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PREHABILITATION (B RIEDEL AND S JACK, SECTION EDITORS)

Preoperative Risk Stratification: Identifying Modifiable Risks for Optimization

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Abstract

Purpose of Review This chapter aims to examine current strategies for risk stratification in the preoperative setting. Risk stratification tools may include commercially available calculators, laboratory assessments, or screening tests. Risk stratification informs the surgical team on the need for preoperative optimization of modifiable risks. Optimization aims to improve clinical, hospital, and patient-centered outcomes across all phases of perioperative care. Preoperative optimization should be a collaborative, multidisciplinary effort that balances the patient's needs and values with the timing and urgency of surgery.
Recent Findings Preoperative patient optimization is feasible, improves patient satisfaction, reduces clinical complications, and lowers hospital costs.
Summary Preoperative physicians are encouraged to use risk stratification tools to identify patients with modifiable risks and implement optimization plans to mitigate postoperative complications.

Keywords Modifiable risk · Optimization · Risk calculation · Perioperative · Risk stratification

Introduction

Approximately 27 million patients undergo noncardiac surgery yearly in the USA. Of these patients, more than 50,000 will sustain a postoperative myocardial infarction, and over 20,000 of these patients die from cardiovascular causes in the perioperative period [1]. Poor surgical outcomes are multifactorial, with medical issues rather than surgical being the most common cause of complications following anesthesia and surgery. Following the publication of *To Err is Human* and *Crossing the Quality Chasm* in 1999 and 2001, there has been a tremendous push to improve the quality of healthcare delivered in the USA. In response to these reports, the Institute for Healthcare Improvement launched the Triple Aim Initiative, a drive designed to improve patients' healthcare experience, including quality, safety, and satisfaction, while improving the health of the patient population and reducing the per capita cost of healthcare [2]. Preoperative risk

This article is part of the Topical Collection on *Prehabilitation*

Search Strategy
The authors of this chapter currently lead the preoperative optimization effort at the University of Alabama at Birmingham (UAB Medicine). The Preoperative Assessment, Consultation, and Treatment Clinic (PACT) focuses on identifying modifiable conditions in surgical patients, and we have developed optimization strategies for these. Modifiable conditions include smoking cessation, hyperglycemia, hypertension, malnutrition, poor dentition, elder care and frailty, obstructive sleep apnea, anemia, opioid use, and cardiac risk assessment. The authors examined current topics discussed at the American Society of Enhanced Recovery (ASER) and Society for Perioperative Assessment and Quality Improvement (SPAQI) conferences for inclusion in this chapter. Both societies focus on perioperative optimization for modifiable risks and improvement of patient outcomes. The most useful risk stratification tools were selected based on the authors' experience and examination of "hot topics" at recent annual meetings.

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stratification identifies patients at risk for adverse outcomes following surgery. The risk stratification results drive prehabilitation programs, such as nutritional supplementation, smoking cessation, and anemia correction, with the intent of reducing morbidity and mortality, improving postoperative outcomes, and longitudinal population health (Table 1).

What Are Preoperative Modifiable Risks and How Do They Impact Postoperative Outcomes?

Modifiable risks are patient comorbidities with specific therapies available to them such that the disease can be optimized in the preoperative setting. The time from the first surgical clinic encounter until the day of surgery defines the preoperative setting. Perioperative physicians should consider optimization for all surgical patients, but the highest value may be seen in certain high-risk surgeries (total joint replacements or abdominal surgery or major cancer surgery) and frail patients. Optimization aims to improve patient outcomes throughout all phases of care (preoperative to discharge after surgery) and to improve all aspects of care (clinical, hospital, and patient-centered) (Table 2).

Identifying Patients at High Risk of Cardiac Complications Before Surgery

The preoperative identification of patients at increased risk of adverse surgical outcomes guides the process of shared decision-making between patients, caregivers, and providers. Additionally, preoperative risk stratification identifies the need for specialty referral, ordering additional diagnostic testing, and initiating prehabilitative efforts to reduce perioperative risk. In the setting of the very-high risk patient, preoperative risk stratification sometimes prompts delay of the surgical procedure for optimization or cancellation of the surgical procedure in favor of less invasive treatment options.

There are numerous preoperative cardiac risk stratification models available for use. The most used risk stratification models intend to predict the incidence of perioperative major adverse cardiac events (MACEs), defined as a postoperative myocardial ischemic event such as myocardial infarction, heart failure, stroke, or sudden death. MACE is relatively common following noncardiac surgery, with an

Table 1 Risk calculators discussed in this chapter

Cardiac	• Metabolic equivalent (METS) assessment • Duke Activity Status Index (DASI) • N-terminal pro-B-type natriuretic peptide (NT pro-BNP) biomarker • Revised Cardiac Risk Index (RCRI) • Gupta risk score for perioperative major adverse cardiac events (MACEs)-myocardial infarction or cardiac arrest (MICA) • American College of Surgeons National Surgical Quality Improvement Program (ACS NSQIP) MICA Risk Index • Cardiovascular risk index (CVRI) • ACS NSQIP Surgical Risk Calculator (SRC)
Global patient indexes	• American Society of Anesthesiologists (ASA) Physical Status Score • ACS NSQIP Surgical Risk Calculator (SRC)
Social determinants of health	No specific calculator. Based on individual factors
Anemia	No specific calculator. Based on laboratory assessment
Pulmonary	• Assess Respiratory Risk in Surgical Patients in Catalonia (ARISCAT) risk score • Gupta Postoperative Pneumonia Risk • Arozullah Respiratory Failure Index • STOP-BANG score for obstructive sleep apnea
Nutrition	• Nutritional Risk Index (NRI) • Nestle Mini Nutritional Assessment-Short Form (MNA) • Malnutrition Universal Screening Tool (MUST) • Perioperative Nutrition Screen (PONS) • Sarcopenia Ultrasound Imaging
Cognition	• Six-item Screener (SIS) • MINI-COG cognitive assessment
Frailty	• Edmonton Frail Scale • Clinical Frailty Scale (CFS)
Postoperative and post discharge nausea and vomiting	• Apfel Score • ASA Risk Factor Identification
Opioid abuse	Opioid Risk Tool (ORT)
Risk calculator commercial applications	MDCalc: www.mdcalc.com QxMD: www.qxmd.com

Table 2 Preoperative optimization to improve aspects of care

Clinical outcomes	*Hospital outcomes*	*Patient-centered outcomes*
Reduction in • Stroke risk • Major adverse cardiac events (MACEs) • Pulmonary complications • Renal failure • Surgical site infections (SSI) • Venous thromboembolic disease (VTE) • Transfusion-related complications	Reduction in • Same-day surgery delays • Surgery cancellations • Blood transfusions • ICU admissions • Hospital length of stay • Discharge to nursing home • Readmissions • Overall costs	Improvement in • Energy levels for rehabilitation • Vitality • Mental health • Satisfaction of care • Return to work

Table 3 Independent preoperative predictors of MINS

Age ≥ 75 years	Female	Current atrial fibrillation
History of coronary artery disease	History of hypertension	History of congestive heart failure
History of diabetes	Peripheral vascular disease	Stroke
Glomerular filtration rate (GFR) < 60 mL/min	Urgent/emergent surgery	

incidence of postoperative myocardial infarction of 0.9% [3]. Perioperative MACE results in increased hospitalization, ICU admission, and mortality.

