C. Ronald MacKenzie
Charles N. Cornell
Stavros G. Memtsoudis
Editors

Perioperative Care of the Orthopedic Patient

Second Edition

Springer

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ISBN 978-3-030-35569-2 ISBN 978-3-030-35570-8 (eBook)
https://doi.org/10.1007/978-3-030-35570-8

This Springer imprint is published by the registered company Springer Nature Switzerland AG
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

This book is dedicated to:

Stephen A. Paget, MD (C. Ronald MacKenzie)

David H. Baker, MD, Emeritus Professor of Radiology at Columbia College of Physicians and Surgeons, lifelong mentor, and friend (Charles N. Cornell)

Madhu Mazumdar, PhD, my mentor (Stavros G. Memtsoudis)

Foreword to the Second Edition

Millions of patients worldwide benefit from the significant advances made in orthopedic care over the last half-century. Patients live longer lives, with less pain and greater mobility. Innovations in surgical techniques, perioperative medicine, and anesthesia practice over this time period have helped facilitate this progress. As a consequence of these advances, orthopedic surgical procedures are increasingly extended to a wider range of patients, including the elderly and those with significant medical comorbidities. The opportunities provided by these life-changing procedures, together with the growing need for a multidisciplinary approach to assure optimal outcomes, stimulated the development of the clinical and academic discipline that is perioperative care. At Hospital for Special Surgery, we have been at the forefront of this field. As this second edition demonstrates, we continue to evolve and improve our approach in order to assure optimal outcomes.

The perioperative care of patients presenting for orthopedic surgery requires a team approach, a model of the delivery of care that is coordinated and optimized by a physician-directed, multidisciplinary group working together throughout the perioperative continuum. The process begins with the decision to perform surgery and requires preparation of the patient and an optimization of their general medical condition. Intraoperatively, the most current anesthetic and surgical techniques are utilized to minimize complications and to support the patient's ability to recover from the trauma of surgery. Postoperatively, a seamless transition of care from the recovery room, occasionally the intensive care unit, and then to the hospital floors is achieved by minimizing pain, maximizing the patient's ability to rehabilitate, and ensuring that postoperative medical care mitigates the impact of preexisting comorbidities. This entire continuum is carried out in a safe, cost-efficient, and patient-centered manner. Perioperative care at Hospital for Special Surgery remains premised on these principles.

Our model of care, presented comprehensively in the second edition of this book, is responsible for an unparalleled surgical, medical, and anesthesiologic record of success. As advances in orthopedics continue to challenge those engaged in perioperative care, we will continue to evaluate and adapt our processes. The updates in this edition are illustrative of our effort to address new challenges and persistently refine our system of collaborative care to achieve the highest level of quality and outcomes for all patients. Drs. MacKenzie, Cornell, and Memtsoudis have expertly amended and enhanced their original roadmap and provided an invaluable guide for the perioperative community.

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Bryan T. Kelly, MD
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Preface to the Second Edition

Six years have passed since the publication of our textbook examining the challenges of caring for the orthopedic patient in the surgical setting. The response to this work, the first devoted exclusively to perioperative orthopedic care, has been highly favorable, seemingly striking a cord in the orthopedic, rheumatologic, and perioperative community. Having kept in close contact with contributors, readers, and publishers over the years, we the editors began to feel it is time for a reconsideration of the work, reevaluating its content, addressing perceived weaknesses and omissions, and enhancing its presentation. This second edition is now the product of the efforts of over 70 experts, 19 of whom are new contributors. Each chapter has been reconsidered, updated, and, in a few instances, replaced. Seven new chapters expand the content of the book, filling important gaps of the first edition. One major modification is the new placement of the case studies: formerly presented in an Appendix, they are now at the end of the chapters pertaining to the clinical vignette presented. We remain grateful to the Springer staff, in particular Liz Corra, who has shepherded us through both editions of the book.

In closing, we, as before, take full responsibility for the content of this book and hope it will continue to provide value in the care of the patient undergoing orthopedic surgery.

New York, NY, USA C. Ronald MacKenzie, MD
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Preface to the First Edition

Arthritis is the leading cause of disability in the adult US population. Twenty-one percent of adults report physician-diagnosed arthritis, a prevalence projected to increase markedly for the foreseeable future. As conditions for which surgery is often required, the arthritides, in their various presentations, will continue to fuel the need for surgical intervention for years to come. Furthermore, societal demographics underscore the importance of these projections, especially for elderly patient populations, since the elderly are not only the fastest growing segment of Western society, but arthritis as a disease category reaches its peak in older populations. Even today, this is the demographic group that already accounts for the majority of such procedures, particularly total joint arthroplasty.

Medical management in the setting of surgery is a relatively new consultative arena, one spurred on in contemporary times by the aging patient population, a rising prevalence of complex chronic disease, and an ever-expanding surgical armamentarium. Nowhere has the confluence of these forces been more evident than in orthopedic surgery, a highly innovative field, the advances in which continue to enhance the functional capacity and quality of life of patients across the entire span of life.

Although a number of comprehensive textbooks pertaining to perioperative medicine are currently available, none focuses exclusively and comprehensively on the patient undergoing orthopedic surgery. The format of this book was developed with several purposes in mind. A primary goal was the development of the first published comprehensive overview of the challenges presented by the orthopedic surgical environment; as such, the book covers most of the relevant domains of orthopedic surgery. A second ambition was to provide an overview of the innovative and sometimes unique approaches to anesthesia in this patient population. A third objective was a presentation of a general approach to the preoperative evaluation of patients, while the fourth and final aim was to offer an up-to-date review of the disease-specific challenges to the care of patients undergoing surgery, maintaining a particular focus on orthopedic procedures whenever possible. In order to achieve these goals, the book is divided into five primary sections: (1) Preoperative Considerations; (2) Anesthesiologic Management; (3) Medical Management in Specific Clinical Settings; (4) Specific Perioperative Problems in Orthopedic Surgery; (5) Role of Allied Services. The book closes with a chapter providing a number of cases and clinical vignettes illustrating the challenges of caring for patients in the orthopedic surgical setting.

A word about us and our institution also seems appropriate. Hospital for Special Surgery is one of the world's premier hospitals devoted to orthopedic and rheumatologic care. Its functions are supported by 140 inpatient beds, over 60 recovery room/acute carebeds, and 35 in- and outpatient operating rooms. A full complement of orthopedic subspecialties is backed by the Departments of Medicine, Rheumatology, and Perioperative Medicine as well as a 57 member Department of Anesthesiology. Fourteen thousand inpatient and a comparable number of outpatient orthopedic procedures generate over 13,000 preoperative consultations annually. Given this extensive experience, we felt the time was right to contribute in a comprehensive and multidisciplinary way our collective approach to perioperative orthopedic care. The editors, whose tenures at HSS date back 30 years, feel well positioned to lead this effort.

