Prediction model for postoperative pneumonia in abdominal surgery: results of an observational multicenter study

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Модель прогнозирования послеоперационной пневмонии в абдоминальной хирургии: результаты наблюдательного многоцентрового исследования

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Abstract

INTRODUCTION: Taking into account the prevalence of postoperative pneumonia and the increase in the number of surgical procedures, forecasting its development is an urgent task that allows taking measures to reduce the frequency of its occurrence by optimizing the perioperative period. Despite their value, the existing scales for predicting postoperative pneumonia do not provide domestic specialists with a reliable and consistent method by which to stratify the risk of developing postoperative pneumonia in our population. **OBJECTIVE:** To develop a model for predicting postoperative pneumonia based on the identification of risk factors for its development. **MATERIALS AND METHODS:** A multicenter prospective study of 6844 patients over 18 years of age undergoing elective abdominal surgery. 30-day mortality and postoperative pneumonia were assessed. In the first phase of the study, a comparison was made between the pneumonia and non-pneumonia group of baseline patient data, as well as factors associated with surgery and anesthesia. At the second stage of the study, a logistic regression analysis was performed to assess the contribution of factors to the development of postoperative pneumonia. At the third stage of the study, a model for predicting postoperative pneumonia was built according to the data of multivariate logistic regression analysis. At the final stage, the obtained model was compared with the forecasting models of other authors found in the world literature. **RESULTS:** Pneumonia was detected in 53 patients (0.77 %). A lethal outcome was observed in 39 patients: in patients with pneumonia in 15 cases (28.3 %), and without pneumonia in 24 cases (0.4 %). Retrospectively, taking into account the obtained model, 933 patients were assigned to the high-risk group for developing pneumonia, the incidence of pneumonia was 4.5 %. In the low-risk group for developing pneumonia — 5911 patients, the incidence of pneumonia was 0.19 %. **CONCLUSIONS:** Eight independent variables associated with postoperative pneumonia were identified: duration of surgery, smoking, complete functional dependence, perioperative anemia requiring iron supplementation, intraoperative use

Реферат

АКТУАЛЬНОСТЬ: Ведущее место в структуре послеоперационных осложнений занимает послеоперационная пневмония. Учитывая распространенность послеоперационной пневмонии и рост числа хирургических процедур, прогнозирование ее развития является актуальной задачей, позволяющей принять меры по снижению частоты ее возникновения путем оптимизации периоперационного периода. Несмотря на свою ценность, существующие шкалы прогнозирования послеоперационной пневмонии не обеспечивают отечественных специалистов надежным и постоянным методом, с помощью которого можно стратифицировать риск развития послеоперационной пневмонии в нашей популяции. **ЦЕЛЬ ИССЛЕДОВАНИЯ:** разработка модели прогнозирования послеоперационной пневмонии на основе выявления факторов риска ее развития. **МАТЕРИАЛЫ И МЕТОДЫ:** Многоцентровое проспективное исследование, 6844 пациента старше 18 лет, подвергающиеся плановым оперативным вмешательствам на органах брюшной полости. Оценивали 30-дневную летальность и послеоперационную пневмонию. На первом этапе исследования проводилось сравнение между группой с пневмонией и группой без пневмонии исходных данных пациентов, а также факторов, связанных с операцией и анестезией. На втором этапе исследования проводился логистический регрессионный анализ для оценки вклада факторов в развитие послеоперационной пневмонии. На третьем этапе исследования выполнялось построение модели прогнозирования послеоперационной пневмонии по данным многомерного логистического регрессионного анализа. На заключительном этапе производилось сравнение полученной модели с моделями прогнозирования других авторов, встречающихся в мировой литературе. **РЕЗУЛЬТАТЫ:** Пневмония выявлена у 53 пациентов (0,77 %). Летальный исход наблюдался у 39 пациентов: у пациентов с пневмонией в 15 случаях (28,3 %), а без пневмонии — в 24 случаях (0,4 %). Ретроспективно с учетом полученной модели к группе высокого риска развития

of vasopressors, American Society of Anesthesiologists classification 3 functional class, use of bronchodilators for chronic obstructive pulmonary disease, and high operative risk. The postoperative pneumonia prediction model has excellent predictive value (AUROC = 0.904).

пневмонии были отнесены 933 пациента, частота развития пневмонии составляла 4,5 %. В группе низкого риска развития пневмонии — 5911 пациентов, частота развития пневмонии составляла 0,19 %. **ВЫВОДЫ:** Выявлены восемь независимых переменных, связанных с послеоперационной пневмонией: длительность операции, курение, полная функциональная зависимость, периоперационная анемия, требующая применения препаратов железа, интраоперационное применение вазопрессоров, III функциональный класс по классификации Американского общества анестезиологов, применение бронходилатирующих препаратов по поводу хронической обструктивной болезни легких, высокий операционный риск. Модель прогнозирования послеоперационной пневмонии имеет отличную прогностическую значимость (AUROC = 0,904).

REGISTRATION: Clinicaltrials.gov identifier: NCT03945968. The study was registered under the auspices of the All-Russian Public Organization "Federation of Anesthesiologists and Reanimatologists" (principal investigator I.B. Zabolotskikh), study number NCT03945968.

РЕГИСТРАЦИЯ: идентификатор Clinicaltrials.gov: NCT03945968. Исследование зарегистрировано под эгидой Общероссийской общественной организации «Федерация анестезиологов и реаниматологов» (главный исследователь — И.Б. Заболотских).

