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The concept of perioperative risk: a narrative review

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Abstract

INTRODUCTION: Perioperative risk refers to the likelihood of adverse events occurring during and after surgery. For the purpose of defining and classifying adverse events and predicting them, a comprehensive search of Pubmed and Lens.org was made according to the author expert opinion. **OBSERVATIONS:** Traditionally, two main types of postoperative adverse events have been investigated: complications and mortality. However, over the past decade, there has been a growing trend to expand the range of adverse events analyzed, from intraoperative critical events and the quality of recovery from anesthesia to the development of intensive care syndrome, assessing quality of life, disability, and survival over time. An important aspect associated with adverse events and outcomes is the provision of additional resources for a long-term stay for patients with acute respiratory viral infections and inpatient care after discharge, among other things. The review formulates the expert opinion concept of perioperative risk, based on a critical analysis of literature, with an emphasis on the need to create an ideal tool, such as a calculator, which must undergo external validation. This tool should include available, modifiable variables, and accurately determine the full range of adverse events and outcomes during the intra- and early postoperative periods, as well as delayed events. The concept shall also focus on identifying and characterizing patients with a high risk of perioperative complications.

Концепция периоперационного риска: обзор литературы

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Реферат

АКТУАЛЬНОСТЬ: Периоперационный риск характеризует вероятность развития неблагоприятных исходов в течение и разные сроки после операции. **ЦЕЛЬ ОБЗОРА:** Обосновать концепцию периоперационного риска на основе анализа современных подходов к дефинициям и классификации неблагоприятных исходов и их прогнозированию. Традиционно исследуют 2 основных вида послеоперационных неблагоприятных исходов — осложнения и летальность. Однако в последнее десятилетие наметилась и усиливается тенденция к существенному расширению спектра анализируемых неблагоприятных исходов от интраоперационных КИ и качества восстановления после анестезии до развития синдрома последствий интенсивной терапии, оценки качества жизни, степени инвалидности и выживаемости в течение года. Важным аспектом, ассоциированным с неблагоприятными событиями и исходами, является дополнительное ресурсное обеспечение длительного пребывания пациента в отделении анестезиологии, реанимации и интенсивной терапии (ОАРИТ) и стационаре, внеплановая госпитализация после выписки и т. п. В обзоре сформулирована собственная концепция периоперационного риска на основе критического анализа данных литературы с акцентом на необходимость создания идеального инструмента (калькулятора), который должен пройти внешнюю валидацию, включать доступные, в том числе модифицируемые переменные, точно определять весь спектр неблагоприятных событий и исходов в интра- и раннем послеоперационном периоде, а также отсроченные неблагоприятные события и дифференцировать конкретные высокие риски. Особое внимание уделено идентификации и характеристике пациентов высокого периоперационного риска.

KEYWORDS: patient outcome assessment, risk assessment, risk evaluation and mitigation, intraoperative complications, postoperative complications, risk factors, hospital mortality

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КЛЮЧЕВЫЕ СЛОВА: периоперационный риск, неблагоприятные послеоперационные исходы, эпидемиология послеоперационных осложнений и летальности, пациенты высокого риска

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Introduction

Perioperative risk is a multifactorial concept that characterizes the likelihood of adverse outcomes during and at different terms after surgery. Perioperative risk is determined by two key determinants: the risk of surgery and the risk associated with the patient's condition, which include a significant range of risk factors, the combination and significance of which determine the likelihood of an adverse outcome [1, 2, 3].

The risk factors for surgical intervention include injury, urgency, duration, position on the operating table (positioning) and localization of the operation [4, 5, 6]. There are significantly more risk factors associated with the patient conditions such as concomitant diseases, age, functional dependence, nutritional status, anxiety, depression, functional state and others [7, 8, 9, 10].

Objective

Substantiating the concept of perioperative risk based on the analysis of modern approaches to the definition and classification of adverse outcomes and their prediction.

Materials and methods

The evidence considered in this work combines the expert opinion of the author with a comprehensive search in several English-language databases (which are also indexed by Russian sources) and subsequent analysis of relevant publications. The search on the Pubmed database was supplemented by the search on Lens.org where articles that were not included in Pubmed were taken into account, provided they had a DOI and at least one citation. The search depth was 25 years.

The main content of the review

Adverse perioperative outcomes

Prevalence

About 313 million operations are performed annually in the world; according to data from twenty-nine countries (half of which are developing countries), the 30-day mortality rate after all operations is 7.7 % and ranks third in the structure of causes of mortality after heart attack and stroke [11].

After planned non-cardiac operations, the 30-day mortality rate varies from 0.4 % in economically developed countries [12] to 2.25 % in countries with low economic development (Degu S, 2023), and after emergency operations, it is 3.7 % and 6.36 % [12, 13], respectively. At the same time, the complication rate ranges from 7–15 % [14] to 51 % [15].

Definitions and classifications

In 2022, the group for standardization of perioperative outcomes - Standardized Endpoints in Perioperative Medicine-Core Outcome Measures in Perioperative and Anaesthetic Care (StEP-COMPAC) published a consensus opinion on the definition of the main perioperative outcomes [16]:

1. Mortality/survival: postoperative mortality, long-term survival.
2. Perioperative complications: transient complications and undesirable events (including critical incidents), complications and undesirable events leading to disability.
3. Resource usage: length of hospital stay, unplanned readmission within 30 days.
4. Short-term recovery: routing after discharge from the hospital (own home/rehabilitation center/nursing home), the level of dependence (need for care), or both.
5. Long-term recovery: assessment of the quality of life.