Much has changed since the days during which most of our surgery was conducted on an inpatient basis, all patients admitted (and usually evaluated medically for the first time) the day before their procedure; 5–7 days of postoperative care and rehabilitation generally followed, even after routine total joint arthroplasty. Indeed, the modernization of care, driven though it was by outside forces and unwelcome in its time, has forced greater efficiencies in care, promoted (not stifled) innovation, and lowered cost, while minimizing patient exposure to the hospital environment—all outcomes for the better.

In closing, the editors want to express their gratitude first to the contributors to this book. As a "ground-up" endeavor, we appreciate your efforts, diligence, and particularly your patience. Thanks are also extended to Liz Corra, our development editor at Springer, for her encouragement and endurance. Finally, a word to our readers, ultimately the judges of this effort: we hope you find this reference useful in your daily striving to provide the best possible care for patients. While we take full responsibility for its content, we recognize there may be shortcomings and even important omissions in this first edition. Thus, at a time when knowledge and innovation are advancing medical care on a daily basis, we invite commentary and constructive criticism from the broader perioperative and surgical community. Future editions can only benefit from such collective wisdom.

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Part I

Preoperative Considerations

General Principles and Practices of Perioperative Medicine

1

C. Ronald MacKenzie

Objectives

- To review the rationale for the preoperative medical evaluation
- To review the goals of the preoperative medical evaluation
- To review the literature pertaining to the efficacy of preoperative medical evaluation

Key Points

- Medical evaluation of a patient prior to surgery remains a widespread clinical practice.
- Such consultation is supported by clinical investigation, growing literature, and national conferences.
- The principles and practices of perioperative medicine have been evolving, influenced by the quality movement of the last 15 years.
- An orderly structure for the preoperative evaluation includes: the identification of the nature, severity, and degree of control of all comorbid conditions that may impact perioperative decision-making; the optimization of treatment of all active medical problems; the assessment of anesthesia- and surgery-associated risk; education of patients and families concerning the perioperative experience; and motivation of the patient to commit to preoperative preventive practices.

Introduction

Growing numbers of patients of ever-increasing age and often advanced medical conditions undergo surgery annually. Owing to developments in surgical technique and advances in the understanding of perioperative medical care, patients of much greater complexity are being considered suitable surgical candidates. Nowhere is this confluence of developments greater than in the field of orthopedics where advances in total joint arthroplasty, spine procedures, and trauma-related surgery have expanded the indications for surgery and pushed the boundaries of perioperative care. As such a familiarity with the literature pertaining to medical care in the perioperative setting is required for those who provide care to the patient undergoing surgery [1–5].

This chapter reviews the clinical domain and literature pertaining to the perioperative medical evaluation emphasizing the patient undergoing orthopedic procedures. Supported by a now extensive literature, a stepwise approach to the preoperative consultation and the assessment of perioperative risk is herein presented.

Preoperative Consultation

As a consequence of medical advances as well as the impact of financial and resource constraints on the medical system at large, the percentage of all surgical procedures performed on an outpatient basis in the USA rose from 20% in 1982 to 60% in 1995, a trend particularly relevant to the arthroscopic techniques of orthopedic surgery [6, 7]. Among the benefits of these developments has been the opportunity to move the preoperative medical evaluation to the outpatient arena as well, often weeks prior to the surgical date. This change in practice has important consequences, enhancing the opportunity for discourse among the physicians, for supplementary consultation and investigation, and for the institution of therapy directed at optimizing the patient's medical status

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C. R. MacKenzie et al. (eds.), *Perioperative Care of the Orthopedic Patient*, https://doi.org/10.1007/978-3-030-35570-8_1

prior to surgery. Practiced in this anticipatory manner, the preoperative evaluation becomes a focal point of communication between all professionals involved in caring for the patient, enhancing the deliberative and collaborative nature of the consultative process and ultimately the patient's care.

Depending on the setting and institutional approach to perioperative care, the preoperative consultation may be conducted by an MD (internist, medical subspecialist, hospitalist, or anesthesiologist) or by physician extenders (nurse practitioners, physician assistants) under MD supervision. Owing to the complexity of medicine, especially the growth in pharmacology, challenges of the elderly with their comorbidities and restricted physiologic reserve, and productivity and reimbursement pressures that keep surgeons in the operating room (as opposed to rounding on the floors), surgeons are desirous of a more involved consultant [8]. This may take the form of a more active participation in the patient's care (ordering rather than recommending medications), adopting a comanagement strategy for postoperative care or in some instances assuming full responsibility for the patient after completion of the surgery. Regardless of the institutional model, communication between the referring and consulting physicians remains essential to the provision of optimal perioperative care. Evolving from earlier guidelines regarding effective consultation [9], a conceptual revision stressed such considerations as determining the customer, establishing the urgency, gathering your own information, being brief, being specific and talking to the referring physician, establishing contingency plans, establishing one's turf, teaching with tact, talking with the primary physicians, and providing follow-up [8]. While each of these tenants is central to the whole, the first priority is to insure clarity regarding the question asked, as a lack of transparency about the stimulus for the consultation is sure to get the process off on the wrong foot.

Given its elemental purpose, consultation as a practice is essentially the provision of advice regarding diagnosis and management. In the context of general medical care, it affords an opportunity to initiate or modify treatment whether primary or secondary (preventive). Although the goals may be of shorter term in the preoperative setting, such consultations can still be most complex, taxing the knowledge and skill of the medical consultant and anesthesiologist alike. Further, the role of the preoperative medical consultant may subsume even broader responsibilities, going beyond the evaluation of the patient's current medical status. Additional responsibilities, germane to the preoperative setting, include the estimation of the patient's risk for surgery, decisions regarding the need for additional testing prior to surgery, and the preoperative optimization of the patient's medical condition, the purpose of which is to reduce the risk of postoperative complications [10]. Further, in the domain of orthopedics, the assessment of bone quality is a new and increasingly appreciated preoperative consideration, highly relevant in the setting of spine and hip surgery. This emerging topic is extensively reviewed in Chap. 30.

The success of this process therefore depends on a number of elements including a thorough knowledge of those illnesses which impact upon surgical outcome, an understanding of the surgical procedure and anesthetic strategies that might be employed, and an integration of a management plan across the range of physicians and other professional staff who will be caring for the patient [10]. Implicit is the need for effective communication, as the consultant's clinical judgment will impact outcome only if the recommendations are conveyed and then implemented effectively.

Finally a word about the concept of surgical "clearance" is in order. Though widely ensconced in the clinical vernacular, this notion has been decried by the perioperative medical community citing its lack of specification and that the term "cleared" implies that patients will not experience postoperative complications, a sequel that can never be guaranteed [10]. As you will see shortly, the term "optimized for surgery" is more appropriate and better aligned with the goals of preoperative consultation. What are these goals and how do we approach them?