A larger percentage of surgical patients experience a myocardial injury after noncardiac surgery (MINS). MINS is characterized by a perioperative increase in serum cardiac troponin concentration without other diagnostic criteria for myocardial infarction. MINS occurs during the hospital stay or within 30 days of noncardiac surgery and is associated with significant mortality. Risk stratification models are not predictive for MINS, but a 2014 study by the VISION writing group identified several risk factors independently predictive of MINS [4]. Despite the appreciation that MINS contributes significantly to mortality following noncardiac surgery, there is no consensus on treatment or prevention strategies (Table 3).

Assessment of Functional Capacity

Clarifying a patient's functional capacity is inherent to preoperative risk assessment and is a primary determinant of the need for further cardiovascular testing. Patients who achieve four metabolic equivalents (METS) or higher functional capacity without developing cardiopulmonary symptoms are deemed low risk and may proceed to surgery without additional cardiac testing. The majority of METS assessment is based on subjective patient responses when asked about the ability to walk a given distance on level ground or climb two flights of stairs without becoming short of breath. Wijeysundera and colleagues compared a patient-reported subjective METS assessment with more objective measures, such as cardiopulmonary exercise testing (CPET), the Duke Activity Status Index (DASI) functional assessment, and biomarkers such as serum concentrations of N-terminal pro-B-type natriuretic peptide (NT pro-BNP) for the ability to predict death or major cardiac complications following noncardiac surgery. Subjective functional capacity assessment is only 19.2% sensitive and 94.7% specific for predicting a patient's ability to obtain 4 METS on CPET testing [5••]. Only objective METS evaluation by DASI accurately predicted death or myocardial infarction within 30 days of surgery, suggesting that perioperative clinicians should abandon subjective assessment of functional capacity.

Models of Preoperative Risk Stratification and Clinical Risk Indices

The American College of Cardiology/American Heart Association (ACC/AHA) guidelines on perioperative evaluation for noncardiac surgery categorizes cardiac risk factors as active (previously termed major risk factors) or clinical (previously termed intermediate-risk factors) risk factors [6]. The stepwise approach to preoperative cardiac risk stratification considers active and clinical risk factors with procedural risk and patient functional capacity. Patients with active cardiac conditions or vascular surgery patients with three or more clinical risk factors and low functional capacity warrant further preoperative cardiac evaluation (Table 4).

There are numerous preoperative cardiac risk stratification models available for use. Three commonly used models include the Revised Cardiac Risk Index (RCRI), the American College of Surgeons National Surgical Quality Improvement Program (ACS NSQIP) database myocardial infarction/cardiac arrest (MICA) risk model, and the American College of Surgeons Surgical Risk Calculator (ACS SRC).

The preoperative cardiovascular risk index (CVRI) is a newer model that estimates 30-day all-cause mortality risk. Validation of the CVRI against the NSQIP database demonstrates greater discriminatory power over the RCRI, which includes only inpatient complications, but needs further

Table 4 Active cardiac conditions

Unstable coronary syndromes	• Unstable or severe angina • Myocardial infarction (MI) within previous 30 days
Decompensated heart failure	• New York Heart Association (NYHA) functional classes III–IV • Worsening or new-onset heart failure
Significant arrhythmias	• High-grade atrioventricular (AV) conduction block • Symptomatic ventricular arrhythmias • Supraventricular arrhythmias with uncontrolled ventricular rate (> 100 bpm at rest) • Symptomatic bradycardia
Severe valvular disease	• Severe aortic stenosis (mean gradient > 40 mmHg, valve area < 1 cm^2, or symptomatic) • Symptomatic mitral stenosis

validation against specific patient subpopulations [7]. A benefit of the CVRI is that it identifies several preoperative patient risk factors that are amenable to preoperative intervention. Other modifiable factors not included in these models that contribute to adverse outcomes are anemia, malnutrition, chronic pain, obstructive sleep apnea, and obesity. Certain cardiac conditions amenable to optimization also increase perioperative risks, such as atrial fibrillation and pulmonary hypertension.

Practical Considerations and Limitations of the RCRI and the ACS MICA Risk Indices

The RCRI, introduced in 1999 by Lee et al. [8] and based on the original Goldman Cardiac Risk Index, is still a widely used risk stratification tool (Table 5). Compared with the Goldman Cardiac Risk Index, the RCRI is more accurate and easier to use. However, the RCRI is based on a single institution's database and is not accurately predictive in patients with long-standing vascular disease or those scheduled for low-risk surgery. For patients having more extensive surgery, the RCRI discriminates moderately well between observed and expected MACE risk. The RCRI is a useful tool for screening for additional testing [9•].

The ACS MICA has a potential bias since only hospitals participating in the ACS NSQIP are included in the database. However, this is offset by the database exceeding one million patients. While the RCRI is validated in several studies, the ACS MICA is only retrospectively validated [10••]. Consequently, it corresponds very well with ACS SRC, the database from which it is derived. Compared to the RCRI, the MICA more accurately predicts MACE risk in low-risk surgical procedures, and those patients expected to have less than 2-day hospital admission. It underestimates MACE in high-risk patients. Additionally, the MICA provides excellent risk prediction for perioperative stroke in patients undergoing noncardiac surgery, although its discriminatory power is reduced in patients undergoing vascular surgery [11]. Incorporation of biomarkers into the MICA and RCRI will enhance the predictive capabilities of both (Table 5).

A notable limitation of risk stratification tools is the exclusion of low-prevalence, high-risk conditions that contribute significantly to adverse perioperative outcomes, such as decompensated heart failure, severe pulmonary hypertension, and severe valvular heart disease.