KEYWORDS: postoperative pulmonary complications, postoperative pneumonia, mortality, risk factors

КЛЮЧЕВЫЕ СЛОВА: послеоперационные легочные осложнения, послеоперационная пневмония, летальность, факторы риска

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For citation: Veyler R.V., Trembach N.V., Musaeva T.S., Magomedov M.A., Popov A.S., Fisher V.V., Khoronenko V.E., Gritsan A.I., Dunts P.V., Bayalieva A. Zh., Ovezov A.M., Lebedinskii K.M., Martynov D.V., Spasova A.P., Stadler V.V., Levit D.A., Shapovalov K.G., Kokhno V.N., Golubtsov V.V., Zabolotskikh I.B. Prediction model for postoperative pneumonia in abdominal surgery: results of an observational multicenter study. Annals of Critical Care. 2023;4:43–59. https://doi.org/10.21320/1818-474X-2023-4-43-59

Для цитирования: Вейлер Р.В., Трембач Н.В., Мусаева Т.С., Магомедов М.А., Попов А.С., Фишер В.В., Хороненко В.Э., Грицан А.И., Дунц П.В., Баялиева А.Ж., Овезов А.М., Лебединский К.М., Мартынов Д.В., Спасова А.П., Стадлер В.В., Левит Д.А., Шаповалов К.Г., Кохно В.Н., Голубцов В.В., Заболотских И.Б. Модель прогнозирования послеоперационной пневмонии в абдоминальной хирургии: результаты наблюдательного многоцентрового исследования. Вестник интенсивной терапии им. А.И. Салтанова. 2023;4:43–59. https://doi.org/10.21320/1818-474X-2023-4-43-59

Received: 18.08.2023
Accepted: 04.09.2023
Published online: 31.10.2023

Поступила: 18.08.2023
Принята к печати: 04.09.2023
Дата онлайн-публикации: 31.10.2023

DOI: 10.21320/1818-474X-2023-4-43-59

Introduction

Postoperative respiratory function disorders remain one of the most significant problems in anesthesiology and intensive care [1]. Postoperative pulmonary complications (POPC) have a significant impact on perioperative morbidity and mortality, increase the likelihood of re-hospitalization and contribute to a longer hospital stay [2], thereby making a significant contribution to health care costs [3–6]. The frequency of POPC in the general surgical population ranges from 2.0% to 5.6%, and during operations on the upper abdominal tract and chest it varies from 20 to 70% [7–10]. It is important to note that almost 25% of postoperative deaths occurring in the first week after surgery are associated with POPC [10].

One of the leading places in the structure of POPC is occupied by postoperative pneumonia (PP). Currently, PP accounts for about 50% of all nosocomial pneumonias, and the frequency of its development ranges from 1.5 to 15.8% [9, 11–13]. PP adversely affects the outcome of treatment of surgical patients and even threatens their lives. It has been reported that the mortality associated with PP among surgical patients ranges from 9 to 50%, and its level depends on the type of operation [14]. There is also evidence that it adversely affects the early postoperative recovery of patients and the long-term quality of life. In addition, PP can significantly lengthen the stay of surgical patients in the hospital, increase the frequency of repeated transfers to intensive care units, the frequency of repeated operations and mortality [14, 15], which leads to an increase in medical expenses on average by 2–10 times [12, 15]. Given its prevalence and the increase in the number of surgical procedures, predicting its development is an urgent task that allows taking measures to reduce the frequency of its occurrence by influencing the risk factors of PP that can be corrected, or increasing alertness and conducting more thorough monitoring in patients with conditions that cannot be changed [16, 17].

Preoperative risk assessment requires a structured approach and the use of scales to identify risk factors for the development of PP, which is a significant part of the POPC. These scales include A.M. Arozullah PP risk index [18], P.K. Gupta calculators for PP [19], V.Russotto PP prediction model [14], K.Kawasaki PP prediction nomogram [20], Y.Takesue PP risk calculator [21], H.Baba PP risk factors [22] (appendix).

A.M. Arozullah PP risk index [18], includes the type of surgery, age, functional condition, weight loss, chronic obstructive pulmonary disease (COPD), general anesthesia, sensitivity disorder, cerebral circulation disorder, urea nitrogen level in the blood, blood transfusion, emergency surgery, long-term steroid intake, smoking and alcohol abuse. Patients were divided into five classes using risk index indicators. This scale showed good prognostic significance (AUROC = 0.817), but it was too time-consuming and inconvenient for routine clinical practice.

The P.K. Gupta calculator [19] presents seven preoperative predictors for PP such as age, functional class according to the classification of the American Society of Anesthesiologists (ASA), COPD, functional dependence, preoperative sepsis, smoking before surgery and type of surgery. This scale had good prognostic significance (AUROC = 0.855).

The V. Russotto prediction model [14] identifies five factors independently related to PP: functional dependence, preoperative oxygen saturation of blood (SpO_2), intraoperative administration of colloids, intraoperative transfusion of blood preparations and the area of operation. The regression model with five variables was of good predictive value (C-statistics 0.89) and calibration (Hosmer—Lemeshow $\chi^2 = 6.69$, $p = 0.572$).

K.Kawasaki [20] demonstrated that age, male gender, a history of cerebrovascular diseases, Brinkman index ≥ 900 and upper median laparotomy were independent prognostic factors of PP. The nomogram showed good predictive value with a compliance index of 0.77.

