.512 Portal triad clamping period, (IQR min) 0 (0, 12) 0 (0, 12) 0 (0, 12) 0.212 Associated extrahepatic procedures*, n (%) 106 (37.9) 00 (26.9) 0.010 Anesthetic characteristics General anesthesia method 27 Total intravenous inhalational anesthesia 27 Combined intravenous inhalational anesthesia 253 196 Intraoperative hypotension**, n (%) 62 (22.2) 27 (12.1) 0.004 Temperature, (mean ± SD),°C 358 d± 2.23 35.92 ± 0.91 0.723 Intraoperative infusion volume, (IQR L) 481 (3.50, 7.28) 4.20 (3.10, 5.70) <0.001 Blood loss, (QR L) 1.28 (0.51, 2.40) 1.00 (0.50, 1.80) 0.009 Urine volume, (IQR L) A81 (3.50, 7.28) 4.20 (3.10, 5.70) <0.001 Intraoperative infusion volume, (IQR L) 380 (0.55, 1.30) 0.75 (0.45, 1.05) 0.012 Nerve block, n (%) 11(1) 32 (14.4) 0.263 Intraoperative or postoperative blood transfusion, n (%) 221 (78.9) 150 (67.3) 0.003	Malign	250	188	
Lumor size, (QR cm)6 (3, 10)6 (4, 10)0.986Tumor number ≥ 2, n(%)118 (42.1)86 (38.6)0.417Bilateral subcostal incision54 (19.3)57 (25.6)0.093Hemihepatectomy, n(%)88 (31.4)74 (33.2)0.676Drainage tube, (QR)1 (1, 2)1 (1, 2)0.701T-tube drainage, n(%)34 (12.2)21 (9.5)0.326Operative time, (IQR min)320 (250, 420)290 (225, 360)<0.001	Surgery characteristics			
Tumor number 2, 2, n(%)       118 (42.1)       86 (38.6)       0.417         Bilateral subcostal incision       54 (19.3)       57 (25.6)       0.093         Hemihepatectomy, n(%)       88 (31.4)       74 (33.2)       0.676         Drainage tube, (QR)       1 (1, 2)       1 (1, 2)       0.701         T-tube drainage, n(%)       34 (12.2)       21 (9.5)       0.326         Operative time, (QR min)       320 (250, 420)       290 (225, 360)       <0.001	Tumor size. (IOR cm)	6 (3.3, 10)	6 (4, 10)	0.986
Bilateral subcostal incision       F4 (19.3)       57 (25.6)       0.093         Hemihepatectomy, n(%)       88 (31.4)       74 (33.2)       0.676         Drainage tube, (IQR)       1 (1, 2)       1 (1, 2)       0.701         T-tube drainage, n(%)       34 (12.2)       21 (9.5)       0.326         Operative time, (IQR min)       320 (250, 420)       290 (225, 360)       <0.001	Tumor number > 2, n(%)	118 (42.1)	86 (38.6)	0.417
Hemihepatectomy, n(%)       88 (31.4)       74 (33.2)       0.676         Drainage tube, (IQR)       1 (1, 2)       1 (1, 2)       0.701         T-tube drainage, n(%)       34 (12.2)       21 (9.5)       0.326         Operative time, (IQR min)       320 (250, 420)       290 (225, 360)       <0.001	Bilateral subcostal incision	54 (19.3)	57 (25.6)	0.093
Drainage tube, (IQR)       1 (1, 2)       1 (1, 2)       0.701         T-tube drainage, n(%)       34 (12.2)       21 (9.5)       0.326         Operative time, (IQR min)       320 (250, 420)       290 (225, 360)       <0001	Hemihepatectomy, n(%)	88 (31.4)	74 (33.2)	0.676
T-tube drainage, n(%)       34 (12.2)       21 (9.5)       0.326         Operative time, (IQR min)       320 (250, 420)       290 (225, 360)       <0001	Drainage tube (IOB)	1 (1 2)	1 (1 2)	0 701
Operative time, (IQR min)       320 (250, 420)       290 (225, 360)       <0.001	T-tube drainage n(%)	34 (12 2)	21 (9 5)	0.326