Table 5 The Revised Cardiac Risk Index (RCRI): independent predictors of perioperative MACE [8]

High-risk surgery (including major vascular, open intra-abdominal, intrathoracic)

History of ischemic heart disease (history of MI, positive stress test, active cardiac conditions, use of nitrate therapy, pathologic Q-waves on EKG). Note: this does not include prior PCI unless other criteria are met

History of heart failure

History of cerebrovascular disease

Diabetes mellitus requiring insulin management

Serum creatinine > 2.0 mg/dL

Rate of pulmonary edema, ventricular fibrillation, primary cardiac arrest, and complete heart block [8]		**Rate of cardiac death, non-fatal myocardial infarction, and non-fatal cardiac arrest by number of predictors** [12]	
No. predictors	*Rate*	*No. predictors*	*Rate*
0	0.5%	0	0.4%
1	1.3%	1	1%
2	3.6%	2	2.4%
3 or more	9.1%	3 or more	5.4%

The ACS MICA estimation does not include congestive heart failure or coronary artery disease history despite numerous studies establishing the predictive risk of both conditions. The exclusion of coronary artery disease from the ACS MICA and the ACS SRC likely reflects a difference in coronary artery disease definition, where both define myocardial infarction as troponin concentrations 3 times the upper limit of normal [13]. The differences in input variables, definitions of MACE, and the validation population create variability in calculated risk estimations. Further increasing variation is the multiple versions of the RCRI, which undergoes periodic revision and updates as diagnostic modalities, medical therapy, and surgical and anesthetic techniques evolve. These revisions reflecting current management and diagnostic criteria render the older calculators such as the Detsky modified risk index, the Eagle criteria, and the original Goldman Cardiac Risk Index obsolete.

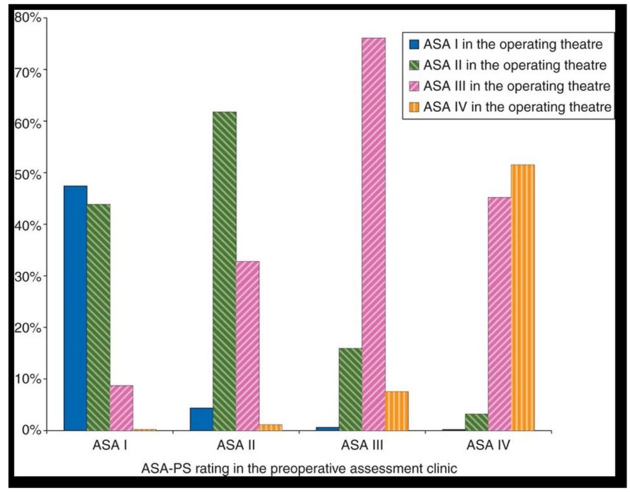

Fig. 1 Inter-rater variability of American Society of Anesthesiologists Physical Status (ASA-PS) scoring. The *x*-labels show the rating in the preoperative assessment clinic, while the columns in each class represent subsequent assigned rating in the operating room (used with permission [14])

Noncardiac Determinants of Perioperative Risk

While most preoperative risk models focus on risk assessment for MACE, other medical and non-medical factors contribute significantly to poor surgical outcomes.

ASA Physical Status Score

The ASA-PS score is a subjective preoperative assessment of patient health. Several studies demonstrate an association with perioperative risk. Its main limitation is the inherent inter-rater variability in its application between the preoperative clinic and operating rooms where the assigned ASA-PS scores differed significantly [14]. Similarly, it lacks objective assessment of functional status of the patient. While the ASA-PS score is an integral part of the ACS MICA and the ACS SRC, its use introduces an element of subjectivity and may over- or underestimate the risk depending on the provider. The assignment of inappropriate ASA-PS scores has significant impact on pre-surgical patients and their caregivers. Since the ASA-PS score drives the decision to pursue additional preoperative cardiac and laboratory testing, misclassification of patients results in unnecessary surgical delays and cancellations and unnecessarily increased healthcare expenditures. In addition to inter-rater variability (Fig. 1), the ASA-PS score omits the systemic effect of acute surgical pathology, a consideration included in many surgical risk calculators.

Socioeconomic Determinants of Healthcare

Socioeconomic status directly affects surgical outcomes yet is not reflected in risk assessment models. These factors include six broad categories of health determinants: economic stability, physical environment, education, food, community, social context, and healthcare system access [15]. These six classes synergistically act with medical and surgical risk factors in determining a patient's response to the surgical outcome (Table 6). Patients from lower socioeconomic status communities have higher rates of many medical comorbidities and higher predicted rates of postoperative complications determined by ACS SRC. They also have increased 30-day mortality, postoperative complications, readmission rates, and higher healthcare resource utilization [16].

Anemia

Anemia is a known predictor of poor postoperative outcomes and is therefore an important preoperative optimization target. Anemia may be one of the most prevalent modifiable conditions in the preoperative setting, affecting approximately 40% of patients [17]. Preoperative anemia is linked to renal failure, infection, pulmonary complications, increased transfusion rates, and mortality [18••]. Transfusion has its own risks and is associated with increased mortality, increased length of hospital stays, and increased surgical site infections [19]. Identifying preoperative anemia informs providers on the need for certain medications such as preoperative tranexamic acid to reduce bleeding, oral or

Table 6 Socioeconomic determinants of healthcare [15]

Economic stability	Employment, income, debt, support
Physical environment	Housing, transportation, safety, parks, geography (zip code)
Education	Literacy, education level, vocational training
Food	Hunger, malnutrition, access to healthy food options
Community and social context	Social integration, support systems, community engagement, discrimination, social stressors
Healthcare system access	Healthcare coverage, provider availability, provider linguistic and cultural competency, quality of care delivered

Table 7 Components of preoperative complete blood count (CBC) with anemia panel

Complete blood count	Anemia panel
White blood cell count, without differential	Ferritin
Hemoglobin	Total iron binding capacity
Hematocrit	Transferrin saturation percentage
Platelets	Vitamin B12
Mean corpuscular volume	Folate

intravenous iron therapy, erythropoietin stimulation, coordination of pre- and postoperative consults, and the need for appropriate blood ordering.

Preoperative risk stratification for anemia includes obtaining a preoperative complete/full blood count (CBC and FBC). A complete blood count should be ordered based on the type of surgery, patient comorbidities, or known history of anemia. Obtaining a complete blood count with an anemia panel (including iron, B12, and folate studies) clarifies the reason for anemia and avoids the patient returning to the preoperative clinic for additional studies (Table 7).

Once a complete blood count with an anemia panel is obtained, a simple algorithmic approach towards preoperative treatment can be activated (Fig. 2). The algorithm should incorporate hemoglobin level, mean corpuscular volume, and transferrin saturation. For example, patients with a hemoglobin < 120 g/L (12 g/dL) and transferrin saturation of less than 20% can be preoperatively treated with oral or preferably intravenous iron. Further research is required to elucidate if this threshold should be > 130 g/L for both males and females and in fact if non-anemic iron deficient patients require preoperative iron therapy. Guidelines can also be found on software application platforms (e.g., CLOTS app—https://apps.apple.com/us/app/clots/id1436672491) which provide hematinic optimization guidelines (as well as guidance for surgical thromboembolism prevention, management of antithrombotic drugs, and fast track warfarin reversal).