Eighteen characteristics, including gender, COPD, sepsis, and functional dependence, six laboratory parameters and two intraoperative factors were used by Y.Takesue [21] to calculate the risk of PP. This scale had good prognostic significance (AUROC = 0.826). However, this model was evaluated only in patients after gastroenterological operations and in the Japanese population and proved to be too time-consuming and inconvenient for routine clinical practice.

In the paper of H.Baba et al. [22] it was shown that significant predictors of postoperative PP were low forced vital capacity and low forced expiratory volume in 1 second, malnutrition (low serum albumin and low nutritional status control indicators and values of the prognostic nutrition index), esophagectomy, surgery of the upper gastrointestinal tract and non-laparoscopic surgery. This scale had satisfactory prognostic significance (AUROC = 0.709). In addition, it was also too time-consuming and inconvenient for routine clinical practice.

In contrast to the developed models for predicting postoperative PP, which have limitations [14, 18–22], POPC prediction models have been developed and confirmed on a large group of patients [23, 24]. However, they predicted all DISEASES, such as respiratory failure, PP, pleural effusion, atelectasis, bronchospasm, pneumothorax, and aspiration pneumonitis, without singling out the risks of PP development separately.

Despite their value, these assessment systems do not provide local specialists with a reliable and permanent method by which to stratify the risk of developing PP in our population.

Purpose of the study

Thus, the main purpose of this work is to develop a model for predicting PP based on the identification of risk factors for its development.

Materials and methods

The data of the STOPRISK study on the perioperative parameters of 6844 patients operated on abdominal and pelvic organs from 32 centers in 21 cities representing 8 federal districts for the period from July 1, 2019 to June 30, 2022 were analyzed [25]. All patients signed a voluntary informed consent to participate in the study.

Criteria for inclusion in the study: patients over 18 years of age undergoing planned surgical interventions on abdominal organs, whose physical status corresponds to classes I–III according to ASA.

Exclusion criteria: acute massive blood loss, aspiration, bronchospasm, anaphylactic reactions, malignant hyperthermia, transurethral and transvaginal operations, operations on peripheral vessels and heart, thoracic operations, neck, head operations, traumatological operations.

Criteria for non-inclusion in the study: lack of informed consent of the patient, inability to assess the factors included in the study (lack of data).

Estimated outcomes

The 30-day mortality and PP were evaluated, according to the definition of the working group of the European Society of Anesthesiology and the European Society for Intensive Care [26]. According to the definitions of 2015, pneumonia is defined by chest X-ray, with at least one of the changes such as infiltration, consolidation, cavity; plus one of the conditions such as presence of fever more than 38 °C for no other reason, the number of leukocytes less than 4 or more than 12×10^9/l; plus at least 2 of the following signs: purulent/altered sputum, increased secretion/aspiration of contents, cough/shortness of breath/tachypnea, wheezing/bronchial breathing or deterioration of gas exchange [26].

All patients included in the study, depending on the presence of PP, were divided into 2 groups: patients with PP (n = 53); patients without PP (n = 6791).

Statistical analysis

Statistical data analysis was performed using MedCalc (MedCalc Software Ltd, Belgium) version 19.1.3.

Data with a normal distribution is presented as an average value ± standard deviation, data with a distribution other than normal is presented as a median (25–75 percentiles).

At the first stage of the study, a comparison was made between the group with PP and without PP of the initial data of patients, as well as factors related to surgery and anesthesia. The Fisher exact test was used to compare qualitative variables, and the Mann—Whitney test was used for quantitative variables. In all cases, the p level of less than 0.05 was considered statistically significant [27].

At the second stage of the study, a logistic regression analysis was carried out to assess the contribution of factors to the development of the outcome (by the method of simultaneous inclusion of independent variables): the odds ratio (OR) and 95 % confidence interval (CI) were estimated. Independent variables were introduced into the model if their statistical significance was revealed during two-dimensional analysis ($p < 0.05$).

At the third stage of the study, the construction of a model for forecasting PP was conducted based on the data of multidimensional logistic regression analysis. The predictive value of the obtained model was evaluated using ROC analysis and determination of the area under the ROC curve (AUROC). The AUROC result of 0.70–0.79 was considered to have a satisfactory prognostic value, the result of 0.80–0.89 was considered to have a good prognostic value, and the result of 0.9 or more was evaluated as having excellent prognostic value.

At the final stage, the obtained model was compared with the prediction models of PP by other authors found in the world literature. This comparison was conducted by comparing the ROC curves constructed for each model.

Results

When analyzing the frequency of occurrence of PP and 30-day mortality, the following data were obtained. Postoperative pneumonia was found in 53 patients (0.77 %). The fatal outcome occurred in 39 patients. In patients with PP, it was noted in 15 cases (28.3 %), and in patients without PP it was seen in 24 cases (0.4 %) ($p < 0.05$ according to the exact Fisher criterion). In all cases, acute cardiovascular insufficiency was the cause of death, developing against the background of decompensation of chronic pathology or complications of the postoperative period. Pneumonia, as an independent pathology, was not the direct cause of death in any of the cases.

When comparing the group of patients with PP and without PP, the following data were obtained (Table 1).

A multidimensional analysis of factors independently related to PP is presented below (Tables 2 and 3). This analysis includes the risk factors responsible for the development of PP related to both the patient's condition and surgical intervention.

According to the multidimensional logistic analysis, there were selected the variables that were significantly associated with the development of PP ($p < 0.05$) (Table 4).