Indeed, complications and mortality are traditionally analyzed as unfavorable perioperative outcomes [17]. At the same time, it is important to note that the hierarchy of adverse outcomes also includes intraoperative adverse events, which, in the absence of timely correction, and sometimes despite it, transform into complications [18, 19, 20].

To date, there is no agreed definition of adverse events during surgery and anesthesia. One of the approaches includes the following components of this concept [21]:

- Near misses — actions that could lead to an unfavorable outcome.
- Critical incidents — events that could lead to an unfavorable outcome and events that led to an unfavorable result.
- Adverse events — an adverse outcome that has occurred that has harmed the patient.
- Errors — an error that led to an unfavorable outcome.
- Medicine errors — errors in the use of medicines.
- Harm — injury, suffering, disability and death.

In relation to surgery, at least two classifications of severity of adverse intraoperative events (AIE) are proposed. The first one is focused only on AIE related to the actions of the surgeon (table 1), the second describes in detail the gradations of severity of AIE in abdominal surgery from the positions of both the surgeon and the anesthesiologist-resuscitator (table 2).

The above definition of a "critical incident" (CI) can also be found in recent publications with the caveat that the consequences of CI may be significant not only for the patient, but indirectly for his relatives [23, 24].

Belka K et al. [23] propose to classify CI as follows:

1. In relation to general anesthesia:
   - from the respiratory system (difficult intubation of the trachea, unsuccessful intubation, repeated intubation, unintentional intubation of the esophagus, difficult ventilation in a mask or putting on a laryngeal mask, unintentional extubation, bronchospasm, laryngospasm, decreased oxygen saturation < 90 %, hypo-/hypercapnia, pneumothorax, aspiration),
   - from the circulatory system (hypotension - systolic blood pressure < 70 mmHg), bradycardia (heart rate < 40/min), tachycardia (heart rate > 140/min), tachyarrhythmia, arterial hypertension (systolic blood pressure > 200 mmHg), cardiogenic pulmonary edema, acute myocardial ischemia, cardiac arrest, hemolytic reaction during blood transfusion, massive bleeding volume > 1000 ml, air embolism, collapse)
2. In relation to regional anesthesia (improper administration of the drug, high spinal block, systemic toxicity of local anesthetic, paresthesia, nerve damage, intraneural injection of local anesthetic).
3. Errors in the use of medicines (allergies, anaphylaxis, missed dose, side effects, malignant hyperthermia)

Table 1. Classification of the severity of adverse intraoperative events associated with the actions of the surgeon [18]

Severity	Description of intraoperative events
I	Damage that does not require correction within the same procedure (for example, coagulation, use of hemostatic material, ligation of small vessels)
II	Damage requiring surgical repair without removing organs or changing the originally planned procedure (for example, suturing, plastic surgery)
III	Injury requiring removal of tissue or organ with completion of the originally planned procedure
IV	Damage requiring significant modification and/or abandonment of the originally planned procedure (excludes minimally invasive conversions to open operations)
V	An undiagnosed injury that required repeated surgery within 7 days
VI	Intraoperative fatal outcome
T	It is added if the damage required transfusion of ≥2 units of red blood cells

Table 2. ClassIntra Abdominal Surgery Adverse Event Severity Scale

(ClassIntra)	Definition	Examples
Class 0	There are no deviations from the operation protocol	—
Class I	Any deviation from the operation protocol: ■ without the need for additional treatment or intervention ■ patient without symptoms or with mild symptoms	■ Bleeding: above normal from small vessels; self-limiting or controlled without additional correction ■ Minimal damage to intestinal serosa that does not require treatment ■ Coagulation: minor burns on the skin that do not require treatment ■ Arrhythmia: without significant consequence
Class II	Any deviation from the operation protocol: ■ the need for minor treatment or intervention ■ a patient with moderate symptoms that are not life-threatening and do not lead to disability	■ Moderate bleeding, the use of tranexamic acid ■ Partial damage to the intestinal wall, requiring sutures ■ Coagulation: moderate burns, without invasive treatment ■ Arrhythmia on the background of stable hemodynamics, antiarrhythmics are required
Class III	Any deviation from the operation protocol: ■ the need for moderate treatment or intervention ■ a patient with severe symptoms, potentially life-threatening or leading to disability	■ Bleeding from large vessels, with temporary hemodynamic disorders, requires blood transfusion ■ Damage to the intestinal wall requiring resection ■ Coagulation: severe burns requiring surgical rehabilitation ■ Arrhythmia on the background of transient hemodynamic changes or causing transient hemodynamic instability: antiarrhythmics and/or hemodynamic correction are required
Class IV	Any deviation from the operation protocol: ■ The need for serious and urgent treatment ■ * Patients with life-threatening symptoms or with disabilities	■ Massive bleeding requiring erythrocyte transfusion, replacement of vital functions ■ Damage to a major artery requiring emergency resection ■ Coagulation: life-threatening burns requiring surgical rehabilitation ■ Arrhythmia: requires pacing or defibrillation and/or hemodynamic correction, transfer to OAR
Class V	Any deviation from the protocol of the operation is fatal	—

4. Equipment malfunction (malfunction of the laryngoscope or video laryngoscope, leakage of the breathing circuit, lack of adsorbent) is rarely considered and reported by doctors (surgeons, anesthesiologists) [24].