The goals of preoperative anemia treatment are to improve hemoglobin and reduce the patient's risk of transfusion. A minimum of 2 weeks is needed for treatment to improve hemoglobin, by approximately 2 g/dL. Preoperative intravenous iron infusions have recently been called into question as they were not shown to reduce blood transfusions [20•]. Secondary analysis of this study, however, suggested iron infusion was associated with reduced postoperative readmission to hospital. Other smaller studies have demonstrated that preoperative iron treatment improves hemoglobin and reduces blood transfusion [21, 22]. Treatment of anemia postoperatively may improve a patient's ability to ambulate owing to increased energy levels. Anemia optimization is ideally a collaborative, multidisciplinary effort that may include anesthesia, surgery, and hematology.

Pulmonary

Postoperative pulmonary complications (PPCs) are one of the most common adverse events following anesthesia and surgery. Patients experiencing PPC have higher morbidity and mortality rates, increased hospitalization, and increased healthcare costs [23]. The Assess Respiratory Risk in Surgical Patients in Catalonia (ARISCAT) score determines PPC risk based on seven objectives: categorized as low, intermediate, or high (1.6%, 13.3%, and 42.2%) risk of postoperative pulmonary complications, respectively (Table 8) [24].

Practical Considerations in Implementing the ARISCAT Tool

The ARISCAT score has been validated in multiple surgical patient populations for predicting patients at risk of postoperative pulmonary complications. In particular, the three factors with the highest correlation were preoperative anemia, emergency surgery, and surgery exceeding 2 h in duration [25]. While many of the factors contributing to the increased risk are beyond the perioperative specialist's control, this tool calls attention to the significant effect that anemia has on PPC development. Intermediate- and high-risk patients benefit from prehabilitation efforts, such as anemia correction, preoperative incentive spirometry or breathing exercises using the active cycle of breathing technique (ACBT), smoking cessation, and increased physical activity. Interestingly, patients who received a preoperative influenza vaccine had lower postoperative pneumonia rates and reduced inhospital mortality (Table 9) [26].

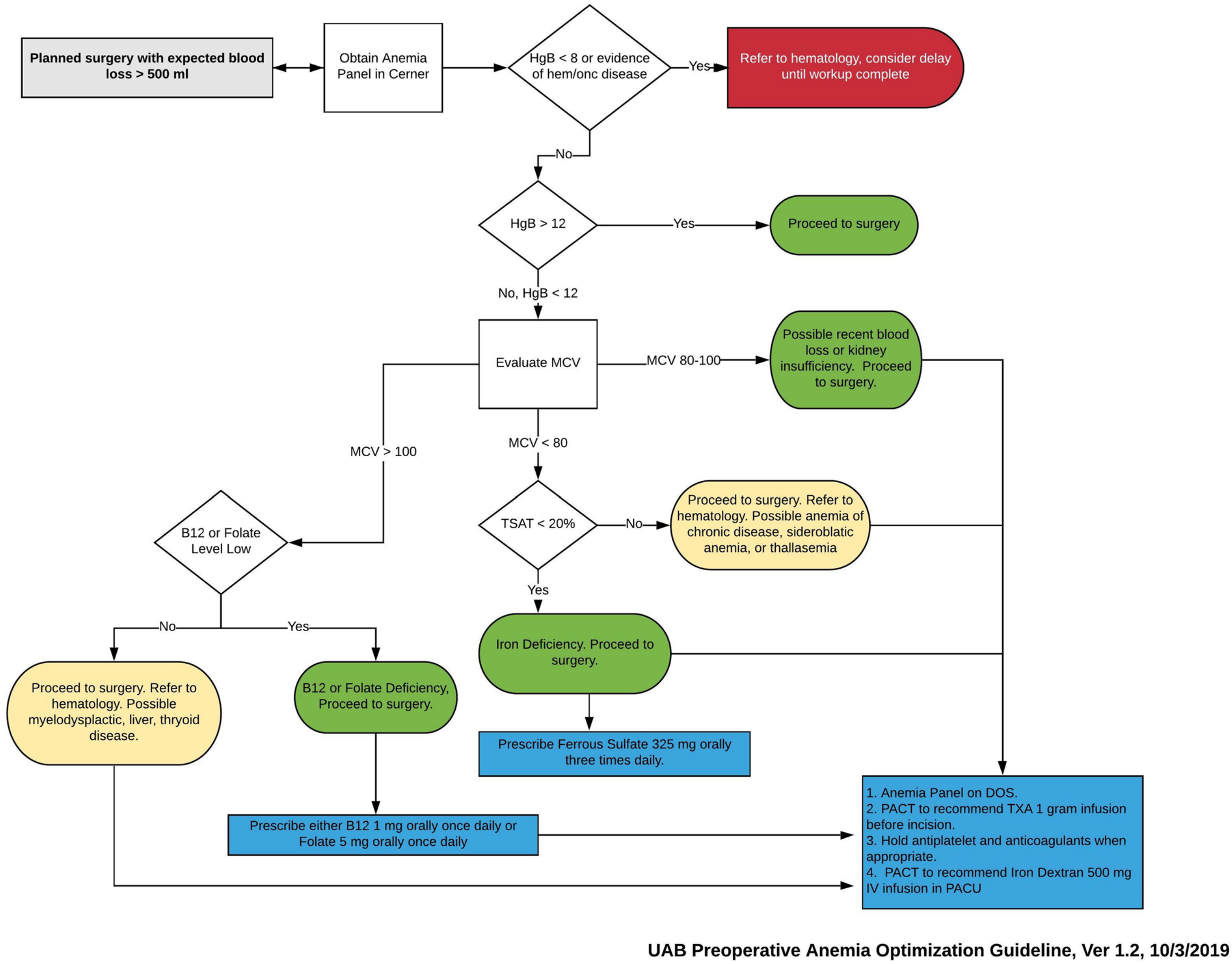

Fig. 2 Sample of a preoperative anemia screening guideline. Abbreviations: B12, vitamin B12; DOS, day of surgery; Hem/onc, hematologic or oncologic; HgB, hemoglobin; MCV, mean corpuscular volume; PACT, Preoperative Assessment, Consultation, and Treatment Clinic; PACU, post anesthesia care unit; TSAT, transferrin saturation percentage; TXA, tranexamic acid

Table 8 ARISCAT score risk factors for postoperative pulmonary complications (PPCs)

Age, in years
Preoperative SpO_2
Respiratory infection (pneumonia, URI, bronchitis) within the past month
Preoperative anemia (HgB ≤ 100 g/L)
Surgical incision (upper abdominal and thoracic having highest risk)
Duration of surgery (risk increases for duration ≥ 2 h)
Emergency procedure

Abbreviations: *HgB* hemoglobin, *SpO_2* peripheral oxygen saturation, *URI* upper respiratory tract infection

Other pulmonary risk calculators determine the risk of developing specific postoperative complications, such as the Gupta calculator for postoperative respiratory failure, which predicts the risk of failure to wean from mechanical ventilation in the 48 h following surgery, and the Gupta calculator for postoperative pneumonia. The Arozullah Respiratory Failure Index predicts postoperative respiratory failure risk, defined as the need for mechanical ventilation for longer than 48 h after surgery. It is complicated to use but incorporates additional factors relevant to pulmonary function such as nutrition and renal status and functional capacity.