At the next stage, risk factors with a significant influence on the frequency of its development ($p < 0.05$) were selected to build a model for predicting the development of PP according to regression analysis (Table 5).

To assess the prognostic significance of the developed forecasting model, a ROC analysis was performed with the determination of the area under the ROC curve (AUROC). The following data were obtained: AUROC = 0.904; st. error — 0.0197; 95 % CI 0.897–0.911 (Figure 1).

Table 1. Comparative characteristics of patients depending on the development of postoperative pneumonia

Parameters	Pneumonia	Without pneumonia	*p*
Gender			
male	39.6 %	64.8 %	0.00024*
female	60.4 %	35.2 %	
BMI	26.1 (23–31.6)	26.9 (23.5–30.9)	0.7652
Age	63 (53–69.3)	56 (42–65)	0.0010#
Duration of the operation	225 (133.8–361.3)	80 (55–130)	< 0.0001#
Operational risk			
low	3.8 %	39.1 %	< 0.0001#
medium	54.7 %	51.8 %	
high	41.5 %	9.1 %	
HT	75.5 %	50.1 %	0.00026*
CHD	43.4 %	19.1 %	0.00008*
CHF	45.3 %	20.1 %	0.00004*
CF	13.2 %	6.5 %	0.083
COPD	20.8 %	5.2 %	0.00008*
Smoking	34 %	12.1 %	0.00003*
CKD	9.4 %	3.6 %	0.045*
ACVA	5.7 %	2.2 %	0.114
Partial and full functional dependence	11.3 %	3.3 %	0.0088*
Diabetes mellitus	20.8 %	8.8 %	0.006*
Cancer disease	49.1 %	22 %	0.00002*
Intake of beta blockers	34 %	20.6 %	0.025*
Intake of ACE inhibitors	54.7 %	34.2 %	0.003*
Intake of statins	11.3 %	9 %	0.473
Intake of anticoagulants	24.5 %	16.9 %	0.142
Intake of diuretics	24.5 %	9.5 %	0.0016*
Intake of bronchodilators	13.2 %	1.6 %	0.000028*

According to the analysis of the ROC curve, a cut-off point was determined and groups of high (probability of developing PP more than 1.2 %) and low risk of developing PP (1.2 % or less) were identified (sensitivity 79.2 %, specificity 86.9 %). Retrospectively, considering the obtained model, 933 patients were assigned to the high-risk group for the development of PP, the incidence of PP was 4.5 %. In the low-risk group of PP there were 5911 patients, the incidence of PP was 0.19 % (Table 6).

hen conducting ROC analysis with the factors used in the study by P.K. Gupta et al. [19], the following data were obtained in our patient population: AUROC = 0.852; st. error — 0.023; 95 % CI 0.843–0.861 (Figure 2).

Parameters	Pneumonia	Without pneumonia	*p*
Insulin injections	3.8 %	1.6 %	0.204
Intake of oral hypoglycemic drugs	17 %	5.8 %	0.0034*
Intake of iron drugs	13.2 %	2.6 %	0.00048*
Antibiotic prophylaxis	88.7 %	85.6 %	0.694
ASA Class			
I	1.9 %	18.9 %	< 0.0001#
II	17 %	53.4 %	
III	81.1 %	27.7 %	
Revised cardiac risk index	1 (1–2)	0 (0–1)	< 0.0001#
Rod test	33 (24.8–39)	39 (31–45)	0.0007#
Hemoglobin, g/l	124 (112.8–134.3)	133 (123–143)	0.0001#
Type of anesthesia			
combined	49.1 %	75.6 %	< 0.0001*
neuroaxial	0 %	7.6 %	
combined	49.11 %	11.7 %	
total intravenous	1.9 %	5.1 %	
Intraoperative blood loss, ml	200 (150–300)	50 (30–100)	< 0.0001#
Infusion rate, ml/min	11.1 (8–15.2)	12.5 (8.3–18.8)	0.1067
Infusion volume	2500 (2000–3000)	1000 (750–1500)	< 0.0001#
The need for vasopressors	34 %	4 %	< 0.000000001*
The need for blood transfusions	20.8 %	2.2 %	0.000000025*
Decurarization	5.7 %	15.5 %	0.054
Monitoring of neuromuscular conduction	3.8 %	12.7 %	0.059

# $p < 0.0$ according to the Mann—Whitney criterion 5.
* $p < 0.05$ by Fisher's exact criterion.

ACE — angiotensin-converting enzyme; ACVA — acute cerebrovascular accident; ASA — American Society of Anesthesiologists; BMI — body mass index; CHD — coronary heart disease; CHF — chronic heart failure; CKD — chronic kidney disease; COPD — chronic obstructive pulmonary disease; HT — hypertension; NMC — neuromuscular conduction.

When comparing the data obtained during the ROC analysis of the developed PP forecasting model and the P.K. Gupta model (Figure 3), the following results were obtained (Tables 7 and 8). As follows from these figures, the developed forecasting model has greater significance compared to the P.K. Gupta model ($p < 0.05$) (Table 8).

Discussion

In the studied patient population, the incidence of PP was 0.77 %, eight independent variables associated with its development were determined.