Laparotomy, n (%)         Dec (us), n(x)         Dec	Operative time (IOR min)	320 (250, 420)	290 (225, 360)	< 0.001
Laplaced (I) (1,1)       Last (2,13)       Last (2,13)       Last (2,13)       Last (2,13)       Last (2,13)         Microwave ablation, n (%)       75 (26.8)       54 (24.2)       0.512         Portal triad clamping period, (IQR min)       0 (0, 12)       0 (0, 12)       0.212         Associated extrahepatic procedures*, n (%)       106 (37.9)       60 (26.9)       0.010         Anesthetic characteristics	Laparotomy n (%)	263 (93.9)	204 (91 5)	0.292
Portal triad clamping period, (IQR min)       0 (0, 12)       0 (0, 12)       0 (0, 12)         Associated extrahepatic procedures*, n (%)       106 (37.9)       60 (26.9)       0.010         Anesthetic characteristics       General anesthesia method         Total intravenous anesthesia       27       27         Combined intravenous inhalational anesthesia       253       196         Intraoperative hypotension**, n (%)       62 (22.2)       27 (12.1)       0.004         Temperature, (mean ± SD),°C       35.86 ± 2.23       35.92 ± 0.91       0.723         Intraoperative infusion volume, (IQR L)       4.81 (3.50, 7.28)       4.20 (3.10, 5.70)       <0.001	Microwave ablation n (%)	75 (26.8)	54 (24 2)	0.512
Associated extrahepatic procedures*, n (%)       106 (37.9)       60 (26.9)       0.010         Anesthetic characteristics       0.376         General anesthesia method       27       27         Combined intravenous anesthesia       253       196         Intraoperative hypotension**, n (%)       62 (22.2)       27 (12.1)       0.004         Temperature, (mean ± SD),°C       35.86 ± 2.23       35.92 ± 0.91       0.723         Intraoperative infusion volume, (IQR L)       4.81 (3.50, 7.28)       4.20 (3.10, 5.70)       <0.001	Portal triad clamping period (IOR min)	0 (0 12)	0 (0, 12)	0.212
Anesthetic characteristics       0.376         General anesthesia method       27         Total intravenous anesthesia       253         Intraoperative hypotension**, n (%)       62 (22.2)         Intraoperative hypotension**, n (%)       62 (22.2)         Temperature, (mean ± SD),°C       35.86 ± 2.23         Intraoperative infusion volume, (IQR L)       4.81 (3.50, 7.28)         Blood loss, (IQR L)       1.28 (0.51, 2.40)         Urine volume, (IQR L)       0.80 (0.55, 1.30)         Nerve block, n (%)       31 (11.1)         Intraoperative or postoperative blood transfusion, n (%)       221 (78.9)         Intraoperative or postoperative blood transfusion, n (%)       221 (78.9)	Associated extrahenatic procedures* n (%)	106 (37 9)	60 (26 9)	0.010
General anesthesia method       0.376         Total intravenous anesthesia       27       27         Combined intravenous inhalational anesthesia       253       196         Intraoperative hypotension**, n (%)       62 (22.2)       27 (12.1)       0.004         Temperature, (mean ± SD),°C       35.86 ± 2.23       35.92 ± 0.91       0.723         Intraoperative infusion volume, (IQR L)       4.81 (3.50, 7.28)       4.20 (3.10, 5.70)       <0.001	Anesthetic characteristics	100 (37.5)	00 (20.3)	0.010