Obstructive sleep apnea (OSA) predisposes surgical patients to postoperative pulmonary complications, including hypoxemia, pneumonia, myocardial infarction, pulmonary embolism, atelectasis, and unplanned ICU admission [27, 28]. Preoperative screening and recognition of OSA allows for perioperative risk mitigation with strategies such as those in Table 8. While the gold standard for diagnosing OSA is polysomnography, the STOP-BANG questionnaire

Table 9 Perioperative maneuvers to mitigate the risk of postoperative pulmonary complications (PPCs) (used with permission from Pfeifer, K. Guide to Preoperative Evaluation, www.preopevalguide.com, 2020)

Low risk of PPC	*Intermediate risk of PPC*	*High risk of PPC*
• Early mobilization • Good oral hygiene • Optimization of chronic lung disease • Smoking cessation counseling and resources	All of the low risk maneuvers, plus • Postoperative incentive spirometry • Identification and communication of "increased risk" status • Regional anesthesia/analgesia, if applicable • Lung-protective ventilation	All of the low and intermediate risk maneuvers, plus • 1–2 weeks preoperative incentive spirometry • Increased postoperative surveillance

is highly sensitive for OSA identification and easy to implement preoperatively [29].

Nutrition

Suboptimal nutrition in the perioperative period is an independent predictor of poor surgical outcomes. Specifically, malnutrition is associated with increased postoperative morbidity and mortality, hospital readmission, length of stay, and cost. Malnourished colorectal surgery patients are twice as likely to be readmitted to the hospital within 30 days of elective surgery [30]. Logically, perioperative nutritional therapeutic interventions improve outcomes in gastrointestinal cancer surgery. Despite the long history of randomized controlled trials and meta-analyses, demonstrating perioperative benefit from nutritional intervention, acceptance, and implementation of evidence-based nutrition practices remains poor, with only 20% of US gastrointestinal cancer patients receiving nutritional supplementations perioperatively, and only 1 in 5 hospitals utilize formal nutrition screening tools [31••].

Various screening tools exist to identify preoperative malnutrition. The Nutritional Risk Index (NRI) is a classic formula used to identify malnutrition risk upon hospital admission (not specific to surgery). The formula for NRI is as follows:

$$\text{NRI} = (1.519 \times \text{serum albumin, g/L}) + (41.7 \times \text{present/usual body weight})$$

An NRI score of 100 indicates no risk, 97.5 to 100 mild risk, 83.5 to 97.5 moderate risk, and less than 83.5 severe malnutrition risk. Severe risk of malnutrition using NRI is correlated with an extended hospital stay. Difficulty in determining usual body weight, particularly among elderly patients, may limit the practicality of this tool [32].

The Nestlé Mini Nutritional Assessment Short Form (MNA®-SF) is a validated screening tool that uses the quantitative parameters of body mass index (BMI) and recent oral intake, weight loss, mobility, psychological stress, and neuropsychological problems. A numerical score identifies patients as malnourished, at risk of malnutrition, or of normal nutritional status. The MNA®-SF, when explicitly used to assess nutritional risk in patients before elective surgery, has 97.9% sensitivity and 100% specificity, with a diagnostic accuracy of 99% for predicting undernutrition. The MNA®-SF is easy to use and efficient and minimally impacts workflow [33].

The Perioperative Nutrition Screen (PONS) is a modified version of the Malnutrition Universal Screening Tool (MUST) that has been adapted to surgical patients. PONS is promoted by the American College of Surgeons "Strong for Surgery" initiative. PONS identifies nutritional risk based on four criteria: BMI (less than 18.5 for patients under 65 years or less than 20 for patients over 65 years), unintentional weight loss (greater than 10% weight loss in 6 months), decreased oral intake (less than 50% of average intake in the last week), and low serum albumin (less than 3 g/L). Any positive response identifies patients at high risk for malnutrition and warrants nutritional intervention [34].

Recently, the concept of sarcopenia as a surrogate for frailty, malnutrition, and worsened surgical outcomes has become a target of study. The gold standard for sarcopenia diagnosis is quantifying skeletal muscle mass by computed tomography (CT). This method carries the risk of radiation exposure and the expense of specialized equipment and specially trained personnel. Portability, ease of use, and lower cost make bedside ultrasound an attractive alternative for sarcopenia assessment. Recent data involving elderly patients undergoing emergency abdominal surgery shows that thigh muscle thickness ultrasound correlates with CT estimates of skeletal mass index. This data can be of use by providing a rapid, low-cost option for objectively assessing sarcopenia and frailty and associated risk of developing major postoperative complications [35].

While some clinics have implemented programs for dietician referral, other programs utilize simple nutrition supplementation algorithms using high-protein oral nutritional supplements (ONS) and immunonutrition (IMN) supplements [34]. A regimen of three high-protein ONS servings a day achieves the goal of 1.2 g/kg/day of protein. Arginine, omega-3 fatty acid, and antioxidant containing immunonutrition supplements are recommended over supplements containing a single immunonutrient alone. Arginine supports immune function through activation and promotion of T lymphocytes and T-helper cells, respectively. Arginine also promotes wound and anastomotic healing by serving as a precursor to proline and nitric oxide, and omega-3 fatty acids play a wide range of anti-inflammatory roles. Infectious complications can be reduced by up to 40% by immunonutrition supplementation regimens [36]. The guidelines for duration and composition of perioperative nutritional support vary widely, but data indicates that even 5–7 days of preoperative nutrition therapy can decrease morbidity by 50%. Other perioperative nutritional interventions include minimizing preoperative fasting, providing preoperative oral carbohydrate loading, and early resumption of oral intake postoperatively [31••].