However, one of the few audits revealed an overall incidence of CI 9.35 cases per 1,000 anesthetics. The most frequent CI were:

- from the rleespiratory system: difficult intubation (26.8 %), reintubation (6.4 %), desaturation (13.8 %).
- from the circulatory system: hypotension (14.9 %), tachycardia (6.4 %), bradycardia (11.7 %), hypertension (5.3 %), collapse (3.2 %), massive blood loss (17 %).

The audit also revealed the most common causes of CI:

- individual characteristics of the patient (47 %),
- surgical tactics (18 %),
- anesthesia technique (16 %)
- the human factor (12 %).

The causes of CI associated with the actions of the anesthesiologist included:

- insufficient preoperative assessment (44 %),
- erroneous interpretation of the patient's condition (33 %),
- incorrect manipulation technique (14 %),
- misunderstanding with the surgical team (13 %) and
- delay in delivery of the emergency care (10 %).

According to the estimates of the audit participants, 48 % of CI cases could have been prevented, and the consequences in another 18 % of cases could have been minimized. The consequences of CI were insignificant in more than half of the cases, in 24.5 % of cases they led to a prolonged stay in the hospital, 16 % of patients required urgent transfer to the ICU, and 3 % of patients had a fatal outcome [23].

Postoperative complications: definition, prevalence, and classification

The analysis of 4.000 CI also revealed their significant role in the delayed consequences of complications (918 cases, 23 %) and fatal outcomes (151 cases, 3.8 %) [25].

Thus, adverse intraoperative events, in particular CI, in case of their timely detection (and preferably recording) can significantly affect the reduction of postoperative complications, their severity and consequences.

To this end, the American and European classifications of complications have been developed and are increasingly being used in clinical practice and scientific research, which combine 6 main groups: cardiac, respiratory, cerebral, renal, infectious and surgical [26, 27]. However, the specific complications in each group differ significantly both in number and structure (table 3).

Since 2007, it has been proposed to screen for complications on days 3, 5, 8 and 15 after the operation [28].

The contribution of complications to postoperative mortality is heterogeneous and is related to their nature and frequency. Septic shock, acute kidney injury, pneumonia and postoperative bleeding make the greatest contribution to postoperative mortality. Wound infection, acute myocardial infarction, acute cerebrovascular accident and pulmonary embolism are of lesser importance, primarily due to the rarer occurrence [29] (table 4).

Thus, a "postoperative complication" is defined as any deviation from the normal course of the postoperative period. This means that the severity varies from non-life-threatening complications without permanent disability to fatal outcomes [30, 31, 32]. A postoperative complication can have a serious impact on a patient, potentially leading to a decrease in both quality of life and functional capabilities [33].

Approaches to the assessment of postoperative complications and mortality

The assessment of the severity of postoperative complications according to the Clavien-Dindo classification is appropriate, since it directly reflects the need for hospitalization of the patient to the ICU, the duration of stay in the ICU and in the hospital, unplanned admission to the hospital and postoperative mortality [3, 34].

The traditional approach to assessing complications and mortality has a number of significant drawbacks it does not include an analysis of long-term postoperative recovery and quality of life. To address this problem, the StEP-COMPAC group published a systematic consensus review in 2019, which aimed to identify a set of standard outcomes that

Table 3. Comparative characteristics of postoperative complications included in the American and European classifications

№	Postoperative complications	ACS-NSQIP	ESA-ESICM
	Cardiovascular complications		
1.	Myocardial infarction	X	X
2.	Deep vein thrombosis	X	X
3.	PE	X	X
4.	Cardiac arrest	X	X
5.	Myocardial damage after non-cardiac surgery		X
6.	Cardiogenic pulmonary edema		X
7.	Arrhythmia		X
	Respiratory complications		
8.	Pneumonia	X	X
9.	Respiratory failure	X	X
10.	Unscheduled tracheal intubation	X	
11.	Atelectasis		X
12.	ARDS		X
13.	Aspiration pneumonitis		X
14.	Pneumothorax		X
15.	Hydrothorax		X
16.	Bronchospasm		X
	Renal complications		
17.	Acute kidney injury	X	X
	Cerebral complications		
18.	CVA	X	X
19.	Delirium		X
	Infectious complications		
20.	Infection	X	
21.	Infection without a specific source		X
22.	Urinary tract infection		X
23.	Postoperative infection (organ/space)		X
24.	Postoperative wound infection (deep)		X
25.	Postoperative wound infection (superficial)		X
26.	Respiratory infection		X
27.	Laboratory-confirmed bacteremia		X
28.	Sepsis/septic shock	X	
	Surgical complications		
29.	Divergence of the wound edges	X	
30.	Paralytic intestinal obstruction (gastrointestinal paresis)		X
31.	Postoperative bleeding		X
32.	Gastrointestinal bleeding		X
33.	Anastomosis leak		X

PE — pulmonary embolism; ARDS — acute respiratory distress syndrome; CVA — cerebrovascular accident.

should be used in future studies with a particular focus on patient-centered outcomes [35].