Total intravenous anesthesia       27       27         Combined intravenous inhalational anesthesia       253       196         Intraoperative hypotension**, n (%)       62 (22.2)       27 (12.1)       0.004         Temperature, (mean ± SD),°C       35.86 ± 2.23       35.92 ± 0.91       0.723         Intraoperative infusion volume, (IQR L)       4.81 (3.50, 7.28)       4.20 (3.10, 5.70)       <0.001	General anesthesia method			0 376
Combined intravenous inhalational anesthesia       257       27         Intraoperative hypotension**, n (%)       62 (22.2)       27 (12.1)       0.004         Temperature, (mean ± SD),°C       35.86 ± 2.23       35.92 ± 0.91       0.723         Intraoperative infusion volume, (IQR L)       4.81 (3.50, 7.28)       4.20 (3.10, 5.70)       <0.001	Total intravenous anesthesia	27	27	0.570
Intraoperative hypotension**, n (%)       62 (22.2)       27 (12.1)       0.004         Temperature, (mean ± SD),°C       35.86 ± 2.23       35.92 ± 0.91       0.723         Intraoperative infusion volume, (IQR L)       4.81 (3.50, 7.28)       4.20 (3.10, 5.70)       <0.001		27	106	
Temperature (mean ± SD),°C       35.86 ± 2.23       35.92 ± 0.91       0.723         Intraoperative infusion volume, (IQR L)       4.81 (3.50, 7.28)       4.20 (3.10, 5.70)       <0.001		200 62 (22 2)	27 (12 1)	0.004
Intraoperative infusion volume, (IQR L)       4.81 (3.50, 7.28)       4.20 (3.10, 5.70)       < 0.001	Tomporature (moan $\pm$ SD) °C	35 86 + 2 23	27(12.1) $35.02 \pm 0.01$	0.004
Hitradperative initiation volume, (IQR L)       4.81 (S.50, 7.28)       4.20 (S.10, 5.70)       < 0.001		4 91 (2 EO 7 29)	4 20 (2 10 5 70)	< 0.001
Incode ross, (ign E)       1.26 (0.51, 2.40)       1.00 (0.50, 1.60)       0.009         Urine volume, (IQR L)       0.80 (0.55, 1.30)       0.75 (0.45, 1.05)       0.012         Nerve block, n (%)       31 (11.1)       32 (14.4)       0.263         Intraoperative or postoperative blood transfusion, n (%)       221 (78.9)       150 (67.3)       0.003         ICL first day infusion volume (IOR L)       6.91 (5.25, 9.47)       5.96 (4.59, 7.75)       < 0.011		4.01 (J.JU, 7.20) 1.28 (0.51, 2.40)	4.20 (3.10, 3.70)	< 0.001
Online volume, (iQN L)         0.80 (0.55, 1.50)         0.75 (0.45, 1.05)         0.012           Nerve block, n (%)         31 (11.1)         32 (14.4)         0.263           Intraoperative or postoperative blood transfusion, n (%)         221 (78.9)         150 (67.3)         0.003           ICLL first day infusion volume (IOR L)         691 (5.25, 9.47)         5.96 (4.59, 7.75)         <0.001		1.20 (U.31, 2.4U)	1.00 (0.20, 1.00) 0.75 (0.45, 1.05)	0.009
Intraoperative or postoperative blood transfusion, n (%)       221 (78.9)       150 (67.3)       0.003         ICLL first day infusion volume (IOR L)       6.01 (5.25.0.47)       5.96 (4.50.7.75)       0.001	Narve black p (0()	0.00 (0.33, 1.30)	0.75 (0.45, 1.05)	0.012
Initiaciperative or postoperative or pos	Interve DIUCK, II (70)	) (II.I) ) ) (II.I)	32 (14.4) 150 (67.2)	0.203
	ICLI first day infusion volume (ICP L)	22 I (70.9) 6 01 (5 25 0 47)	5 86 (1 50 7 75)	0.005 - 0.001

