DOI: https://doi.org/10.30841/2786-7323.1.2026.358693

Mathematical model for predicting complications in acute small bowel obstruction: a retrospective study

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Acute small bowel obstruction (ASBO) is a critical condition in abdominal surgery with a high postoperative mortality rate, largely due to prolonged small bowel paresis and associated complications such as intestinal failure, bacterial translocation, and multiple organ failure.
***The objective*: to develop a mathematical model to predict the likelihood of complications in patients with ASBO, based on various clinical and risk factors.**
***Materials and methods*. A retrospective examination of 52 male patients with ASBO was conducted. The study analysed factors such as the duration and type of ASBO, age, presence of comorbidities, and other pre- and intraoperative variables. Statistical methods, including multiple regression analysis, were used to create the predictive model. The research adhered to ethical guidelines and received approval from the Ethics Committee of Ivan Horbachevsky Ternopil National Medical University of MOH of Ukraine.**
***Results*. The study identified nine significant risk factors for ASBO complications, including age, duration of obstruction, type of obstruction, comorbidity, and the presence of peritonitis. A multiple regression model was created with a sensitivity of 97% and specificity of 96%, enabling the prediction of ASBO complications with high accuracy.**
***Conclusions*. The proposed mathematical model for predicting complications in ASBO can significantly aid in early diagnosis and the implementation of effective treatment and prevention strategies. This model has the potential to reduce postoperative complications and improve patient outcomes in ASBO cases.**
Keywords: *acute small bowel obstruction, complications, mathematical model, regression analysis, predictive model, postoperative mortality, risk factors, metabolic syndrome.*

Математична модель для прогнозування ускладнень при гострій непрохідності тонкої кишки: ретроспективне дослідження

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Гостра непрохідність тонкої кишки (ГНТК) є критичним станом в абдомінальній хірургії з високим рівнем післяопераційної смертності, зумовленої переважно тривалим парезом тонкої кишки й такими супутніми ускладненнями, як кишкова недостатність, бактеріальна транслокація та поліорганна недостатність.
Мета дослідження: розробка математичної моделі для прогнозування ймовірності ускладнень у пацієнтів із ГНТК на основі різних клінічних факторів та чинників ризику.
Матеріали та методи. Проведено ретроспективне дослідження 52 пацієнтів чоловічої статі з ГНТК. Під час дослідження аналізували такі фактори, як тривалість і тип ГНТК, вік пацієнтів, наявність супутніх захворювань, а також інші перед- та інтраопераційні змінні. Для побудови прогностичної моделі використано статистичні методи, зокрема аналіз множинної регресії. Дослідження відповідало етичним принципам і отримало схвалення етичного комітету Тернопільського національного медичного університету імені І. Я. Горбачевського МОЗ України.
Результати. Виявлено 9 значущих факторів ризику розвитку ускладнень при ГНТК, серед яких вік, тривалість обструкції, тип обструкції, супутні захворювання та наявність перитоніту. Створено модель множинної регресії з чутливістю 97% і специфічністю 96%, що дає змогу з високою точністю прогнозувати ускладнення при ГНТК.
Висновки. Запропонована математична модель для прогнозування ускладнень при ГНТК може суттєво сприяти ранній діагностиці та впровадженню ефективних стратегій лікування й профілактики. Модель має потенціал для зниження частоти післяопераційних ускладнень і поліпшення результатів лікування пацієнтів із ГНТК.
Ключові слова: *гостра непрохідність тонкої кишки, ускладнення, математична модель, регресійний аналіз, прогнозна модель, післяопераційна летальність, фактори ризик, метаболічний синдром.*

Acute small bowel obstruction (ASBO) remains one of the most challenging problems in abdominal surgery. The postoperative mortality rate for ASBO ranges from 3 to 25% [1]. This is associated with prolonged postoperative small bowel paresis, which has not been eliminated, contributing to the development of intestinal failure syndrome, failure of interintestinal anastomoses and translocation of bacterial flora into the abdominal cavity, as well as, as a consequence of the development, multiple organ failure [2, 3].

Global clinical guidelines provide clear recommendations on the management of patients with ASBO in the preoperative stage. However, the assessment of the functional state of the small intestine and methods of its correction are practically not taken into account in approaches to treatment in the intraoperative and postoperative periods after the elimination of ASBO [4–6].