The results of the systematic review included thirty-three methods for assessing patient-oriented postoperative outcomes (satisfaction, quality of life, well-being, functional status, survival during the year). The Delphic Consensus has identified three main outcomes for inclusion in future clinical trials:

1. Quality of life — EuroQol 5 Dimension (EQ-5D) in a version with a visual analog scale [36, 37].
2. Functional status (degree of disability of the patient) — WHO Disability Assessment Schedule (WHODAS) version 2.0 (12 questions) [38].
3. Impact on life — survival for 30, 90 and 180 days after surgery in hospital or after discharge (DAOH30) [39].

It is recommended to assess the quality of life and the degree of disability 6 or 12 months after surgery in comparison with the preoperative level [36, 37, 38].

The consensus of the authors [35] was not reached on the recommendation of the QoR-15 recovery quality assessment tool, which was previously proposed by another StEP group [40]. A score of 118 or more (out of 150 possible) indicates a good recovery after anesthesia. Lower values on this scale obtained a day, three days and a week after surgery may indicate the development of postoperative complications [41].

In patients with a complicated postoperative period, it is important to assess the post intensive care syndrome (PICS) — a set of somatic, neurological, and socio-psychological consequences of staying in the ICU for more than 72 hours, requiring rehabilitation [42,43].

Summarizing, it can be stated that it is advisable to include the following postoperative outcomes:

- lethality;
- complications, their severity and duration of development;
- critical incidents;
- recovery after anesthesia;
- re-admission to the ICU;
- unplanned admission to the ICU;
- repeated unplanned admission to the hospital;
- quality of life;
- disability;
- PICS syndrome.

The main task of the preoperative assessment is to identify the risks of the entire complex of adverse outcomes in a particular patient, which is included in the modern concept of perioperative risk (fig. 1).

Currently, this task is usually solved by using a large set of tools for predicting specific risks, which cannot be implemented in routine clinical practice.

Perioperative risk: assessment methodology

The assessment of perioperative risk is clinically appropriate, as it implies the solution of many tasks [44, 45, 46]:

- obtaining informed consent of the patient,
- justification of the necessary preoperative examination,
- interdisciplinary interaction,
- identification of modifiable risk factors,
- individualization of preoperative preparation,
- patient education and joint decision-making,
- selection of the method and drugs for anesthesia,
- optimization/minimization of surgical intervention,
- argumentation of extended monitoring,
- routing of the patient after surgery (ICU),
- targeted prevention of perioperative complications.

Table 4. Frequency and mortality after serious postoperative complications

Complications	Incidence %	Mortality because of complications, %	The contribution of complications to mortality*, %
Pneumonia	2.1 %	19.1 %	0.40 %
Deep wound infection	1.9 %	4.5 %	0.09 %
Organ/cavity infection	3.3 %	6.7 %	0.22 %
Septic shock	2.1 %	36.3 %	0.76 %
AKI	1.5 %	43.7 %	0.66 %
CVA	0.2 %	35.1 %	0.07 %
MI	0.5 %	32.1 %	0.16 %
PE	0.7 %	7.7 %	0.05 %
Postoperative bleeding	1.4 %	29.9 %	0.42 %

* — mortality from complication x complication frequency = complication contribution to overall mortality

The methodology for assessing perioperative risk is extensive and includes a large number of tools that can be used to predict immediate and delayed adverse outcomes not only in the preoperative period, but also in the intra- and postoperative periods (fig. 2).

The creation and implementation of scales and models for assessing perioperative risk is the basis of the concept of humane surgery developed in recent years [47, 48].

There is a certain sequence of steps that are necessary for the development, validation and implementation of perioperative risk assessment tools [44, 45, 49, 50, 51, 20].

I. Justification of the need (model concept): identification and confirmation of the need for a new perioperative risk assessment model, analysis and identification of shortcomings or limitations of current methods.

II. Development: creation of a prototype model, identification of key parameters for risk assessment.

III. Internal validation: verification of the model on the retrospective data that were used for its development, with an analysis of the accuracy and reproducibility of the results within the study sample.

IV. External validation and refinement:
- limited validation (homogeneous cohort) - testing the model on a new but homogeneous retrospective or prospective (with or without randomization) sample of patients similar to the original group;
- extensive validation (heterogeneous cohort) - testing the model on a diverse retrospective or prospective (with or without randomization) sample of patients to verify its versatility and ability to work in various clinical settings.

V. Impact on clinical practice: assessment of the impact of the new model on changing medical tactics (decision-making) and improving clinical outcomes (reducing complications, increasing survival).

VI. Updating, if necessary: constant monitoring of the model in clinical practice and making changes, if necessary, to maintain its relevance and accuracy.

VII. Cost-effectiveness: an analysis of the economic feasibility of the model with an assessment of the costs of implementing and using the model and a comparison with the benefits obtained, such as reducing treatment costs due to a more accurate risk assessment.