Data are expressed as mean $\pm$ SD, median (interquartile range), or number (%). PPCs: postoperative pulmonary complications, IQR: inter quartile range, BMI: body mass index, CK-MB: creatine kinase MB, BNP: brain natriuretic peptide. \*  $\geq$ 1 associated procedures in the same patient. \*\*Vasoactive drugs were pumped intraoperatively to maintain blood pressure

## Table 4 Risk factors for PPCs: multivariate analysis

Variable	β	Wald	OR	[95% CI]	Р
Age	0.025	7.057	1.026	1.007-1.045	0.008
BMI	0.130	17.843	1.139	1.072-1.210	0.000
Diabetes	0.296	1.210	1.344	0.794-2.277	0.271
Hypertension	0.462	3.763	1.588	0.995-2.533	0.052
Preoperative serum albumin level	-0.040	4.368	0.961	0.925-0.998	0.037
Postoperative CK-MB	-0.014	0.127	0.986	0.915-1.064	0.721
Liver lesion	0.259	0.697	1.296	0.705-2.379	0.404
Bilateral subcostal incision	-0.215	0.812	0.806	0.505-1.288	0.367
Operative time	0.002	1.644	1.002	0.999-1.004	0.200
Associated extrahepatic procedures	0.350	2.493	1.419	0.919-2.191	0.114
Intraoperative hypotension	0.418	2.019	1.519	0.853-2.703	0.155
Intraoperative infusion volume	0.004	0.007	1.004	0.907-1.112	0.933
Blood loss	-0.107	1.099	0.899	0.736-1.098	0.295
Urine volume	0.069	0.129	1.072	0.734-1.566	0.720
Intraoperative or postoperative blood transfusion	0.268	1.090	1.308	0.790-2.164	0.296
ICU first day infusion volume	0.142	4.204	1.152	1.006-1.319	0.040

PPCs: postoperative pulmonary complications, OR: Odds ratio, BMI: Body mass index, CK-MB: creatine kinase MB. Odds ratios show the relative incremental risk of each complication when the predictive factor is present. Logistic regression provides 95% confidence intervals as an estimation of relative risk in the general population

Points	0	10	2	0 :	30	40	50	60	70		BO	90	100
Age (years)	20	30 40	50	60 70	80 9	0							
Preoperative serum albumin level (g/L)	140	130	120	110	100 9	0 8	0 70	60	50	40	30	20	10
BMI	12	16	20	24	28	3	2 3	6 4	0				
ICU first day infusion volume (L)	0	ţ	5	10	15		20	25		30	3	5	
Total Points	0	20	40	60	80	100	120	140	160	180	200	220	240
Predicted probability of PPCs					0.	05 0.1	0.2 0.3	0,40,50.6 (	0.7 0.8	0.9 0.5	)5	0.99	

Fig. 2 Nomogram for occurrence of PPCs. To estimate the probability of PPCs, mark patient values at each axis, draw a straight line perpendicular to the point axis, and sum the points for all variables. Next, mark the sum on the total point axis and draw a straight line perpendicular to the probability axis. BMI, Body Mass Index. PPCs, Postoperative pulmonary complications



Fig. 3 Receiver operating characteristic curve for the prediction model Area under the curve was 0.713 (95% confidence interval 0.668–0.758)

In this retrospective study, we observed that PPCs occurred in 55.7% of the critical patients admitted in the ICU after hepatectomy. The rates of overall pleural effusion, respiratory failure, atelectasis, respiratory infection, pneumothorax, aspiration pneumonitis, and bronchospasm were 42.5% (n=214), 31.7% (n=159), 22.5% (n=113), 11.1% (n=56), 0.4% (n=2), 0.2% (n=1), and 0% (n=0), respectively. The incidence of PPCs in our study was higher than that in previous studies [8, 16, 17], which is due to the fact that all patients in our study were critical, and their overall situation after surgery was more complicated. The presence of PPCs was significantly associated with increased postoperative mortality, longer mechanical ventilation time, and prolonged length of stay (LOS) in the ICU and hospital.

In this study, we identified four independent risk factors of PPCs, including advanced age, higher BMI, lower preoperative serum albumin level, and ICU first day infusion volume.

Advanced age as a predictor of PPCs has been proven by previous studies. Several studies [18, 19] have found that age>60 or 65 years is a risk factor for PPCs, which is in agreement with our finding that age was positively correlated with the occurrence of PPCs. In the elderly, elastic fibers around alveoli and capillaries gradually decrease, and the lung tissue elasticity weakens and the retractive ability decreases. Moreover, arteriosclerosis occurs, vascular lumens become thinner, and the number of capillary networks decreases, resulting in reduced pulmonary blood flow, and reduced effective exchange area of the respiratory membrane, all of which greatly weaken lung function in the elderly. However, some studies have also suggested that frailty may be closely related to PPCs in the elderly, and frailty may be a confounding factor between age and PPCs. Future research could further attempt to differentiate frail and non-frail patients in the elderly.