Cognition

The incidence of cognitive dysfunction is markedly associated with advanced age [37]. One in three patients presenting for surgery is now over the age of 65 years [38]. Cognitive dysfunction has been associated with an increased odds ratio of discharge to nursing homes and increased hospital length of stay [39•]. Consequently, risk stratification and identification of preoperative cognitive dysfunction offer the surgical team the ability to preplan hospital management. The MINI-COG and Six-Item Screener are two commercially available screening tools for preoperative assessment. The MINI-COG test is a simple screening tool with external validation incorporating a three-item recall challenge with a clock-drawing challenge. A 2019 study from Brigham and Women's Hospital demonstrated that the entire test could be completed in less than 5 min when performed in patients over 65 years [40]. Trained nurse practitioners and residents administered these tests. Similarly, the Six-Item Screener uses a three-word recall challenge coupled with three questions on orientation. This screening can also be accomplished in less than 5 min. Currently, the MINI-COG test is the most validated test for preoperative screening. Comparing the two tests, the MINI-COG has 99% sensitivity and 93% specificity for dementia, while the Six-Item Screener has 88.7% sensitivity and 88% specificity [41].

Practical considerations in cognitive function screening should include appropriate training for staff and workflow considerations. All patients over the age of 65 years should be screened. Screening should be accomplished early in the preoperative assessment to allow for teaching adjustment if the patient has dysfunction. The patient with cognitive dysfunction may not fully engage in the decision-making process or comprehend preoperative instructions. Patients with cognitive dysfunction will also benefit from specialized pathways in the perioperative setting, such as family presence in recovery, cognitive stimulation postoperatively, and medication management to avoid potentially inappropriate medication use in older adults as listed by the American Geriatrics Society Beers Criteria. Optimal perioperative management of the geriatric patient has been described by the American College of Surgeons in 2016 [42].

Frailty

Preoperative frailty is a common problem with a significant association with postoperative mortality owing to increased vulnerability to surgical stressors [43]. Frailty in the general population of patients over the age of 65 years has been estimated between 15 and 20%. The prevalence increases by up to 43% in older patients with cancer [44]. Multiple modifiable comorbidities often burden the frail patient. Frail patients often have deficits in nutrition, mobility, and cognition. These modifiable risks are exacerbated by social determinants of health and availability of assistance in the home. Frailty is a specific concern for geriatric patients but can exist at any age. In 2016, a Johns Hopkins study revealed over 67 instruments that have been used to define frailty [45]. A subsequent study in 2017 demonstrated significant heterogeneity and a lack of consensus among many of these tools [46].

As there is no single best tool for evaluating frailty, multiple techniques should be employed to create a frailty index [47]. When evaluating patients with this method, the accumulation of deficits is viewed and individually treated. For example, a patient may have deficits in cognition without malnutrition and be treated accordingly. The Edmonton Frail Scale (EFS) is one such index that evaluates multiple parameters for frailty [48]. Another useful tool with high inter-rater reliability and association with postoperative outcomes is the Clinical Frailty Scale (CFS) [49]. The Clinical Frailty Scale uses a phenotypic description of frailty and includes pictures to increase the inter-rater reliability of preoperative assessment and is strongly correlated to the Edmonton Frail Scale in a single-center prospective cohort study [50]. In practice, frailty is best identified with a thorough screening of all preoperative patients and then a treatment based upon the deficits identified.

Postoperative Nausea and Vomiting (PONV) and Post Discharge Nausea and Vomiting (PDNV)

Postoperative nausea and vomiting (PONV) is a significant patient dissatisfier following surgery. Vomiting and retching may cause wound dehiscence, aspiration, esophageal rupture, increased intracranial pressure, and dehydration. PONV contributes to delayed recovery and discharge from the post anesthesia care unit (PACU) and may result in unplanned hospital admission and increased healthcare costs.

There are several PONV risk assessment models available for preoperative use. The most used tool is the model for adult patients developed by Apfel and colleagues with validation across several institutions without losing discriminatory power [51]. The Apfel PONV prediction models evaluate four risk factors as shown in Table 10 [52•], with the corresponding incidence of PONV shown in Fig. 3. PONV is easily predicted in the preoperative setting. Communication to the day-of-surgery anesthesia team allows for modification of the anesthetic plan to reduce the risk, such as regional anesthesia/analgesia, opioid-sparing multimodal analgesia, prophylactic anti-emetic administration, or techniques such as P6 acupressure point injection. Current guidelines recommend multimodal prophylaxis in patients with one or more risk factors for PONV and PDNV [52•].

Post discharge nausea and vomiting (PDNV) significantly impacts a patient's quality of recovery and functional status. A study from 2014 noted a high correlation (Pearson correlation coefficient of 0.77) between PDNV and adverse effects on the patient's quality of life and recovery [53]. The PDNV risk factors are similar to PONV, and identification and mitigation improve patient outcomes and reduce healthcare costs and indirect societal costs related to prolonged recovery (Fig. 3).

Future PONV and PDNV risk prediction models will likely be strengthened by emerging data in the field of genomic medicine. Identifying multiple alleles of cytochrome P450 coupled with a patient's current medication regimen allows for more precise anesthetic planning and PONV/PDNV risk reduction strategies.

Table 10 PONV and PDNV risk factors

PONV	*PDNV*
• Female gender • History of PONV or motion sickness • Intended use of postoperative opioids • Non-smoker	• Female gender • History of PONV • Use of opioids in PACU • Age < 50 years • Nausea in PACU

Abbreviation: *PACU* post anesthesia care unit

Opioid Abuse and Persistent Postoperative Use Risk

Appropriate treatment of pre- and postoperative pain is paramount. Likewise, screening for potential postoperative opioid abuse and persistent postoperative opioid use is critically important to all patients' well-being and function. Persistent use after surgery depends on the type of surgery performed and the time after surgery. Estimates range from 0.7 to 14% of previously opioid-naive surgical patients still using opioids 1 year after surgery [54]. Risk tools exist for opioid abuse, such as the Opioid Risk Tool (ORT). The ORT is well validated in both men and women with pain conditions and can be administered in under a few minutes. The ORT assesses personal and family history of substance abuse, sexual abuse, psychological illness, and age [55].