VIII. Long-term implementation and dissemination: integration of the model into clinical practice on a long-term basis and its dissemination in other medical institutions, including staff training and the creation of infrastructure for continuous use of the model.

Each stage plays an important role in ensuring the reliability and effectiveness of the developed tools.

It is important to note that the evolution of many predictive tools ends at the stage of internal validation. For example, in a systematic review by Arina P et al, [20] it was demonstrated that only 13 of the 76 machine learning models developed for the perioperative period underwent ex-

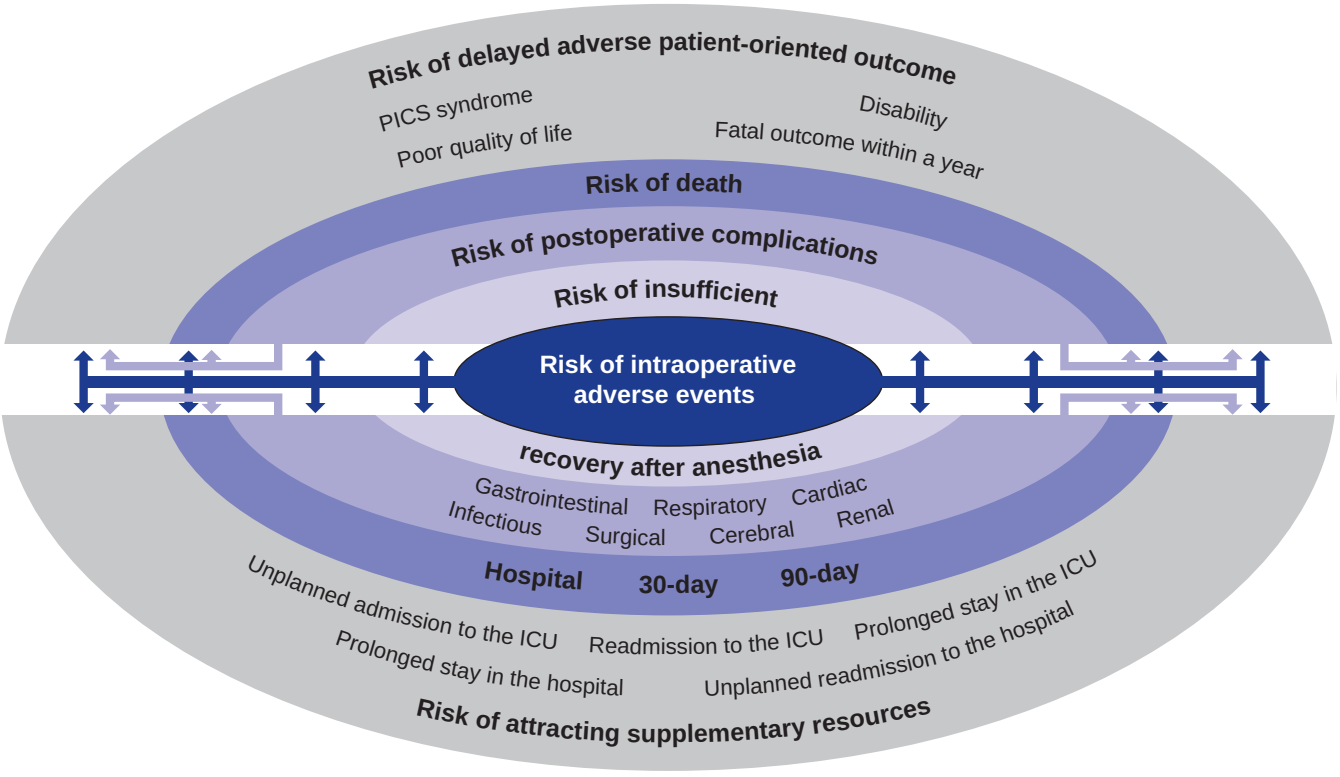

Fig. 1. Components of the perioperative risk concept.

ternal validation, and only one showed advantage for real clinical practice when conducting a randomized trial.

Many tools were originally developed only for the purpose of predicting postoperative mortality (hospital, 30-day or 90-day). Therefore, it is not surprising that attempts to use them for predicting complications appeared at the stage of external validation and, as a rule, had lower prognostic value in comparison with the assessment of mortality risk. Nevertheless, it is important to note that the accuracy of predicting postoperative complications based on introductory variables for predicting mortality is not inferior to the prognostic value of specialized risk scales for specific complications.

As a rule, external validation does not confirm the value of the scale or calculator, especially over time and in other patient populations. A significant number of tools have not been subjected to external validation at all. In particular, the spectrum of major complications has been studied in only three of the 13 regression models and in six of the seven machine learning tools. Of the 27 analyzed methods, 18 methods for predicting mortality and only five calculators for predicting the spectrum of major complications (POSSUM, ACS-SRC, SUPRAS, MSR and POTTER) underwent external validation.

Thus, in the vast majority of studies, one or more adverse postoperative outcomes are evaluated using appropriate specific scales designed to predict mortality and individual complications (for example, respiratory failure, delirium, major cardiac complications, etc.). A comprehensive assessment of perioperative risk (an ideal tool) implies covering the maximum number of adverse postoperative outcomes using a single prognostic tool, including mortality, major complications, undesirable intraoperative events, the need for additional resources, and quality of life.