There is mixed evidence about whether higher BMI is a risk of PPCs in the previous literature. Although some studies have shown that obesity conferred a protective factor against PPCs [20, 21], they stress that BMI does not consider an individual's body size, and that



Fig. 4 Calibration of the nomogram for PPCs. The x-axis shows the predicted probability of PPCs, and the y-axis shows the observed probability of PPCs. Postoperative pulmonary complications

chest size is more predictive than absolute BMI. In our study, increasing BMI was found to be predictive of PPCs. Obesity causes decreased chest wall compliance, decreased lung volumes, increased oxygen consumption, and increased airway resistance [22–24]. As our study focused on critical patients, the impact of obesity is even more pronounced.

Hypoalbuminemia was also found to be a risk factor for PPCs in our study, which is in agreement with several previous studies [25–27]. The serum albumin level represents the patients' general nutritional status and their liver reserve function [28], and albumin is responsible for various biological functions. Decreased albumin concentrations inhibit the activation of macrophages, impair the immune response, and increase susceptibility to infection [29]. Besides, hypoalbuminemia reduces plasma colloid osmotic pressure, causing pulmonary edema and pleural effusion and making the lungs susceptible to infection [23, 30].

ICU first day infusion volume in our study means the 24 h infusion volume of the operative day. On one hand,

the infusion volume often corelated with the surgery trauma and the hypotension. Larger trauma would cause the severer inflammatory response that would trigger more complications of the patients. And the hypotension is followed by tissue hypoperfusion, which increases postoperative morbidity and mortality [31, 32]. On the other hand, the infusion volume is associated with the clinician's cognition and habit of the fluid management and resuscitation. More fluid infusion often associated with the more serious edema that would give rise to the pulmonary edema and the abdominal edema and swelling, eventually, these lead to PPCs. And limited fluid resuscitation has gained more international recognition in recent years [33]. This study also supports the clinical implementation of restricted fluid resuscitation.

Risk factors are generally divided into two categories: modifiable factors and unmodifiable factors. In our study, the modifiable factors include preoperative serum albumin level and ICU first day infusion while the unmodifiable factors include age and BMI. To reduce the PPCs, a more aggressive human albumin infusion before surgery to elevate the preoperative serum albumin level may be beneficial and the restricted fluid management and resuscitation would help to reduce the PPCs [34–36]. However, all these findings need to be further verified by conducting large-scale prospective randomized controlled trials.

Meanwhile, we create a nomogram to predict the occurrence of PPCs after hepatectomy in critical patients. The nomogram is composed of age, BMI, preoperative serum albumin level and ICU first day infusion volume, and can be fully utilized soon after surgery. When patients with higher probability of PPCs identified by the nomogram, they should be monitored more carefully during the postoperative period. More aggressive lung revascularization, protein supplementation, and fluid restriction may be helpful. To the best of our knowledge, until now there is no study has build a nomogram for PPCs in these patients after hepatectomy especially in the critical patients.

This study has several limitations. First, this is a singlecenter retrospective study and the lack of reliable information about pulmonary functional tests did not allow precise assessment of the severity of the underlying pulmonary disease. Second, as the sample size of the study was modest, a lack of power is plausible. Third, for our nomogram external validation is required and furthermore, this model would better be developed into both a user-friendly web-based decision aid platform to assist clinicians.

## Conclusion

PPCs which are common after hepatectomy, were found to be significantly associated with increased postoperative mortality, longer mechanical ventilation time, and prolonged LOS in the ICU and hospital. Advanced age, higher BMI, lower preoperative serum albumin, and the ICU first day infusion volume were independent risk factors for PPCs in critical patients after hepatectomy. And we created a nomogram model which can be used to predict the occurrence of PPCs.

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Not applicable.

#### **Author Contribution**

(I) Conception and design: B Wang, HS Liang, Y Feng, YZ An; (II) Administrative support: YZ An; (III) Provision of study materials or patients: B Wang, HY Zhao, JW Sheng; (IV) Collection and assembly of data: B Wang; (V) Data analysis and interpretation: B Wang, JW Sheng, HY Zhao; (VI) Manuscript writing: All authors; (VII) Final approval of manuscript: All authors.

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#### **Data Availability**

The datasets used during the current study available from the corresponding author on reasonable request.