Practical applications of the ORT include identifying patients at high risk of persistent postoperative use or opioid abuse and planning perioperative interventions to reduce the overall need for opioids. These measures may include planning for non-opioid preoperative medications (NSAIDs, acetaminophen/paracetamol), preoperative regional nerve blockade, intraoperative non-opioid adjuncts (lidocaine infusions, ketamine, and magnesium), and postoperative physical and psychological therapy. Preoperative clinics may consider prescribing naloxone nasal spray for patients

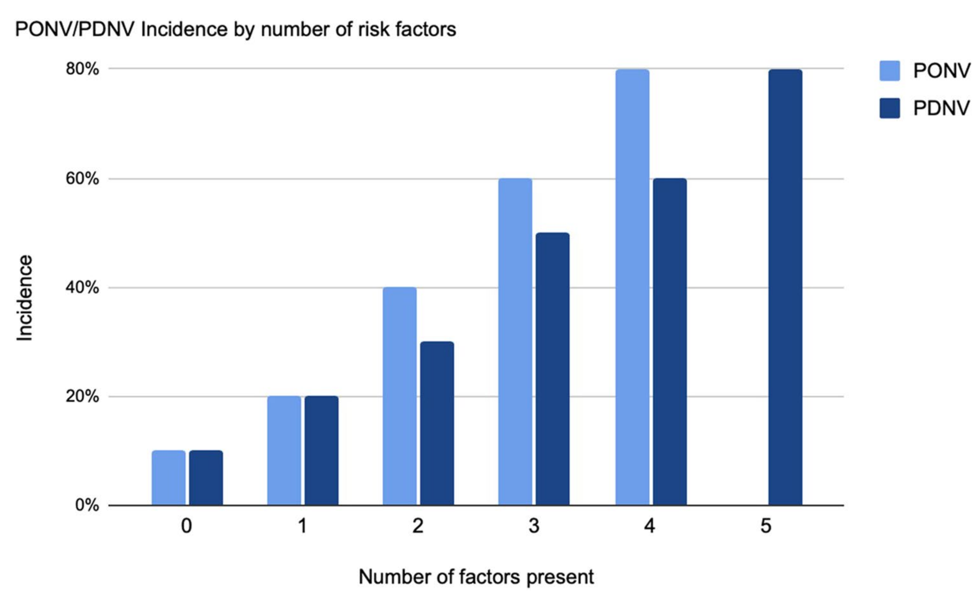

Fig. 3 Incidence of PONV and PDNV by number of risk factors listed in Table 10

at high risk for opioid abuse, understanding that they will likely have increased need for pain medications after surgery and would be at higher risk for adverse respiratory complications.

Global Risk Calculators

The American College of Surgeons (ACS) National Surgical Quality Improvement Program (NSQIP) Surgical Risk Calculator (SRC) is a global risk calculator tool. The NSQIP calculator uses 20 patient predictors and the planned surgery (based on current surgical procedural terminology (CPT) code) to predict 18 different outcomes within 30 days of surgery [56]. The calculator was built on data from over 4.3 million operations performed at 780 participating hospitals from 2013 to 2017. Since August 2019, the ACS NSQIP Surgical Risk Calculator also has the option to view geriatric outcomes for patients 65 + years of age.

Practical considerations for using the SRC include staff training and workflow adjustments. We recommend using this tool at the end of the preoperative visit to allow for patient discussions in real time. The tool provides a color-coded estimate of risk compared to a cohort of similar patients having the same procedure. Demonstration of certain risks may motivate patients to adhere to optimization programs. An example here is provided using a fictitious patient (Fig. 4).

Future Models

Biomarkers

Two extensively studied biomarkers for perioperative MACE prediction are brain natriuretic peptide (BNP) and N-terminal-pro-BNP (NT pro-BNP). These peptides leak from the myocardium in response to increased cardiac wall stress resulting from ischemia, pressure overload, or volume expansion. BNP values above established thresholds support a diagnosis of heart failure. Still, they are not conclusive, as other medical conditions such as glomerular filtration rates (GFRs) below 60 are also associated with increased serum BNP concentrations. Several studies have demonstrated an independent association between a preoperative BNP or NT pro-BNP level exceeding established thresholds (372 pg/mL) and an increased risk of MACE or MINS within 30 days of noncardiac surgery [57]. The Canadian Cardiovascular Society Guidelines on Perioperative Cardiac Risk Assessment and Management for Patients undergoing noncardiac surgery recommend obtaining a preoperative BNP level (or NT pro-BNP) to increase the predictive accuracy of MACE risk in patients age 65 years or older, those aged 45–64 years with significant cardiovascular disease, or patients with an RCRI score ≥ 1 [10••].

Asymmetric dimethylarginine (ADMA) is a naturally occurring inhibitor of nitric oxide synthesis and closely related to L-arginine. High serum levels of ADMA independently predict mortality irrespective of other cardiovascular risk factors [58]. The use of ADMA levels in conjunction with other risk stratification models provides a more accurate MACE risk assessment than either alone. Patients treated preoperatively with supplementation of L-arginine and L-citrulline had higher arginine and lower ADMA levels on the day of surgery and decreased MACE and 30-day mortality [58]. While this study's results were not statistically significant, it suggests clinical significance since high ADMA levels are associated with increased length of hospital and ICU stay and prolonged mechanical ventilation [59].

Genetics

Along with biomarkers, genetic polymorphisms may provide unique and precise information on perioperative risk. Currently, genetic variants have promise in predicting multiple perioperative complications (Table 11). Obtaining genetic profiles and tailoring therapy will require further investigations towards outcome improvement, creating electronic medical record (EMR) displays to flag relevant variants, and developing workflows to obtain genetic profiles in a timely manner [60]. The *All of Us* National Institute of Health study is one such study that aims to collect a diverse genetic database to advance precision medicine [61].

The "Big Data" Era and Risk Stratification

The overwhelming amount of data stored in the electronic medical record must be transformed into useful information for clinical decision making. Data is stored as file images, numerical laboratory data, and narrative in both discrete fields and natural language. Harnessing this data will require the power of computing, using predictive analytics and artificial intelligence (AI). Predictive analytics (PA) encompasses various statistical techniques from data mining, predictive modeling, and machine learning that analyze current and historical facts to make predictions about future or otherwise unknown events. This topic's scope is well beyond what can be described in this chapter; however, clinical applications are developing rapidly [66]. The challenge to today's physicians will be to become knowledgeable with and interact with deep neural network capabilities and to trust the computer-generated suggestions that impact patient care (Table 12).