The main purpose of using tools to determine the likelihood of adverse outcomes is to identify patients with high perioperative risk.

High perioperative risk: definition, epidemiology, validation and patient identification models

The dominant contribution to postoperative mortality is made by patients with high perioperative risk (table 6).

Approaches to the identification of patients with high perioperative risk can be classified as follows:

1. Comparison with empirically determined thresholds for the frequency of adverse outcomes according to literature data (for example, SAMPE, Ex-Care).
2. Comparison with the average risk values in the calculator database (ACS-SRC, SUPRAS, ACS-NSQIP neural network analysis).
3. Use of calculators designed to assess high risk (SORT, SORTv2).
4. Separation of risk into high and low by cut-off point(s) on the AUROC curve (SAS, Pythia, MSR).

The empirical determination of mortality and complication thresholds for the verification of patients with high perioperative risk is associated with the following values:

- the probability of hospital mortality is ≥ 5 % [97],
- the probability of hospital mortality is ≥ 4 % [98],
- the probability of hospital complications ≥ 50 % [99],
- the probability of hospital complications is ≥ 15 % [92].

An audit of the causes of excessively high mortality (more than three times) in the UK compared with the USA revealed as the main reason a high threshold for hospitalization in the ICU - the risk of hospital mortality ≥ 10 % [100]. After a two-fold decrease in the threshold for hospitalization in the ICU to a level of ≥ 5 %, the mortality rate decreased significantly [97, 101]. Nevertheless, there is an ongoing discussion about the argumentation of indications for transferring a patient to the ICU after surgery, when the threshold probability of death is ≥ 2% [69].

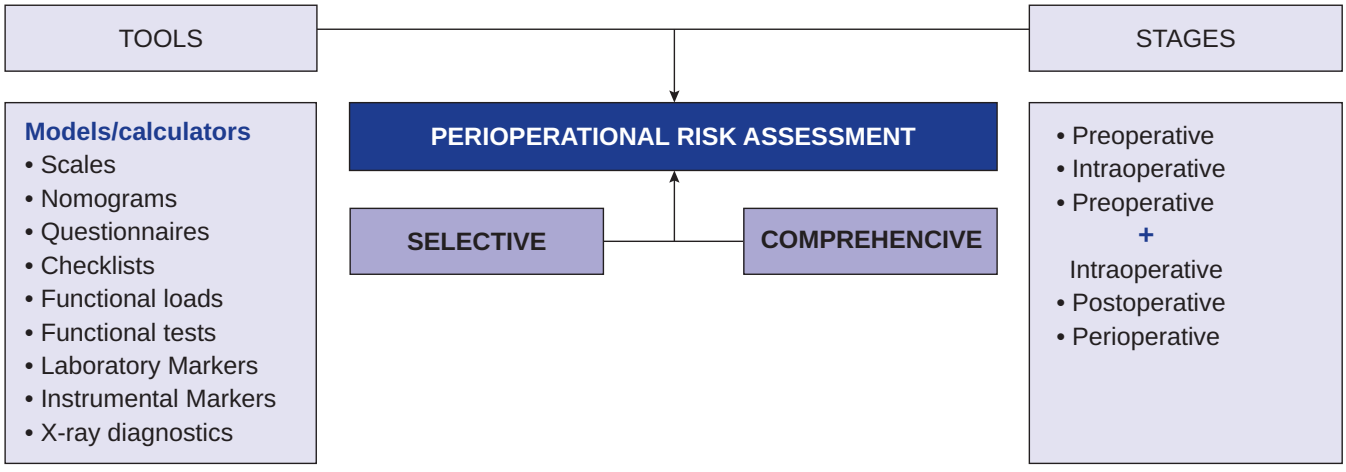

Fig. 2. Approaches to assessing perioperative risk.

Table 5. Prognostic value of risk assessment tools for postoperative complications and mortality