Goals of the Preoperative Medical Consultation

The goals of the preoperative medical evaluation are as follows:

- Identification of the nature, severity, and degree of control of all *comorbid conditions* that may affect perioperative clinical decision-making and medical care
- *Optimization* of the treatment of all active medical problems
- Assessment of anesthesia- and surgery-associated *risk* (magnitude and type)
- *Education* of patients and families concerning the perioperative experience
- Motivation of the patient to commit to preoperative *preventive* practices

Identification of Conditions that Affect Postoperative Outcome

The needs of the patient in the perioperative context depend on a number of considerations notably age, comorbidity, functional capacity, and the type of anesthesia and surgery to be performed. A complete medical history and physical examination constitute the bedrock preoperative evaluation providing a clinically relevant framework upon which informed decisions concerning the value of additional ancillary testing can be premised. The focus and content of the preoperative history does differ from general medical practice, however. For instance, the indication for any type of surgery is an essential component, as the perioperative risk will vary with the magnitude and urgency of the procedure. Patients should also be asked about their prior experience with surgery and anesthesia. Further, the presence, severity, and stability of all comorbid conditions should be established. In the setting of orthopedic procedures, particularly lower extremity arthroplasty, a patient (or family history) of thromboembolic phenomenon may denote the patient at heightened risk for this well-recognized complication of these procedures. Also relevant to this consideration is the association of various connective tissue diseases with antiphospholipid antibodies, a disorder of (hyper) coagulation that places patients at high thrombotic risk after surgery. This condition presents significant management challenges in the perioperative setting and is reviewed elsewhere (Chap. 24). The use of tobacco, alcohol, and other drugs should also be documented, as should the patient's allergic history. All prescription and over-the-counter medications, including the use of herbs and supplements, should be recorded with their dosages and dosing schedules, as decisions need to be made concerning which therapies should be continued (and which should not) prior to surgery. In addition to a traditional review of systems, certain anesthesia-related checks are also important: these include airway problems and a history of snoring, daytime sleepiness, and hypertension which, if present in the morbidly obese patient, suggest the presence of sleep apnea, a medical problem underappreciated both in the general and perioperative settings (Chap. 19).

An understanding of specific intraoperative events and practices associated with the range of orthopedic procedures cannot be overemphasized when performing preoperative evaluations and may help avoid delays and cancellations on the day of surgery. For example, the simple knowledge of positioning practices may alert the examiner to evaluate the patency of potential femoral vascular grafts, ventriculo-peritoneal shunts, and the accessibility of implanted cardiac defibrillators in the prone or lateral position as is utilized for spine and hip procedures, respectively. Further, an appreciation of factors like expected blood loss and specialized ventilation strategies such as one-lung ventilation, will allow for a better assessment of the impact of such an approach on various organs and the ability for any given patient to tolerate such interventions. Lastly, consideration of anesthetic practices for specific procedures (i.e., neuraxial versus general approaches) and their physiologic impact, such as effects on cardiac preload and afterload, should be taken into account when evaluating patients with specific diseases. The effect of prone positioning on positive pressure ventilation may be another example to consider specifically in the obese patient. Thorough evaluation of a patient's possible spinal pathology, including the extent and type of prior back fusions, may avoid confusion on the day of surgery when a neuraxial technique is planned for lower extremity arthroplasty. In selected patients a preoperative consultation with an anesthesiologist may be indicated as to more accurately assess the compatibility of a patient's pathophysiology with an anticipated surgical and anesthetic approach.

Last there has been considerable interest in the estimation of the patient's functional capacity, a surrogate for cardiopulmonary fitness, in the prediction of postoperative outcome [11, 12]. Exercise capacity, quantified in metabolic equivalents (METS), can be easily estimated according to the ability to perform simple everyday tasks of living [10]. Patients with functional limitations so determined have been shown to be at risk for postoperative complications [10]. Although often cited as an easily measured predictor of surgical outcome, the applicability of such assessments is constrained in orthopedic populations, owing to the disability associated with chronic, painful joint conditions.

The physical examination confirms and often amplifies information obtained from the medical history. In the preoperative context, the examination should focus on patient characteristics known to adversely impact upon postoperative course. In addition to the vital signs, body mass index (BMI) should be calculated as this parameter is associated with the development of various chronic diseases, but obesity is also an important independent risk factor for surgery and highly correlated with the underappreciated condition, sleep apnea syndrome. Careful auscultation of the heart is important as the presence of third and fourth heart sounds may indicate left ventricular dysfunction or incipient congestive heart failure while cardiac murmurs imply the presence of valvular heart disease. Depending on the nature and severity of the valvular anomaly, valvular heart disease may compromise cardiac function at times of physiological stress such as surgery. Obesity, large neck circumference, and hypertension predict obstructive sleep apnea; obesity is also associated with insulin resistance and thus diabetes mellitus.

The benefit of preoperative laboratory testing has been examined in many studies, and its benefit (or lack thereof) continues to be widely debated. Several comprehensive reviews pertaining to the commonly performed preoperative studies have been published. Should the determinants of such testing be disease-related or procedure-related? Is the common practice of screening laboratory panels justified in the preoperative setting? With respect to testing when there are no clinical indications, less than 1% of such testing has been shown to provide useful information [13]; indeed, there is evidence that overall this approach may actually be harmful [14]. Not surprisingly, preoperative diagnostic tests ordered as a consequence of a finding uncovered on history and physical examination are more likely to be abnormal [15]; of particular importance is the previously abnormal result that is associated with new or persistent abnormalities [16]. Finally there is the economics of such testing. Although not extensively examined, one study relevant to the orthopedic population examined the costs associated with routine urinalysis prior to knee arthroscopy; $1.5 million dollars were spent in order to prevent a single urinary tract infection [17].

In response to observations from clinical practice and a literature that fails to demonstrate benefit, support from experienced perioperative clinicians for the global or "shotgun" approach to preoperative testing has waned over time [18]. The establishment of guidelines, the effect of which was to reduce preoperative testing, has been shown to have several advantages These include the standardization of practice, improved efficiency, and a substantial reduction in costs; further, these benefits occur with no adverse effect on outcome [19, 20]. Indeed in studies involving healthy patients undergoing minor procedures (i.e., cataract extraction), routine preoperative laboratory testing appears completely unnecessary [21–23]. Although definitive studies in an orthopedic population have not been conducted, a restrictive preoperative testing model might also apply to many of the minor or regional orthopedic procedures (i.e., hand and foot surgery, arthroscopy). Nonetheless, old practices "die hard" and what appears to be excessive preoperative testing remain a widespread practice. Further, depending on the patient and the nature and magnitude of the surgery, a number of investigations may be considered appropriate and are still commonly performed on patients prior to major surgical procedures.

Optimization of Conditions that May Affect Postoperative Outcome

Patient-related factors, specifically existing medical comorbidities, are now viewed as the most important determinant of postoperative outcome. Part III and Part IV of this book present a comprehensive overview of the perioperative management across the spectrum of chronic medical conditions encountered in orthopedic patients. Optimization of the treatment of these conditions is an important goal of the preoperative evaluation. Common examples of this practice include the control of blood pressure in the patient with hypertension, the resolution of bronchospasm in the asthmatic, the achievement of satisfactory glucose control in the diabetic, electrolyte abnormalities (often medication-induced), and heart rate control in patients with coronary artery disease. Unfortunately, for many relevant conditions (i.e., obesity, smoking practices), time constraints and patient compliance impose substantial obstacles.