It is known that prolonged impairment of small intestine motor activity during the first 3 days after ASBO elimination leads to local morphofunctional changes, which

in conditions of paresis are accompanied by intestinal tissue hypoxia and impaired cellular metabolism, contributing to necrobiotic processes in the small intestine membranes [7]. It is also known that prolonged suppression of the motor-evacuation function of the small intestine, due to asynchronous activity of different parts of the digestive tract, leads to deepening metabolic changes in the intestinal wall, namely electrolyte and energy balances with the development of endogenous intoxication syndrome, which, in turn, exacerbates the phenomena of paresis in the postoperative period [8, 9]. Endogenous intoxication syndrome also exacerbates inflammatory processes, which can be complicated by peritonitis. Animal studies confirm the effect of endogenous intoxication on the development of inflammatory reactions in peritonitis [10].

Some success has been achieved in the treatment of ASBO. In particular, many researchers recommend complex therapy, including combating tissue hypoxia, small intestine decompression, early enteral nutrition, and various schemes of drug and physiotherapeutic stimulation of the digestive tract [11, 12]. At the same time, the results of surgical treatment are often disappointing. According to the literature [13], the development of ASBO complications remains at a fairly high level and does not show a stable downward trend [14].

Currently, most scientific works are devoted to various methods of surgical treatment of ASBO and very few to the possible causes of the development of possible complications. Thus, we considered it appropriate to analyse the factors that directly influence the occurrence of ASBO complications in order to prevent them in a timely manner.

The objective: to create a mathematical model for predicting the likelihood of complications in ASBO.

MATERIALS AND METHODS

A comprehensive examination of 52 patients with ASBO was conducted using standard methods. To achieve the objectives and tasks of the study, it was conducted at the Department of Surgery of the Faculty of Postgraduate Education of Ivan Horbachevsky Ternopil National Medical University of MOH of Ukraine and in the surgery department of the Ternopil City Clinical Hospital No. 2. The study is retrospective, as data were collected by analysing medical records and examination results of patients who had already been hospitalised and operated on. Patients were selected from existing archives, and no new procedures or interventions were performed for the purposes of this study. The study included 52 male patients with ASBO. The average age of the patients was 65.1 ± 7.8 years. This allows for a more accurate assessment of the impact of age and gender on the course of the disease and treatment outcomes. The inclusion criteria were patients diagnosed with ASBO requiring surgery, and the exclusion criteria were patients with chronic diseases that complicate the assessment of the surgery results (e.g., severe heart or renal failure). 52 patients with ASBO were divided into two groups: patients with primary obstruction and patients with recurrent obstruction.

The following factors were studied to predict the development of complications in patients with ASBO: duration of ASBO, type of ASBO, age of patients, presence of cardiac and respiratory failure, degree of small bowel obstruction, diameter of small bowel lumen enlargement, type of peritonitis and episode of ASBO, as well as indicators such as preoperative risk level according to the American Society of Anesthesiologists (ASA) scale and Charlson Comorbidity Index (CCI). Analysed complications included: intestinal necrosis, peritonitis, anastomotic leakage, intra-abdominal abscess, intestinal fistula, prolonged postoperative ileus. No mortality cases were recorded. The ethical principles included in the Declaration of Human Rights, adopted in Helsinki in 1975 and revised in 2008, were fully adhered to in this study. The study participants took part voluntarily, completing and signing a written informed consent form. The study protocol No. 74 on 10 October 2022 was approved by the Ethics Committee of Ivan Horbachevsky Ternopil National Medical University of MOH of Ukraine.

This retrospective study consisted of two stages: stage 1 – model development cohort: 52 male patients with surgically treated ASBO; stage 2 – external validation cohort: 50 independent patients with ASBO treated at the same institution during a different observation period.

A predictive model of the risk of ASBO complications in men was constructed using multiple regression analysis. Statistical processing of the obtained research results was performed using the Statistica 10.0 statistical package and the Microsoft Excel 2010 spreadsheet editor. The normality of the distribution of characteristics was assessed using asymmetry and excess coefficients, as well as the Shapiro–Wilk test. The difference between the comparative groups was considered statistically significant at $p < 0.05$.