#### Declarations

#### Ethics approval and consent to participate

This retrospective study was approved by the Ethics Committee of Peking University People's Hospital. All methods were carried out in accordance with institutional guidelines and regulations. Due to the retrospective nature of the study, the need for informed consent was waived by the Ethics Committee of Peking University People's Hospital.

#### **Consent for publication**

Not applicable.

#### **Competing interests**

The authors have no competing interests to declare.

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#### References

- Karalapillai D, Weinberg L, Peyton P, et al. Effect of intraoperative low tidal volume vs conventional tidal volume on postoperative pulmonary complications in patients undergoing major surgery: a randomized clinical Trial[J]. JAMA The Journal of the American Medical Association, 2020, 324(9):848.
- Collaborative C, Collaborative G S. Effects of pre-operative isolation on postoperative pulmonary complications after elective surgery: an international prospective cohort study[J]. Anaesthesia, 2021, 76(11):1454–1464.
- Togioka B M, Yanez D, Aziz M F, et al. Randomised controlled trial of sugammadex or neostigmine for reversal of neuromuscular block on the incidence of pulmonary complications in older adults undergoing prolonged surgery[J]. British journal of anaesthesia, 124(5):553–561.
- Nobili C, Marzano E, Oussoultzoglou E, et al. Multivariate analysis of risk factors for pulmonary complications after hepatic resection. Ann Surg 2012; 255:540–50.
- Topaloglu S, Inci I, Calik A, et al. Intensive pulmonary care after liver surgery: a retrospective survey from a single center. Transpl P 2013; 45:986–92.
- Garrouste-Orgeas M, Flahault C, Vinatier I, et al. Effect of an ICU Diary on Posttraumatic stress disorder symptoms among patients receiving mechanical ventilation: a randomized clinical Trial[J]. JAMA The Journal of the American Medical Association, 2019, 322(3):229.
- Patel B K, Pohlman A S, Hall J B, et al. Impact of early mobilization on glycemic control and ICU-acquired weakness in critically ill patients who are mechanically ventilated.[J]. Chest, 2014, 146(3):583–589.
- 8. Lepere V, Vanier A, Loncar Y, et al. Risk factors for pulmonary complications after hepatic resection: role of intraoperative hemodynamic instability and hepatic ischemia. Bmc Anesthesiol 2017; 17:84.
- Fuks D, Cauchy F, Ftériche S, et al. Laparoscopy decreases pulmonary complications in patients undergoing Major Liver Resection: a propensity score analysis. Ann Surg 2016; 263:353–61.
- 10. Choudhuri AH, Chandra S, Aggarwal G, et al. Predictors of postoperative pulmonary complications after liver resection: results from a tertiary care intensive care unit. Indian J Crit Care M 2014; 18:358–62.
- Zhang S D, Surgery D O, Hospital R, et al. Formalized therapeutic guideline for hyperlipidemic severe acute pancreatitis[J]. World Journal of Gastroenterology 2003; 9(11):5.
- Parviainen I, Herranen A, Holm A, et al. Results and costs of intensive care in a tertiary university hospital from 1996–2000[J]. Acta Anaesthesiologica Scandinavica, 2010, 48(1):55–60.
- 13. Jammer I, Wickboldt N, Sander M, et al. Standards for definitions and use of outcome measures for clinical effectiveness research in perioperative medicine: european Perioperative Clinical Outcome (EPCO) definitions: a statement from the ESA-ESICM joint taskforce on perioperative outcome measure. Eur J Anaesth 2015; 32:88–105.
- 14. Bijker JB, Persoon S, Peelen LM, et al. Intraoperative hypotension and perioperative ischemic stroke after general surgery: a nested case-control study. Anesthesiology 2012; 116:658–64.
- Ondrej J, Jan M, Jirina K, et al. Hypotension after induction of general anesthesia: occurrence, risk factors, and therapy. A prospective multicentre observational study. J Anesth 2018; 32:673–80.