In practice, the process of optimization generally involves medication adjustments. Medications may be started, discontinued, or their dosages changed, before or on the day of surgery. Further, because perioperative care is a dynamic process, medication modifications are often required after the surgical procedure as well. The medications involved encompass the entire pharmacopeia, including complementary and alternative therapies. Of note are such pharmacological categories as antihypertensive agents (including beta-blockers), antiarrhythmic agents, statin drugs, bronchodilators, insulin and oral hypoglycemic agents, drugs with effects on coagulation, antidepressants, and analgesics. For example, angiotensin enzyme (ACE) inhibitors and angiotensin receptor antagonists (ARA) are common antihypertensive agents and thus frequently encountered in the preoperative setting. Such medications, which are often combined with a diuretic, are associated with significant hypotension in association with anesthesia and should be held on the day of surgery [24, 25]. Other such disease-related optimization strategies are dealt with in the individual chapters comprising Part III and Part IV of the book.

A decision to hold medication prior to or on the morning of surgery must balance the potential adverse influences of those medications in the short term (in the setting of anesthesia and surgery) versus their long-term indications and benefits. Such decisions must be made on an individual basis. Table 1.1 summarizes these considerations across a range of common medications. The management of anti-rheumatic medications is a unique and relevant subset of this consideration and is dealt with in Chap. 12.

The Assessment of Perioperative Risk

The determinants of perioperative risk fall into four categories [26]. The first and least discussed in the perioperative literature involves various system-related phenomena, including the hospital–institutional model of perioperative care (general vs subspecialty, inpatient vs outpatient, comanagement methodologies), approaches to staffing (nursing, physician assistants, hospitalists), and the role of information systems, all of which are important determinants of outcome. The second category of risk relates to anesthetic management and includes such factors as choice of anesthesia (regional vs general), monitoring techniques, airway considerations, and the approach to postoperative pain control, topics covered in Part II of this book. The third includes the surgery-mediated risks, while the fourth category subsumes those influences arising as a consequence of existing medical comorbidity. The impact of preexisting medical conditions on postoperative complications is a subject about which an extensive literature now exists. Indeed, medical comorbidity is now viewed as the primary determinant of adverse surgical outcome. Apropos of this point, an early study is illustrative. Of 599,548 anesthetics, periopera-

Table 1.1 (A) Medications commonly discontinued several days before surgery. (B) Medications commonly withheld on morning of surgery

Medication	Special considerations and comments
(A) Medications commonly discontinued several days before surgery	
Tricyclic antidepressants	Continue for severe depression
Monoamine oxidase inhibitors (MAOIs)	Continue if severe condition (use MAOI-safe anesthetic that avoids meperidine)
Metformin	May stop 24–48 h to decrease risk of lactic acidosis
Birth control pills, estrogen replacement, tamoxifen	Prolonged risk of thromboembolism, especially after major oncologic and orthopedic surgery. Decision by surgeon or oncologist
Aspirin, clopidogrel (Plavix), cliostazol (Pletal), dipyridamole (Persantine)	May continue in patients with critical need for antithrombotic therapy and/or low risk of significant surgical bleeding. Duration of effect of cilostazol and dipyridamole < clopidogrel, aspirin, and ticlidopine. However, if major concern about intraoperative bleeding, stop for up to 10 days
Warfarin (anticoagulants)	Generally stop for 2–5 days. If high risk of thromboembolism, may replace with heparin or low-molecular-weight heparin
Nonsteroidal anti-inflammatory drugs	May continue for severe inflammatory disorder
Cyclooxygenase type 2 inhibitors	May continue to avoid flare-up (despite potential thrombosis or delayed healing)
Fish oil, vitamin E (>250 U/day), and many herbal medicinals	Potential multisystem (anticoagulant, cardiovascular) effects. Standard vitamins acceptable
(B) Medications commonly withheld on the morning of surgery	
ACE inhibitors, angiotensin receptor blockers	Continue if refractory hypertension, fragile aneurysm, severe congestive heart failure (CHF), valvular insufficiency
Diuretics	May continue for CHF
Phosphodiesterase-5 inhibitors	May predispose to hypotension
Lithium	Interacts with anesthetic agents
Bupropion, trazodone	Predispose to exaggerated sympathetic response
Disulfiram (Antabuse)	Affects metabolism (e.g., phenytoin, warfarin).
Alendronate sodium (Fosamax)	Causes transient esophageal irritation
Particulate antacids	Cause pneumonitis if aspirated
Oral hypoglycemics	Risk of hypoglycemia in fasting patient
Long-acting insulin (no available IV access—e.g., day-of-surgery admission)	May also decrease dose night before surgery if patient is prone to morning hypoglycemia. Initiate tighter control when IV access available
Rapidly acting insulin	Administer preoperatively only if hyperglycemia
Insulin pump	Withhold bolus; may continue basal rate.
Pyridostigmine (for myasthenia gravis)	May complicate use of neuromuscular blocking drugs. Continue if risk of severe weakness or dysphagia
Low-molecular-weight heparin (enoxaparin)	Can replace warfarin; typically withhold for 12–24 h

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tive death was proportionately attributed to anesthesiological practices (1/2680), the surgeon (1/420), and patient comorbidity (1/95) [27]. This, the first paper to feature the key role played by patient comorbidity in surgical outcome, was buttressed by a second report in which patient-related comorbidity was the major contributor to the mortality in 485,850 of surgical procedures [28].

The identification of the factors that may alter the risk associated with surgery has, until recently, been the purview of the anesthesiologist. Surgical practice has, however, changed. An ever-aging patient population, with an increasing burden of medical comorbidity, is now considered as a suitable candidate for surgical intervention. Such patient-related characteristics, coupled with the technical evolution of surgical practice, now require the input other clinical disciplines, specifically internal medicine or the medical subspecialists, professionals who by necessity have entered the perioperative arena and now play a key collaborative role.

The concept of preoperative risk assessment was ushered into clinical practice by anesthesiologists in the 1940s [29]. Discouraged by the complexity of the problem, investigators initially regarded the challenge as too daunting owing to such problems as the magnitude of the data required, practice variation, and to the lack of agreement regarding key definitions and terms. Early investigators did, however, develop a scale for the assessment of the patient's state of health prior to surgery. Indeed, the *American Society of Anesthesiologists (ASA) Physical Status Scale* has proven among the most durable tools of clinical medicine [30]. Employed for decades in the setting of anesthesia and surgery, the ASA scale has high correlation with a patient's postoperative course. Five levels of risk based on the presence of a systemic disturbance (illness or comorbidity) are defined with the associated surgical mortality in parentheses: I absent (0.2%), II mild (0.5%), III severe/non-incapacitating (1.9%), IV incapacitating/threat to life (4.9%), and V moribund/survival <24 h without surgery (NA); the subdesignation E denotes emergency surgery which doubles the risk [31]. First proposed in 1941 [29], a revision of the scale remains in virtual universal use to this day [32]. Although criticized for the vagueness of its criteria, it has proven an extraordinarily enduring assessment tool. The search for more robust surgical prediction methodologies has continued and achieved considerable success. The prodigious literature pertaining to surgical risk prediction, both global and organ-specific risk, is fully reviewed in Chap. 2.