The available models for predicting PP have their limitations. A.M. Arozullah et al. [18] retrospective-

Table 2. Multivariate analysis of factors independently associated with postoperative pneumonia

Factor	Ratio	St. error	Wald Test	*p*
Gender	0.47513	0.29595	2.5774	0.1084
BMI	–0.037705	0.025856	2.1265	0.1448
Age	–0.0096934	0.013512	0.5146	0.4731
Duration of the operation	0.0062108	0.00098144	40.0459	< 0.0001
Operational risk	0.85190	0.25749	10.9457	0.0009
HT	–0.47176	0.40071	1.3860	0.2391
CHD	–0.17143	0.37196	0.2124	0.6449
CHF	0.53332	0.36229	2.1670	0.1410
Cardiac arrythmia	–0.055035	0.43850	0.01575	0.9001
COPD	–0.96695	0.36693	6.9444	0.0084
Smoking	0.77606	0.33465	5.3778	0.0204
CKD	0.36335	0.48839	0.5535	0.4569
ACVA	0.16474	0.62281	0.06997	0.7914
Partial and full functional dependence	1.30942	0.45622	8.2377	0.0041
Diabetes mellitus	0.42001	0.35807	1.3759	0.2408
Cancer disease	0.69374	0.29638	5.4789	0.0192
Intake of beta blockers	–0.12871	0.32112	0.1607	0.6886
Intake of ACE inhibitors	0.23609	0.30151	0.6131	0.4336
Intake of statins	–0.47503	0.45517	1.0892	0.2967
Intake of anticoagulants	–0.059603	0.33649	0.03138	0.8594
Intake of diuretics	0.67223	0.34786	3.7346	0.0770
Intake of bronchodilators	1.67761	0.59517	7.9450	0.0048
Insulin injections	0.63539	0.74319	0.7309	0.3926
Intake of oral hypoglycemic drugs	0.97194	0.37986	6.5469	0.0105
Iron supplementation in connection with perioperative anemia	1.69945	0.42362	16.0938	0.0001
Antibiotic prophylaxis	–0.60409	0.46024	1.7228	0.1893
ASA Class	1.50175	0.23593	40.5175	< 0.0001
Revised cardiac risk index	0.27811	0.15728	3.1266	0.0490
Rod test	–0.024284	0.013482	3.2369	0.0497
Hemoglobin	–0.0068877	0.0077703	0.7857	0.3754
Type of anesthesia	0.32595	0.14137	5.3158	0.0211
Intraoperative blood loss	0.00085206	0.00020566	17.1645	< 0.0001
Infusion rate	–0.060128	0.022771	6.9726	0.0083
Infusion volume	0.00043990	0.000073537	35.7853	< 0.0001
The need for vasopressors	2.16390	0.32480	44.3861	< 0.0001
The need for blood transfusions	–0.91392	0.46619	3.8432	0.0499
Decurarization	–0.96631	0.59866	2.6054	0.1065
Monitoring of neuromuscular conduction	–1.02227	0.72810	1.9713	0.1603

ACE — angiotensin-converting enzyme; ACVA — acute cerebrovascular accident; ASA — American Society of Anesthesiologists; BMI — body mass index; CHD — coronary heart disease; CHF — chronic heart failure; CKD — chronic kidney disease; COPD — chronic obstructive pulmonary disease; HT — hypertension; NMC — neuromuscular conduction.

Table 3. Multivariate analysis of factors independently associated with postoperative pneumonia

Variable	OR	95% CI	*p*
Gender	1.4851	0.8264–2.6687	0.1084
BMI	0.9642	0.9165–1.0145	0.1448
Age	0.9897	0.9637–1.0165	0.4731
Duration of the operation	1.0064	1.0045–1.0083	< 0.0001
Operational risk	2.2684	1.3703–3.7552	0.0009
HT	0.6444	0.2931–1.4169	0.2391
CHD	1.0836	0.5140–2.2847	0.6449
CHF	1.7046	0.8380–3.4674	0.1410
Cardiac Arrythmia	1.1124	0.4713–2.6257	0.9001
COPD	2.6299	1.2812–5.3986	0.0084
Smoking	2.1729	1.1277–4.1870	0.0204
CKD	1.4381	0.5522–3.7456	0.4569
ACVA	1.1791	0.3479–3.9966	0.7914
Partial and full functional dependence	3.7040	1.5147–9.0576	0.0041
Diabetes mellitus	1.5220	0.7544–3.0704	0.2408
Cancer disease	2.0012	1.1194–3.5774	0.0192
Intake of beta blockers	0.8792	0.4686–1.6498	0.6886
Intake of ACE inhibitors	1.2663	0.7013–2.2866	0.4336
Intake of statins	0.6219	0.2548–1.5176	0.2967
Intake of anticoagulants	0.9421	0.4872–1.8220	0.8594
Intake of diuretics	1.9586	0.9905–3.8730	0.0770
Intake of bronchodilators	5.3528	1.6671–17.1870	0.0048
Insulin injections	1.8878	0.4399–8.1015	0.3926
Intake of oral hypoglycemic drugs	2.6431	1.2554–5.5648	0.0105
Iron supplementation in connection with perioperative anemia	5.4709	2.3849–12.5504	0.0001
Antibiotic prophylaxis	0.5466	0.2218–1.3471	0.1893
ASA Class	4.4895	2.8273–7.1289	< 0.0001
Revised cardiac risk index	1.3206	0.9703–1.7975	0.0490
Rod test	0.9760	0.9506–1.0021	0.0497
Hemoglobin	0.9931	0.9781–1.0084	0.3754
Type of anesthesia	1.3853	1.0501–1.8277	0.0211
Intraoperative blood loss	1.0009	1.0004–1.0013	< 0.0001
Infusion rate	0.9416	0.9005–0.9846	0.0083
Infusion volume	1.0004	1.0003–1.0006	< 0.0001
The need for vasopressors	8.7050	4.6057–16.4530	< 0.0001
The need for blood transfusions	0.4009	0.1608–0.9998	0.0499
Decurarization	0.3805	0.1177–1.2301	0.1065
Monitoring of neuromuscular conduction	0.3598	0.0864–1.4990	0.1603

ACE — angiotensin-converting enzyme; ACVA — acute cerebrovascular accident; ASA — American Society of Anesthesiologists; BMI — body mass index; CHD — coronary heart disease; CHF — chronic heart failure; CKD — chronic kidney disease; COPD — chronic obstructive pulmonary disease; HT — hypertension; NMC — neuromuscular conduction.