Scale / Calculator / Machine learning model	Postoperative mortality		Postoperative complications	
	AUROC, development	AUROC, external validation	AUROC, development	AUROC, external validation
Scales				
ASA-PS	–	0.65–0.86 [52, 53, 54, 55]	–	0.652–0.787 (2) [55]
SRS Donati	0.88 [56]	–	–	–
SRS	0.93-0.95 [57]	0.92–0.95 [58, 52]	–	–
RQI	0.915 [59]	0.89 [60]	0.867 (*) [59]	–
SAS	0.81 [61]	0.81–0.88 [54, 62, 63]	0.72–0.73 (21*) [61]	0.58–0.89 (16*) [55]
SASA	0.87 [54]	0.81–0.85 [2, 55]	–	-
POSPOM	0.92 [64]	0.77–0.85 [65, 66]	–	0.65–0.71 (*) [65, 66]
Models / calculators				
S-MPM	0.89 [4]	0.75 [55]	–	–
Michigan Model	0.893-0.905 [67]	–	0.757–0.867 (5) [67]	–
CORES	0.82 [68]	–	–	–
SAMPE	0.913 [53]	–	–	–
Ex-Care	0.90 [69]	–	–	–
CARES	0.936 [70]	–	0.837–0.863 (1) [70]	–
E-PASS	0.81 [71]	0.72–0.86 [72, 73]	0.72 (14*) [71]	–
POSSUM	–	0.915–0.72 [74, 75, 76, 77]	–	0.62–0.82 (6) [74, 75, 76, 77]
P-POSSUM	–	0.912–0.73 [58, 72, 77, 78]	–	0.92 (*) [58, 72, 77, 78]
ACS-SRC	0.937 [79]	0.67–0.95 [80, 81, 82, 83]	0.806–0.895 (7) [79]	0.606–0.887 (7*) [80, 81, 82, 83]
SUPRAS	0.93 [81, 84, 85]	0.86–0.938 [82]	0.772–0.889 (8) [81, 84, 85]	0.724–0.893 (9*) [82]
SORT	0.95 [52]	0.88–0.98 [77, 86, 87]	-	–
SORT-2	0.92 [87]	0.99 [77]	-	–
Machine learning / calculators				
UPMC	0.972 [88]	0.995 [88]	0.899–0.923 (4) [88]	–
Korean models ML	0.96 [89]	0.92–0.94 [89]	–	–
MSR	0.83 [90, 91]	0.82 [19]	0.82–0.92 (8) [90, 91]	0.78–0.92 (7) [19]
Pythie	0.92 [92]	–	0.747–0.924 (13) [92]	–
POP, Austin Health	0.86-0.914 [2]	–	0.747–0.878 (4) [2]	–
Deep ML ACS-SRC	0.942-0.952 [83]	–	0.863–0.876 (18) [83]	–
POTTER	0.86-0.93 [93]	0.89–0.92 [83]	0.642–0.918 (18) [93]	0.733–0.934 (18) [83]

(*n*) — the number of adverse outcomes (complications, adverse intraoperative events, additional resource provision).

* — only the total number of complications was analyzed

The main models that allow to identify and verify patients with high perioperative risk based on a comprehensive prediction of mortality and the main spectrum of complications:

- ACS-SRC calculator [79].
- Models based on the ACS-NSQIP neural network [83].
- Calculator based on the Pythia database, Duke University Health System — DUHS [92].
- The MySurgeryRisk, Florida model [90.91] and its validation [19, 102].

ACS-SRC calculator, which includes 21 input variables (age, gender, functional status, emergency, ASA-PS class, glucocorticosteroid intake due to chronic diseases, ascites within 30 days before surgery, sepsis within 48 hours before surgery, respiratory support with a ventilator, disseminated cancer, diabetes mellitus, arterial hypertension requiring medical correction, a history of heart disease, congestive heart failure for 30 days before surgery, shortness of breath, a history of smoking for a year, COPD, chronic hemodialysis, acute kidney injury, body mass index), available at the link - http://riskcalculator.facs.org [79].

Patients at high perioperative risk are identified based on an increase of predicted mortality rate and each of the 6 complications (pneumonia, cardiac complications, wound infection, urinary tract infection, venous thrombotic events, acute kidney injury) relative to the average in the current calculator database. At the same time, the high risk does not necessarily extend to all complications and mortality [79].

Models based on the ACS-NSQIP neural network. Their basis is a database that includes data from 5,881,881 adult surgical patients in the period from 2012 to 2018. ACS-NSQIP neural network analysis made it possible to predict mortality, surgical wound infections (superficial and deep), pneumonia, acute kidney injury, sepsis, septic shock and others based on three models differing in the number of input variables:

- model 1 (21 variables, as in the traditional ACS-SRC calculator),
- model 2 (supplemented with 13 preoperative laboratory parameters),
- model 3 (supplemented with 23 preoperative variables to model 2).

An external validation of ACS-SRC and POTTER calculators was performed in the ACS-NSQIP neural network analysis model database. The proposed three models demonstrated higher accuracy in predicting sepsis and septic shock and comparable accuracy in predicting other adverse outcomes compared to ACS-SRC and POTTER [83].

A calculator based on the Pythia database was developed in 2018 by the Duke University Health System (DUHS) research team. The calculator includes 9 input variables (operation codes, age, BMI, gender, race, smoking, comorbidity and medications taken) and 14 adverse postoperative outcomes. A comparison of the accuracy of the Pythia and ACS-NSQIP calculators demonstrated the superior accuracy of the Pythia model.

A high perioperative risk is predicted if the probability of any complications is higher than 14.2 % and/or a specific complication is higher than 5 %.

In the studied population, a high perioperative risk was observed in 35–39 % of patients (depending on the applied machine learning model) [92].

The MySurgeryRisk model was developed on the basis of 285 preoperative variables from electronic medical records of 51,457 patients containing information on demographic and socio-economic data, concomitant diseases and medications taken, operations performed, laboratory and clinical data [91, 102]. The model has good prognostic value in predicting 30- and 90-day mortality and most postoperative complications, and high accuracy in predicting the development of sepsis and ventilation for more than 48 hours (table 7).

A retrospective assessment shows that the risk of complications was significantly higher in the high-risk group. AKI and the duration of stay in the ICU was about 5 times higher in such patients and other complications were 10–20 times higher. In contrast to complications, patients at high risk of death, both short-term and long-term, differ by 35–130 times (table 8).