Patient Education and Preventive Practices

Patient education and the introduction of preventive practices represent the final goals of the preoperative evaluation. At our institution, preoperative classes are conducted daily for all patients scheduled for total hip and knee arthroplasty as well as those who are to undergo spinal surgery. These sessions review the entire inpatient and postoperative experience associated with these major orthopedic procedures. Supplemented by a comprehensive guide given to each patient, the classes provide an opportunity for patients and their family members to ask questions of the trained nursing educational leaders about the entire perioperative experience. Studies have been conducted in the orthopedic setting, demonstrating a number of benefits of such educational practices; these include a reduction in surgery-associated anxiety and pain [33] as well as a reduction in length of stay [34].

Arising logically from the educational ethos, the implementation of preventive measures has long been an aspirational element of the preoperative assessment. While the range of putative deterrent interventions and the clinical settings in which they might apply remains poorly characterized, there are few data substantiating the role and effectiveness of such approaches. Smoking cessation has received the most attention, in part because it is a sound health-promoting recommendation in general. Nonetheless, the termination of cigarette smoking is often not practical, as smoking cessation needs to take place many weeks prior to the procedure, generally well before the preoperative consultation takes place. In the realm of orthopedic surgery, however, the opportunity to implement effective prevention is enhanced by the often, elective nature of the procedure. Weight loss is another important target for prevention, as obesity is not uncommon in the orthopedic setting. Indeed, obesity remains a relevant issue with respect to such concerns as prosthetic longevity in the setting of total hip and knee arthroplasty and the long-term results from spinal surgery; obesity as a medical problem remains a major societal challenge fraught with well-known challenges.

Efficacy of Preoperative Consultation

Until recently the efficacy of preoperative assessment has essentially been assumed [35, 36], justified by the aging and increasing complexity of modern-day surgical patients. The anticipated benefits of consultation in the preoperative setting include the documentation of comorbid disease, to optimize such preexisting conditions through the selective performance of additional investigations and timely referral for subspecialty consultation, and the initiation of interventions intended to reduce risk, to anticipate the postoperative needs of the patient and to defer and occasionally cancel surgery [37]. Studies examine a number of aspects of the preoperative consultation including their impact on such adverse outcomes as day of surgery cancellations [38, 39], duration of hospitalization [40, 41], and hospital costs [12, 42] and on patient anxiety [43]. Such studies have focused on quality concerns and the financial impact of preoperative consultation, but there are other important considerations. For example, patient satisfaction is favorably influenced by the preoperative evaluation. In one study patients rated meeting with the anesthesiologist preoperatively a higher priority than that of obtaining information on pain relief, methods of anesthesia, and discussion concerning potential complications of surgery [44].

Data concerning the quality of the preoperative consultation have been published. Observations from the Australian Incident Monitoring Study (AIMS) shed light on this issue [45]. In this study 11% of preoperative assessments were considered either inadequate or incorrect; 3.1% of all adverse postoperative events were judged a direct result of these flawed practices. Among those patients experiencing postoperative complications, the morbidity was considered major and only 5% of such events were considered unpreventable. Another study, of anesthetic-related deaths, further develops this theme. Thirty-nine percent (53/135) of such deaths involved suboptimal preoperative assessment and management [46].

Yet the entrenchment of the preoperative consultation has occurred despite a lack of evidence to support its widespread acceptance. One randomized trial of preoperative medical consultation showed little benefit on postoperative outcome or on quality of care [47]. In another study of 1282 patients undergoing surgery, preoperative consultation resulted in no improvement in quality of care indicators (glucose in the diabetic, DVT prophylaxis, DVT) [48]. Two recent studies have examined the impact of preoperative consultation on a macro level [49, 50]. In these cohort studies, Wijeysundera et al. utilized population-based databases to examine the impact of preoperative anesthesia and medical consultation on a large surgical population (270,000 patients) undergoing a broad range of major procedures. In addition to mortality and length of stay, a number of process-related phenomena were assessed in order to judge how preoperative consultation might influence differentials in outcome.

While modest differences were found according to whether the preoperative consultation was performed by an anesthesiologist or by a medically trained physician, several themes emerged from these reports. First, over the 10-year period (1994–2003) of the study, the rate of preoperative consultation increased from 19% to 53%. Presumably reflecting a perceived benefit of consultation on the part of the referring surgeons, the withdrawal to the operating room by the surgical community is also likely responsible. Among the medical consultations, the majority (94.2%) were performed in the outpatient setting, generally about 2 weeks before the surgery. Consultation was associated with higher rates of preoperative testing, the preoperative use (new) of beta-blockers and statin drugs, and preoperative cardiac interventions suggesting an active engagement in decision-making by the preoperative physicians. In terms of benefit, however, the results were disappointing. Regardless of who performed the consultation (anesthesiologist vs medical physician), no reduction in mortality could be shown; indeed, patients undergoing preoperative medical consultation had a modest increase in 1-year mortality. Length of stay was also longer (+0.67 days) in patients who underwent medical consultation (though −0.35 days shorter in those who saw an anesthesiologist prior to surgery). Given the support and general belief in the practice of preoperative consultation, these results were surprising, and the authors posit a number of potential explanations for their findings. These include the association of consultation with an apparent decrease in the use of epidural anesthesia, the higher use of beta-blockers (now believed to increase the rate of stroke after surgery), and the fact that the study population did not include patients whose surgery had been cancelled, nor were those undergoing urgent/emergent procedures considered. In addition, perhaps those surgeons who felt comfortable managing medical comorbidities on their own provided superior perioperative care, thus diluting the impact of the preoperative consultation.

So what additional approaches to care might be of incremental benefit? In addressing this question, Weed brings us back to one of the foundational elements of effective consultation, that is, communication [51]. Citing Chassin, a leader in the quality movement, Weed shows that the "beneficial effect of process" emphasizes how the achievement of optimal outcomes (i.e., postoperative complications) is inextricably a function of the process used to deliver medical care. Thus, the preoperative consultation in itself is not sufficient. Success requires the fastidious attention to the implementation of the preoperative recommendations. Comanagement, a strategy of perioperative care that emphasizes the active participation of the medical consultant, may provide an effective template [52–54]. However, the experience with this model in the orthopedic and other surgical settings has been mixed and generated commentary of a cautionary nature [55].