Table 4. Multivariate analysis of factors independently associated with postoperative pneumonia

Factor	OR	95% CI	*p*
Duration of the operation	1.0060	1.0038–1.0083	< 0.0001
Smoking	2.6699	1.4220–5.0130	0.0022
Full functional dependence	9.5848	1.1072–82.9745	0.0401
Intake of bronchodilators	7.0942	2.8467–17.6793	< 0.0001
Iron supplementation in connection with perioperative anemia	3.2400	1.2971–8.0927	0.0118
ASA Class III	4.1745	1.9983–8.7206	0.0001
The need for vasopressors	4.1256	2.1220–8.0210	< 0.0001
High operative risk	6.5411	1.3146–32.5475	0.0215
Type of anesthesia	1.2222	0.8833–1.6912	0.2258
Cancer disease	0.4527	0.2327–0.8806	0.0596
ASA Class I	0.8443	0.1008–7.0750	0.8760
COPD	0.8725	0.2906–2.6193	0.8079
Intake of oral hypoglycemic drugs	2.0167	0.8890–4.5747	0.0933
Revised cardiac risk index	1.0249	0.5067–2.0734	0.9454
Infusion rate	1.0069	0.9554–1.0611	0.7972
Infusion volume	1.0002	0.9998–1.0005	0.3188
Intraoperative blood loss	0.9993	0.9986–1.0001	0.0992
The need for blood transfusions	2.1758	0.8238–5.7469	0.1167
Rod test	0.9887	0.9625–1.0157	0.4089
Partial functional dependence	1.4545	0.6006–3.5221	0.4064

ASA — American Society of Anesthesiologists; **COPD** — chronic obstructive pulmonary disease.

Table 5. Postoperative pneumonia prediction model

Factor	OR	95% CI	*p*
Duration of the operation	1.0060	1.0038–1.0083	< 0.0001
Smoking	2.6699	1.4220–5.0130	0.0022
Full functional dependence	9.5848	1.1072–82.9745	0.0401
Intake of bronchodilators	7.0942	2.8467–17.6793	< 0.0001
Iron supplementation in connection with perioperative anemia	3.2400	1.2971–8.0927	0.0118
ASA Class III	4.1745	1.9983–8.7206	0.0001
The need for vasopressors	4.1256	2.1220–8.0210	< 0.0001
High operative risk	6.5411	1.3146–32.5475	0.0215

ASA — American Society of Anesthesiologists.