Table 6. Association of high perioperative risk with mortality

High perioperative risk			Authors
Percentage of patients in the population	Lethality	Contribution to overall mortality	
12.5 %	12.3 %	83 %	Pearse R.M. et al., 2006 [8]
9.3 %	12.2 %	75 %	Jhanji S. et al., 2008 [94]
26 %	14.9 %#	91 %	St-Louis E. et al., 2015 [95]
20 %	3.9 %#	72 %	Froehner M. et al., 2019 [96]
13.8 %	15.2#	84 %	Gutierrez C.S. et al., 2021 [69]

Thus, a high perioperative risk is a "threshold" probability of developing adverse outcomes such as complications and/or death in a particular patient. The basic determinants of high perioperative risk are operational risks, age, concomitant diseases that differ in detail in different forecasting tools.

Before the development of accurate and validated local instruments, it is advisable to stratify patients with high perioperative risk: 1) with the help of specially designed calculators of high risk of death (SORT, SORTv2), 2) by comparing the risk of mortality and postoperative complications with the average in the database of "big data" (ACS-SRC, neural network models of the ACS-NSQIP database. Machine learning-based approaches (MSR and Pythia) are not available for implementation, but they can be useful in comparing mortality and complication data and serve as a guideline for the development of domestic models.

Conclusion

Current approaches to perioperative risk assessment are commonly based on such particular components as risk of death, risk of specific complications, or less commonly, on intraoperative adverse events.

For the proposed concept overall perioperative assessment, it is necessary to create an ideal tool (calculator) that must undergo external validation, include available (including modifiable risk reduction) variables, accurately determine the entire range of adverse events and outcomes in the intra- and early postoperative period, as well as delayed adverse events and differentiate specific high risks.

Table 7. Predicted outcomes and AUROC models designed to identify patients at high perioperative risk in elective and emergency surgery [79, 83, 91, 92]

Predicted outcomes	AUROC			
	ACS-SRC	ACS-SRC Neural Network Analysis (3 models)	MSR	Pythia
Any complications	0,82	0.86–0.88	–	0.84
Stay in the ICU for more than 48 hours	–	–	0.88	–
Ventilator for more than 48 hours for 30 days after surgery	–	–	0.94	–
Pneumonia	0.87	0.86–0.87	–	–
Wound infection	0.82	0.85–0.86	0.82	0,87
AKI	0.90	0.93	0.88	0,91
Cardiac complications	0.89	0.90–0.91	0.85	0.88
Neurological complications	–	–	0.88	0.89
Deep vein thrombosis	0.82	0.77–0.80	0.87	–
Sepsis	–	–	0.91	0.84
Septic shock	–	–	–	0.92
Vascular disorders	–	–	–	0.88
Endocrine disorders	–	–	–	0.82
Gastrointestinal disorders	–	–	–	0.82
Urinary tract infections	0.81	–	–	0.78
Hematological disorders	–	–	–	0.91
30-day mortality rate	0.94	0.94–0.95	0.83	0.92
90-day mortality rate	–	–	0.81	–
180-day mortality rate	–	–	0.79	–
Yearly mortality rate	–	–	0.77	–
Two-year mortality rate	–	–	0.77	–

Table 8. Comparative characteristics of the frequency of adverse outcomes in models designed to identify patients with high perioperative risk [79, 83, 91]

Adverse outcomes	The average in the ACS-NSQIP database*	The average in three models of the ACS-NSQIP neural network	Low-risk MSR group	High-risk MSR group
frequency, %		**Complications**		
Acute kidney injury	0.6 %	0.3 %	14.7 %	72.6 %
Progression of chronic kidney disease	–	0.3 %	–	–
Pneumonia	1.2 %	1.3 %	–	–
Hospitalization in the ICU for more than 48 hours	–	–	11.9 %	68.3 %
Ventilator for more than 48 hours for 30 days after surgery	–	1.1 %	2.5 %	47.6 %
Unsheduled tracheal intubation	–	1.2 %	–	–
Complications from wounds	3.6 %	–	3.7 %	25.9 %
Cardiovascular complications	0.8 %	–	2.2 %	20.5 %
Cardiac arrest requiring cardiopulmonary resuscitation	–	0.4 %	–	–
Myocardial infarction	–	0.6 %	–	–
Neurological complications	–	–	1.8 %	24.1 %
CVA	–	0.3 %	–	–
Sepsis	–	0.8 %	1.2 %	25.8 % (from acute systemic inflammatory response to septic shock)
Septic shock	–	0.5 %	–	–
Deep vein thrombosis	0.9 %	1.8 %	0.7 %	10.1 %
PE	–	–	0.7 %	–
Bleeding requiring red blood cell transfusion	–	10.1 %	–	–
Urinary tract infection	1.5 %	1.6 %	–	–
Superficial wound infection	–	1.7 %	–	–
Deep wound infection	–	0.3 %	–	–
Organ/cavity wound infection	–	1.8 %	–	–
Eventration	–	0.6 %	–	–
Any complications	–	9.7 %	–	–
		Lethality		
a month later	1.3 %	0.7 %	0.4 %	52.6 %
3 months later	–	–	0.7 %	60.6 %
6 months later	–	–	1.2 %	67.3 %
12 months later	–	–	1.7 %	78.8 %
24 months later	–	–	2.1 %	69.9 %

* — high risk above the specified average values

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