Summary

The medical evaluation of a patient prior to surgery remains a widespread clinical practice. Although, as discussed previously, the overall utility of such assessments remains to be demonstrated, the enduring and widespread support for such consultation is supported by clinical investigation and growing literature, even national conferences. Owing to this widespread acceptance, the underpinning of perioperative medicine, its principles and practices, is evolving influenced by the quality movement of the last 15 years. This chapter provides a general overview and approach to the patient in the perioperative setting and offers a template not only for this book but for clinical practice as well.

Summary Bullet Points

- The preoperative medical evaluation offers an important opportunity for communication between all professionals involved in the care of the surgical patient.
- The term surgical "clearance" should be replaced by the notion of preoperative "optimization" for surgery.
- The goals of the preoperative evaluation include the evaluation and optimization of patient comorbidity, the assessment of surgical risk, and to provide an opportunity for patient education and the implementation of preventive practices.
- The practice of the preoperative medical evaluation remains an unproven medical intervention.

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Perioperative Risk Models

2

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Objectives

- To provide an overview of general and system-specific perioperative risk assessment models
- To summarize the strengths and weakness of the most commonly used risk assessment models
- To provide a case example of how to apply the reviewed risk models practically

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Key Points

- Many perioperative risk models have been developed over time; these include both general and organ-system-specific models.
- Models that are not efficient or cumbersome are generally not well adopted for clinical use.
- The ideal risk assessment model should be efficient, easy-to-use, well-validated, and clinically applicable to a range of patients and clinical scenarios.

Introduction

Perioperative risk models hold promise for aiding clinical decision-making in the surgical setting. A variety of models and classification tools have been published over time, with the primary goal to objectively classify risks numerically or into categories that can be readily understood by clinicians and patients. Some models have been extrapolated from nonsurgical patient populations, whereas others have been derived and validated solely in surgical cohorts. The scope of perioperative medicine is broad, and a discussion of risks surrounding the surgical period can vary from general statements noting whether patients are acceptable candidates to detailed problem-specific discussions.

We present here a review of these models and include both risk models and preoperative classification systems, which have overlapping clinical use. Our aim is to summarize the strengths and weaknesses of existing models and highlight how they can be utilized effectively to aid clinical decision-making. Risk models studied exclusively in nonsurgical patient populations will not be reviewed here in detail, although we acknowledge that at times such models can be helpful for clinical decision-making. Studies examining multiple rather than single-variable predictors of risk are discussed here, and we specifically excluded single-variable models.

C. R. MacKenzie et al. (eds.), *Perioperative Care of the Orthopedic Patient*, https://doi.org/10.1007/978-3-030-35570-8_2

Few models have been well-studied and validated in different orthopedic surgery cohorts specifically; thus we draw on literature examining other surgical populations at times. Discussions below have been grouped into several broad areas: general risk models and cardiac, pulmonary, hepatic, hematologic, and renal/genitourinary risk models.

General Risk Assessment Models

Table 2.1 provides a timeline of the major perioperative models reviewed here. The development of general models that capture an overall assessment of patients' health holds value to providers, who often need an efficient tool to assess broadly how patients can be expected to fair during surgery. This can be helpful for patients with multiple interacting medical comorbidities, in whom gestalt assessments can be challenging.

Table 2.1 Risk assessment tools studied in surgical patients

General	Year
American Society of Anesthesiologists (ASA) Physical Status Classification Dripps-ASA classification	1941[a] 1961
Physiologic and Operative Severity Score for the enUmeration of Mortality and Morbidity (POSSUM)	1991
Hilditch Pre-Anesthesia Screening Questionnaire	2003
Holt-Silverman Resilience Index	2006
Surgical Mortality Probability Model (S-MPM)	2012
American College of Surgeons' National Surgical Quality Improvement Program (NSQIP) Risk Calculator	2013
Surgical Outcome Risk Tool (SORT)	2014
Combined Assessment of Risk Encountered in Surgery (CARES)	2018
Cardiac	
Goldman Cardiac Risk Index	1977
Detsky Modified Risk Index	1986
Eagle Criteria	1989
American College of Cardiology/American Heart Association Guidelines	1996[b]
American College of Physicians' Algorithm	1997
Revised Cardiac Risk Index (RCRI)	1999
Fleisher-Eagle Criteria	2001
Fleischer-Eagle Algorithm	2001
Auerback & Goldman Algorithm	2006
NSQIP-Gupta Calculator	2011
Pulmonary	
Epstein Cardiopulmonary Risk Index	1993
Melendez Cardiopulmonary Risk Index	1998
Arozullah Post-Op Respiratory Failure Risk Index	2000
Arozullah Post-Op Pneumonia Risk Index	2001
Canet Prediction of Postoperative Pulmonary Complications	2010
Gupta Postoperative Respiratory Failure Risk Model	2011
Gupta Postoperative Pneumonia Risk Model	2013
OSA Specific Models:	
Berlin Questionnaire for OSA	1999
STOP Questionnaire for OSA	2008
Validation of the Berlin Questionnaire and ASA OSA Checklist	2008
American College of Chest Physicians Perioperative Management of OSA	2010
ASA Practice Guidelines for Perioperative OSA Management, ASA Screening Questionnaire for OSA	2014
Hepatology	
Child-Turcotte-Pugh	1984 1987
Model for End-stage Liver Disease (MELD)	2000
ASA Class	2007
Hematologic	
Caprini Model for Venous Thromboembolism (VTE)	1991
Kucher Model for VTE	2005
Patient Safety in Surgery Study/Rogers et al. VTE model [105]	2007
Padua Prediction Score for VTE	2010
Michigan Surgical Quality Collaborative/Pannucci CJ et al. VTE model [94]	2014
Renal/Genitourinary	
International Prostate Symptoms Score – Model for Postoperative Urinary Retention	1992
Risk, Injury, Failure, Loss, and End-stage Kidney (RIFLE) model for AKI	2004
ACS-NSQIP data/ Kheterpal et al. model for AKI	2009
Kidney Disease: Improving Global Outcomes (KDIGO) model for AKI	2012

[a]The ASA Physical Status Classification System was first developed in 1941, modified to include the Dripps classification in 1961, and then most recently updated in 2014
[b]The ACC/AHA joint guidelines were first published in 1996, and have been revised most recently in 2014

The first general model that garnered widespread use is the American Society of Anesthesiologists (ASA) Physical Status Classification System, first published in 1941 [1] and subsequently modified several times [2]. This tool was initially designed to categorize patients for statistical studies and importantly created a focus on patients' physical state alone, separating out the operative procedures and the ability of the surgeon or anesthesiologist. Its initial use was instrumental in helping clinicians begin to use a common language for describing patients' health preoperatively. While subsequent studies have correlated different grades of the physical status classification with mortality and other outcomes, the original and subsequent authors have been keen to highlight that it was not initially developed as a risk stratification system per se [1, 3].