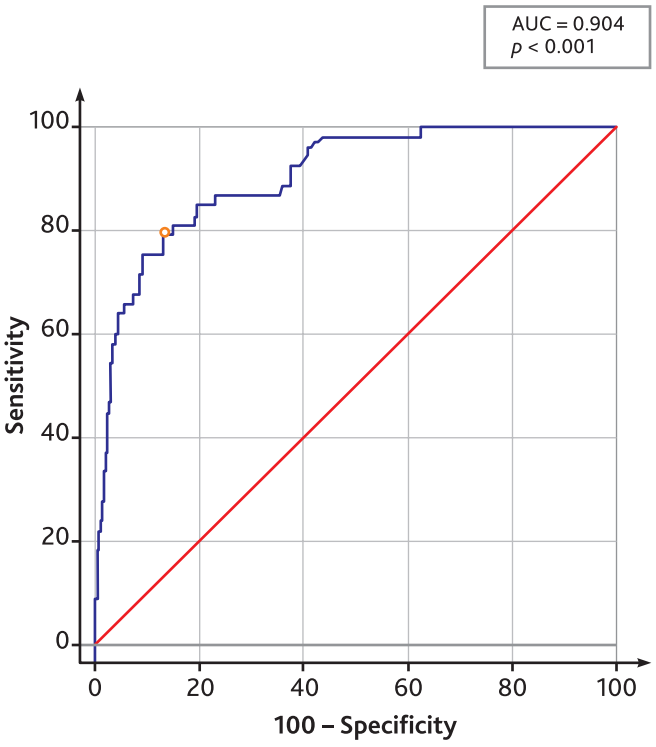

Fig. 1. Analysis of the ROC curve of the PP forecasting model

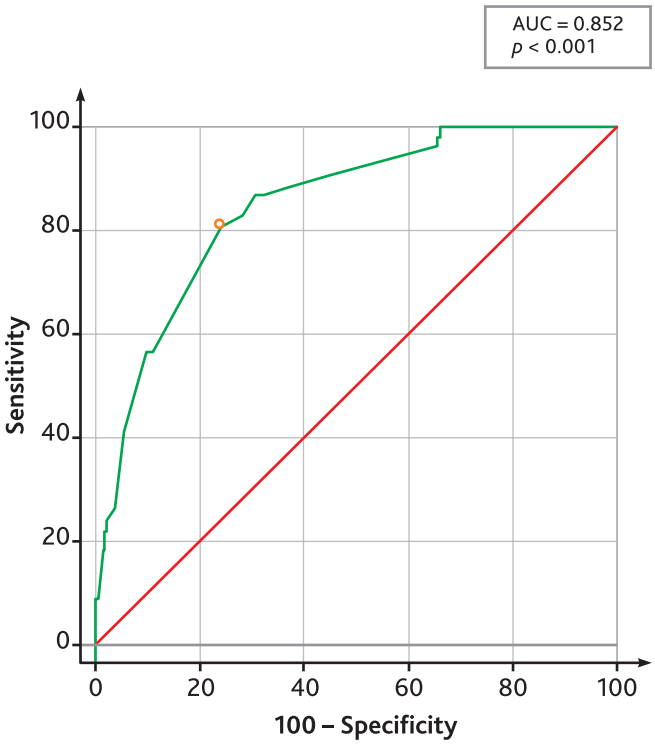

Fig. 2. ROC curve analysis of the Gupta forecasting model

Table 6. The incidence of postoperative pneumonia depending on the risk group

Risk of PP developing	Incidence of PP
Low risk of PP developing (*n* = 5911)	0.19 %
High risk of PP developing (*n* = 933)	4.5 %

Table 7. Comparison of ROC curves

Model	AUC	St. error	95 % CI
Gupta	0.852	0.0234	0.843–0.860
STOPRISK	0.904	0.0197	0.897–0.911

Table 8. Comparison of ROC curves (continued)

Parameters	Meaning
Difference	0.0527
Standard error	0.0155
95 % CI	0.0223–0.0830
z statistics	3.401
Significance level	*p* = 0.0007

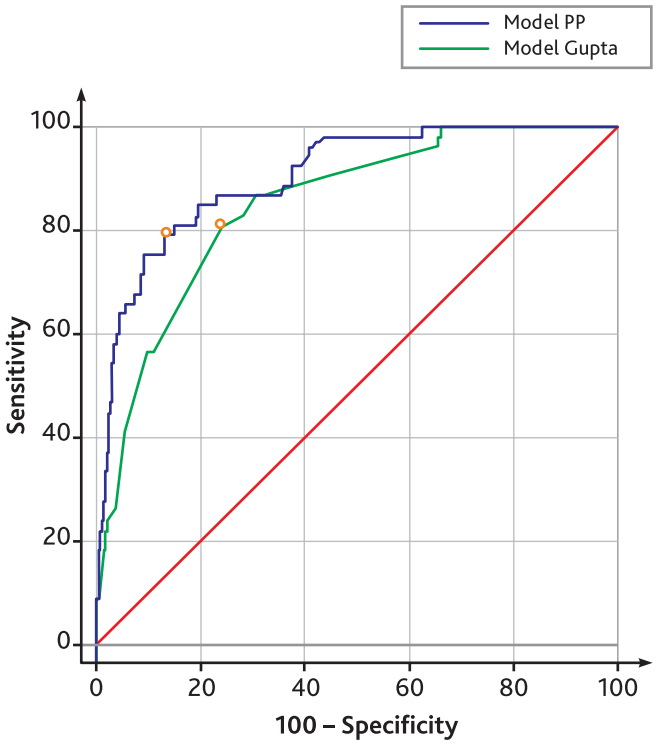

Fig. 3. Comparison of ROC curves of the developed forecasting model and the Gupta mode

ly analyzed data from 100 medical centers performing extensive operations. The main limitation of this study was the low generalizability since the study cohort consisted entirely of male patients. In addition, the retrospective analysis had limitations regarding missing data and potential misclassification of events. Finally, the use of a large database led to the discovery of a number of significant predictors, followed by the development of a scale that is difficult to work with in everyday practice.

P.K. Gupta et al. [19] also used a retrospective database to identify PP risk factors and build a model. Although the authors included a wider range of patient characteristics, this study also has limitations inherent in retrospective analysis.

When conducting ROC analysis with the factors used in the study by P.K. Gupta et al., the following data were obtained in our patient population: AUROC = 0.852; st. error — 0.023; 95 % CI 0.843–0.861. The authors of the model in the initial study obtained comparable results: AUROC = 0.855 [19]. The prediction model we developed had statistically significantly greater predictive value compared to the P.K. Gupta model.

Functional dependence, defined as a reduced ability to perform daily activities, is a recognized factor that increases morbidity and mortality [28]. In previously developed models, it was also mentioned as a risk factor for the development of PP [18, 19]. Moreover, patients with poor functional status have an increased risk of developing aspiration pneumonia [29]. They are more likely to live in nursing homes and long-term treatment facilities and are susceptible to colonization and infection with multidrug-resistant pathogens [30].

High operational risk, which characterizes extensive abdominal operations on the upper abdominal tract, was determined as a predictor of PP. Comparable results were also obtained in previously developed models assessing the risk of PP [18, 19]. Laparoscopic abdominal surgeries expose patients to a relatively lower surgical risk, and, when possible, laparoscopic interventions may be considered to reduce the risk of PP. In addition, prolonged surgical intervention (more than 3 hours) is an independent risk factor for POPC and PP [31].

Patients with COPD are more likely to develop PP due to impaired mucociliary clearance. In addition, smoking is also a risk factor for the development of PP [19, 32]. The risk is reduced to a minimum if a patient gives up smoking 6 months prior to surgery, but the increased risk of PP persists for 1 year [15].