RESULTS AND DISCUSSION

52 patients were examined to predict the development of complications in patients with ASBO, the average age of the examined patients was 65.1 ± 7.8 years. The average duration of ASBO was 23.7 hours. Among all examined patients, there were 21 individuals (40%) with ASBO entrapment and 31 patients (60%) with ASBO obstruction. Among the examined patients, 62% had primary ASBO and 38% had a recurrence. Regarding the grade of small bowel obstruction, the percentage distribution of patients according to this criterion was as follows: 1/3 of the small bowel lumen – 5 patients, 2/3 of the small bowel lumen – 16 patients, 3/3 of the small bowel lumen – 31 patients. In 81% of patients with ASBO, the diameter of small bowel dilation was < 5 cm, while in the remaining 19% it was ≥ 5 cm. Among all patients studied, 31 patients with ASBO did not have peritonitis, 11 had serous peritonitis, and 10 had purulent peritonitis.

When assessing the level of comorbidity in this cohort of patients, the average CCI was 3.9 points. Regarding the degree of surgical and anaesthetic risk according to ASA, about 80% of patients in ASBO had a risk class III on the ASA scale.

The method of regression analysis was used as a mathematical model, which allows, based on the data of regression coefficients and the values of risk factors that have a probable influence on the development of ASBO, to identify the dependence between them and predict the probability of complications of ASBO in patients.

In order to build a mathematical model of forecasting, the probable factors of the development of complications of ASBO in the examined patients were selected. With the help of linear regression analysis, the 9 most significant risk factors that had the greatest influence on the risk of relapse were identified: Y_1 – age; Y_2 – duration of ASBO; Y_3 – type of ASBO; Y_4 – episode of ASBO; Y_5 – length of obstruction of the small intestine; Y_6 – the diameter of the expansion of the lumen of the small intestine; Y_7 – presence and type of peritonitis; Y_8 – CCI; Y_9 – degree of preoperative risk according to the ASA scale (Table 1).

A stepwise logistic regression analysis was performed to assess the probability of selected factor characteristics: multicollinear risk factors for the development of ASBO complications were identified, and a correlation matrix was constructed with the calculation of correlation coefficients. The next step was to determine the relative weight of multicollinear factors in predicting the development of ASBO complications by determining regression coefficients (β), which reflect the association of each with the likelihood of developing ASBO complications in the study population (Table 2).

To estimate the probability of developing ASBO complications, a multiple regression equation was constructed to determine the ASBO complication development coefficient (CDC): $CDC = 3.601 + 0.667Y_1 + 1.429Y_2 + 0.635Y_3 + 1.235Y_4 + 0.667Y_5 + 0.569Y_6 + 1.235Y_7 + 1.103Y_8 + 0.457Y_9$ ($R = 0.996$; $R^2 = 0.986$; $F = 574.65$; $p < 0.05$), where:

- CDC is the probability coefficient for the development of ASBO complications;
- 3.601 is a constant;
- Y_1–Y_9 – coded values of risk factors according to Table 1;
- R – multiple correlation coefficient;
- R^2 – coefficient of determination;
- F – Fisher's F-criterion.

The probability coefficient for the development of complications ranged from 0 to 1 and reflected the probability of developing ASBO complications. This meant that the closer the predicted probability was to 1, the higher the risk of ASBO complications.

We obtained a mathematical model for predicting the probability of developing complications of ASBO. Next, we calculated the specificity and sensitivity for this model using the appropriate formulas and found that its sensitivity was 97% and its specificity was 96%. The predictive model demonstrated high sensitivity and specificity in the development cohort.

External validation on an independent cohort of 50 patients confirmed the predictive accuracy and reproducibility of the model, demonstrating its applicability for clinical use.

Thus, a mathematical model was obtained for predicting the likelihood of ASBO complications in the study population, based on statistically significant prognostic relationships. This model will enable more effective prevention of recurrent ASBO at all levels of medical care, particularly in surgical practice.