The most recent update of the ASA Physical Status Classification System groups patients into one of six categories and allows for an additional "E" designation to denote emergency surgery [2]. Strengths of this tool are that it has been widely studied and used [4–9] and is readily familiar to most clinicians caring for patients perioperatively. Despite not being designed as a risk stratification tool, the classification system has been correlated with operative times, blood loss, delirium, hospital length of stay, postoperative infection rates, and mortality in a wide range of surgical populations [10–14]. The main criticism of the model is the subjective nature of classifying patients into each group. Descriptions used, including "normal healthy patient" or "a patient with mild systemic disease," are subjectively vague, and their variable use can result in different courses of management. Examples of suggested classifications for common conditions exist in the original publication [1], and subsequently [2], but are not commonly utilized, and still allow for subjective interpretation. Assessments of interrater reliability of the model have produced mixed results, ranging from fair to moderate agreement among providers [15–17]. Nonetheless, it remains a widely used tool, and several authors have advocated it is a simple way to help predict postoperative outcomes [5, 7, 14].

Dripps and colleagues later devised their own physical status classification in 1961, with physical statuses one through five, and it is essentially identical to the original ASA model but paired down in wording. In a retrospective study of over 30,000 patients, these authors examined the contribution of anesthesia toward surgical mortality and how this related to preoperative physical status classification [18]. They addressed both the degree and nature of how anesthesia may contribute to perioperative deaths in patients undergoing spinal and general anesthesia. A clear, positive correlation between the number of deaths related to anesthesia and higher preoperative physical status classification was found. The simplified Dripps model became known as the Dripps-ASA classification, and popularly caught on for clinical use, replacing the verbose original ASA model. In 1963 the American Society of Anesthesiologists formally adopted the simplified Dripps-ASA model [19], which is the classification system that most clinicians are now familiar with as the ASA Physical Status Classification. This has been most recently updated in 2014 (Table 2.2).

Table 2.2 American Society of Anesthesiologists (ASA) Physical Status Classification System

ASA PS classification[a]	Definition
ASA I	A normal healthy patient
ASA II	A patient with mild systemic disease
ASA III	A patient with severe systemic disease
ASA IV	A patient with severe systemic disease that is a constant threat to life
ASA V	A moribund patient who is not expected to survive without the operation
ASA VI	A declared brain-dead patient whose organs are being removed for donor purposes

Data from: ASA Physical Status Classification System [2]

[a]The addition of "E" to any of the classes denotes emergency surgery, with emergency defined as existing when delay in treatment of the patient would lead to a significant increase in the threat to life or body part

Another modification of the ASA tool has been developed by Holt and colleagues who proposed a *resilience* score specific to organ systems [20]. This score is derived by adding the ASA class to a surgical complexity score (rated 1 through 5). The maximum score possible is 10, and higher scores correlate with higher rates of end-organ injury. Individual scores for each organ system can be added together to provide a comprehensive assessment. While helpful for focusing on specific organ systems, the tool is not simple or efficient and has not caught on for popular clinical use.

Recognizing the need to improve upon the Dripps-ASA model to further predict morbidity, Copeland and colleagues described a scoring system to be used for auditing purposes in patients undergoing a variety of surgical procedures [21]. The resulting Physiological and Operative Severity Score for the enUmeration of Mortality and Morbidity (POSSUM) was developed utilizing retrospective and prospective data and utilizes 12 physiologic variables and 6 operative parameters. The tool has been studied primarily at the population level. An online calculator of the model is available [22]. Some authors have observed that the POSSUM tool overpredicts both morbidity and mortality and variable results have been demonstrated when applying the model to orthopedic surgery [23–26]. To correct for this, one study added serum albumin and serum protein levels to the POSSUM score and found it an accurate predictor of mortality in patients undergoing surgery for proximal femur fractures [27]. The POSSUM tool has been extrapolated for use in several surgery-specific models (including V-POSSUM for use in vascular surgery and O-POSSUM for use in patients undergoing esophagectomy surgery), and several authors have noted it to be one of the more validated risk tools [28–32]. The downside to the tool is that it requires the input of many variables, including several variables that are not known until postoperatively, which limits its use as a preoperative assessment tool.

Determining which patients will benefit most from formal preoperative consultations and testing can be challenging. Hilditch and colleagues recognized this and devised a screening questionnaire for nursing use. It helps determine appropriate referral of patients that need to be seen prior to the day of surgery [33, 34]. Their methodology for selecting questions was robust, and the resulting 17 selected questions address general health, exercise tolerance, and risk factors for anesthesia. The authors validated their screening questionnaire in a small cohort of 100 patients undergoing inpatient orthopedic and urologic surgery. Patient responses were compared against separate anesthesiologist assessments as a method of determining validity, which was ultimately scored in the "good" or "excellent" range for most of the included questions. Such a tool may be of use in orthopedic and urology surgeries, which are both typically considered intermediate-risk surgical procedures from a cardiac risk standpoint. Use in patients undergoing low-risk or high-risk surgical procedures would require additional study. The tool was specifically designed to determine the need for pre-surgical anesthesiology consultations, with a focus on detecting potential life-threatening complications. Other specialties may find the questions less useful for their screening purposes.

Recognizing changes in the surgical population over time, and examining a more recent surgical cohort, Glance and colleagues published their Surgical Mortality Probability Model (S-MPM) in 2012 [35]. At the time, they noted clinicians relying largely on the Revised Cardiac Risk Index for predicting cardiovascular complications and accurately observed that this later tool was not designed to predict all-cause mortality [36]. In addition, a significant portion of perioperative deaths are accounted for by non-cardiac causes [37]. Having recognized that the POSSUM [21] and Holt and colleagues [20] models were not efficient models to use at the bedside, they sought to find a more practical model. Drawing on the American College of Surgeons' National Surgical Quality Improvement Program (NSQIP) clinical dataset and examining retrospective data of over 290,000 patients, they identified three simple variables to predict 30-day mortality: ASA Physical Status, surgery-specific risk (low, intermediate, high), and emergent versus nonemergent operation. Half of the dataset was utilized for derivation of the risk calculator and the other half for validation. They developed a point system based on these three variables, ranging from zero to nine. The corresponding scoring system, class, and 30-day mortality rates are listed in Tables 2.3 and 2.4 [35]. The strength of this study rests in the large size of its surgical cohort and variety of surgery types included in the NSQIP dataset. Previous trials looked at similar variables as predictors of mortality, including one by Tiret and colleagues [4] estimating 24-hour postoperative complications, as well as the Surgical Risk Scale [38] examining the data of three surgeons, but were both based on much smaller patient groups. In considering drawbacks of the S-MPM, one might criticize the multiple steps necessary to determine a classification and associated mortality, as well as the subjective flaws of the ASA classification system. However, an important theme to highlight with S-MPM and several of the models discussed thus far is the incorporation of the ASA classification system into other tools, as it appears to be a robust predictor of perioperative outcomes.