Preoperative anemia increases the risk of developing PP, which is consistent with recent studies defining anemia as a predictor of an unfavorable outcome in critical and postoperative patients. Even a minimal degree of anemia is associated with a significant increase in the risk of 30-day postoperative mortality and adverse cardiac events [33], although there is still no clear evidence that preoperative blood transfusion can reduce the risk.

Of course, the use of the PP prediction model in clinical practice is important for identifying patients with a high risk of developing this pathology. This will allow the anesthesiologist-resuscitator to optimize the perioperative management of this category of patients, showing clinical caution [15, 17]. It is necessary to continue clinical studies that contribute to the development of measures aimed at correcting the risk factors included in this model.

The main advantages of our model are the prospective design of the study, a wide range of factors included in the analysis and a large sample of patients who underwent abdominal surgical interventions of varying severity and risk.

Study limitations

Despite the strengths of the study, it has a number of limitations. Thus, one of the limitations of the study is the possibility of a systematic selection error, since the centers were recruited on a voluntary basis, and different centers could provide different levels of medical care. Four years have passed since the initial data were collected, and during this period the tactics of perioperative management of patients could change. In addition, even though the data set was quite complete and included a large number of perioperative variables, some comorbidities, such as obstructive sleep apnea, were not included. This mod-

el must undergo internal and external validation to further evaluate its effectiveness and predictive value.

Conclusion

Eight independent variables associated with postoperative pneumonia were identified: duration of surgery, smoking, complete functional dependence, perioperative anemia requiring the use of iron preparations, intraoperative use of vasopressors, ASA functional class 3, intake of bronchodilating drugs for COPD, high operational risk. The model for predicting postoperative pneumonia has excellent prognostic significance (AUROC = 0.904).

Disclosure. A.I Gritsan is the Vice-President of the all-Russian public organization "Federation of anesthesiologists and reanimatologists"; K.M. Lebedinskii is the President of the all-Russian public organization "Federation of anesthesiologists and reanimatologists"; I.B. Zabolotskikh is the First Vice-President of the all-Russian public organization "Federation of anesthesiologists and reanimatologists". Other authors declare that they have no competing interests.

Author contribution. All authors according to the ICMJE criteria participated in the development of the concept of the article, obtaining and analyzing factual data, writing and editing the text of the article, checking and approving the text of the article.

Registration of the study. The study was registered in the international database https://clinicaltrials.gov under the auspices of the All-Russian Public Organization "Federation of Anesthesiologists and Reanimatologists" (principal investigator I.B. Zabolotskikh), study number NCT03945968.

Ethics approval. Not required.

Funding source. This study was not supported by any external sources of funding.

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

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Appendix. Prediction model for postoperative pneumonia in abdominal surgery: results of an observational multicenter study

Table A1. Comparative characteristics of postoperative pneumonia (PP) prognostic scales

Variable	Risk index of PP A.M. Arozullah	Calculator PP P.K. Gupta	Prediction model of PP V. Russotto	Nomogram of forecasting PP K. Kawasaki	Risk Calculator PP Y. Takesue	Risk Factor PP H. Baba
Age	+	+		+	+	
Gender				+	+	
Preoperative SpO_2, %			+			
Localization of the operation	+	+	+	+		+
Duration of the operation					+	
Urgency of surgical intervention	+				+	
Blood urea nitrogen (< 2.86 mmol/l; > 7.85 mmol/l)	+					
Functional state (dependence)	+	+	+		+	
History of COPD	+	+			+	
Weight loss > 10 % in the last 6 months	+				+	
General anesthesia	+					
Violation of sensor perception	+					
ACVA	+			+	+	
Transfusion of more than 4 units of blood components	+					
The use of steroids in chronic diseases	+				+	
Smoking for 1 year	+	+			+	
Alcohol intake > 2 servings per day for the last 2 weeks	+					
ASA class		+			+	
Preoperative sepsis		+			+	
Intraoperative colloid infusion			+			
Intraoperative transfusion of blood components			+			

End of Table A1

Variable	Risk index of PP A.M. Arozullah	Calculator PP P.K. Gupta	Prediction model of PP V. Russotto	Nomogram of forecasting PP K. Kawasaki	Risk Calculator PP Y. Takesue	Risk Factor PP H. Baba
Brinkman Index ≥ 900				+		
Diabetes					+	
Ascites					+	
Hypertension					+	
Blood clotting disorder					+	
Prior percutaneous coronary intervention					+	
Brinkman Index ≥ 400					+	
Preoperative transfusion of blood components					+	
Hematocrit: male > 48 %, female > 42 %					+	
Serum albumin (< 25 g/l)					+	
AST > 35 U/l					+	
Alkaline phosphatase > 340 U/l					+	
Blood Urea Nitrogen (> 25 mg/dl)					+	
Na+ < 138 mmol/l					+	
Severe intraoperative blood loss					+	
Reduced FVC, FEV1 (according to spirometry)						+
Malnutrition (albumin ≤ 35 g/l, nutritional status control indicators > 4, prognostic nutrition index ≤ 40)						+

ACVA — acute cerebrovascular accident; **ASA** — American Society of Anesthesiologists; **AST** — aspartate aminotransferase; **COPD** — chronic obstructive pulmonary disease; **FEV1** — forced expiratory volume in 1 second; **FVC** — forced vital capacity; **PP** — postoperative pneumonia; **SpO_2** — oxygen saturation of the blood.