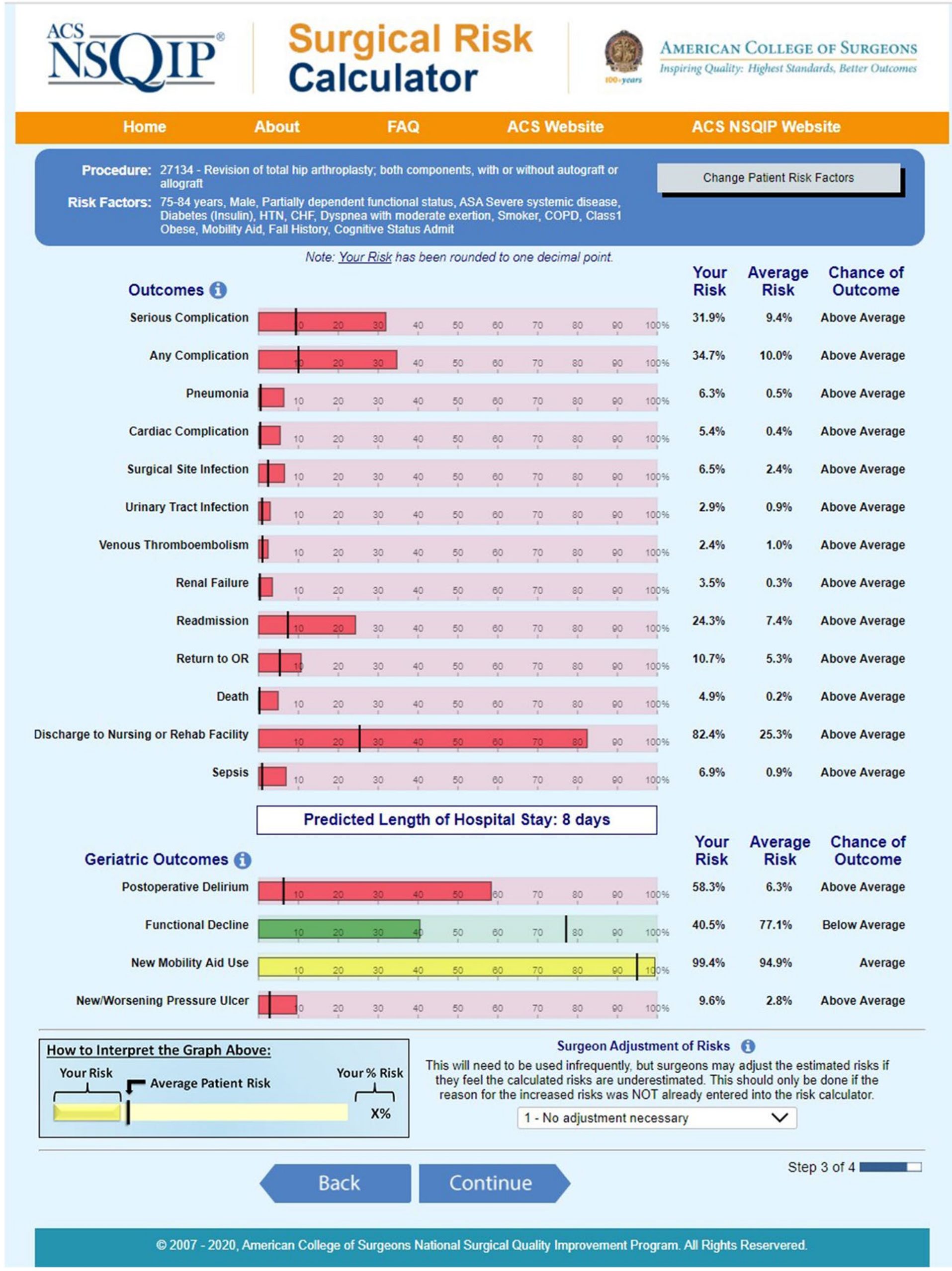

Fig. 4 Sample Output from the ACS NSQIP Surgical Risk Calculator

Table 11 Sample of genetic polymorphisms related to postoperative outcomes

Polymorphism/variant	*Disease*	*Clinical use*
Cytochrome P450 2D6 [62]	Pharmacologic opioid response	Tailors opioid prescribing based on metabolism
Factor V, chromosome 1q23 [63]	Factor V Leiden mutation	Guides anticoagulant therapy
Butyrylcholinesterase variants [63]	Delayed recovery from succinylcholine	Guides medication use
RYR1, CACNA1S [63]	Malignant hyperthermia	Guides anesthetic choice
Polygenic analysis [63]	MINS (myocardial injury after noncardiac surgery)	Guides postoperative ischemia surveillance
Allele at the chromosome 4q25 locus [64]	Postoperative atrial fibrillation	Guides postoperative surveillance
APOE4 allele [65]	Postoperative cognitive dysfunction	Guides medication management and need for specialized consults

Table 12 Applications for predictive analytics, artificial intelligence, and machine learning

Predicting clinical deterioration
Predicting hospital readmission
Recognizing obscure disease patterns
Predicting failure to follow-up
Identifying image pathology
Suggesting optimal workforce and supply chain
Predicting a disease outbreak

Table 13 Practical application of risk calculator data

Alert	*Action*	*Follow-up*
• Identification of modifiable risk and communicated to all members of the team • Clear documentation of risk in preoperative evaluation	• Risk defined by laboratory tests or risk calculator • Timeline established for treatment • Risk reassessed to allow the patient to progress to procedure	• Modifiable risk is managed by the team perioperatively • Consultation for longitudinal management postoperatively is established

The Art and Practice of Risk Calculation

Risk calculators are useful for guiding appropriate preoperative testing, shared-decision making, and preoperative patient motivation. However, a false sense of security is created when we clear patients for surgery based on risk calculation alone. Despite multiple risk factor calculations, the art of medicine must be instilled in preoperative evaluation. The art and practice of medicine rely on careful examination of all the risks followed by coordinated communication and precision planning for optimization. Applying the data obtained from risk calculation equals balancing the art and science of risk optimization [67••]. Coordination starts as a collaborative effort between the preoperative physician, the patient, and the surgical team ("alert phase"). Alerting the team to increased risk for potential complications and the plan to prevent such complications is the first step. Alerts can be accomplished via internal electronic medical record communication and/or telephone conversations. Secondly, defined modifiable risks must be coupled with defined and agreed upon optimization plans ("action phase"). Action plans or preoperative guidelines for optimizing modifiable risks should include the modifiable risk, how it is defined, markers for preoperative measurement, the timeline for optimization, and markers for improvement that allow the patient to progress. Finally, the patient will need careful management of the comorbidity or modifiable risk during and after the hospital stay ("follow-up phase"). In this phase, a global perspective is used to view the patient, and appropriate consultation is sought after the intended procedure (Table 13).

Summary and Conclusion

Numerous simple, readily available, and useful risk stratification tools exist. While risk stratification tools are a useful means of guiding preoperative testing and optimization, they are not designed to take the place of the preoperative history and physical, as doing so could increase unnecessary testing. Although the sheer number of available tools and data can be overwhelming, it is incumbent upon perioperative physicians to research and implement systems and protocols that work within their hospital or ambulatory surgery center settings. While it is true that the level of infrastructure and financial support for such programs varies widely, this chapter has provided numerous tools and recommendations that can be applied effectively, even in facilities with significantly constrained resources.

Compliance with Ethical Standards

Conflict of Interest The authors declare no competing interests.

Human and Animal Rights and Informed Consent This article does not contain any studies with human or animal subjects performed by any of the authors.

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•• Of major importance

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