ASBO is a pathological condition in which the food movement through the intestines is disrupted or even

Table 1

Risk factors for the occurrence of complications of ASBO and their indexing

Predictors	Factors	Indexing
Y_1	**Age, years**	
	< 60	1
	60–80	2
	> 80	3
Y_2	**Duration of ASBO, hours**	
	< 24	1
	24–48	2
	> 48	3
Y_3	**Type of ASBO**	
	Obturation	1
	Strangulation	2
Y_4	**Episode of ASBO**	
	Primary	1
	Recurrence	2
Y_5	**The length of small bowel obstruction**	
	1/3	1
	2/3	2
	3/3	3
Y_6	**Diameter of small intestinal lumen dilation, cm**	
	< 5	1
	≥ 5	2
Y_7	**Presence and type of peritonitis**	
	Without	0
	Serous	1
	Purulent	2
Y_8	**CCI, points**	
	2	1
	3	2
	4	3
Y_9	**Degree of preoperative risk according to the ASA scale**	
	I	1
	II	2
	III	3

Notes: ASBO – acute small bowel obstruction; CCI – Charlson Comorbidity Index; ASA – American Society of Anesthesiologists.

Table 2

Prognostic value of individual parameters for the risk of ASBO complications in the study population

Predictors	Multiple logistic regression		
	β	SE	p-value
Y_1	0.667	0.953	< 0.05
Y_2	1.429	1.945	< 0.05
Y_3	0.635	0.769	< 0.05
Y_4	1.235	1.945	< 0.05
Y_5	0.667	0.633	< 0.05
Y_6	0.569	0.945	< 0.05
Y_7	1.235	1.945	< 0.05
Y_8	1.103	0.945	< 0.05
Y_9	0.457	0.875	< 0.05
Constant	3.601	0.099	< 0.05

Notes: ASBO – acute small bowel obstruction; SE – Standard Error.

HEALTH OF MAN / ЗДОРОВ'Я ЧОЛОВІКА • №1 (96)/2026
ISSN 2786-7315 (Print) | ISSN 2786-7323 (Online)

completely stopped. The problem does not arise on its own, but is usually caused by complications of various diseases of the abdominal cavity, the development of adhesions and tumour processes, etc. [15]. Intestinal obstruction usually requires urgent treatment, which includes both conservative methods of therapy and surgical intervention. In terms of the number of fatalities, this pathology ranks 1st or 2nd among all acute diseases of the abdominal cavity. It is also known that during the treatment of ASBO, there is a fairly high risk of postoperative complications (necrosis of the strangulated intestinal loop, bleeding, anastomotic suture dehiscence, abdominal abscesses, intestinal fistulas, peritonitis) [16].

It is known that one of the leading places in the structure of acute abdominal pathology is occupied by abdominal compartment syndrome (ACS), which is characterised by various clinical manifestations [17]. Despite the advances in medicine in this area, the results of ACS treatment are not entirely satisfactory for surgeons. Diagnostic errors and delays in performing surgical interventions due to the lack of highly informative diagnostic methods lead to many complications of ACS.

The method of multifactorial mathematical analysis, taking into account the most informative factors and their severity options, allows the creation of a system for predicting the development of ASBO complications in patients, which develop as a result of the combined influence of a number of factors [18]. The use of this method allows predicting not only the occurrence of pathology, but also the degree of probability of its complications, which is important for the further creation of effective preventive measures. It can also help in creating a comprehensive approach to correct diagnosis and the development of optimised tactics for the ASBO treatment [19]. The model has several limitations, including: the retrospective nature of the study, the small sample size (52 patients), the inclusion of patients from only one medical centre, and the lack of external validation on an independent sample. Although the model was tested on an independent sample, validation on patients from other medical institutions is necessary to increase the reliability of the results and reduce possible bias. This will allow the universality of the model and its effectiveness in different clinical settings to be assessed.

Using our mathematical model, which accounts for risk factors and the likelihood of ASBO complications, we can predict their development. This will help with earlier diagnosis of ASBO and let us to choose more effective ways to treat the disease.

CONCLUSIONS

The proposed quantitative model assesses existing risk factors and uses regression analysis to predict ASBO complications. It may help reduce complication rates through early diagnosis and guide the development of optimized treatment and prevention strategies.

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Стаття надійшла до редакції 05.01.2026. – Дата першого рішення 14.01.2026. – Стаття подана до друку 10.02.2026