- S Südfeld, Brechnitz S, Wagner JY, et al. Post-induction hypotension and early intraoperative hypotension associated with general anaesthesia. Brit J Anaesth 2017; 119:57–64.
- Dan H, Szab A, Zy B, et al. Lung protective ventilation strategy to reduce postoperative pulmonary complications (PPCs) in patients undergoing robot-assisted laparoscopic radical cystectomy for bladder cancer: a randomized double blinded clinical trial[J]. Journal of Clinical Anesthesia, 71.
- Li C, Yang WH, Zhou J, et al. Risk factors for predicting postoperative complications after open infrarenal abdominal aortic aneurysm repair: results from a single vascular center in China. J Clin Anesth 2013; 25:371–8.
- Blum JM, Stentz MJ, Dechert R, et al. Preoperative and intraoperative predictors of postoperative acute respiratory distress syndrome in a general surgical population. Anesthesiology 2013; 118:19–29.
- Yang CK, Teng A, Lee DY, et al. Pulmonary complications after major abdominal surgery: National Surgical Quality Improvement Program analysis. J Surg Res 2015; 198:441–9.
- Mcalister FA, Bertsch K, Man J, et al. Incidence of and risk factors for pulmonary complications after nonthoracic surgery. Am J Resp Crit Care 2005; 171:514–7.
- Covarrubias J, Grigorian A, Schubl S, et al. Obesity associated with increased postoperative pulmonary complications and mortality after trauma laparotomy. Eur J Trauma Emerg S 2020; 47:1561–8.
- Yu J, Park JY, Kim DH, et al. Incidence and risk factors of Pulmonary Complications after Robot-Assisted laparoscopic prostatectomy: a retrospective observational analysis of 2208 patients at a large single Center. J Clin Med 2019; 8:1509.
- Sudy R, Petak F, Kiss L, et al. Obesity and diabetes: similar respiratory mechanical, but different gas exchange defects[J]. AJP Lung Cellular and Molecular Physiology, 2020, 320(400).
- 25. Smetana GW. Preoperative pulmonary assessment of the older adult. Clin Geriatr Med 2003; 19:35–55.
- Poon RT, Fan ST, Lo CM, et al. Improving perioperative outcome expands the role of hepatectomy in management of benign and malignant hepatobiliary diseases: analysis of 1222 consecutive patients from a prospective database. Ann Surg 2004; 240:698–708.

Page 10 of 10

- Kor DJ, Lingineni RK, Ognjen G, et al. Predicting risk of postoperative lung injury in high-risk surgical patients: a multicenter cohort study. Anesthesiology 2014; 120:1168–81.
- 28. Qaseem T. Risk Assessment for and strategies to reduce Perioperative Pulmonary Complications. Ann Intern Med 2006; 145:553.
- China L, Freemantle N, Forrest E, et al. A Randomized Trial of Albumin Infusions in hospitalized patients with Cirrhosis[J]. New England Journal of Medicine, 2021, 384(9):808–817.
- Rivadeneira DE, Grobmyer SR, Naama HA, et al. Malnutrition-induced macrophage apoptosis. Surgery 2001; 129:617–25.
- Green RS, Butler MB. Postintubation Hypotension in General Anesthesia: a retrospective analysis. J Intensive Care Med 2016; 31:667–75.
- 32. Wijnberge, Marije, Geerts, et al. Effect of a machine learning-derived early warning system for intraoperative hypotension vs Standard Care on depth and duration of intraoperative hypotension during elective noncardiac surgery the HYPE randomized clinical trial. JAMA, 2020 Mar 17;323(11):1052–1060.
- Hjortrup PB, Haase N, Bundgaard H, et al. Restricting volumes of resuscitation fluid in adults with septic shock after initial management: the CLASSIC randomised, parallel-group, multicentre feasibility trial. Intensive Care Med 2016, 42(11):1695–1705.
- Effect of albumin In cirrhotic patients with infection other than spontaneous bacterial peritonitis. A randomized trial[J]. Journal of Hepatology, 2015, 62(4):822–830.
- Network T. Comparison of two fluid-management strategies in acute lung injury[J]. N Engl J Med, 2006 ;354(24):2564–75.
- 36. Siemionow K, Cywinski J, Kusza K, et al. Intraoperative Fluid Therapy and Pulmonary Complications[J]. Orthopedics, 2012, 35(2): e184. mation of relative risk in the general population.

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