More recently the American College of Surgeons has used the NSQIP dataset to develop and validate a tool providing preoperative estimates of eleven different outcomes, as well as a length of stay estimator [39]. This same dataset has also been analyzed on a smaller scale to develop pulmonary and cardiac risk assessment tools [40, 41]. The more comprehensive ACS-developed tool [39] is based on a robust dataset of over one million patients, drawn from over 200 hospitals at the time of its development. It is a free tool that is available online. The ACS NSQIP model has helped appropriately shift the focus toward a more comprehensive risk assessment, including estimates of infectious risks (pneumonia, urinary tract infection, surgical site infection), thromboembolic events, kidney injury, cardiac complications, death, need of returning to operating room, hospital length of stay, and even the chance a patient will need to be discharged to a rehabilitation or nursing facility. They have importantly recognized the changing healthcare environment, where in addition to emphasizing high-quality patient care there is a need to recognize costs and systems issues. The calculator is particularly useful for providing a printable color-coded bar graph for patients to understand their risks as they compare to average-risk patients. This engages patients in an unprecedented way in the informed decision-making process. The tool can be enormously helpful aiding clinicians in the otherwise challenging task of providing perspective for patients to understand risk estimates. As of 2008, only 3% of US hospitals had contributed to the ACS NSQIP dataset, which some have attributed to data collection burden and costs [42]. Notably, the dataset is based on hospitals performing a range of surgical procedures and does not include data from hospitals focusing on one surgical specialty (e.g., orthopedic-specific hospitals are excluded). Additional research is being conducted to help validate this tool in other surgical patient populations outside of the NSQIP dataset. It

Table 2.3 Surgical Mortality Probability Model (S-MPM) risk factors and points assigned

Risk factor	Points assigned
ASA physical status	
I	0
II	2
III	4
IV	5
V	6
Procedure risk	–
Low risk	0
Intermediate risk	1
High risk	2
Emergency	–
Nonemergent	0
Emergency surgery	1

Data from: Glance et al. [35]

Table 2.4 Surgical Mortality Probability Model (S-MPM) class, point total, and 30-day mortality

Class	Point total	Mortality
I	0–4	<0.50%
II	5–6	1.5–4.0%
III	7–9	>10%

Data from: Glance et al. [35]

is anticipated that the tool will become increasingly utilized as clinicians, patients, and institutions recognize its value.

After the release of the ACS NSQIP tool, the Development and Validation of the Surgical Outcome Risk Tool (SORT) was published. It is based upon a large dataset from the United Kingdom and serves as a useful comparative tool to data collected in the United States [43]. The SORT was derived from post hoc analysis of previously prospectively collected data on over 16,000 inpatient surgical procedures of various types. Two-thirds of the data were used for derivation and one-third for validation of the tool. Six variables were identified as significant predictors of 30-day mortality: ASA Physical Status, urgency of surgery, surgical specialty, severity of surgery, presence of cancer, and age. The authors note their risk score is a better predictor of 30-day mortality than some older models, such as the ASA Physical Status score or the Surgical Risk Scale [38, 43], but unfortunately the SORT has not yet been compared to the robust ACS NSQIP tool, nor does it provide outcome data beyond mortality estimates. The SORT is similarly available as a free online calculator [44].

More recently, the Combined Assessment of Risk Encountered in Surgery (CARES) model was published [45]. This tool is based on a retrospective analysis of over 79,000 patients undergoing noncardiac and non-neurological surgery at a single center in Singapore. The analysis was conducted with the aim of developing a tool for predicting both 30-day postsurgical mortality and need for intensive care unit (ICU) stay. The patients were divided randomly into derivation (70%) and validation (30%) cohorts, and the authors formulated a combined assessment using nine variables that contributed to risk across both mortality and ICU admission: age, surgical risk (moderate/severe), ischemic heart disease, ASA classification, emergency surgery, male gender, congestive heart failure, anemia, and – uniquely – red cell distribution width (RDW). Cumulative rank scores were then used to categorize risk as low, low-moderate, moderate-high, and high. The authors note the novelty of using RDW as a predictor of surgical risk, and of predicting need for ICU admission, which could aid in postoperative patient disposition. This model, while promising, is based on single-center data and ideally would benefit from prospective study in a different setting.

Finally, it is also worth briefly noting that several models have studied intraoperative and immediate postoperative variables to predict the postoperative course. Such tools can be particularly helpful for patients who have undergone urgent or emergent procedures and utilize immediate postoperative variables to provide outcome estimates. These include the APACHE II score and the Apgar score for surgery, which have been discussed in detail elsewhere [30, 46–48].

Cardiac Risk Assessment Tools

There are over two hundred million individuals undergoing noncardiac surgery each year worldwide [49], and cardiac complications during or following surgery are among the most feared perioperative events [50]. In one study, among unselected patients over age 40 undergoing elective noncardiac surgery, acute coronary syndrome occurred in 1.4% of patients and cardiac death in almost 1% [51]. Perioperative myocardial infarction affects approximately 60,000 people each year in the United States [52], and there exists a clear need to help predict and prevent such events. Multiple risk models have been developed with this aim [53].

Goldman and colleagues were the first to develop a perioperative Cardiac Risk Index for noncardiac surgery [54]. Goldman recognized that the existing Dripps-ASA screening tool, popularly utilized at the time, was not useful for predicting cardiac events and designed a study to identify risk factors for perioperative fatal and nonfatal cardiac events. The study evaluated 1001 patients undergoing noncardiac surgery over the age of 40 years. Nine independent variables were identified: auscultated S3 or observed jugular venous distention, myocardial infarction in previous 6 months, >5 premature ventricular contractions in 1 minute, rhythm other than sinus, age > 70, intraperitoneal or intrathoracic operation, emergent operation, aortic stenosis, or poor general medical condition. Each variable was given a point value, depending on its impact, and patients were divided into quartiles based on point total. Of the 19 cardiac fatalities in this study, 10 occurred in the 18 patients at highest risk. The risk of postoperative events was 1% in the lowest quartile. The study was a useful start to help predict perioperative outcomes but did not validate the predictive variables in a separate cohort of patients at the time. Limitations of the risk model also include the need to rely on physical examination skills (auscultated S3 or jugular venous distention), and the study did not include many patients undergoing vascular surgery (a group known to be at particularly high risk for cardiac events).

The Eagle Cardiac Risk Index [50] was developed in part to address the limitation of the Goldman model, having not represented vascular surgery patients well. In this retrospective observational study, multivariable analysis showed that the following factors were predictive of adverse events after vascular surgery: Q waves on ECG, history of angina, history of ventricular ectopy requiring treatment, diabetes mellitus, age older than 70 years, thallium redistribution (most sensitive), and ischemic EKG changes during or after dipyridamole infusion. This study provided clinicians a way to improve their risk stratification of patients planning to undergo vascular surgery; however, it incorporated the extra necessity of thallium imaging. This addition may be impractical to routinely perform across many patients undergoing perioperative evaluation and increases costs and exposure to radiation.